Silver Halides, Craft and Laser Beams

Hand-coating as a new creative tool in Holography

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy by exhibition. This is a practice-based PhD submission consisting of an exhibition of produced holograms during the research and the present text. The video of the exhibition is found under:

https://vimeo.com/356984508

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Abstract

The making of silver halide-based material has long been regarded as too complex a task for holographic practitioners. This thesis challenges that popular opinion and proves the feasibility of hand coating by introducing the diffusion method for holographic silver halide-based recording material making. The focus of my research is on how this new method can be developed and improved to make it accessible and usable for creative and general practitioners without the necessity of a background in chemistry. It does this in a practical approach through a process of experimentation with the diffusion method and by the production of holograms in the lab.

My research situates the making of holographic plates in the realm of craft and argues that in-house plate making is not only a realisable option for the artist but a necessity for the survival of creative holography. By producing new tacit knowledge about the method and highlighting its importance, hand-coating in holography is promoted as a feasible way of improving creative holography practice.

The diffusion method also allows for the production of holographic recording material on surfaces other than commonly used glass plates. My research liberates the three dimensional medium of holography from a two dimensional substrate. This gives the medium of creative holography the opportunity to expand the medium’s possibilities, to find a new visual language and to challenge the observer's eye in new ways.

This thesis, and my research, offers a practical, and creatively beneficial, alternative to the expensive and often unreliable commercial holographic material which contemporary holographers currently contend with. It offers the practitioner both an entirely new way to produce holograms and through self-production of their own recording material, greater creative control and potential.

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The images presented in this thesis are substantially photographs which I have taken; illustrations are by Gustavo Vargas; Figures 113-116 are courtesy of the artists; Figure 98 is courtesy of Peter Zec, *Holography*, Koeln, DuMont.

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Holograms in Hemispheres

Introduction

This thesis examines the potential of silver halide-based holographic material as a creative tool through the hand coating of glass objects. I challenge the prevailing opinion that the production of silver halide-based material involves a process which is too complicated and therefore not a feasible method for the practitioner. To do this I introduce, and improve, the diffusion method as a creative tool.

Holography produces three dimensional images that can be seen without any special glasses or lenses between the image and the viewer. Dennis Gabor initially discovered how to make holograms in the 1940s in his work focused upon improving electron microscopes.[1] Holography was, at this point, predominantly in the scientific domain. It took holography until the 1960s and the introduction of the laser, however, to inspire creative potential in the field of image making. In the early 1960s, Emmett Leith and Juris Upatnieks at the University of Michigan developed the off-axis set-up, which made 3-D holography both more viable and attractive to audiences and practitioners.[2] Their breakthrough was based upon working with the greater precision afforded by laser light and focusing on the coherence and specific wavelengths of the light source.[3] To record the hologram permanently, photographic silver halide-based material was used, which was then readily available. Kodak produced fine grained photographic plates – the first plates used for recording viewable holograms.[4]

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[1] The history and invention of holography is described in numerous books and papers on holography. Sean Johnston gives a detailed account in: S. F. Johnston, 'From white elephant to Nobel Prize: Dennis Gabor's wavefront reconstruction' *Historical Studies in the Physical and Biological Sciences*, vol. 36, No. 1, 2005, pp. 35-70. The following papers and articles by Gabor also give accounts: Dennis Gabor 'Microscopy by Reconstructed Wave-Fronts', *Proceedings of the Royal Society*, 197 July (1949), 458-487; Dennis Gabor, 'The principle of wavefront reconstruction', in E. Camatini, (ed.), *Optical and Acoustical Holography*, New York – London, Plenum Press, pp. 9-14; Dennis Gabor, 'Information Theory in Holography', in Camatini, *Optical and Acoustical Holography*, pp. 23-40.

[2] E.N. Leith and J. Upatnieks, 'Wavefront reconstruction with continuous-tone objects.', *Journal of the Optical Society of America*, No. 53, 1963, pp.1377-1381.

[3] Coherence length: The distance over which the phases of the photons making up a light beam remain correlated, that is, the greatest optical path difference between two beams derived from the same source such that when they are recombined they will form interference fringes. Definition from: Saxby, *Practical Holography,* 4th ed., p. 614.

[4] S. A. Gamble, 'The Hologram and its Antecedents 1891–1965: The Illusory History of a Three–Dimensional Illusion', PhD Thesis, University of Cambridge, 2005, p. 50.

Light sensitive plate-making is a technique that to some degree has been rendered obsolete for modern image making as the technology of capturing images has moved from analogue to digital processes. Even though the recording material for holography has developed in different directions since its invention, silver halide-based recording material is still the most widely used.[5] Analogue display holography achieves its highest quality work on silver halide gelatin glass plates. This thesis considers the limited market of silver halide recording material for holographic recordings. Furthermore, it offers a new choice for the practitioner in the process of hand-coating and in the self-production of recording material. In a practical approach, this research further develops the diffusion method, and demonstrates the feasibility of a hand-coating approach to realise projects in display holography.


Figure 1. (left) silver halide-based recording plate hand-coated by me. Figure 2. (right) commercially bought halide-based recording material by Colour Holographics, UK.

Research methodology

A new way for practitioners to generate their own silver halide-based recording material constitutes a significant improvement in holographic practice. Although it may initially seem a complex undertaking, and the actual task of self-production of recording

[5] Different recording materials are described in: H.M. Smith, (ed.), *Holographic Recording Materials*, New York, Springer Verlag, 1977. For photopolymer, see Bjelkhagen, H.I., *Silver-Halide Recording Materials for Holography and Their Processing for Holography and Their Processing*, Berlin, Springer Verlag, 1993.

material may seem an unconventional starting point to creative holographic production, rethinking a medium unconventionally can often uncover new pathways and possibilities. The invention of the sand table in the 1960s, for instance, had a huge impact on the popularity and accessibility of holography. Any vibration during a holographic exposure destroys the hologram: consequently, in scientific labs, massive, heavy, vibration-free tables were used. These tables also had a firm surface where the optical setup could be mounted and precisely controlled. Lloyd Cross and Jerry Pethick, collaborating hologram artists and innovators, invented the sand table, a box filled with washed sand that was mounted on a semi-inflated inner tube to 'float' and isolate the vibration.[6] The optical arrangements, mounted on the end of PVC tubing, were then stuck into the sand where they could be easily manipulated. This innovation removed the need for specialised lab furniture and significantly reduced the set-up costs for a holographic studio. The sand table, even though it was often messy as sand got into the optics, helped to liberate holographic practice and enhance its accessibility. Melissa Crenshaw, a hologram artist, states in her paper on "Jerry Pethick: The Missing History of the Sand Isolation Table":

> The whole philosophy behind the sand isolation table was an accessible approach that liberated holography from the confines of well-funded, off limits labs in research facilities and universities.[7] [...] Colleges and future schools of holography adapted this approach for its simplicity, portability (well, sort of) and affordability [...].[8]

Innovations like the sand table and the diffusion method put holography into the hands of practitioners and made a wider exposure to, and practical education in, holography possible. Without such innovative thinking holography would perhaps have long remained principally a scientific practice. As expensive and vital equipment in the holographic process, the predominant use of standardised recording material poses a comparable threat, which makes research into viable alternative methods of creating light-sensitive holographic materials so important. My research took place in the

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[6] S. F. Johnston, *Holographic Visions: A History of a New Science,* Oxford, Oxford University Press, 2006, p. 266.

[7] M. Crenshaw, 'Jerry Pethick: The Missing History of the Sand Isolation Table', *Journal of Physics: Conference Series 415 012070,* 2013, p. 3.

[8] Crenshaw, 'Jerry Pethick: The Missing History of the Sand Isolation Table', p. 3.

holographic lab of De Montfort University which was partly equipped with expensive equipment such as heavy setup tables. However, De Montfort University, like most formal educational centres of holography, is focused upon the practices involved in the act of recording rather than upon the making of the actual recording material. In terms of my research, therefore, no special equipment for coating processes was present. Of course, special chemicals, such as silver nitrate, are easier to obtain through an official body such as the university. The diffusion method is, however, designed from the very beginning to be used by the practitioner at home. In order to prove that the diffusion method is a feasible way for practitioners to use recording material as a creative tool, and as a critical and necessary aim of my practice-based research process, I used the diffusion method myself to prepare an exhibition.

I applied to take part in an exhibition at the National Space Center in Leicester, UK, at an event called *Steampunks in Space,* to show that handmade recording material could successfully produce an attractive visual outcome. The event took place in November 2017. I presented five holograms on 8cm x 8cm plates, 5 holograms in hemispheres of different sizes, and one hologram in a glass bubble. It was a successful experiment and generated a paper about Hemisphere Holography which I presented at the 11th International Symposium on Display Holography (ISDH) in June 2018 to the Holography community. The paper is to be found in Appendix A, while Appendix B gives a detailed account of the artwork for *Steampunks in Space.*

To achieve the successful presentation at the exhibition and therefore prove that the hand coating of holographic material is a feasible new approach, a process of *rethinking* holography was necessary. The sand table was important not only in revealing how an innovative idea could transform holographic practice but in helping to move holography towards a workshop culture that understood holography as a learnable, accessible craft, instead of a complex science. In this thesis I use the basic meaning of the term *craft* as advocated by Pamela Smith:

> The English word *craft* implies not only ability with hands but understanding of how to accomplish one’s purposes, as in craftiness. The Greek equivalent is

> "metis" (Μήτις), meaning something like the knowledge that comes from doing things with purpose, or in a somewhat archaic English, "cunning".[9]

The use of the term *craft* can be contentious, not least in any definition which is in opposition to the term *art*. It is important, therefore, to consider the issues involved, not only in semantic terms, but in how they apply to the practice of holography and, in particular, how I consider them in relation to my own practice-based research which informs this thesis. In response to Smith's view of craft as a hands-on ability informed by a specific sense of purpose, Glenn Adamson, Editor of the *Journal of Modern Craft* and author of multiple books about craft, argues that '[…] no such innocent usage of the term is possible'.[10] Adamson continues by saying:

> That is because craft is a modern artifact in its own right. For convenience, I use the terms "artisan" and "artisanal" when I want to talk about skilled people and skill-intensive practice in a less ideologically charged manner.[11]

This is a valid distinction but the focus of my research is more upon the learning which arises from personal practice and the accumulated experience involved as opposed to specific learned 'skills'. My thesis looks into the methods and processes which develop knowledge in the craft of making recording material: as such, my interest is focused primarily upon Smith's concept of 'craftiness' and also upon her more classic definition of the artisan as a person 'trained by apprenticeship' where manual work 'has been inculcated by apprenticeship rather than by texts. […]'[12]

In this thesis, therefore, I refer to craft knowledge as knowledge produced and gathered by experimentation and material study, through the actual process of work and practice, with *craft* itself being the skill learned, in contrast to artisanal knowledge, which implies an apprenticeship and therefore learning through observation and imitation. There may appear to be a subtle distinction between these definitions and the two approaches are

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[9] P. H. Smith, A.R.W. Meyers and H. J. Cook, (eds.), *Ways of Making and Knowing: The Material Culture of Empirical Knowledge*, Ann Arbor, University of Michigan Press, 2014, p. 2.

[10] G. Adamson, *The invention of Craft*, London, Bloomsbury Academic, 2013, p. xxiv.

[11] Adamson, *The Invention of Craft*, p. xxiv.

[12] P. H. Smith, *The Body of the Artisan,* Chicago, University of Chicago Press, 2004, p. 243.

not mutually exclusive but I will argue, from my own personal and practical experience in pursuing my research, that the development of craft knowledge, or to be more accurate tacit knowledge, is unique to each learner and goes beyond the master-apprentice relationship implied by artisanal knowledge. It involves the gradual acquisition of tacit knowledge through experimentation and experience and this was central to my methodological approach. Tacit knowledge, therefore, is conceptually important to my practice-based approach.

The term 'tacit knowledge' is attributed to Michael Polanyi, who describes it in his book *Personal Knowledge*, as 'a type of knowledge that is not captured by language or mathematics' and can therefore only be shown but not put into words: as such, texts and recipes in the holographic field are missing information about tacit knowledge.[13] Michael Oakeshott, an English philosopher and cultural theorist, defined practical knowledge as a knowledge that cannot be taught:

> […] practical knowledge can neither be taught nor learned, but only imparted and acquired. It exists only in practice, and the only way to acquire it is by apprenticeship to a master – not because he can teach it (he cannot), but because it can be acquired only by continuous contact with one who is perpetually practising it.[14]

Explicit knowledge, by contrast, refers to that which can be articulated, easily and clearly transmitted, codified and made accessible. My research reflected a conscious process of both explicit and tacit knowledge. The London School of Economics launched a research project in 2005 called 'How well do 'facts' travel?'.[15] To begin the research 'A Toolkit for Travelling Facts' was written. The research team, including important scholars in the field such as economic historians Mary S. Morgan and Peter Howlett, stated that 'tacit knowledge is contrasted with explicit or propositional

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[13] London School of Economics, [website], http://www.lse.ac.uk/Economic-History/Assets/Documents/Research/FACTS/reports/tacit.pdf p. 2, (accessed 7 February 2019).

[14] M. Oakeshott, 'Rationalism in Politics', in *Rationalism in Politics and Other Essays*, London, Methuen and Co., 1962, p. 11.

[15] London School of Economics, [website], http://www.lse.ac.uk/Economic-History/Research/How-Well-do-Facts-Travel/About-the-project, (accessed 7 February 2019).

knowledge.'[16] Adamson defines the terms further, categorising explicit as technical knowledge and tacit as practical knowledge, while simultaneously noting, however, that this comparison may be too simple and leads to a stalemate in the learning process.[17] Explicit and tacit knowledge are not in opposition as such, but complimentary. Throughout my thesis I refer to tacit knowledge as not simply practical knowledge, but as a mixture of explicit and tacit knowledge processes, particularly specific aspects such as gestural knowledge and experience.

Gestural knowledge, which is part of tacit knowledge, can not only be taught but even be written down and be easily shown visually. Arguing that gestural knowledge is an intrinsic part of tacit knowledge may appear to go against Polanyi's statement that tacit knowledge cannot be 'encoded symbolically', as pointed out in 'A Toolkit for Travelling Facts'.[18] I define gestural knowledge, however, as an aspect of tacit knowledge that *can* be transmitted by text or by visual means: however, that does not change the fact that tacit knowledge as a whole cannot.

The other key component of tacit knowledge is experience. I refer not only to the experience gathered while learning and performing the craft, but also, and more importantly, to the *personal* experience that is brought into the craft practice. Adamson refers to anthropologist Alfred Gell who argues that 'Nobody, not even a child, comes to a handmade object with a completely empty mind'.[19]

These components, of practical and gestural knowledge and experience, make it impossible for tacit knowledge to be fully explicit, as it always involves personal experience, process and knowledge, as Polanyi defined it. Parts of tacit knowledge can be taught and learned and imitated, as shown, and parts of it will always be subjective and personal. The forming of tacit knowledge is therefore an act of learning as well as

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[16] London School of Economics, [website], http://www.lse.ac.uk/Economic-History/Assets/Documents/Research/FACTS/reports/tacit.pdf, (accessed 7 February 2019).

[17] Adamson, *The Invention of Craft*, p. 101.

[18] London School of Economics, [website], http://www.lse.ac.uk/Economic-History/Assets/Documents/Research/FACTS/reports/tacit.pdf p. 2, (accessed 7 February 2019).

[19] Adamson, *The Invention of Craft*, p. 101.

discovering and different learning processes and experimental pathways are therefore created and experienced by different practitioners.

As noted before, my research also involves explicit, or technical knowledge. Polanyi, a chemical engineer before becoming a philosopher of science, is well aware of the importance of both. In my thesis I decided to work with the diffusion method to hand coat recording material for holograms. The diffusion method is newly developed and not yet common practice in holography and as such I believed it merited exploration and research into its potential. Indeed, when I started my research, I worked directly and collaboratively with the scientist developing the method in the lab. It is, therefore, a new method and needed considerable experimentation and refinement to become a feasible option. To do so, I studied the principles of the diffusion method in scientific papers and books. The starting point for my research aims was, therefore, founded in the explicit knowledge which currently informed the diffusion method. The method worked but was extremely unreliable in terms of reproduction. Success would be achieved when an experiment produced working recording material and was reproducible. This would prove to be a major challenge and would involve the gaining of tacit knowledge in the process.

The obstacles, improvements and useful by-products found during my research are described in lay terms for an engaged reader or practitioner, and not in a specialist scientific language. The language and voice I have chosen to write this thesis in are deliberately aimed at the holographic artistic practitioner, not the scientist. Many research papers on holographic emulsions are written in a way which is difficult to understand for the non-scientist. While scientific experimentation on holographic emulsions is necessary, it is also equally necessary to convey findings and explanations in an accessible and understandable way: this is more helpful and motivating and avoids adding to the aura of the insuperableness of the complexity of making silver halide-based recording material.

A place for handmade recording material

In Chapter 1, through a review of the literature, I consider why hand-coating by the artist has never been a major focus within the holography community up till now. Principally this is due to the perceived complexity of the actual process and partly because of the general commercial availability of the recording material. These issues are examined in greater detail.

It is recognised that the ability to produce recording material offers the practitioner greater creative control and expressive potential in holography. The dichromate gelatin (DCG) process has been adapted by contemporary artists, such as August Muth and Dora Tass, who worked very successfully with the DCG method by coating their *own* holographic plates.[20] Their work has even found a market in Bonham's Auction House of London, in 2014.[21] Another artist who worked with the DCG method and produced holographic recording material was Richard Rallison**.**[22] During the 1970s and 80s he successfully coated and sold holograms recorded on pendants and on apothecary jars he had coated with dichromate gelatin, a radical move away from the traditional hologram on a glass plate.

There is an important history of holograms being made in different shapes rather than the standard two-dimensional plate, such as the multiplex method invented by Lloyd Cross. Multiplex Holography is a method that uses a filmed sequence which is then projected onto a holographic recording material, and by illumination with a laser, recorded as an animated hologram.[23] Through this approach, holograms can be designed as cylinders, or a part of a cylinder, and shot on film - as film can be manipulated and bent around shapes. One of the most famous of Cross' holograms, created by the multiplex method, was an animated cylindrical hologram of Alice Cooper, commissioned by Salvador Dali. Cross' hologram 'The Kiss' was a major commercial success in 1973 and the concept of the multiplex hologram received wide attention: '[...], the Multiplex Company holograms also sold in large numbers directly to the public.

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[20] DCG process: Dichromate gelatin. A light –sensitive non-silver emulsion consisting of gelatin sensitized by dichromate ions which promote cross-liking when stimulated by short-wave light energy, and producing on processing a phase hologram of high diffraction efficiency. Definition from Saxby, *Practical Holography*, 4th ed., p.615.

[21] Bonhams London, *A Contemporary Edge, 4th of March 2014*, [website], http://www.bonhams.com/auctions/21527/#/MR0_page=4&MR0_length=10&MR0_category=list&m0=0 (accessed 4 May 2017).

[22] Richard D. Rallison, *The History of Dichromates*, [website], https://wasatchphotonics.com/wp-content/uploads/The-History-of-Dichromates1.pdf
(accessed 23 October 2018).

[23] Saxby, *Practical Holography,* 1st ed., pp. 249-253.

Such holograms became the most widely seen types during the late 1970s'.[24] 'The Kiss' was followed in 1975 by its even more successful sequel 'The Kiss 2'.[25] Two other artists who worked successfully with the Multiplex Hologram were Anaït Arutunoff Stephens and Simone Forti. Stephens, who had studied at the School of Holography in San Francisco, finished her works called *Holodeon* in 1974 combining three separate multiplex films on one substrate, a drum.[26] Simone Forti, an artist who often uses dance to express her ideas, collaborated with Cross to produce Multiplex Holograms of solo dance movements.[27] Her holograms formed part of the performance, sometimes illuminated by candle and rotated for viewers sitting on the floor.

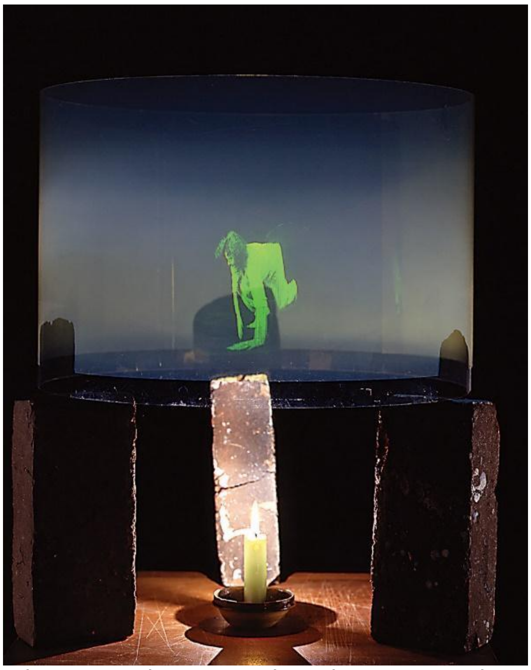

Figure 3. Simone Forti, Hologram *Angel*, 1976 illuminated by candle.

Ray Park is another modern artist working with holography and he produced cylindrical holograms on holographic film up to 2014. He now dedicates his time to synthetic holography. He ceased working on 360-degree holography, however, as the diffraction efficiency was low and dark and the whole process was rather difficult.

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[24] Johnston, *Holographic Visions,* pp. 214-215.

[25] Bjelkhagen and Brotherton-Ratcliffe, *Ultra-Realistic Imaging,* p. 34.

[26] Anaït Arutunoff Stephens, 'My art in the domain of Reflection Holography', *Leonardo,* Vol. 11, No.4, 1978 p.306.

[27] Solveig Nelson, 'Phantom Limbs', *Artforum*, 2018, pp. 260-268.

Like the Multiplex Hologram, many efforts to produce 360-degree holography have been on film, as film can be bent and manipulated in form. Saxby describes two different types of 360-degree holograms on film: the cylindrical hologram (for example 'The Kiss') and the conical hologram, which has never actually been adopted by artists.[28] With hemispheres and wine glasses, without the flat planes of cylinders or cones, film finds its limits as the shape is not easy to achieve.

Although the examples of curved holograms are relatively few in number, the committed and constantly exploratory work of holographic artists shows a creative desire to overcome the belief that holography is limited to two-dimensional framing and standard wall display. Throughout the history of holographic art, artists have experimented with the holographic image, even though recorded on a conventional glass plate or film, in contexts other than the gallery wall.

Artists like Sam Moree, who has worked with holography for over 40 years, experimented with holograms and sculptures. His works *Arrow* (1978), *The Talker* (1992) and *Phoenix 46* (1996) are examples of holography being displayed in ways beyond the gallery wall.

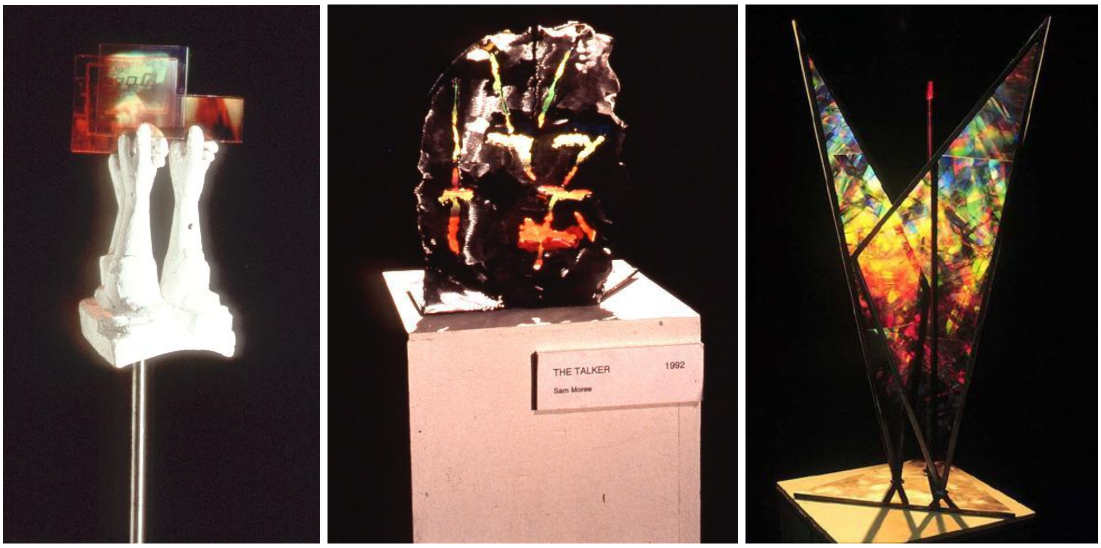

Figure 4. Arrow (1978), The Talker (1992) and Phoenix 46 (1996) by Sam Moree as displayed in the gallery space. www.holocenter.org/sam-moree (accessed 4 July 2019)

[28] Saxby, *Practical Holography,* 1st ed., pp. 128-132.

Integrating the hologram into a sculpture or, additionally, playing with the actual form of the glass plates provide possibilities for new visual encounters with holography, as a recent work of Betsy Connors shows.[29] Titled *Light Ocean: and what the poor fish ate*, her work is a holographic installation inspired by the environment.

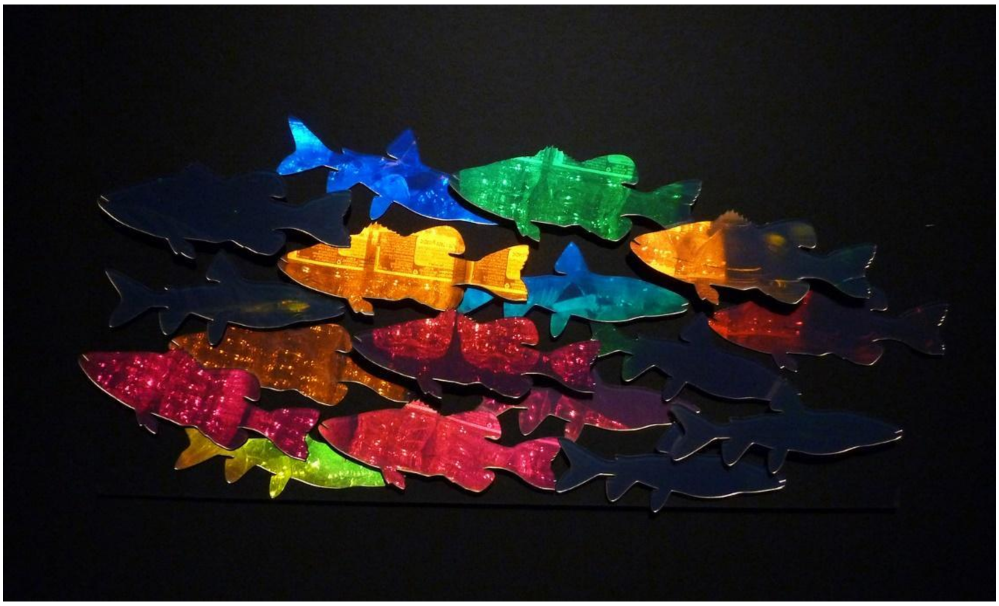

Figure 5. Project by Betsy Connors from 2015.

Rudie Berkhout, one of the leading holographic artists when the medium emerged, mounted a series of holograms on tripods in 1978.

Figure 6. Still from Berkhout's installation which can be seen on: https://www.youtube.com/watch?v=GeoMqFbHzi8 (accessed 20 June 2019).

29 http://www.betsyconnors.com/ (accessed 23 June 2019)

In addition, contemporary examples exhibit the potential of holography going beyond the traditional framed image. Martina Mrongovius, for example, has exhibited holographic works which radically diverge from standard display modes and involve the kinetic engagement of the viewer. Her 2009 work, *Jumping Jellyfish,* required the viewer to jump on a trampoline to see the hologram of the jellyfish actually move. In an instance such as this, the concept of interactivity resides in the very act of viewing, in the relationship between the viewer and the actual holographic object.

Figure 7. *Jumping Jellyfish* installation by Martina Mrongovius.

Melissa Crenshaw and her project *The Traveling Optics Vanity Series* from 2015 is another example. In this work, holograms on plates are displayed in a box as a Vanity Set with optics that distort and redirect the holographic image.

Figure 8. *The Traveling Optics Vanity Series* by Melissa Crenshaw.

This continued and growing success of different methods of making holograms - in terms of shapes, hand-coating and off-the-wall holograms and the variety of visual outcomes – are testament to the potentials of the medium itself. In this environment, everything suggests that hand-coating silver halide-based material, in giving the creative practitioner more autonomy and expressive freedom, and liberating holographs from two-dimensional substrates, will have the same success.

The Creative Holographer

Echoing the early days of photography, and other art forms where technology plays a major role, the question of whether holography is art or not has been discussed on many occasions. The journal *Leonardo* even dedicated a special volume to this question in 1989, with the title *Holography as an art medium,* in which an international group of authors, most of them practitioners in the field themselves, discussed the issue.[30] Although this was in 1989, the interest in the question is still strong. *Arts*, an

[30] Louis M. Brill, (guest ed.), 'Holography as an Art Medium', *Leonardo*, vol. 22, No. 3-4, Pergamon Press, Oxford, 1989.

online, peer-reviewed journal is currently seeking article submissions by July 2019, for a special issue on *Holography-A Critical Debate within Contemporary Visual Culture*.[31]

My thesis is not primarily concerned with answering the particular question of whether holography is to be considered art or not - as opposed to a craft, or a science, or a set of techniques – since artists have clearly used holography for defined artistic purposes. However, I am more specifically concerned with how artistic holography has been handled inside the holographic community and how it has been perceived and organised.

Sean F. Johnston has written papers on holography, its relationship to photography and books about the development and growth of holography, and its related cultural and political influences.[32] I have mentioned his work earlier in my thesis, as his book *Holographic Visions* paints a detailed picture of the journey of holography with a deep insight into the technical environment holography was born into and a brilliant account of key personalities influencing the new medium. It is the definitive book on the cultural history of holography.

In part three of the book, Johnston describes three groups of holographers: The Scientific Holographer, the Artisan Holographer and the Aesthetic Holographer. The group of the Scientific Holographers is straight forward: they are the first holographers, predominantly scientists who were introduced to holography within the field of their scientific speciality, or as Johnston describes them: 'Different practitioners learned of holography either as a new optical science, as an expression of information theory, or as a new application for microscopy, acoustics, metrology, or mechanical

[31] https://www.mdpi.com/journal/arts/special_issues/holography?fbclid=IwAR32KxzPlRPsSZd2E9dr5TNZ0u4cVQOWCx45CiEfDHToaY1MLa_Nk6Us5ql (accessed 15 February 2019).

[32] S.F. Johnston, 'Absorbing new subjects: Holography as an Analog of Photography', *Physics in Perspective*, 8(2), 2006, pp. 164-188; Johnston, 'Shifting Perspectives: Holography and the Emergence of Technical Communities', *Technology and Culture*, vol. 46, No. 1, 2005, pp. 77-103; Johnston, 'Whatever Became of Holography?', *American Scientist,* vol. 99, 2011, pp. 482-489; Johnston, 'A Cultural History of the Hologram', *Leonardo,* vol. 41, No.3, 2008, pp. 223-229; Johnston, 'A Historian's view of Holography', in H.J. Caulfield and C.S. Vikram, (eds.), *New Directions in Holography*, Stevenson Ranch, CA., Scientific Publishers, 2008, pp. 3-15; Johnston, *Holographic Visions,* 2006; Johnston, *Holograms: A Cultural History,* 2015.

engineering'.[33] The Scientific Holographer exists today and looks at holography as a tool for science in areas such as these, seeking new applications.

Some scientists, however, are curious about the image-making potential of holography and, often in collaboration with artists, explore the possibilities further. In contrast, Johnston defines the Artisan Holographer as follows:

> [...] I use it to distinguish holographers who have developed wide-ranging competences underlain by tacit knowledge, and trained outside universities or art schools, making them distinct from scientists, engineers, and artists. They are not merely practical tradesmen of a stable art, but rather innovators who saw beyond the contextual channels of earlier workers.[34]

Johnston refers with this description to a group of practitioners that evolved in the late 1960s and took holography out of the science lab and searched for ways to make the medium more accessible. Lloyd Cross and Jerry Pethick, the innovators of the sand table mentioned earlier in this introduction, were among the leading figures in this new movement. They made their first hologram together in London, as Cross recounts, when he visited Pethick there:

> I went over to London to help him set up a rudimentary holographic arrangement on his studio floor which we made a couple of very tenuous sort of holograms on.[35]

This creative group of practitioners and innovators started out small, but made holography possible for anybody interested. They used unconventional methods and worked in a way which was quite distinctly different to the Scientific Holographer described by Johnston. Encouraging a 'found material philosophy', they showed that

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[33] Johnston, *Holographic Visions,* p. 236.

[34] Johnston, *Holographic Visions,* p. 253.

[35] L. Cross, *The Story of Multiplex,* [website], http://www.holophile.com/downloads/pdfs/Story%20of%20Multiplex.pdf (accessed 19 February 2019), p. 1.

holography could be done outside the scientific lab.[36] Eventually they started a school in San Francisco in 1971.[37]

When Johnston describes the Aesthetic Holographer, the third group, he starts by explaining his choice of terminology and states that existing terms are not precise enough: 'Andrew Pepper defined the domain of art holographer as creative holography, but this common term is contentious: how are art, artists, and creativity to be defined?'.[38] Johnston goes on and explains why the term *aesthetic* is more suitable:

> I will use the term aesthetic according to its philosophical definition, namely the study of what is beautiful or valued, [...]. More broadly, I will use the term aesthetic holographers for practitioners concerned with producing holograms that have a purpose transcending mere utilitarian value. [...]. And an aesthetic practitioner seeks explicitly to create a piece having transcendent qualities, while an optical engineer or artisanal holographer does not.[39]

For a hands-on medium such as holography it is risky to split the artisan from the artist so definitively, as both are needed, as is the 'scientist', in the creative enhancements of holography. Indeed, they are often found in the same person. Johnston, however, divides even the Aesthetic Holographer into two groups. The first group being artists employing holography for a project with the help of a Scientific Holographer. Those *Aesthetic Holographers* are essential conceptual artists who employed holography to communicate an idea: the holographer however, is the scientist who helped them. Dormer calls artists who delegate the making of their art *designers* and is of the opinion that the artist loses control over his artwork:

> [...] the artist has put himself or herself into the role of designer. Designers lose control over their creation once they relinquish it to production, whereas one of the strengths of a handicraft-based art form is the flexibility it allows for the artist

[36] Nancy Gorglione, 'Forms of Light: A Personal History in Holography', *Leonardo*, vol. 25, No.5, 1992, p. 473.

[37] John Fairstein, [website], http://www.jfairstein.com/SOH.html, (accessed 4 January 2019); Johnston, *Holograms: A Cultural History*, p. 124.

[38] Johnston, *Holographic Visions,* p. 289.

[39] Johnston, *Holographic Visions,* pp. 287-288.

> to change, expand and explore his original intention (or design) until the point he or she considers that the art work is complete.[40]

In my experience this is an extreme view and collaborations of this kind can be very successful. However, the credit as holographer in those cases should go to the artisan or scientist and not the artist, as a certain amount of skill is required which invariably the artist does not possess. I was recently hired to produce a holographic artwork for a children's theatre in Norway. Clearly the holographer of the project was me, as no one in the team possessed the skill to record a hologram. At the same time, I would not have claimed the concept, even though certain artistic decisions, particularly those involving lighting and background, were made by me.

For the second group of Aesthetic Holographer, artists learning the skill of holography and then pursuing a career in holography, Johnston gives two examples: Margaret Benyon and Harriet Casdin-Silver. Casdin-Silver entered into an artist-scientist collaboration with Stephen Benton, while Benyon was one of the few art holographers, if not the only one who was truly self-taught in holography, with her knowledge learned mostly from texts. She was the first acknowledged holographic artist in Britain. Benyon became interested in holography because she had worked with interference pattern in her work as a painter to create the illusion of depth.

Not counting the conceptual artist, Johnston defines the group of the Aesthetic Holographer by two examples and he quotes Jonathan Benthall, in defining the Aesthetic Holographer further, '[...] the key attributes of an artist are a sense of creative imagination combined with skills in a technical medium which transmits his or her perceptions'.[41] He concludes that this 'conveniently distinguishes the aesthetic holographer from the artisan'.[42] Artists like Rudie Berkhout, mentioned before, and John Kaufman, to name only two, trained by artisans and emerging from the San Francisco school, prove that the category of the Aesthetic Holographer as Johnston describes it does not, in effect, exist. They created a holographic body of work, that exhibits a great sense of creative imagination and, at the same time, they were major innovators in new

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[40] Dormer, *The Art of the Maker,* p. 30.
[41] Johnston, *Holographic Visions,* p. 289.
[42] Johnston, *Holographic Visions,* p. 289.

techniques of creating holograms, a capability Johnston attributes to the Artisan Holographer.[43]

John Kaufman developed the multicolor reflection technique by trial and error for reflection holograms with colour registration through pre-swelling; Steve McGrew, another student from the San Francisco school provided the mathematical approach later.

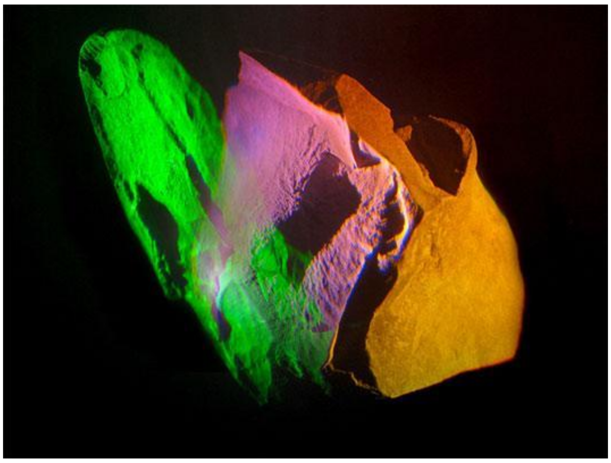

Figure 9. John Kaufman, *Canted Fragment*, 1994.

Rudie Berkhout created worlds in his holograms with the help of holographic optical elements which he designed himself tailored to his needs.[44]

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[43] Johnston, *Holographic Visions,* p. 253.

[44] Rudie Berkhout, 'Holography: Exploring a New Art Realm - Shaping Empty Space with Light.', *Leonardo*, vol. 22, No.3 und 4, 1989, p. 315; Holographic optical elements (HOE): A diffractive optical element (DOE) made holographically rather than mechanically ruled or computer drawn. Saxby, *Practical Holography*, p. 620.

Figure 10. Rudie Berkhout, *Matrix #2*.

Holography, as the complex medium that it is, cannot be categorized and split into discrete practitioner groups so easily. As a medium that seems to be in between different art worlds and still in its early stages, holography needs the artist to become the artisan, for without both approaches, holography remains static in its developmental progress. As previously noted, holography became more accessible in the 1970s principally because artisans like Cross and Pethick developed the sand table making holography more readily accessible to a wider number of practitioners. To separate the artisan and the artist in holography is not only risky but damaging to the medium. This was true in the early days of holography and is still true today. The term *Creative Holography* and *Creative Holographer*, which Pepper advocated for art holography and Johnston dismisses, are therefore more fitting, considering the wide spectrum of skills that are needed when creating holograms. The diffusion method, with its potential of making recording material more accessible and at the same time significantly expanding creative possibilities, stresses the point that holography needs both: the artisan *and* the artist. This perception has been articulated earlier by William Morris, one of the major contributors, alongside John Ruskin, of the Arts and Crafts Movement in the 19th century in England:

> Time was when the mystery and wonder of handicrafts were well acknowledged by the world, when imagination and fancy mingled with all things made by man; and in those days all handicraftsmen were *artists*, as we should now call them.[45]

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[45] William Morris, *Hopes and Fears for Art*, Ellis & White, London, 1882 p.10

My practice-based research, therefore, was principally founded upon tacit knowledge gained through trial and error experimentation, intuitive and personal experiences of manipulating materials, honing techniques, understanding the nuances and variables of different laboratory and practical contexts - and learning from these. These were the necessary artisanal steps in my practice and in my learning and their successful outcome provided the platform for artistic expression.

The language of holography

In my research I have sought to find a system that gives the practitioner the possibility of producing their own silver halide-based material but does not compel them to become a chemist.

Johnston described the relationship between the Scientific Holographer and the Aesthetic Holographer as complicated, as noted earlier in this chapter. It is a collaboration that is often challenging. Scientists and artists do not necessarily have the same goals when producing holograms. The collaboration between Casdin-Silver and Benton ended when Casdin-Silver went in her own creative direction. As Benton puts it:

> That's when it really stopped, when she really just wanted people to make holograms the way she liked them. I said 'Well, that's really not much fun for me. [...] I was really just interested in inventions, when it came right down to it. Harriet was great to work for that first year, but [...] artists just love to become independent.[46]

After that, as Johnston explains in *Artists and Artisans,* collaborations between artists and scientists appeared to fade, through various complications, often only continuing in the form of commercial relationships.[47] In my experience this is not surprising. While collaborations of this nature are necessary for both sides to evolve and look at things

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[46] Johnston, *Holographic Visions,* p. 301. Casdin-Silver gives an account of her collaboration with Benton in: Harriet Casdin-Silver, 'My first 10 years as Artist/Holographer (1968-1977) ', *Leonardo*, vol. 22, No. 3/4, Holography as an Art Medium: Special Double Issue, 1989, pp. 317-326.
[47] Johnston, *Holographic Visions,* p. 303.

from different perspectives it should not be the only viable route. When I met Blyth, we had the same goal in the beginning, which is why our time together in the lab was very successful. I wanted to learn the diffusion method and he wanted to pass on what he knew so far. The main obstacle was my restricted chemistry knowledge and the resulting communication barrier. After the necessary learning and translation, I now have the ability to pass on my knowledge in a more comprehensible way for the holography practitioner who is not specialised in chemistry. When Lloyd and Pethick met in the 1960s and made holography more accessible through the sand table, they were very much aware of the fact that only by the passing on of information in an understandable way would a difference actually be made. Melissa Crenshaw describes it as a 'down to earth way': 'Jerry (Pethick) would later write in a down to earth way about building the sand system'.[48] His book *On Holography and A Way to make Holograms* is written in the same spirit:

> Excerpts from this book defined a language that encouraged access by anyone to this rather obscure and esoteric science/art. The language he used, although technically correct, set the tone for the intimidation-busting that was necessary for holography to open up to a wide circle of practitioners. [...][49]

The first Artisan Holographers, as Johnston defines them, were on the right track. The success they had later on when establishing the San Francisco school and the many successful artists and innovators that came from that school speaks for itself. Unfortunately, such dedicated schools for holography are hard to find these days. Some universities offer courses inside the bigger scheme of physics studies and every now and then workshops pop up. The Holocentre in New York is doing exceptional work to keep holography education alive, including the possibility of exhibiting holographic art. Holographic studios exist all over the world, some even offering workshops. All these educational courses and options start with the setup and with commercially-bought recording material: these are places where holographers are taught by holographers. This is very important. New influences through scientists are also rewarding, as long as somebody does the 'translation' work into non-scientific 'down to earth' language for new practitioners. However, it is even more crucial in taking

[48] Crenshaw, 'Jerry Pethick: The Missing History of the Sand Isolation Table', p. 3.

[49] Crenshaw, 'Jerry Pethick: The Missing History of the Sand Isolation Table', pp. 4-5.

a medium forward to have a group of practitioners and educators who share the same goal: in this case to make good holographic art.

Thesis outline

In Chapter One, I discuss the limited access to standardised recording material in holography and examine the literature on holography with regard to recording material. Both aspects underline the importance of this thesis. In Chapter Two, I amplify the idea and importance of tacit knowledge in the practice of producing silver halide-based recording material. Chapter Three explains the mechanics of the diffusion method used and states the existing technical knowledge to give the reader the necessary information for understanding the process and how it is beneficial for holographic practice. A journey into the origins and roots of the diffusion method helps the reader to situate the method in the realm of light sensitive recording material. Chapter Four communicates the first steps of the diffusion method, explaining the recipe, the handling of the glass and the actual coating of the glass object. Chapter Five is concerned with the important step of putting the silver nitrate into the gelatin layer. Furthermore, important changes and improvements in the recipe are explained. Chapter Six concludes the making of the recording material, by improving its light sensitivity to the laser chosen. The recording and processing of the hologram on the finished glass objects is communicated in Chapter Seven. In Chapter Eight I conclude the research and summarise the outcome.

Chapter One

Holographic recording material

In this chapter I discuss the situation of hand-coated material in holography and how it has been considered in the literature from the 1980s till today and additionally the holographic recording material currently available on the market.

Holographic plate making in the literature

Research on the making of silver halide-based recording material for holography has been scarce. Furthermore the emulsion making technique, which is how the plates are usually made, has been adopted from film and plate making for photography and is predicated upon mass production. Holography, unlike photography, does not have a long history regarding the making of recording material. For my research, this meant that there was not a substantial body of literature specific to the making of holographic recording material which I could learn from. Three of the most relevant books are *Practical Holography* by Saxby and *Ultra-realistic Imaging* and *Silver-Halide Recording Materials* by Bjelkhagen.[50] Other than those my reference sources are principally from books on photography, as chemically the recording processes are closely related to holography.

The technical and chemical impulses which drove early photography were focused on how to fix images made with sunlight permanently. There was, inevitably, an abundance of experimentation and the evolution of a wide range of different techniques to resolve this fundamental challenge, and an extensive literature and history recorded these developments.[51] For holography, using available photographic recording material, the fundamental problem was the understanding of how light worked *rather* than in how to preserve the image. Sean F. Johnston points this out in his book

[50]Graham Saxby, *Practical Holography,* 4th ed., Boca Raton, CRC Press, 2016; Hans Bjelkhagen and David Brotherton-Ratcliffe, *Ultra-Realistic Imaging: Advanced Techniques in Analogue and Digital Colour Holography*, Boca Raton, Taylor & Francis Group, 2013; H.I. Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, Berlin, Springer Verlag, 1993.

[51] J.-C. Lemagny and A. Rouillé, (eds), *A history of Photography,* Cambridge, Cambridge University Press, 1987, pp. 11- 18; Helmut Gernsheim, *The Origins of Photography*, London, Thames and Hudson, 1982.

Holographic Visions, a History of New Science and cites Kendall Preston, an optics research manager:

> The understanding you need to be really effective in holography must come from an understanding of electromagnetic radiation, not silver halide emulsions. Therefore, you need a concentration of people whose background lies in electric field theory, and this invariably means electrical engineers and physicists rather than chemists.[52]

Johnston describes those first holographers as *Scientific Holographers*. The quote reflects the relative importance the research into silver halide was given in comparison to an understanding of electromagnetic radiation. Hans Bjelkhagen comments on this distinction in a similar way in his book, *Silver-Halide Recording Materials:*

> [...] papers on holography have continued to appear in a variety of journals, with a peak in the 70's. Most of these papers deal with holographic techniques or applications, whereas only a limited number of them is directly concerned with the recording material and the problems associated with its processing.[53]

In addition, these papers are often very specific, scientifically-focused and complex for the layperson (and, indeed, for creative holographic practitioners) in their presentation, approach, language and content. When the image making aspect of holography became more popular and a group, whose members Johnston calls *Artisan Holographers*, concentrated on teaching new holographers, a series of books on how to make a hologram came onto the market, many of which attempted to reduce the distance between expert and layperson.[54] *Practical Holography* has been the definitive book for anybody involved, or getting involved, in holography ever since its first publication in 1988. The late Graham Saxby, its author, is a recognised member of the holography community. He worked as a photographer in the Royal Air Force before joining the University of Wolverhampton, building his own holography lab and starting to teach holography. His material is known for not only being accurate, but accessible

[52] Johnston, *Holographic Visions*, p. 236.
[53] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing,* p. 8.
[54] Johnston, *Holographic Visions*, p. 268.

and easy to follow for beginners, and at the same time informative for the professional holographer.

The four editions of his book tell us a lot about how plate making in holography evolved over the years. The first edition, for example, does not mention silver halide plate making at all. Only the processing of silver halide materials is explained, as a necessary step in the making of holograms, and primarily because the silver halide process is the most widely used: ‘Several categories of light-sensitive material can be used for making holograms, but the most widely-used of these is the silver-halide emulsion’.[55] Much later in the book, Saxby explains the DCG process as one of the non-silver processes. Saxby explains the need for the practitioner to make DCG plates quickly: it was generally recognised that the shelf-life of unexposed DCG coating was very short and it was therefore best to produce the plates and use them shortly afterwards. However, Saxby did not encourage or motivate the reader to experiment with the actual production of the plates:

> The coating process is tedious, and if you are going to coat a large number of plates you need to have a high threshold of boredom (and a personal stereo).[56]

This opinion was written down by one of the most respected figures of holography at the time and the tedium of the production was confirmed by the small number of holographers who actually tried this task. The small number of practitioners making their own DCG recording material suggest that this is a view and opinion that has persisted to this day. When I presented my paper at the ISDH 2018 on Hemisphere Holography on silver halide-based hand coated glass hemispheres - the question I was most asked was why I would do that myself, as silver halide has a reputation for even greater complexity than DCG.[57] Bjelkhagen, one of the leading scientists on silver halide-based material and author of *Silver-Halide Recording Materials*, published in 1993, expresses his opinion on the issue in a similar way:

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[55] Saxby, *Practical Holography,* 1st ed., p. 68.
[56] Saxby, *Practical Holography,* 1st ed., p. 276.
[57] Christine Barkmann, Martin Richardson and Jeff Blyth, ´Hemisphere Holography’, *Proceedings of the 11th International Symposium on Display Holography – ISDH 2018*, Aveiro, UA Editora, 2018, p. 45, Appendix A.

> However, the preparation of silver-halide emulsions is a tedious and difficult process and is therefore not to recommend for normal applications of holography. Moreover, a number of manufacturers do produce silver-halide holographic emulsions.[58]

Again, the voice of a highly respected figure not only actively advises against the hand coating process of silver halide emulsions but also recommends an easier alternative, the use of commercially produced plates. Bjelkhagen does, nevertheless, describe the process of how to make such an emulsion.

The first revision to this viewpoint, or subtle change in thinking, emerged in the second edition of *Practical Holography* by Saxby, published in 1994. The former Chapter 5 of *Material, Exposure and Processing* had been moved to Chapter 6 and had been shortened by two pages. There was no further mention of hand-coating and the making of silver halide-based recording material. The DCG process, however, was a different matter. The discouraging comment on coating plates is missing, and in contrast, Saxby now writes that: '[…] DCG techniques are now becoming popular with private holographic enthusiasts.'[59]

The next part of the Chapter was even dedicated to a new method to sensitize the DCG process for a red HeNe laser. This makes the DCG process more accessible as blue and green powerful lasers, which the DCG process usually relies upon, are much more expensive and harder to obtain. Saxby claims that 'The success of this technique has been confirmed many times, and DCG holography with a HeNe laser is now well established'.[60] However, there are few examples of such holograms around at present. The appendix in the second edition, *Processing Formulae*, consisting of mainly recipes for developer, bleach and other minor corrections, was now extended and included a section on the *Preparation of a red-sensitive dichromate (DCG) emulsion.* With little changes this development on DCG hand coating is also found in the two subsequent editions.

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[58] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 34.
[59] Saxby, *Practical Holography,* 2nd ed., p. 346.
[60] Saxby, *Practical Holography,* 2nd ed., p. 347.

From the release of the first edition in 1988 to the revision of the second edition in 1994, the hand coating of the DCG process had evolved from an initially tedious task to a more viable and popular practice. As the holographic community is small, however, the concept of 'popular' has to be seen in context. It did not mean that the DCG process took over and became a dominant method; silver halide was, and still is, the most widely used method, but it gave holographers the chance to produce their own material and avoid the high costs of commercial material. Saxby commented to this effect in the 3rd edition of *Practical Holography*, published ten years later, in 2004: '[…] DCG techniques are now becoming popular with private holographic enthusiasts, not least because of the cheapness of the raw materials'.[61] In the 3rd edition the appendix on processing formulas is extended once more, with an additional section on *Making your own holographic emulsion.*[62] The holographic emulsion explained in the appendix is one of the early versions of the diffusion method. It was given two pages of explanation but no mention in the chapter on *Materials, Exposure and Processing*. It nevertheless shows, by the fact that it was included in what was perhaps the key book on holography that the mindset was changing. The making of one's own material was now more than just a tedious task that would test the boundaries of boredom. In addition, Saxby acknowledges in the third edition, for the first time, that the reader might feel the need to read up on more information concerning silver halide material:

> If you feel that this Chapter has gone through everything at a bit of a gallop, you can stop and admire the scenery in detail, at least as far as silver halide technology is concerned, with Hans Bjelkhagen's book Silver Halide Recording Materials for Holography and Their Processing [...].[63]

Bjelkhagen's book is also one of the definitive books to read for anybody working with holographic recording material. It was published only a year before the second edition of Saxby's *Practical Holography*, and Saxby recommends it highly to 'anyone who wishes to experiment with emulsion and processing systems'.[64] It is also indicative of the changing perception of the importance of the control over the recording material at the time, that Saxby gives the reader not only references and guidance for further

[61] Saxby, *Practical Holography,* 3rd ed., p. 316.
[62] Saxby, *Practical Holography,* 3rd ed., pp. 475-477.
[63] Saxby, *Practical Holography,* 3rd ed., p. 65.
[64] Saxby, *Practical Holography,* 2nd ed., p. 528.

research but even expresses the feeling of having previously covered the subject too quickly.

Up to this point, as mentioned before, books on different aspects of holographic practice had been written, explaining in detail the optics and physics of holography, how to start a holography practice, to build a laboratory and how to shoot the first hologram.[65] Most of them included a chapter on processing chemicals but unfortunately all of them were oblivious to silver halide-based plate making and therefore not of direct interest for my research. However, this now seems to have changed.

Bjelkhagen, despite his discouraging words about plate making quoted before, launched a new project in 2004: the European-funded Silver Cross Project, a project for the mass production of silver halide recording material for full colour holographic applications.[66] Besides Bjelkhagen, it brought together four experts in the field of silver halide recording materials; Darran P.M. Green, who worked extensively on the Lippmann technique and therefore on fine grain silver material; Professor Nicholas J. Phillips, an expert in processing methods; Peter G. Crosby who had previously worked with Bjelkhagen on applications for colour holography; and Evangelos Mirlis, a PhD student of Bjelkhagen.[67] The project was carried out from 2004 to 2007 and concluded with the successful recording of full colour holograms with high efficiency and low noise. The necessity of this research at such an advanced point of holography practice reveals the prior lack of praxis based knowledge in the field. Even though silver halide-based holographic material existed commercially there had always been considerable secrecy about its production. Bjelkhagen commented on it as follows:

[65] In addition to Saxby's *Practical Holography*, see P. Hariharan, *Optical Holography; Principles, Technique, and Applications*, 2nd ed., Cambridge. Cambridge University Press, 1996 and P. Hariharan, *Basics of Holography*, Cambridge, Cambridge University Press, 2002; John Iovine, *Holography for Photographers,* Boston; Oxford, Focal Press, 1997; Joseph E. Kasper, Stephen A. Feller, *The Complete Book of Holograms; How they work and how to make them*, New York, John Wiley & Sons, Inc., 1987.
[66] SilverCross - Final Report Summary, [website], 2007 https://cordis.europa.eu/project/rcn/86350/reporting/en, (accessed 11 January 2019).
[67] N.J. Phillips, D. Porter, 'An Advance in the Processing of Holograms', *Journal of Physics*. Part E 9, 1976, pp. 631-634; Hans I. Bjelkhagen, Darran P.M. Green, 'The True Colour of Photography', [website], http://nebula.wsimg.com/9b5cae4ea96ef01114473b7a87bfc276?AccessKeyId=35F2F777C356CDF4D97C&disposition=0&alloworigin=1, (accessed 3 June 2018).

> [...], the number of papers dealing with the preparation of holographic silver-halide emulsions is quite small, especially when compared to the amount of literature published on dichromate gelatin plates for holography. The reason for this may be that although commercial companies have extensive knowledge of the field, much of it is regarded as industrial secrets and does not appear in the scientific literature.[68]

Saxby had also commented in the first edition of *Practical Holography* upon the inadequacy of papers written on DCG in terms of praxis when he wrote 'There have been a great many papers on DCG holography, and most of them have proved unreliable in practice'.[69]

The same appears true regarding silver halide material, even though the amount of written papers is considerable smaller, as noted before. Many of the published sources and paper are for scientists and not for the average practitioner, while others are written about very specific aspects of a problem.[70] The prevailing literature on silver halide-based emulsions, and the complicated nature of it, underlines the popular opinion that producing silver halide material is too complex a task. As noted before, this prevailing opinion is changing with the emergence of projects such as Silver Cross, greater transparency of research findings and communication, and, indeed, with the publication of the fourth edition of *Practical Holography*. In this most up-to-date edition, published in 2016, Saxby worked with a co-author, Stanislovas Zacharovas, the director and head researcher at Geola Digital at that time. They changed the structure of the fourth edition and Chapter 5 on *Materials, Exposure, and Processing* expanded noticeably. A major difference to previous editions was that silver and non-silver processes were no longer categorically separated and the DCG process found its place, including the coating of plates, alongside the silver halide materials and processes. However, how to actually coat and make a silver halide-based emulsion was still relegated to the appendix with only little changes from the version in the third edition.

[68] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 34.
[69] Saxby, *Practical Holography,* 1st ed., p. 275.
[70] P. Mas-Abellana, R.F. Madrigal, A. Fimia, 'Ascorbic Acid in Reflection Holography', *ISDH 2018 Proceedings,* Aveiro, UA Editora, 2018, pp. 233-235.

Two other books about the techniques of holography with regard to the making of silver halide material are worth consideration. Bjelkhagen's second book *Ultra-Realistic Imaging* written in collaboration with David Brotherton-Ratcliffe, was published in 2013.[71] The Silver Cross Project is discussed and Bjelkhagen now, in contrast to his first book, actually recommends the self-production of holographic material, due to the poor and unreliable supply of commercial material:

> As such, the serious worker in modern colour holography often needs to consider either sorting and calibrating commercial batches before use or, in many cases, actually producing the materials in-house.[72]

The 2018 published book *The Hologram, principles and techniques* by Martin J. Richardson and John D. Wiltshire, mentions the diffusion method briefly in its Chapter on *Recording Material for Holography* but no detailed account on the coating process is given.[73] Nevertheless, examples such as these and the increasing reference to plate coating in important holographic literature indicates a change in the mindset of the authors and readers. Awareness of the importance of control over the holographic recording material is increasing.

Commercial holographic recording material

The perception that making silver halide plates was too complex a task and the fact that recording materials for holography were readily available unfortunately led, therefore, to a stagnation in research in the field of recording material by practitioners. This has deprived holography of a potentially fruitful and beneficial journey in creativity in the realm of silver halide recording material. Equally, an initially optimistic view towards a greater variety in creative choices can change easily, particularly when the first experience of hand coating plates results not in a bright joyful hologram but in a dim, obscure hologram on a dirty plate. Sometimes the chemistry will play a trick before that and you end up with a fogged plate even before exposure.

[71] Bjelkhagen and Brotherton-Ratcliffe, *Ultra-Realistic Imaging.*
[72] Bjelkhagen and Brotherton-Ratcliffe, *Ultra-Realistic Imaging,* p. 89.
[73] M. Richardson and J.D. Wiltshire, *The Hologram*, West Sussex, John Wiley and Sons, 2018, p. 105.

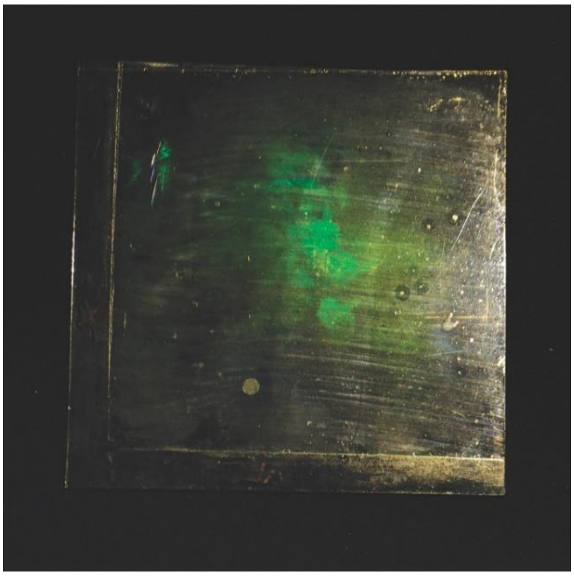

Figure 11. A dirty plate, not uncommon when starting to coat silver halide-based recording material.

During my research, more than once in the lab on the long journey of experimentation to find a feasible hand-coating method, I asked myself: Why go through all this trouble, when photographic plates, particularly today when plates meet holography's high-quality demands, are readily available?

There are, nevertheless, a few points to consider in the favour of handmade recording material. For instance, the problematic accessibility of affordable recording material and its changing characteristics as much as the limited variety of such material which, in turn, produces an equally limited visual outcome. In this part of the chapter I amplify on these problems and clarify why the situation has reached a point where hand coated plates are a complex but, more importantly, a necessary alternative.

Holographic recording material has its roots in conventional photographic practice and development. Gabriel Lippmann was the first to make an image through the recording of an interference pattern.[74] This is the recording of the moment when two laser light

[74] Hans I., Bjelkhagen, 'Lippmann Photography', *History of Photography*, 23(3), 2015, pp. 274-280; N.J., Philips, 'Links between Photography and Holography: The Legacy of Gabriel Lippmann', *Proceedings of SPIE,* 523, 1985, pp. 313-318; Jean-Marc, Fournier, 'Interference Color Photography: One Hundred Years Later', *Journal of Optics*, 22, no.6, 1991, pp. 259-256.

waves meet and the very basis of holography.[75] Lippmann was looking for a way to achieve colour photographs and produced fine-grain plates that met the demanding requirements needed to record an interference pattern. Good quality material is available now, derived from Lippmann's fine grain plates. The material is, however, expensive and unfortunately prone to inconsistent results in reacting exactly in the same way to laser light from batch to batch.[76] Due to the complexity of the production of fine grain recording material, only a few reliable suppliers exist on the worldwide market of which three are recognised for the high quality they produce: Colour Holographics in the UK, Ultimate Holography in France and Slavich in Lithuania.[77]

Unfortunately, it does not seem like this narrow market is going to change and expand in the near future, as manufactures who discover methods of making high quality emulsion often restrict the precise details of their processes in the interest of industry confidentiality, a not uncommon phenomenon in the history of light sensitive material development.[78] Richard Leach Maddox, the inventor of silver-bromide in gelatin emulsions, although known as the gelatin dry plate, printed his findings quickly and therefore made it possibly to reveal the photographic practice and disclose the chemical process involved to a far wider audience. Maddox' laboratory notes were printed in the *British Journal of Photography* in 1871, with a plea for other researchers to continue and complete his experiments:

> As there will be no chance of me being able to continue these experiments, they are placed in their crude state before the readers of the Journal, and may eventually receive correction and improvement under abler hands.[79]

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75 *Interference:* 'When two coherent wavefronts of the same frequency are superposed, their instantaneous amplitudes add algebraically at every point. If the amplitude of the resultant is greater than that of the component waves, the interference is said to be constructive; if it is less, the interference is said to be destructive.' *Interference fringes*: 'The pattern of light and dark bars that appears on a screen when it is positioned in the path of two interfering light beams.' Saxby, *Practical Holography,* 4th ed., p. 621.

76 Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 94.

77 http://www.slavich.com, https://www.ultimate-holography.com, and https://www.colourholographic.com (accessed 11 January 2019).

78 Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 34.

79 R.L. Maddox, 'An Experiment with Gelatino Bromide', in B. Newhall (ed.), *Photography: Essays and Images*, New York, The Museum of Modern Art, 1980, p. 145.

In the years following Maddox' initial explanations, the first emulsion on the market was manufactured in secret by John Burgess, in spite of Maddox' transparency about the process. This secrecy in the chemistry of photography struck historians like Baines as a new phenomenon:

> Prior to the 1870's it had been the usual practice to publish improvements in emulsion-making technique so that they could be generally adopted. Now that livelihoods depended upon the quality of the material, the tendency to publish methods of improvement diminished, and as early as 1873, Burgess marketed a dry plate made according to a secret formula, thus setting the pattern for subsequent manufactures.[80]

This secretive behaviour became more common, however, and continues with modern holographic recording material suppliers, as Bjelkhagen notes:

> [...], the number of papers dealing with the preparation of holographic silver-halide emulsions is quite small, especially when compared to the amount of literature published on dichromated gelatin plates for holography. The reason for this may be that although commercial companies have extensive knowledge of the field, much of it is regarded as industrial secrets and does not appear in the scientific literature.[81]

This secrecy about the production of the material was not a problem in the early days of holography, because when holography was invented it was only natural to use recording material that already existed. Lippmann had shown how interference pattern could be recorded on fine grain silver halide-based emulsions, producing colour photographs, and so the companies supplying the photographic industry started producing holographic recording material as well. An evidently shared heritage, and underlying common principles, created a perception of holography as an offshoot of photography, particularly in darkroom practice, rather than as a distinct and specific practice in its own right. The comparison between holography and photography started in the early days of holography in the 1960s and continued, ultimately defining the two

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[80] H. Baines, *The Science of Photography,* London, Fountain Press, 1958, p. 21.
[81] Bjelkhagen*, Silver-Halide Recording Materials for Holography and Their Processing*, p. 34.

mediums as sharing common fundamental principles but delivering separate and different visual outcomes. The early names given to holography reflect this association with photography. Yuri Denisyuk, the inventor of the reflection hologram, called holography 'Wave Photography', while in America holography was known as 'Lensless Photography'.[82] In England it was often known as 'Wavefront Reconstruction' after Dennis Gabor, its inventor.[83] Margaret Benyon, sometimes referred to as 'mother of British holography', called holography '3D Photography'.[84] Holography was practised, and perceived, as a different visual branch of photography by the audience and the practitioner.

Consequently, in the early stages of holography's development, holographic plates were supplied by established producers of photographic material. Manufacturers, such as Agfa-Gevaert, Eastman Kodak, Ilford, saw a new market in the production of holographic material.[85] All of these suppliers have subsequently suffered, however, due to the decline of analogue photography and the rise of digital applications, and many of them have since abandoned the production of holographic material. Ilford was the first to do so, in 1993, as Bjelkhagen noted:

> After the manuscript [of the book *Silver Halide Recording Material*] was completed, Ilford ceased the production of holographic materials. Instead of removing the Ilford section, it was kept for comparison and historical reasons. Included are also many Russian and some East-European materials.[86]

In the second edition of Graham Saxby's *Practical Holography,* only Agfa and Kodak were left in the list of suppliers:

> Agfa emulsions are available world-wide; Eastman Kodak emulsions are not generally available in Europe. Ilford no longer manufactures holographic

[82] Yuri, Denisyuk, 'My way in Holography', *Leonardo*, vol. 25 No.5, 1992, p. 426; Yuri, Denisyuk, *Fundamentals of Holography*, Moscow, Mir Publishers, 1984.
[83] Dennis Gabor, 'The principle of wavefront reconstruction', in Camatini, *Optical and Acoustical Holography*, pp. 9-14.
[84] Jonathan Duffy, *Holograms: High art or just a gimmick?*, [website], http://news.bbc.co.uk/1/hi/magazine/3832361.stm (accessed 4 July 2018).
[85] Saxby, *Practical Holography,* 1st ed., UK, Prentice Hall International, 1988, p. 69.
[86] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 93.

> materials. Emulsions are sometimes available from Eastern Europe and the Far East, but information is scanty.[87]

This decline in supply, and apparent dearth of information, with even a major manufacturer such as Ilford giving up production of holographic material entirely in the mid 1990s, went hand in hand with a fading of interest in holography. During these years, the Royal College of Art closed its Fine Art Holography Department and The Museum of Holography in New York closed its doors.[88] Holography, as an artistic and creative practice persisted, however, and the need for specialist suppliers and manufacturers of holographic material generated a new range of providers. Slavich in Lithuania, Color Holographic in the UK and Ultimate in France, became the standard bearers and suppliers for the decreasing but enduring market for holographic material, as noted by Saxby in 2016.[89] Due to the small size of the market, holographic plates were, and still are, expensive -and often only fabricated on demand. This can lead to long production and delivery times and, in addition, process details are still mostly protected and kept a secret. This market specialisation of the recording material to produce high quality holograms has perhaps been an inevitable consequence of changing demands but while the quality of the plates is better than ever, accessibility and general availability has reduced. All of these circumstances have led to diminished and restricted options for recording material for holographic practitioners; and ultimately to standardized and expensive materials which can be difficult to obtain. In this context, it is remarkable that not more holographers are working on producing their own material.

Holographers who do produce their own material tend to use a method mentioned before, based on dichromate gelatin, called DCG, rather than silver halide material. The DCG process has its roots, as the silver halide-based material, in photography, like the gum bichromate process, for example.[90] Both processes, DCG and silver halide, have

[87] Graham, Saxby, *Practical Holography,* 2nd ed., p. 59.
[88] Sheila Rule, 'Museum of Holography in SoHo Closes, Citing Finances', *New York Times*, 5 March 1992, https://www.nytimes.com/1992/03/05/arts/museum-of-holography-in-soho-closes-citing-finances.html (accessed 14 march 2019); Sean Johnston, *Holograms: A Cultural History*, Oxford, Oxford University Press, 2015, p. 136.
[89] Saxby, *Practical Holography,* 4th ed., p. 96.
[90] Robert, Hirsch, *Photographic Possibilities: The Expressive Use of Equipment, Ideas, Materials, and Processes*, New York, Focal Press, 2009, p. 217; N.J., Phillips, et al., 'Dichromated Gelatin – some

advantages and disadvantages, in terms of chemical processes involved, and in difference of outcome. Silver halide-based material has a higher sensitivity to light, which is advantageous for exposure time, but more difficult to handle when coating, as a lot of the work has to be done under dim safelights. DCG on the other hand, has a far higher level of toxicity than silver halide and demands a much higher-powered laser in the blue or green frequency than silver halide which can be shot with a low powered red Helium Neon (HeNe) laser, which is cheaper and more easily obtainable.

While a DCG hologram needs to be sealed after processing, as it suffers from, and can be destroyed by, air humidity, silver halide materials by contrast suffer from print out, and the hologram may turn darker over time, particularly if any unexposed silver halides are left in the emulsion. DCG holograms tend to have the higher diffraction efficiency which means they are often brighter, and in addition, they generate a different palette of tones compared to silver halide materials, which are the first choice for panchromatic material, reproducing real colour.[91] All this leads to different brightness and different colour palettes. This is now a choice the practitioner is able to make. Up till now, practitioners who wanted to use DCG hand coat their plates, as the ready-to-shoot DCG plate has a very low shelf life and needs to be used soon after production. The holographer using silver halide material, by comparison, could buy the plates and store them in light-tight boxes for later use. This thesis contends that the holographic practitioner can exercise a greater choice by presenting a feasible method for coating silver halide material.

This choice is important and it brings me back to the dim foggy hologram on a dirty plate. The history of photography is characterised by an immense variety of different techniques, printing and processing materials and therefore visual outcomes. It was only through research and experiments during photography's explorative developmental phases that Lippmann developed interference colour photography, supplying the first plates for holography. The standardised options for silver halide-based recording material holographers which are currently offered limit the creativity of

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heretical comments', *Practical Holography VII: Imaging and Materials, Proceedings of SPIE1914,* 1993; D. Meyerhofer, 'Dichromated Gelatin', in H. M. Smith, *Holographic Recording Materials*, Berlin, Springer Verlag, 1977, pp. 75-100.

91 *Diffraction efficiency*: 'In a hologram, the ratio of image-forming to incident light in terms of intensity.' Saxby, *Practical Holography,* 4th ed., p. 616.

the holographer and ultimately undermine and jeopardise holography's attraction to practitioners and a wider audience as an image making medium.

With my research I have proved that, despite technical challenges, there are rewarding creative benefits for practitioners in making their own recording material. There is a double liberation: the practitioner is liberated from the standardised products on the market and holography itself is liberated from the standardised two-dimensional substrate, the glass plate. Once the process of coating has been practised and is successfully achieved, the substrate can be any shape the holographer wishes it to be. The recording material is a pivotal part of the process and cannot be overlooked simply because of the popular and outdated perception that the making of silver halide-based recording material is too complex.

Chapter Two

Tacit knowledge in holographic plate making

Chapter 1 explained why the option of hand coated material is increasingly a necessity for holographic practice and provided me with the evidence for the need of further research into silver halide recording material for holography. The goal of this chapter is to explain why a practical approach for research in the field is essential. It does that by exploring the making of holographic recording material as a craft, and therefore as a hands-on medium learned through the act of making. I examine the importance of tacit knowledge in learning to use the diffusion method to produce holographic recording material and how this knowledge is created through making. Even though tacit knowledge cannot be written down, I found that an awareness of the processes involved in gaining tacit knowledge was, in itself, a major part of my methodological practice: an understanding of tacit knowledge, and the conscious experience of developing it, changes the attitude towards a complicated task, and in itself becomes a key to success.

For the practitioner this shifts the perception of the task from being too complex to being manageable with a certain amount of practice. Furthermore, in this chapter I examine the experience of working hand-in-hand with a scientist in the lab and the step from there to further learning by working on my own. Both methods are practice-based approaches and in both cases the learning takes place through making rather than upon relying on texts.

Plate making is a process that requires practice and a certain amount of experience to be successful. Michael A. Robinson recently stated in his thesis on *The Techniques and Material Aesthetics of the Daguerreotype* that in Daguerreotype ‘It is important to recognize the role of human agency when investigating the daguerreotype processes because it is essentially a handmade system’.[92] The same applies to holography when coating material.

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[92] Daguerreotype: ‘In this process, a copper plate that has been coated with silver, polished, and sensitized, is exposed to light and then chemically treated to produce and fix a single positive photographic image. The finely detailed picture that results from the process alternately appears to its viewer as a positive or

Robinson expands on this further when talking about the polishing of the silver plate in preparation for the recording of a Daguerreotype: 'This requires experience and craft knowledge, otherwise known as tacit knowledge'.[93] Tacit knowledge and the role of human agency are the factors that make it so difficult to learn from texts when practicing a craft, as they are not easy to convey in text. Robinson's whole research motivation is to rediscover the tacit knowledge in the process of making Daguerreotypes:

> As a contemporary Daguerreian artist with over sixteen years' experience making daguerreotypes, I have the skills to replicate the methods of nineteenth century daguerreotypists in order to re-discover tacit knowledge omitted from the historical record.[94]

In order to create or rediscover tacit knowledge, practical work is not only important but inevitable. Tacit knowledge cannot be obtained through texts but by observation, experimentation and experience.

Saxby writes in *Practical Holography* that the texts for DCG coating are unreliable.[95] The skills and understanding provided by tacit knowledge are absent from texts. By this understanding, the account Saxby gives in *Practical Holography* on how to coat plates following the recipe for the diffusion method is unreliable.[96] Not because the information is wrong in itself, but because making photographic or holographic plates is ultimately a craft involving tacit knowledge that cannot be measured and given out like a recipe. Polanyi calls recipes the 'Rules of art' that 'can be useful, but they do not determine the practice of an art; they are maxims which can serve as a guide to the art only if they can be integrated into the practical knowledge of art. They cannot replace this knowledge.'[97] The concept that recipes and rules in the field of crafts, in other words explicit knowledge, are helpful but only a first step, is shared by art critic Peter Dormer:

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negative, depending on the angle of light in which the cased mirror-like plate is held.' See: John Hannavy (ed.) *Encyclopedia of Nineteenth-Century Photography Vol.1*, New York-London, Routledge, 2008, p. 367; Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. 39.

[93] Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. 2.

[94] Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', pp. 2-3.

[95] Saxby, *Practical Holography,* 1st ed., p. 275.

[96] Saxby, *Practical Holography,* 4th ed., p. 595.

[97] Michael Polanyi, *Personal Knowledge: Towards a Post-critical Philosophy*, London, Routledge, 1997, p. 50.

> Recipes are useful in the process of learning a skill; they are useful in the exercise of expertise; but they become handicaps if they constitute the entirety of one's practical knowledge.[98]

The notion that there is more than a detailed recipe to the success when learning a skill is crucial and is shared by Suzanne B. Butters, who writes about passing on knowledge in *Ways of Making and Knowing* and what happens when a food recipe is given to a beginner in the kitchen:

> But novices are not always able to produce decent food, even with long recipes, whereas talented and experienced cooks can produce exquisite results with very short ones, because they can transcend the instructions and improvise.[99]

Tacit knowledge, formed from experience and from practical and gestural knowledge, is vital in successfully interpreting a recipe, whether in cooking or in the coating of recording material. The old photographic processes, where the diffusion method has its roots, serve as a good example. Photographers who practice the wet collodion process today, have developed a workshop culture, where the craft is passed on directly from master to apprentice.[100] This was and still is a crucial method for the practitioner to create and develop tacit knowledge. As Robinson stresses in his thesis: 'Tacit knowledge is retained and transferred directly from master to apprentice and throughout a community of practitioners.'[101] I agree about the importance of a community and a workshop culture to transfer parts of the tacit knowledge and to create space for developing tacit knowledge, I disagree, however, that tacit knowledge can be passed on completely, as it is connected to the experience and individual knowledge each practitioner develops and, ultimately, uniquely possesses. Later in the text Robinson emphasises this point: 'Artisanal knowledge exists tacitly within the

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98 Peter Dormer, *The Art of the Maker,* London, Thames and Hudson Ltd., 1994, p. 56.
99 Smith, Meyers and Cook (eds.), *Ways of Making and Knowing*, p. 59.
100 Wet Collodion Negative: 'The process derived its name from the use of collodion in liquid suspension to coat glass plates at the beginning of the sensitizing process before exposure.' See:
John Hannavy, (ed.), *Encyclopedia of Nineteenth-Century Photography Vol.2*, New York-London, Routledge, 2008, p. 1485: for more information on the wet collodion process: Helmut Gernsheim, *The Rise of Photography 1850-1880; The Age of Collodion*, London, Thames and Hudson, 1987.
101 Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. 3.

craftsperson and is specifically learned through experience and apprenticeship. Such know-how, for the most part, lies outside of the textual record'.[102]

Unfortunately, in holography a workshop culture for plate making, and especially silver halide-based material, is not only not a common practice, it simply does not exist.

Scientist/ artist collaboration

Without a workshop culture for making silver halide-based holographic recording material, it was not possible for me to learn the craft directly from a master in an apprentice-type relationship. However, I was able to engage in a scientist/ artist collaboration. In his book, *Holographic Visions: A History of New Science*, Sean F. Johnston has written about the scientist/ artist collaboration, remarking upon its limited success, quoting Steve McGrew:

> Collaboration between scientists and artists in holography is mostly a myth. A few members of the scientific community, tossing out tidbits to hungry artists, have done their reputations a lot of good while not doing more than momentary good for art holography.[103]

Harriet Casdin-Silver, an artist holographer who had collaborated with different scientists, echoes this perception:

> Even Harriet Casdin-Silver was concerned about the 'second class citizenship of the artist in this supposed union of scientists and artists. Everyone working together to send holography into space. The artists know this is untrue.[104]

Jeff Blyth, a chemist and a former researcher at the Institute of Biotechnology in Cambridge, UK, who started his investigation into holographic recording material in the late 1970s, was working on developing the diffusion method when I joined him in the

[102] Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. 28.
[103] Johnston, *Holographic Visions*, p. 303.
[104] Johnston, *Holographic Visions*, p. 303.

lab at De Montfort University in Leicester, and fortunately my experience was quite different. My time in the lab with Blyth has been a fruitful learning experience for me.

Holography practitioners in general have an idea of the chemistry involved in silver-halide holography, as the method relies on a wet process after the exposure to be developed, much like photographers working in a black and white laboratory. They know about the chemical mechanism but not necessarily about how the recording material they work with is produced. That was similar to my starting point. My education up to this point had been in photography, including working in both black and white and colour photography laboratories. I found myself starting out with a limited, yet existing, knowledge of chemistry, when I met Blyth.

I have learned a lot by just being there, observing Blyth's movements in the dark with only a ghostly green or sometimes red safelight. To some degree, the problems of scientist/ artist collaborations described above still apply. As there is no workshop culture, there are no rules and a common language does not exist. Questions I occasionally asked were always answered but at that stage mostly in the more specialist language of chemists. I would write the answer down as accurately as I could and translate it later with the help of beginners' texts in chemistry and from my knowledge of light sensitive material in photography. This pragmatic approach, and my complete engagement in an entirely new world, gradually transformed into an intense study of how knowledge of plate making is formed. I *now* know, from experience, that close and engaged observation of somebody performing the craft is a major necessity.

I had read Blyth's recipe on the diffusion method which was available online, where people would also post problems and queries.[105] One problem which emerged from the online discussion was that the gelatin would not dissolve properly after putting in the 4 ml of glycerol noted in the recipe. The advice was to reduce the glycerol, check if it might be contaminated or just leave it out altogether. But why would 4 ml of glycerol work for Blyth but apparently not for everybody else? I learned the answer when I worked in the lab alongside Blyth: the 4 ml of glycerol never fully made it into the emulsion. A good portion, as glycerol is a rather viscous and sticky substance, stuck to

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[105] Jeff Blyth, 'New Ag Coating Process', *holographyforum*, [web blog], 6 June 2017, https://www.holographyforum.org/forum/viewtopic.php?t=8578 (accessed 19 February 2019).

the glass of the beaker it was measured in. It would had never occurred to me that this could generate a problem. I had the advantage that I had been there and in many ways I could just copy procedures which I had observed and could therefore change them later on where I found appropriate.

Being in the lab with a scientist like Blyth can be simultaneously very frustrating and immensely rewarding. The fact that I had to learn *his* specialist language made it more challenging. My knowledge about plate making was mainly formed by observing and listening to things which I was not even close to understanding initially. When I first joined Blyth in the lab, he was in the middle of working on the diffusion method. The first task I actually did by myself was putting the silver into an already coated plate. Issues such as how the gelatin was actually coated, why it stuck to the plate, and the fact that that could even be a problem, were things I learned much later in the lab process. Although it would have been certainly easier for me to understand the underlying mechanisms and processes from an informed chemistry viewpoint, this situation was never a problem (certainly not one which Blyth had to solve), but much more a defect in holography practice and the fact that there is a gap of research that my thesis would start to fill. I now, after learning in practical collaboration with Blyth, have working experience and knowledge of the diffusion method. I can now pass this on to fellow holographers in a more accessible and comprehensible, non-scientific language.

McGrew speaks about ‘momentary good for art holography’, a lot depends, however, on what the artist can take with him from an experience that transforms useful knowledge from the *momentary* to *permanent.* After I learned the basics with Blyth, we operated and worked separately. My next step had to be the task of working with the method on my own, on improving it, of creating permanent knowledge and actually making it possible to realise an artistic project using the diffusion method. That was not Blyth’s goal. He liked to see the method work but was well aware of the fact that it had to move on from his research if it was to be transformed into a common practice in creative holography.

Learning by doing and forming tacit knowledge

In this initial period, I had been simultaneously observing and actively working on the development of the diffusion method with Blyth for five months, once or twice a week. It had given me a good insight into how to coat plates, in using Blyth's method and in how to use the chemicals. This period proved a vital stepping stone for me as it gave me the knowledge I needed to develop my own way of managing in the lab. Alone in the lab, I had to first of all test where I was standing. To have a starting point, I repeated the wine glass experiment. When Blyth had exposed the wine glass, I still had not joined him in the lab. I had never observed him actually coating a wine glass, but the process is explained in the publication of the diffusion method.[106] I entered now into the second phase of producing knowledge about handmade recording material in holography, combining a recipe and the tacit knowledge I had created about the making of recording material on plates. The first coating alone went well, but there was room for improvement, as anticipated. Coating a plate and coating a wine glass is not the same, even though the recipe may be.

Figure 12. Hologram of Domino Stones in a Wine Glass.

First, I had been observing and imitating: now I was experimenting by myself, something Dormer describes as 'intelligent studentship':

[106] Jeff Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', *The Royal Photographic Society 3D Imaging and Holography Group Newsletter*, 2016, p. 93.

> Practical know-how is a spur to conceptual reflection: it prompts questions such as 'what happens if I try it this way?' Such questions, however, imply you have a choice: that choice is only earned by intelligent studentship.[107]

Observation and experimentation when learning a skill go hand-in-hand in order to pose critical questions about the process and therefore develop it further. Both are important in the development of knowledge about a craft as is pointed out in the introduction of *Ways of Making and Knowing*:

> More intensive examination of material practices makes it clear that the methods of the artisan represent a process of knowledge-making that involved both extensive experimentation and observation and generalizations about matter and nature.[108]

After coating and recording a hologram in a wine glass I moved on to hemispheres. Hemispheres had not been used as a substrate before in holography, and were an interesting shape to experiment with. First of all, it was not too removed from the shape of the wine glass, and this gave me confidence. And secondly, as my ultimate goal was to create a 360 degree hologram, the idea was eventually to move from hemispheres to glass bubbles and to analyse the reaction of the audience.

[107] Dormer, *The Art of the Maker,* p. 57.
[108] Smith, Meyers and Cook (eds.), *Ways of Making and Knowing,* pp. 12 -13.


Figure 13. Space-Bubble for the exhibition *Steampunks in Space.*

It soon became evident that changing the shape of the object to be coated changed the method required. The whole process broke down and the diffusion method stopped working. The hemispheres were foggy and milky blue before even exposing them to laser light. To record a hologram was out of the question. This changed the goal of the research and shaped my understanding of how craft knowledge is generated. The research now focused on getting the process to work. Even with the help of correspondence with Blyth, I could not find an answer to this unexpected failure of the method. Only through practice, observation and actually trial-and-error experimentation, could I finally solve the problem. I had reached a point of frustration in my research, when there seemed to be nothing else to do but to continue coating hemispheres. Thinking about the problem and reading about the chemical compounds and what might have gone wrong, did not bring an answer and neither did any of the changes I would make in the recipe.

This was the point when the tacit knowledge Blyth had passed on reached its limits but was recreated by me for the coating of the hemispheres. Working on the holograms, I realised that due to the experience I had gathered and my familiarity with the hemispheres, when coating them, my movements had changed from being hesitant and interruptive to one smooth and flowing motion. My gestural knowledge had adapted to the new shape. The recipe remained mainly consistent, and any minor changes I made are explained in Chapters 4 to 7: the real change was that of tacit knowledge. Consequently, the hemispheres could not be handled like the plates had been handled. An extensive observation of the material went along with the repetitive task of coating the hemispheres and seeing the system fail. The fact that no two hemispheres in the lab were exactly the same finally helped to solve the problem. Due to individual irregularities, little bumps, bubbles and slightly different shapes and the particular characteristics of each and every hemisphere, knowledge about the hemispheres could not be generalised as had been possible with plate making. A detailed account of the failure of the initial system and the eventual solution is found in Chapter 5 in the section *Troubleshooting and improvements.*

Occasionally one hemisphere would work, but to establish a reliable system it was important to find out why. A big part of my research was forming the tacit knowledge of the coating of curved surfaces, as the experimentation and observation of the material is a lengthy undertaking.

The fact that tacit knowledge is not completely transferable makes my practical approach yet more important. Apart from the tacit knowledge and all the variables, such as the temperature in the lab and of the solutions, the humidity, and the consistency of the gelatin - all of which can affect the successful outcome - an equally important factor is the human agency, as noted before. Robinson summarises in his thesis:

> Historians, curators and material scientists, engaging with the latter historic literature, have perceived a standardization of practice, and lacking tacit and gestural knowledge of the art, have not recognized that the daguerreotype is a highly malleable process dependent on upon the nuances of human agency.[109]

This statement applies to the making of recording material for holography and makes it even more understandable why any dependence upon written accounts are often unreliable. Furthermore, I know from experience that such anecdotal concepts as *not a good day for holography* and the *gut feeling* do exist. They are, however, connected to very measurable factors like air humidity or the external temperature, especially

[109] Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. 343.

when working in a lab, where those factors are not controlled. But they are also connected to practice, routine and experience, through to a point in practice where it may seem that choices are made by intuition, but actually are the fruitful result of accumulated experience. This experience of learning a craft and the challenge of getting to that point of *intuition* has been documented before:

> Learning a skill is not the same as being an expert. Being an expert in a body of craft knowledge means living that knowledge. The problem with being a beginner at a skill, or even at being 'pretty proficient', is that fluency in the body of knowledge cannot be taken for granted. This makes learning a skill a hard business: doing a skill badly when wanting to create something excellent is a demoralizing experience. [...] Learning a skill is not a mechanical activity but an emotional as well as intellectual and physical process.[110]

The emotional factors, and the level of frustration, when learning a craft, are not to be underestimated. I was determined to make the diffusion method work, as I had experienced how much creative energy and satisfaction it brings to actually produce a hologram out of nothing.

An important part of my research, especially when I was on my own, was to understand how intrinsically tacit knowledge is tied to the successful making of the recording material and that this therefore places the creative act into the realm of craft and not science or fine art. The *tedious task,* as discussed in the first chapter of my thesis, is, in truth, learnable.[111] But in being a craft, and therefore shaped by tacit knowledge, it is a skill that requires time to be learned. When Dormer talks about the 'misconceptions that have developed about tacit knowledge' he refers to the idea in art education and art theory that skills can be learned when they are needed 'as if craft knowledge can be taken from a supermarket shelf'.[112] Furthermore he argues against the reductive notion that 'a common assumption is that craft skills are mechanically learned and exercised; and that they are thus obviously unthinking and uncreative'.[113] Those prejudices are underlined by comments by Saxby, mentioned in Chapter 1, when he

[110] Dormer, *The Art of the Maker,* p.40.
[111] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 34.
[112] Dormer, *The Art of the Maker,* p.39.
[113] Dormer, *The Art of the Maker,* p.40.

writes about ‘a high threshold of boredom’.[114] I can confirm that the process of making silver halide recording material is demanding and requires considerable tolerance of frustration but is at the same time highly rewarding, creative and satisfactory.

There will always be a bit of experimentation for everybody who starts producing their own material, due to work circumstances and special requirements from the project at hand. The master – apprenticeship relationship and collaboration is a first necessary step, but the actual practice, dedicated work and experience is of the same importance, if not more. The time spent with the material, observing it and working with it cannot be replaced by another person, or by detailed recipes or explanatory accounts in the literature. Once the real need for individual engagement and dedicated work was understood, I was able to establish a stable emulsion practice.

In this chapter the importance of the forming of tacit knowledge has been highlighted. In the next chapter, in contrast, explicit knowledge and underlying mechanism of the diffusion method are discussed.

[114] Saxby, *Practical Holography,* 1st ed., p. 276.

Chapter Three

Explicit knowledge and the diffusion method

Chapter 1 discussed the perception of hand coated plates in holography and accentuated the missing research in the field. My research fills this gap by researching and improving a newly designed method to present a new creative tool for the holographic practice. Chapter 2 examined the forming of tacit knowledge in plate making. In Chapter 3, I discover the historical roots of the diffusion method and explain the fundamental mechanics, explicit knowledge about the process of emulsion making. This chapter also shows how the diffusion method is different and why that gives the method an advantage for being a feasible tool.

Holography has been in constant flow in its short lifespan. Invented as a scientific tool, it was liberated from the science lab by the invention of the sand table and practitioners have constantly searched for new applications.[115] In the rush, however, to claim a place in an increasingly digital society, vital research in the darkroom was rendered obsolete. Recording material existed and the goal was to move on to material like photopolymer that would not need any wet processing in the darkroom at all. Materials like photopolymers exist, but they do not meet the high quality of silver halide-based recordings. Projects like the recording of the Russian state treasures carried out on silver halide material underline this.[116]

The diffusion method is a silver halide-based bathing method and therefore capable of producing high quality holograms. In the diffusion method, the gelatin-coated glass is submerged in different baths to make it light sensitive and ready for exposure. Photography has a long history of silver halide-based material and holography, is with its chemical aspects, like the processing after recording and the light sensitive recording

[115] Yu. I. Ostrovsky, *Holography and its Application,* Moscow, Mir Publisher, 1977; Euval S. Barrekette, et al., (eds.), 'Applications of Holography', *Proceedings of the United States-Japan Seminar on Information Processing by Holography*, New York-London, Plenum Press, 1971; H.J. Caulfield, *The Applications of Holography,* New York; Chichester, Wiley-Interscience, 1970; P. Hariharan, *Optical Holography; Principles, technique, and applications*, 2nd ed., Cambridge. Cambridge University Press, 1996.
[116] Reconnaissance Holography News, *Optoclones of Russian State Treasures*, [website], 2018, https://www.reconnaissance.net/holography-news/issues/february-2018/
(accessed 13 February 2019).

material used, connected to photography. Holography therefore finds a lot of its technical inspiration in the old processes of photography. Therefore, even with a lack in research in the darkroom for holographic recording material, the technical, or explicit knowledge of photographic processes can be transferred up to a point to the making of holographic silver halide-based recording material.

Historical roots

To be able to put the diffusion method in context and to understand its historical roots, a quick overview of both the history and the basic chemistry of silver halide-based recording material in photography is helpful. This is not intended to be an in-depth review of the history of the birth of photography. Instead I highlight the inventions and chemicals in the field of silver halide-based recording material which are explicitly important to my research, starting with the historical roots of the diffusion method.

William Henry Fox Talbot was a critically important figure in early photography. He invented the Calotype process in parallel to Louis Jacques Mandé Daguerre's development of the Daguerreotype in France.[117] Talbot's experiments began in 1834 and he finally introduced the Calotype process in 1841. Baines describes in *The Science of Photography* the production of a Calotype paper as follows:

> [...], his (William Henry Fox Talbot) early experiments consisted in soaking paper in common salt solution and then in silver nitrate solution, thus forming silver chloride in the body of the paper.[118]

Not only was this one of the very first techniques to produce photographic recording material based on a bathing method, but we find the basic ingredients here, which are found in different variations, and considered later in detail, in any silver halide-based

[117] The Calotype was among the first of the silver-iodized techniques that were created to be used as a negative in order to reproduce an image multiple times from a single source. Definition in C. James, *Alternative Photographic Processes*, USA, Cengage Learning, 2016, p. 60; further information in Larry J. Schaaf, *Out of the Shadows: Herschel, Talbot & the Invention of Photography,* New Haven, Connecticut; London, Yale University Press, 1992; William Henry Fox Talbot, 'The Process of Calotype Photogenic Drawing', in B. Newhall (ed.), *Photography: Essays and Images*, New York, The Museum of Modern Art, 1980, pp. 33-35.

[118] Baines, *The Science of Photography,* p. 17.

material: silver nitrate in solution and a member of the halogen family, in this case chloride, found in common table salt. These two compounds form the silver halide which gives the material its name and its light sensitivity. In the case of the daguerreotype, the vaporised halogen reacts with the silver in the silver plate, the substrate of the method, and forms silver halides.

Talbot also experimented with gelatin and gum binders to prevent the chemicals from being absorbed by the paper, making the image look rather lifeless.[119] Using these colloids, Talbot also started to use glass as his substrate. Eventually, these experiments led to the invention of the albumen print. The first official lengthy report on this technique was published in a French scientific journal in 1847, authored by Claude Felix Abel Niépce de St. Victor. His albumen print method is described as follows:

> He (Niépce de Saint Victor) coated glass with albumen and then used the albumen layer as a carrier for the silver iodide, incorporating potassium iodide in the albumen, dried the plate, and then immersed it in a silver nitrate bath.[120]

The technique was refined over the years, but the challenge of a long exposure time made it problematic for use in portrait photography. The detail rendered on the glass plates, however, was astonishing for the time. Louis-Désirée Blanquart-Evrard founded the first printing and publishing business coating albumen on paper in 1851, the same year when Frederick Scott Archer introduced the wet collodion glass plate negative process. Combined, the two processes, were considered the first true and repeatable paper-based imaging system. In terms of detail quality in the photograph, the technique was compared to daguerreotypes, at that time the leading technique in terms of detail. The collodion wet plate process was also based on the bathing method:

> A solution of potassium iodide in collodion was coated on glass, allowed to set, and soaked in silver nitrate solution, thus forming silver iodide in the collodion layer, the excess silver nitrate acting as a sensitizer.[121]

[119] C. James, *Alternative Photographic Processes*, p. 388.
[120] C.E.K. Mees, *From Dry Plates to Ektachrome Film: A story of photographic research*, New York, Ziff-Davis Publishing Company, 1961, p. 8.
[121] Baines, *The Science of Photography,* p. 18.

The quote states that the collodion wet plate process has the halide, in this case the halogen iodine in form of potassium iodide, incorporated in the collodion before it is dried and dipped into a silver nitrate bath. The albumen print works under the same principal. The subsequent step to emulsion making, where not only the halide but also the silver is incorporated in the colloid before coating, was achieved in 1864:

> [...] when B.J. Sayce and W.B Bolton had prepared plates without the silver bath by adding both the salts and the silver nitrate to the collodion itself and thus prepared a collodion emulsion.[122]

This is the first time the making of an emulsion in photographic practice was documented and dry plates were created to liberate the photographer from the need to make plates, as they could now be pre-prepared, stored and transported.[123] These plates were put on the market in 1867 under the name *collodio-bromide,* albeit with an inherent disadvantage of an exposure time three times as long as the wet plate technique.[124] This collodion emulsion was the result of numerous attempts to make the wet collodion process more practical.

Even though the plates could now be stored, which made it easier to take photographs externally outside studio contexts, there was nevertheless further room for improvement, especially in the exposure time. Only when dry photographic plates substituted collodion with gelatin and it was found that gelatin acted as a sensitizer, making the emulsion more light sensitive, was a step in the direction of a shorter exposure time achieved.[125] There had been a few experiments with gelatin before, but these were never very successful due to the quality of gelatin available or failures of reaction to the processing chemicals in the new colloid: '[...] they quickly disappeared, a result probably due to the acetic acid (in which gelatin is soluble), then used as an ingredient of the developer'.[126] Richard Leach Maddox invented the first gelatin based emulsion in 1871 as seen in Chapter 1. The result of his experiments was a silver

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122 Mees, *From Dry Plates to Ektachrome Film: a story of photographic research*, p. 11.
123 Beaumont Newhall, *The History of Photography*, 5th ed., New York, The Museum of Modern Art, 2005, p. 54.
124 Newhall, *The History of Photography,* p. 123.
125 W.J. Harrison, *A History of Photography*, New York, Arno Press, 1973, p. 59.
126 Harrison, *A History of Photography,* p. 59.

bromide gelatin emulsion, which was, compared to the collodion process, odorless, easier to manipulate and, most importantly, had a much higher light sensitivity, which was even increased in the following years.

Maddox' invention of a bromide-gelatin emulsion was first refined by Richard Kennett, who invented a system called 'noodling' to wash the emulsion in 1873. The washing of the emulsion is still necessary today, but has moved on to more effective methods when mass production emulsion.[127] When mixing potassium bromide with silver nitrate, the desired silver bromide is formed but the byproduct potassium nitrate can cause problems, as it crystallizes when drying. To avoid this, the potassium nitrate needs to be simply washed out.[128] As it is easier to wash the whole emulsion, instead of every single plate, the emulsion was chilled to jelly and then pressed through a noodle press, thus making the surface area greater and the washing in cold water more effective. The second important improvement was achieved by Charles Harper Bennett in 1878.[129] He developed a more light sensitive emulsion by heating it up before washing, a procedure called 'ripening', also still used today.[130]

Maddox fabricated his emulsion by first adding cadmium bromide to the melted gelatin and then silver nitrate, and by stirring the solution constantly.[131] This method, in a more elaborate and precise way to increase control, is still used today for mass production of silver halide-based material and known as the jetting method. For example, Bjelkhagen's Silver Cross Project in 2004 employed this method, aiming for mass production of fine grain holographic recording material:

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127 Noodling: 'Potassium nitrate is washed out of the emulsion by first allowing the hot emulsion to chill to a still jelly in a refrigerator. Once chilled, the firm emulsion is put into a noodles press and extruded into gelatin noodles. […] These thin noodles give the emulsion a greater surface area that aids in releasing the water soluble potassium nitrate when they are washed in very cold water.' Definition in James, C., *Alternative Photographic Processes*, p. 693.

128 The role of potassium nitrate in the diffusion method is important and will be discussed in Chapter 5.

129 Beaumont Newhall, *The History of Photography*, 2005, p. 124.

130 Ripening: 'The hot emulsion is kept at a constant temperature for a prescribed length of time to promote the growth of large silver halide particles upon the nucleus of already established silver halide grains. These larger grains are more sensitive to light than the initial smaller particles formed when first adding the silver. The hotter the temperature of the emulsion and the longer the ripening period, the larger the silver halide grains will become.' Definition in James, C., *Alternative Photographic Processes*, p. 694.

131 Maddox, 'An Experiment with Gelatino Bromide', p. 144.

> Jetting is the controlled discharge of one or both salt solutions into a stirred gelatin solution and it divides into two basic categories, single jetting and double jetting. [...] By far the most successful is the double jetting technique whereby silver and halide solutions are jetted simultaneously into a stirred gelatin solution.[132]

Generally, an emulsion is mixed before coating. With the diffusion method, however, that is not the case. The diffusion method has its roots much earlier in the history of silver halide recording material, when it was common practice for the photographer to make plates. As noted in Chapter 1, holography used photographic plates when it was first invented, and consequently adapted the mechanism to make silver halide emulsions from photography for mass production of holographic recording material. My research, on the other hand, is not looking into the mass production of the material but for means to equip the practitioner with the possibility of producing their own material, much as the photographer did before the dry plate was produced on a major scale and became commercially available. At that time, in the early developmental phases of photography, the objective for the photographer was different to the contemporary holographer. A key goal and desire of photographic practitioners at that time was for their medium to be portable. Baines describes the situation as follows:

> The necessity for the photographer to manufacture his plates just before use was a great inconvenience in studio work, but the difficulties were greatly enhanced when the wet collodion process was applied to work in the field.[133]

Newhall gives a more graphic and visual description:

> In the field he (the photographer) had to bring along some kind of darkroom - usually a wagon or a tent, chemicals and processing equipment - the camera, plate holders, as well as the essential tripod, for the exposure times were too long to permit the camera to be hand-held.[134]

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[132] H.I. Bjelkhagen, et al., 'Fabrication of ultra-fine-grain silver halide recording material for color holography', *Practical Holography XXII: Materials and Applications, Proceedings of SPIE - The International Society for Optical Engineering,* Washington, SPIE - The International Society for Optical Engineering, 2008, p. 7.
[133] Baines, *The Science of Photography,* p. 20.
[134] Newhall, *The History of Photography,* p. 59.

Holographic practice, by contrast, is necessarily lab-based as the holographer is dependent on the laser. There is no *work in the field* as such, as there is in photography. In addition, the material produced with the diffusion method does not have to be produced directly before the exposure. It is a dry plate method and the coated material can actually be stored, if desired. The diffusion method, benefits from the research done in photography practice. The extensive research on gelatin, to use glass as a substrate, and different coating methods are all ideas and techniques that can be adapted and modified according to the individual needs. However, the diffusion method then goes back in time and mixes these insights with the bathing method first used by Talbot. Without mass production as a goal, the practitioner, using the diffusion method, can concentrate on the visual outcome desired by working on every coated object individually. Holography is a small market and the possibility to create recording material that matches the practitioners recording circumstances, in terms of lasers used, can only be beneficial and lead to a qualitatively higher outcome.

Halogens in photography and holography

When talking about halogens in photography and holography, it is very important to keep in mind that even though in both cases light is recorded by silver halides, the goals are different. In photography the intensity of light is recorded, while holography creates an interference pattern. Naturally the demands on the recording material are different. Photography is interested in, among other things, an emulsion that reacts quickly to the visible spectrum of light and therefore allows hand held photography and the freezing of motion. Silver halides are crystals and as such they can grow: their growth can be controlled and pushed or the crystals, in light sensitive emulsions known as grains, can be prevented from growing, thus staying small in the emulsion.[135] Characteristics such as film speed - and therefore exposure time - and contrast of the photo are determined by the grain size. Photography has developed a variety of emulsions with different characteristics for different visual outcomes.

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[135] A very effective method is the method of freezing and thawing, applied in emulsion making: For an explanation of this method, see Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 45.

The main criterion for holographic recording material is the ability of recording an interference pattern and a bright and scatter-free visual outcome. This requires a fine grain coating. The circumstances when recording a hologram are more restricted due the nature of the formation of a holographic image. To create an interference pattern, the object has to be still, as any vibration destroys the recording, freezing a motion in holography is only possible with a pulsed laser, that acts like a flash and creates the interference pattern in one quick powerful shoot of the laser beam. To obtain the recording of a clean hologram, the important factor is the grain size, as scattering of the light through bigger grains is an issue. Holography therefore prefers slower emulsions which consist of a smaller grain. Keeping that in mind, there are some general characteristics of silver halides important for both photography and holography.

Silver halide recording materials are based on the fact that silver halides are sensitive to light.[136] The silver halides develop when silver nitrate is mixed with a halogen salt, as seen before with potassium bromide or sodium chloride. There are three halogens important for making light sensitive recording material: chlorine, bromine and iodine; they react to silver chloride (AgCl), silver bromide (AgBr) and silver iodide (AgI). The early processes of photography had to experiment in using them effectively and often there was no consensus on the best method. Much depended on the technique used and the goal pursued. Talbot started his experiments conveniently with table salt (sodium chloride), which was easy and widely available. Daguerre on the other hand, used vaporized iodine for the first daguerreotypes and bromine was the next to follow.[137] Later the Daguerreotype used the three elements of chlorine, bromine and iodine to fume silver plates and create silver halides. It was a challenge, not only to obtain them, bromine having only been discovered shortly before the birth of the Daguerreotype in 1826, but also because they were a hazard to handle:

> Chlorine is a corrosive gas. Bromine is a vile red liquid that gives off an equally vile gas at room temperature. Iodine is not much better, but it is crystalline at room temperature and therefore is easier to handle than either bromine or chlorine.[138]

[136] Hugh Aldersey-Williams, *Periodic Tales,* London, Penguin Books, 2011, p. 235.
[137] Susan Barger and William B. White, *The Daguerreotype: Nineteenth - Century Technology and Modern Science*, Baltimore, Smithsonian Institution, 1991, p. 32.
[138] Barger and White, *The Daguerreotype,* p. 32.

However, too long of an exposure time was a problematic concern and therefore mixing halogens, whose light sensitivity properties were understood, became the next logical development step. Robinson points this out when writing about the process of Daguerreotype:

> Portrait photographers gradually introduced bromine due to its unquestionable speed advantage at five or six times quicker than chlorine, and bromine eventually became the main constituent of all accelerating compounds.[139]

The use of bromine was introduced in the process of the Daguerreotype in late 1839 and made public in 1842.[140] Paper based methods on the other hand still held on to sodium chloride.

> Talbot remarked that he had also observed the light sensitivity of silver iodide but he chose to experiment with silver chloride instead that prints-out quicker than silver iodide (on paper).[141]

Another reason for early photography to mix bromine and iodine in the emulsion, was that iodine is known for causing little defects in the silver halide crystal lattice which increased the light sensitivity.[142] This chemical sensitization is a common practice when producing photographic emulsions. Gold or sulphur were often used as well, but iodine had another interesting characteristic. The different silver halides are sensitive to the light of different wavelength. Chloride is only sensitive to short wavelengths up to 420 nm, mostly in the ultraviolet region. Bromide however reacts with wavelengths up to 480 nm. The widest range of spectral sensitivity is reached with an emulsion of silver bromide (AgBr) and as little as 3% of iodide. The emulsion sensitivity is extended up to 525 nm.[143] It is understandable that this characteristic was very attractive, especially before 1873, when H.W. Vogel started to experiment with dyes to extend the light sensitivity over the whole visible spectrum.[144] The increasing of the spectral sensitivity

139 Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. 214.
140 Barger and White, *The Daguerreotype,* p. 36.
141 Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', pp. 146-147.
142 G.F. Duffin, *Photographic Emulsion Chemistry*, London, The Focal Press, 1966, p. 25.
143 L. Stroebel, et.al, *Photographic Materials and Processes*, Boston, Focal Press, 1986, p. 270.
144 Jost J. Marchesi, *Photokollegium*, Schaffhausen, Verlag Photographie, 1988, p. 8.

through different halogens is of little interest for the plate making of holography, however, as holographic plates are always treated with dyes, and there is therefore no reason for using a mixture of bromine and iodine. The mentioned chemical sensitization is not important in terms of the type of wavelength it reacts to, but how quick the incoming light energy is absorbed and a latent image is formed which then can be developed.[145] The AgBr and iodide mixture has proved to be very successful for making photographic material. Consequently, silver halides present in the negative material are usually AgBr and iodide in combination, due to the high light sensitivity that can be achieved and silver chloride (AgCl) is employed, often in a mix with AgBr, for the less sensitive photographic paper.[146] For what is publicly known through projects like Silver Cross, AgBr in a mixture with iodide is the preferred mixture of silver halides in holography as it is in photography. This is curious because holography's priority requirement is smaller grains and AgCl is known for producing smaller grain than AgBr or iodide. The matter of grain size and grain growth is complex in holography and is therefore discussed in length now.

The battle of grain growth and light sensitivity in the diffusion method

From the beginning of photography, photographers experimented with which silver halide, or mixture of different silver halides, most suited specific photographic methods, techniques or objectives. In holography, that has not been the case, at least not to the same extent. As noted earlier, there still is a certain secrecy about the manufacturing of emulsions for silver halide-based recording material. This continuing inclination of manufacturers towards secrecy about the manufacturing of silver halide recording material for holography remains a problem because of the high demands on the material and the lack of shared information and findings regarding processes inhibits progress in the research.

The important underlying mechanism of light sensitivity is grain growth as the size of silver halide crystals is proportional to the sensitivity.[147] Consequently when a photographic emulsion is made silver halides need ripening, as it is called, when the

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145 Latent image: 'In silver halide photography, small clusters of silver atoms formed in crystals that have been exposed to light, which render the crystals developable.' Saxby, *Practical Holography*, p. 622.
146 Duffin, *Photographic Emulsion Chemistry*, p. 18.
147 Saxby, *Practical Holography,* 4th ed., p. 77.

silver halides are growing. Silver halides are produced by infusing the melted colloid, usually gelatin, with the silver and the halogens to form crystals. How those crystals are formed, in terms of quantity and crystal shape, depends on various parameters as temperature of the colloid and speed of the infusion. A photographic emulsion with only one halogen is rare to find. A mixture, however, proves to increase light sensitivity. In addition, iodine is known for producing little defects in a crystal which then leads to a quicker reaction to the light during exposure.

Most holographic emulsion, as discussed before, are made from AgBr and AgI (silver iodine), similar to the negative material of photography. One of the major changes Blyth introduced into the diffusion method was using only one halogen. In a first version he published in 1999, the halogen used is bromine, as it is the one that has the highest light sensitivity. In a revised version from 2016, Blyth changed to chlorine, an unusual step as AgCl is known for lesser light sensitivity. However, it does produce smaller grains. This characteristic is quite attractive for holographic recording material which depends on very fine grain to be able to record the required detail.[148] Even though chlorine can form smaller grains than bromine, as chlorine is smaller than bromine, it is not a common halogen to use in holography. Its uncontrollable grain growth due to its high reactivity and solubility when produced makes chlorine less attractive.[149] However, the importance of small grain in holography, and therefore why it is interesting to consider chlorine, despite the problems it causes, is explained by Bjelkhagen as follows:

> It needs to be emphasised that, while it is nice to have high sensitivity for recording materials for colour holograms, it is not acceptable if it comes with an increased grain size. Unfortunately, it is much better to accept a longer exposure time (or to use a higher energy laser) and to obtain a scatter-free recording.[150]

Consequently, the diffusion method is not using any of the usual procedures, chemical sensitization and ripening, that promote grain growth. No chemical sensitization takes place. Introducing another halogen would promote bigger grains to form, as both

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[148] Saxby, *Practical Holography,* 4th ed., p. 77.
[149] Richardson and Wiltshire, *The Hologram*, p. 93.
[150] Bjelkhagen and Brotherton-Ratcliffe, *Ultra-Realistic Imaging,* p. 104.

bromine and iodine are bigger than chlorine. Since the only reason for letting an emulsion ripen is to increase its light sensitivity through grain growth, this step is eliminated from the diffusion method. It should be noted that Bjelkhagen, in the quote above, refers to a true colour hologram. A panchromatic recording of a hologram has even higher demands on the recording material as scattering increases with wavelength of a higher frequency and bigger grains. The diffusion method has been tested successfully with red, green and blue lasers individually but not mixed together in a panchromatic coating.

With the use of a single halogen the diffusion method pursues a new method for producing fine grain holographic recording material: one which has its roots in the history of many successful hand coating process and differs from the process of emulsion making which is optimized for the mass production of photographic material. A critical second step which the diffusion method handles differently, compared to other known emulsion making processes, is the building of the silver halide crystals. The jetting method introduces the silver and the halide slowly to each other to control grain growth: the diffusion method does it in one quick movement. It is a very sudden action, using lots of silver nitrate (20-22%). The silver nitrate, dispersed in the gelatin coating, is suddenly put into a bath consisting of dye with sodium chloride for a short period. Chlorine binds with the silver of the silver nitrate in a reaction called double decomposition:

$$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$$

The dye used (pinacyanol chloride) has the ability to wrap itself around the silver halide and consequently slows down further grain growth, as Bjelkhagen explains:

> Just like there are chemicals that encourage grain growth, there are also chemicals that discourage grain growth. [...] It just so happens that the dye used in the diffusion process (pinacyanol chloride) is one of those chemicals that help prevent grain growth.[151]

[151] Hans Bjelkhagen, 'DIY Silver Halide Film', *holographyforum*, [web blog], https://www.holographyforum.org/wiki/DIY_Silver_Halide_Film#Hans.27_Diffusion_Post, (accessed 20 December 2018).

However, the dye cannot stop the silver chloride grains from growing completely, which is why the time the coated object spends in the dye bath is vital. For example, for a plate measuring 8cm x 8cm, no longer than 45 seconds is required, as Blyth describes it: ‘I take the dried plate containing the AgNO3 and plunge it **quickly** into the chloride/dye bath for 45 seconds, agitating it **constantly**’.[152] (author’s emphasis). This can be used as a guide value for bigger objects, when time might have to be increased to make sure all of the silver nitrate is converted to silver chloride. Any trace of chloride that is in the coating before this step will cause problems and most probably lead to unacceptable grain growth which is why a clean working method and the use of de-ionized water throughout the process is necessary. When sensitizing for a green laser, the dye used is acridine orange and other than the fact that the dye changes, the process is exactly the same.

Another difference is, as noted before, related to the halogen used. In the first experiments Talbot made he used only silver chloride, as sodium chloride was easy to obtain. For very different reasons the diffusion method also uses silver chloride exclusively. Blyth, in introducing the diffusion method, claims that ‘AgCl is used because it was found that it was more than three times more photosensitive than AgBr in the recording process!’[153] This is simply an observation: there is no explanation or theory behind it. It is quite a startling statement given that the prevailing findings on silver halides in photographic material is that silver bromide gives the higher photosensitivity. During my experiments with the diffusion method I made the same observation many times. Coatings I had produced using sodium chloride were quicker, by factors 3x to 5x, than coatings produced with potassium bromide. The explanation must lie in the nature of the diffusion method.

When a photographic emulsion is made, the speed of how the silver is mixed with the halide and the concentration of both the solution and the temperature afterwards are all crucial parameters for the light sensitivity of the finished material. The ripening and growing of silver halides to the exact sizes and shapes in order to achieve the sensitivity desired is not easily accomplished. There is no detailed research as yet on why the

[152] Blyth, ‘The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.’, p. 90.
[153] Blyth, ‘The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.’, p. 79.

silver chlorides fabricated in the diffusion method produce such a high light sensitivity. A possible reason could be the reaction of the dyes with the silver chloride. The diffusion method uses an extreme high level of silver. That certainly increases light sensitivity. Due to the amount of silver lots of small grains are formed quickly and they are all closely connected with the dye added. Duffin states that the dye can have a significant effect on the sensitization of chloride emulsions, but that there is a lack of substantive and qualitative research:

> Very little has been published on the spectral sensitization of silver-chloride or chlorobromide emulsions, although this is of technological importance. Although these emulsions and iodobromide emulsions respond in a comparable manner to the action of similar types of dyes, there is an outstanding difference. The addition of a spectral sensitizer to an iodobromide emulsion rarely confers an increased total sensitivity because the natural sensitivity of the silver halide is high and the blue speed decreases as the spectrally-sensitized speed rises; [...] On the other hand, a powerful sensitizer can increase the total speed of a chloride or chlorobromide emulsion by as much as thirty times, probably because of the low light-absorbing power of silver chloride and also because very little desensitization occurs in the region of natural sensitivity.[154]

Another speculation is, as the diffusion method works with a very high content of silver, lots of small grains are produced which leads to an increased surface area, which might lead to higher light sensitivity. Closer research has to be done on these theories in the future.

Conclusion

A vital ambition of early photography practitioners was to take the camera, and the very act of photography, out of the studio and into the external world. Consequently, photographic scientists, developers and practitioners sought a more practical recording material than the wet plate. The development of the bromino-gelatine dry plate by Maddox made that possible and the production of more practical plates quickly

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[154] Duffin, *Photographic Emulsion Chemistry*, p. 127.

developed commercially, serving photographers of the time perfectly. In contrast to plate making with collodion (which essentially was a do-it-yourself method), dry plates could be mass produced, and the making of one's own recording material quickly became an obsolete activity for photographers. Manufacturing of the dry plate was optimised for mass production and for optimal control, allowing mass production with consistent quality control from batch to batch. The emulsion is completed before coating the plate and can be frozen and used again later. This is a very effective method with high control over the grain growth and the ability to guarantee consistent and equal reaction to light within the same batch of emulsion.

The diffusion method, by contrast, does not find its roots in the dry plate method but in the earlier original processes of photography when recording material was produced plate by plate, as in the wet collodion process and Daguerreotypes. Whole batches of emulsion are not produced, but rather each gelatin-coated substrate is treated individually. The consequence is that variations in terms of light sensitivity can occur not only from batch to batch, but from plate to plate.

The reliability of material, however, is a crucial factor to success in the business as the customer, photographer and holographer, expects it. While photographic material has achieved high standards of quality and reproducibility, the same cannot be said of holographic commercial material, as Bjelkhagen notes: 'Holographic sensitivity can vary to a certain degree from batch to batch, which is rare in conventional photographic material'.[155] This changing quality, however, makes it even more attractive for the practitioner to produce their own material. In my experience it is even helpful, as I am able to modify my routine immediately whenever I feel I could achieve a better result for my goals.

The Silver Cross Project was launched to mass produce a fine-grained panchromatic emulsion. By contrast, Blyth developed the diffusion method for the home-based amateur.[156] This thesis targets the creative holographer, who is looking for choice, greater autonomy and a new tool. The creative holographer comes in many different

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[155] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 94.

[156] Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 79.

shapes and forms, with different starting points, different goals and different equipment. My research provides the practitioner with the means to use a flexible coating method that can be adjusted not only to the project at hand but to the laser used.

The diffusion method combines the advantage of the dry gelatin plate with the flexibility and possibilities of hand coating, as it was done before the mass production of photographic plates. It finds its inspiration and origins from before the wet plate technique. The roots of the diffusion method are to found in techniques as early as the Calotype, Daguerreotype and Albumen Print. The diffusion method was not the first attempt to employ earlier photographic processes for the recording of holograms: however, none has proved as successful as the diffusion method and further research has not been pursued. For example, the technique of Daguerreotype, being a silver halide process, works with fumes and vapour rather than solutions and is therefore a very different process. It is nevertheless hand-made and has been the subject of further experimentation into the possibilities of being a suitable recording material for holography. A team from the RMIT University in Melbourne, Australia presented a paper at the 7th International Symposium on Display Holography in 2006 called 'Daguerreotype holography'. The paper stated that it was possible to record holograms on a Daguerreotype plate but that no further research has been done in that area.[157] Additionally, there have been attempts to produce a fine grain coating using the Albumen Print. The fringes were created but unfortunately a thick fog developed, possible due to grain growth.[158]

The concept of a diffusion method for the preparations of plates to record interference pattern is not entirely new either. After Gabriel Lippmann looked for a way to record colour photographs by recording an interference pattern, research was made into the production of such plates. Raphael Eduard Liesegang, a German chemist, published his article 'Über ein Badeferfahren zur Herstellung von Lippmann-Platten'[159] in 1915, describing a procedure similar to the proposed technique by Blyth, who had started his

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157 S. Miller et al., 'Daguerreotype holography', *Advances in Display Holography, Proceedings of the Seventh International Symposium on Display Holography,* Edinburgh, River Valley Press, 2006, p. 20.
158 Filipe Alves, 'Albumen Silver Bromide Emulsion, *holographyforum,* [web blog], 6 April 2014, https://www.holographyforum.org/forum/viewtopic.php?t=831 (accessed 21 February 2018).
159 R.E. Liesegang, 'Über ein Badeferfahren zur Herstellung von Lippmann-Platten', Photographische Rundschau 15, 1915, pp. 198-200.

research on the diffusion method without prior knowledge to the experiments made in Germany 85 years before.[160] Echoing the early experiments of Liesegang, Blyth's method faces the danger of oblivion. The self-production of recording material is still not recommended by scientists, reflecting the prevailing attitude from the early days of photography, as this quote from 1929 shows: '[...] there are a few misguided enthusiasts who hope that they can make as good sensitive materials as are obtainable commercially, and at a much lower cost'.[161] Those opinions were, in photography and holography, based on the presumption that the commercially-available and standardised processes of emulsion making were better options, much to the detriment of practitioners gaining greater knowledge and insight into the possibilities of their medium and the creative potential unlocked by developing their own emulsion-making abilities. With the diffusion method a new door has opened for hand-made holography. This thesis argues, and proves, that hand-coated material is a feasible and successful method of producing holograms.

Chapter 1 focused on how hand coated material for holograms was received over the years and why it is important for holography to have the option of producing in-house material. Chapter 2 emphasised the important role of the creation of tacit knowledge when practicing a craft like making holographic recording material. Chapter 3 supplied the reader with important explicit knowledge about the making of light sensitive material and the diffusion method. The next three chapters explain the diffusion method in detail.

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[160] Jeff Blyth, 'A diffusion method for making silver bromide based holographic recording material.' *The Imaging Science Journal*, vol.47, 1999, pp. 87-91.

[161] E.J. Wall, *Photographic Emulsions*, Boston, American Photographic Publishing Co., 1929, p. iii.

Chapter Four

Gelatin Coating

In the preceding chapters I have presented the theoretical background to the diffusion method, considered the reasons for its development and argued why it is now important to establish this feasible and accessible option for holographic practitioners. In the following three chapters I explain every step of the process involved in coating glass objects successfully and consider the chemicals and their relevance for the recording material in detail. I further explain the changes I have made from the original recipe, and how the tacit knowledge, gained from the experience of constant work and experimentation in the lab, changed the recipe.

Producing holographic images on any level, working with commercially-bought plates or making recording material, involves handling chemicals. Gloves, goggles and a lab coat for protection are all recommended. I use the standard sign, colloquially called the ‘Safety Square’, to indicate hazardous chemicals.

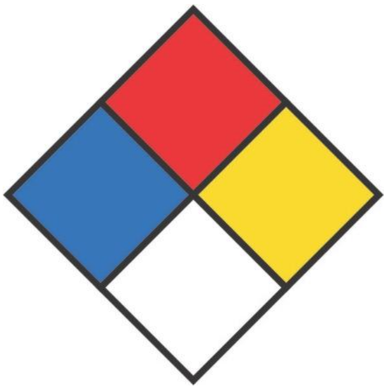

Figure 14. ‘Safety Square’: NFPA 704: Standard System for the Identification of the Hazards of Materials for Emergency Response.

Blue, indicates a health risk, red flammability and yellow indicates instability and reactivity of the substance. The white square gives space for special notes or indications; for example, OX stands for a strong oxidizer. Furthermore I provide images of the bottles of the chemicals used to minimize the change of confusion, as for the beginner slight changes in the chemicals name might be easy to overlook. I do this to give the practitioner a sense of control, to feel secure and to minimize variables where mistakes can occur.

The recipe

The figure below shows the chemicals and recipes used for preparing silver halide-based recording material with the diffusion method. On the right, Blyth's method is shown as printed in the April 2016 newsletter of the 3D Imaging & Holography Group of the Royal Photographic Society.[162] There is also a presentation of his method online, where updates on the process might be indicated.[163] At the point of writing, however, the last update had taken place on the 21st of April 2016 and only minor changes are shown to the printed version. On the left side, the method with the modifications and improvements I made is shown. These changes are explained in the following three chapters, as I go through the process step by step.

	Me	**Jeff Blyth**
1.	**Whiting formula:** 80 g whiting 100 ml water 20 ml grain alcohol	
2.	**Gelatin 1:** 5 ml dissolved gelatin 2 + 5 ml stock chromium in 100 ml de-ionized water	**Gelatin 1:** 5 ml dissolved gelatin 2 + 5 ml stock chromium in 100 ml warm water
3.	**Gelatin 2:**	**Gelatin 2:**

[162] Jeff Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', pp. 78- 104.
[163] Jeff Blyth, 'DIY Hologram Recording Plate – and Holograms on wine glasses', *d-i-yscience*, [web blog], 21 April 2016, http://d-i-yscience.blogspot.com/2016/04/holograms-on-wine-glasses-and-glass.html?m=1 (accessed 1 November 2018).

	10 g of granulated gelatin (photo grade) in 100 ml de-ionized water	12 g of leaf gelatin (food grade) in 100 ml de-ionized water 0,5 g Copper (II) Sulfate CuSO4.5H2O + 3 ml de-ionized water 4 ml glycerol $C_3H_8O_3$
4.	**Hardener:** 4 g chromium potassium sulfate $KCrS_2O_8$ in 100 ml de-ionized water + 4 ml glycerol $C_3H_8O_3$	**Hardener:** 4 g chromium potassium sulfate $KCrS_2O_8$ in 100 ml de-ionized water + 4 ml glycerol $C_3H_8O_3$
4a.	***Alternative Hardener:*** *1,5 g chromium (lll) acetate hydroxide* $(CH_3CO_2)_7\ CR_3\ (OH)_2$ *in 100 ml de-ionized water* *+ 4 ml glycerol* $C_3H_8O_3$	***Alternative Hardener:*** *1,5 g chromium (lll) acetate hydroxide* $(CH_3CO_2)_7\ CR_3\ (OH)_2$ *in 100 ml de-ionized water* *+ 4 ml glycerol* $C_3H_8O_3$
5.	**Wash 1:** 0,1 g sodium carbonate Na_2CO_3 in 100 ml de-ionized water	**Wash 1:** 0,1 g sodium carbonate Na_2CO_3 in 100 ml de-ionized water
6.		**Wash 2:** 10 g sodium nitrate $NaNO_3$ in 100 ml de-ionized water
7.	**Silver nitrate solution:** 2,2 g silver nitrate $AgNO_3$ in 10 ml de-ionized water	**Silver nitrate solution:** 2 g silver nitrate $AgNO_3$ in 10 ml de-ionized water
8.	**Dye Solution:** 100 ml of **Stock dye solution 1** is mixed with 2 ml of **Stock dye solution 2.**	**Dye Solution:** 100 ml of **Stock dye solution 1** is mixed with 2 ml of **Stock dye solution 2.**
8a.	**Stock dye solution 1:**	**Stock dye solution 1:**

	41 g sodium chloride NaCl in 334 ml de-ionized water + 666 ml ethanol C_2H_6O or methanol CH_3OH (de-ionized water: alcohol in relation 1:2)	41 g sodium chloride NaCl in 334 ml de-ionized water + 666 ml ethanol C_2H_6O or methanol CH_3OH (de-ionized water: alcohol in relation 1:2)
8b.	**Stock dye solution 2:** For red laser light: 0,3 g pinacyanol chloride $C_{25}H_{25}ClN_2$ + 100 ml ethanol or methanol For green laser light: 0,5 g acridine orange $C_{17}H_{19}N_3$ + 100 ml 1:2 de-ionized water: alcohol	**Stock dye solution 2:** For red laser light: 0,3 g pinacyanol chloride $C_{25}H_{25}ClN_2$ + 100 ml ethanol or methanol For green laser light: 0,5 g acridine orange $C_{17}H_{19}N_3$ + 100 ml 1:2 de-ionized water: alcohol
9.	**Sensitizer:** 2 g Ascorbic Acid $C_6H_8O_6$ + 100 ml de-ionized water + sodium hydroxide NaOH until pH is at 4,5 or 5	**Sensitizer:** 2 g Ascorbic Acid $C_6H_8O_6$ + 100 ml de-ionized water + sodium hydroxide NaOH until pH is at 4,5 or 5
9a.	**TEA:** 15 % triethanolamine in de-ionized water	**TEA:** 15 % triethanolamine in de-ionized water

Table 1. The recipe of the diffusion method, showing my changes and improvements from the original Blyth recipe.

Step 1: The glass

To avoid cuts when working with glass, especially glass plates which I cut to size myself, the corners and sides of the glass should be smoothed. This is easily and quickly achieved with a whetstone, immersed in water: the glass edges can be ground down to a smooth finish.

Figure 15. Glass plate and whetstone for smoothing the edges and corners.

The second step in starting to make recording material for holography or photography, is to ensure high standards of cleanliness. Making and producing sensitive material successfully requires a clean laboratory.

> One point must be recognized once for all, that to expect to turn out good results in a darkroom that has been used for the ordinary operations of development and fixing is utterly hopeless. Perfect cleanliness and freedom from chemical dirt is a sine qua non.[164]

[164] E.J. Wall, *Photographic Emulsions*, p. iii.

This vehement statement was made about the producing of photographic plates in 1929. Bjelkhagen makes the same observation regarding the cleanliness required in a photographic factory:

> Dust can cause severe problems, which is why the personnel have to be dressed from head to foot in lintless clothing. Actually, the standard of cleanliness in a photographic factory is often much higher than in the food industry, so that a photographic plant resembles a biochemical laboratory or an operating theatre rather than a factory in the traditional sense of the word.[165]

Bjelkhagen, of course, refers to mass production of photographic material. For handmade recording material, in my experience, a sensible standard of cleanliness and tidiness in the darkroom is essential to process a hologram or a photo with a clean finish: the same level of cleanliness is necessary for the successful practice of holographic material making with the diffusion method. This includes clean beakers and a clean work surface: a clean working environment, equipment and process can make all the difference.

	Me	**Jeff Blyth**
1.	**Whiting formula:** 80 g whiting 100 ml water 20 ml grain alcohol	

Table 2. Recipe for glass cleaning.

[165] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 36

Figure 16. Calcium carbonate for cleaning the glass objects.

Figure 17. Grain alcohol.

The chosen glass substrate should be as clean as possible, especially if it has been coated before and the hologram did not turn out the way imagined. There is absolutely no problem in recycling the glass for re-use, or in coating glass objects formerly used for other purposes. However, the object must be clean, with no traces of other substances which will cause problems at later stages. If re-using a glass object that has been previously coated, it can be cleaned by submerging it in household bleach. The gelatin usually comes off easily after 30 minutes. If the gelatin is still stuck after 30 minutes, there is no harm in leaving the glass longer in the household bleach. I have left objects for as long as 48 hours.

Figure 18. Cleaning glass objects with household bleach for re-use.

After immersing the object in bleach, it is important to make sure that there are no traces of bleach or other chemicals left on the glass. I usually rinse the object with hot water until the bleach is gone and then apply a whiting solution. Cleaning glass with a whiting solution is a common technique when preparing glass plates for alternative photography processes: the less grease on the glass the better for the emulsion, or in case of the diffusion method, the gelatin layer to stick. Due to the alcohol content, gloves should be worn when cleaning the glass:

> Apply the whiting solution to the glass liberally, and with one piece of cloth, or a cotton pad, vigorously cover the plate in a swirling motion until you hear a squeaking sound.[166]

The glass objects need to be given a good wash in tap water and a final rinse in de-ionized water. De-ionized or single distilled water is preferable from this stage onwards

[166] James, *Alternative Photographic Processes,* pp. 428-429.

throughout the process: tap water can contain traces of chlorides or other chemicals which lead to later problems. It is also possible to wash the glass with ordinary dishwasher instead of the whiting solution.

In my thesis I worked with two types of glass. My hemispheres are hand blown at De Montfort University, by a fellow student, Charlotte Wilkinson.[167] The glass she used is called Glasma. The second kind of glass I used were either cheap glass objects bought from different suppliers on the internet, often on eBay, or pre-used drinking glasses and jars. It is reasonable to assume that the quality of these glass objects was not very high. However, after thorough cleaning this did not have any influence on the recorded holograms in terms of impurities on a chemical level. However, if the object contains impurities in the glass itself, this will obviously be seen in the finished hologram.

In theory, the choice of substrate is really just a question of taste and the particular creative goal one is pursuing.

Step 2: The subbing

	Me	**Jeff Blyth**
2.	**Gelatin 1:** 5 ml dissolved gelatin 2 + 5 ml stock chromium in 100 ml de-ionized water	**Gelatin 1:** 5 ml dissolved gelatin 2 + 5 ml stock chromium in 100 ml warm water

Table 3. Recipe for the subbing solution: Gelatin 1.

[167] https://www.charlottewilkinsonglass.com/ (accessed 9 August 2018).

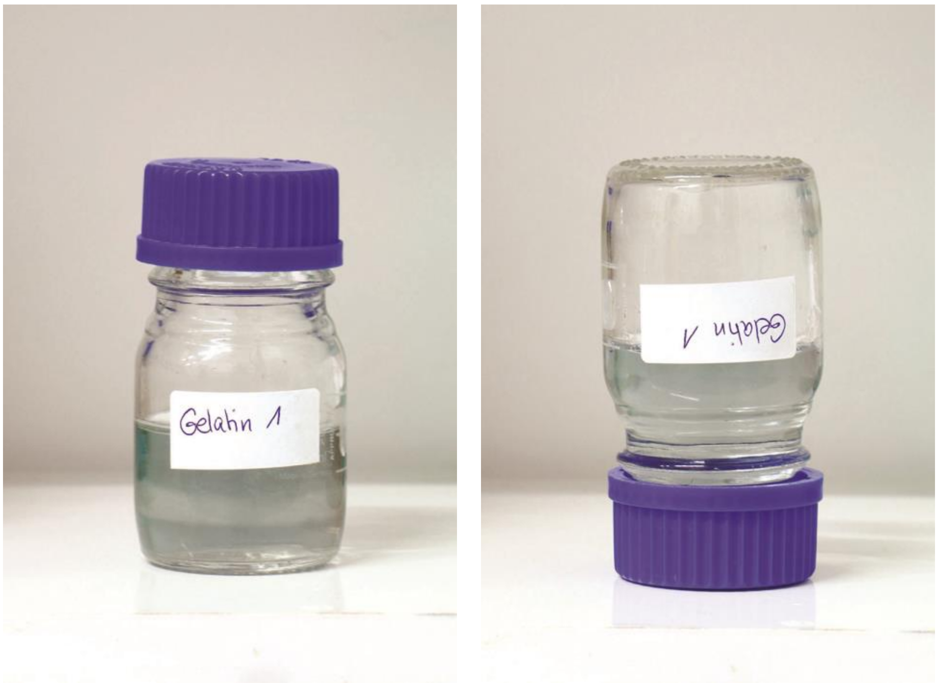

Figure 19. Gelatin 1 is a liquid that behaves like water and is easy to apply to the glass object. The colour changes depending on the hardener used, from light blue, as seen in the pictures, to light purple.

After having the glass cleaned properly, it is subbed with **Gelatin 1**. Subbing of the glass is a simple technique, long known in alternative photographic processes, and designed to make the **Gelatin 2** stick:

> But the greatest problem is during wet processing, when the gelatin of the emulsion takes up a considerable amount of water, and some processing chemicals exacerbate this effect. The resultant swelling of the emulsion is such that it will probably leave the support altogether, unless some precaution is taken by preparing the base before emulsion coating.[168]

The clean glass is coated with the **Gelatin 1** solution. This solution it is very liquid and will, even when cooled down, not harden. It feels and behaves like water and flows easily and uniformly over the glass. The glass object has to be moved smoothly around, so the parts where the hologram will be recorded later are fully covered. It then needs to rest for 20 minutes. Some of the solution drips off but some of the solution will stick,

[168] M. Reed and S. Jones, *Silver Gelatin: A User's Guide to Liquid Photographic Emulsions*, London, Aurum Press Limited, 2004, p. 66.

and that is all that is needed. The hemispheres go in an oven for 30 minutes at 160 degrees. That ensures the **Gelatin 1** sticks to the glass. Blyth recommends 190-200 degrees. I found that too much for the hemispheres: they tend to burn a little on top as they are closer to the heat than glass plates. The safe choice for the hemispheres is to lower the temperature and check after 20 minutes to ensure they do not get burned. Different shapes of glass objects might need appropriate adjustments. With 160 degree heat and careful checking after 20 minutes, I never had problems. If it seems there is a chance of burning, it is advisable to either lower the temperature, lower the object or cover the parts close to burning to shield them from too much heat, as you would do with a cake in the oven.

Figure 20. Hemispheres in the oven for subbing.

Figure 21. Bubbles in the oven for subbing.

When finished in the oven, it is recommended to let the glass cool down slightly before coating. Additionally, I have had problems with glass cracking if removed too quickly from hot to cold. It is advisable, therefore, to let them cool down, with the oven turned off and the door open for 10 to 20 minutes, so they are still warm but comfortable to touch.

Creative possibilities during subbing

It is important to keep in mind that the process of hand coating plates gives control over the process from the outset. The subbing is done to adhere the second gelatin coating to the substrate. Glass is a substrate which gelatin sticks to better in a dry state than wet and without subbing the glass first, the gelatin layer will potentially come off during processing after exposure.[169] While usually the goal is to avoid the gelatin layer from coming off when processing the hologram, this property or tendency can be used, however, for a technique called emulsion lifting. This technique is most popular with photographers using Polaroids.[170] I first did an emulsion lift when I prepared several silicon wafers in an attempt to analyse the coating by enlarging it under the university's electron microscope.[171]

The lifting technique requires an extremely careful handling of the plate throughout the process. The best results are achieved by doing the lift directly after processing and not letting the gelatin dry on the original plate. Each time the gelatin is submerged in liquid and dried again puts stress on the layer and increases the danger of ripping it apart or to causing other damage.

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[169] Reed and Jones, *Silver Gelatin: A User's Guide to Liquid Photographic Emulsions*, p. 66.
[170] Jane A. Linders, [website], https://www.alternativephotography.com/polaroid-emulsion-lifts/, (accessed 14 February 2019).
[171] Results are to find in Appendix C

Figure 22. The plate with the unsubbed gelatin layer is submerged in lukewarm water and left until it starts to lift.

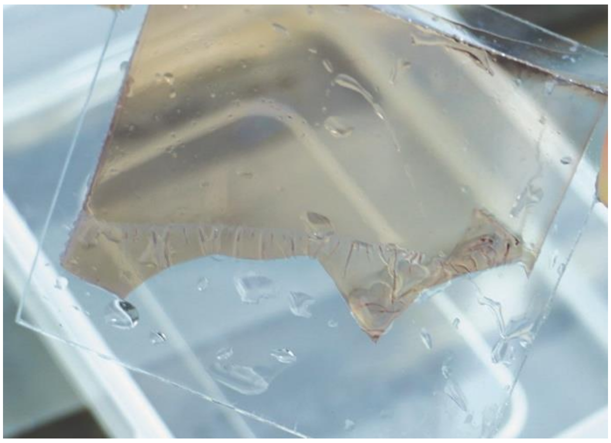

Figure 23. Light rippling on the edges indicates that the gelatin is lifting from the substrate.

Figure 24. Slight lifting of the gelatin.

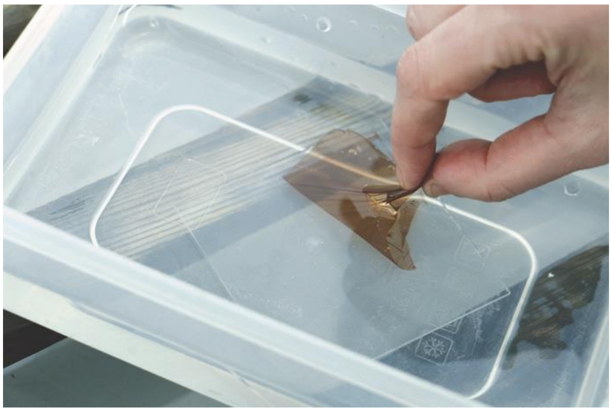

Figure 25. The gelatin can gently be lifted after the edges have parted from the substrate.

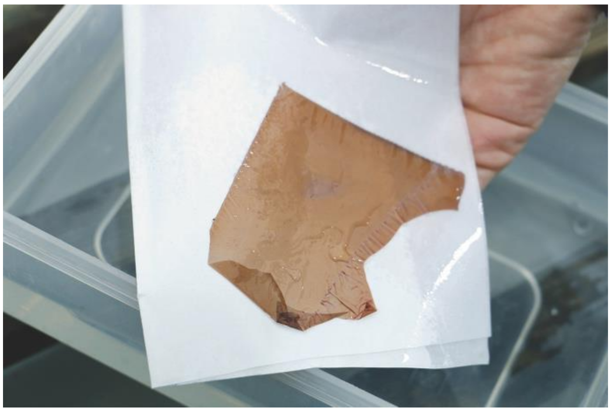

Figure 26. After the coating has been lifted completely it can be transferred to any substrate.

If carried out carefully, however, the technique of emulsion lifting is very rewarding, especially when working with a single beam reflection set up. Because the laser has to penetrate the substrate, the holographer inevitably works with transparent substrates, mostly glass. With the emulsion lift, however, the hologram can be transferred to any imaginable surface, such as mirrors and pictures. This opens up a whole new possibility of image making with holograms.

Step 3: The gelatin layer

	Me	Jeff Blyth
3.	**Gelatin 2:** 10 g of granulated gelatin (photo grade) in 100 ml de-ionized water	**Gelatin 2:** 12 g of leaf gelatin (food grade) in 100 ml de-ionized water 0,5 g Copper (II) Sulfate CuSO4.5H2O + 3 ml de-ionized water 4 ml glycerol $C_3H_8O_3$

Table 4. Recipe of the coating for the gelatin layer.

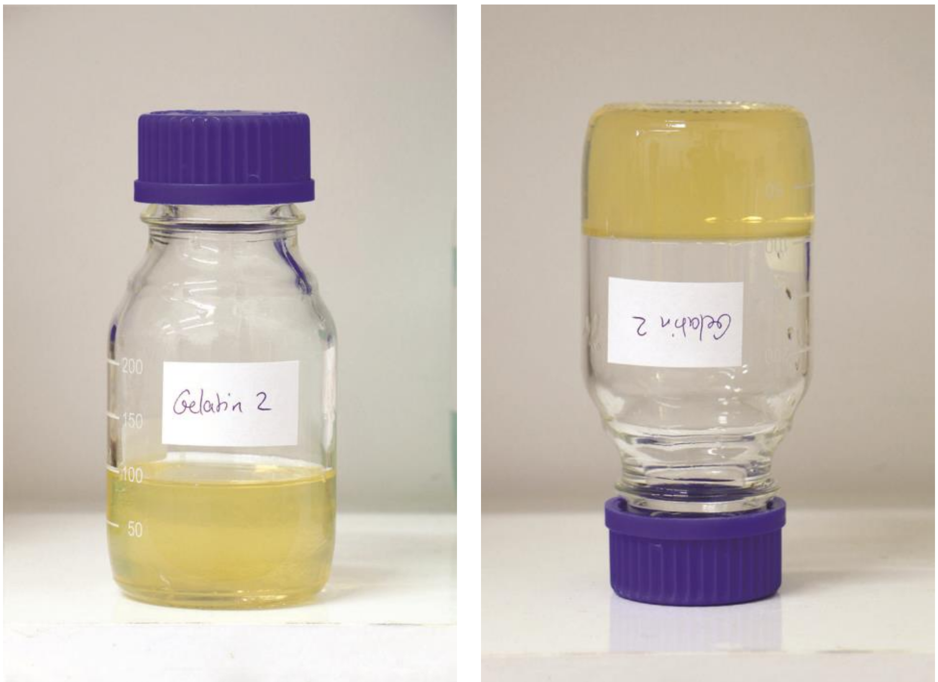

Figure 27. The Gelatin 2 is a liquid when heated but turns into a jelly at room temperature. This Gelatin 2 is prepared after the improvements I made to the recipe. The Gelatin 1 prepared after the original recipe has a light turquoise colour due to the copper sulfate.

The preparation of the gelatin

The gelatin layer is applied to disperse the silver halides added later in the process. Gelatin has been the most used colloid in photography since the invention of the dry plate in 1871. As a vital part of light sensitive recording material, it has been subject to intensive research.[172] This covers a wide area, so I concentrate on those characteristics important for my research.

The quality of gelatin is divided into food grade and photo grade and both are used in modern plate making. The ingredients of photo grade gelatin are more carefully selected then those used for food grade gelatin: photo grade gelatin is purer and therefore the first choice for the making of recording material.

Blyth however was very specific about his goal '[...] to make this method useable for the home-based amateur using only items purchased from the Internet or from local shops, [...]'.[173] Shop-bought gelatin works fine, and my first wine glasses and hemispheres were made following the original recipe. However, there can be some impurities in the gelatin which can cause chemical fogging in the final hologram.[174] As photo grade gelatin can be easily ordered on the internet at a reasonable price, I decided to use the purer gelatin.[175] The goal of my research was to make the production of the recording material feasible and as easy as possible without losing quality. Deciding on the cleaner gelatin was one of those steps towards that goal and it came with another benefit: the reduction of air bubbles, one of the major problems of hand coating. Air bubbles are produced in the gelatin if stirred when melted or reheated. They can also appear when coating. Although they can be used creatively, equally they can be avoided by treating the gelatin slowly and with care. They appear as little bumps in the coating.

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172 S. E. Sheppard, *Gelatin in photography,* New York, Eastman Kodak Company, 1923.
173 Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.' p. 79.
174 Chemical fogging is a term that indicates a darkening in the coating that is not caused by the developer and therefore not by light energy. It occurs before exposure.
175 https://www.silverprint.co.uk/ (accessed 12 July 2018).

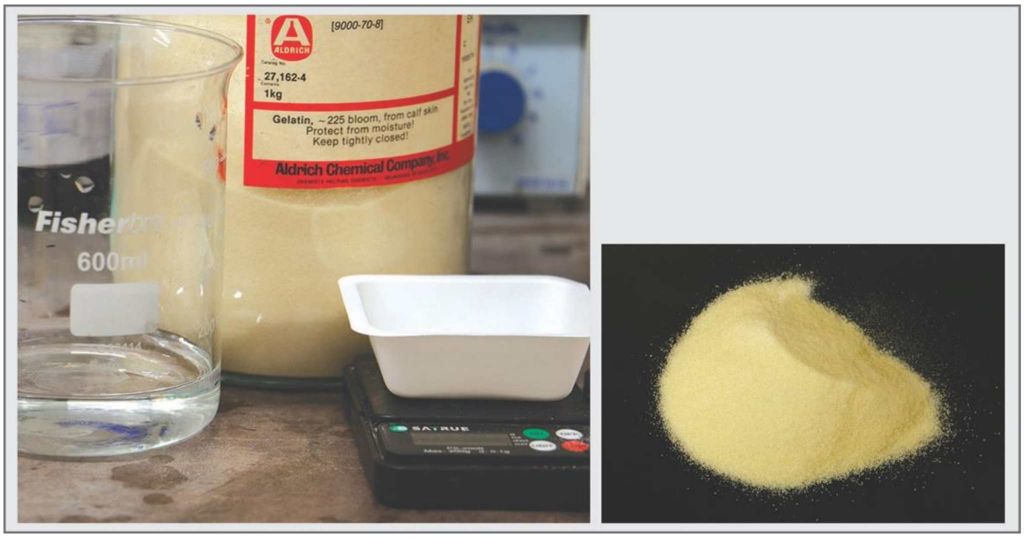

Figure 28. Gelatin to be weighed and put into de-ionized water for blooming and melting.

To prepare the gelatin to Blyth's recipe and method is a more complicated process than using more pure gelatin from the start. Blyth puts 12 g of leaf gelatin into 100 ml of cold de-ionized water and places the beaker into a water bath since it is important that the gelatin does not overheat. Overheating can lead to fogging of the gelatin layer and therefore ruining the hologram. He then heats the gelatin up to 51 degree celsius but warns about overheating: 'This is then placed in a water bath to prevent the gelatin getting over-heated. [...] if the gelatin soln is over-heated this chemical fogging can become severe'.[176] I use 10 g of granulated photo grade gelatin. Before melting, the gelatin is left to pre-soak, also called bloom, for about 20 minutes in 100 ml of cold de-ionized water. Blooming of the gelatin promotes even melting without lumps.

Figure 29. Gelatin just put in the de-ionized water on the left and gelatin after being in the water for 15 minutes on the right.

[176] Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', pp. 84-85.

The bloomed gelatin is then put it in the water bath.

Figure 30. Gelatin in the water bath.

The photo grade gelatin I work with has a bloom factor of 225, while the food grade gelatin I used when working in the lab with Blyth was platinum grade which is usually rated between 160 and 180. The higher the bloom factor the harder the gelatin is supposed to be. The photo grade gelatin finishes a bit more stable and scratch-resistant compared to the food grade gelatin. I work with 10 g instead of 12 g of gelatin, as the less gelatin used, the easier it is to coat a uniformly thin gelatin layer. During my work in the laboratory I reduced gelatin little by little down to 8 g but found that 10 g gave me a good stable gelatin layer which was able to disperse the high amount of silver halides required in the diffusion method. Blyth describes why a thin gelatin layer is essential in his review of one of his earlier versions of the diffusion method:

> If the diffusion method is tried on coating much thicker than 7 microns it is troublesome. I have tried it on ~ 100 micron gelatin and decided that it was not viable. The problem being that the rate of diffusion decreases exponentially with time and AgNO3 can carry on diffusing into the thick film and away from the incoming bromide ions.[177]

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[177] Bjelkhagen, ‘DIY Silver Halide Film‘, *holographyforum,* [web blog], https://www.holographyforum.org/wiki/DIY_Silver_Halide_Film#Hans.27_Diffusion_Post, (accessed 20 December 2018).

He continues to explain that this leads to uncontrolled grain growth in the front end, where the bromide ions have reached the silver nitrate. While they are growing bigger, close to the glass the silver nitrate and bromide ions still have not met and that provokes another problem:

> If you can't catch those unreacted Ag ions at the glass end then they quite rapidly develop up in the (ascorbic acid pH 6) sensitizer bath causing bad darkening or bad fog.[178]

This can be observed on the edges of plates or hemispheres where the gelatin has accumulated. Those edges turn dark immediately when submerged into the sensitizer bath. This darkening can be stopped by a longer tap water bath before putting the coated glass in the sensitizer bath:

> What you get is then virtually all the silver bromide in the first few microns and none in the gelatin nearer to the glass, you might just as well have coated it thinner in the first place.[179]

Hence, I reduced the gelatin from 12 g to 10 g in 100 ml de-ionized water.

I do not let the temperature rise higher than 40 degrees celsius, as low temperatures from 37 degrees celsius to 40 degrees celsius have been recommended in various different papers to prevent fogging of the hologram.[180]

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[178] Bjelkhagen, 'DIY Silver Halide Film', *holographyforum,* [web blog], https://www.holographyforum.org/wiki/DIY_Silver_Halide_Film#Hans.27_Diffusion_Post, (accessed 20 December 2018).

[179] Bjelkhagen, 'DIY Silver Halide Film', *holographyforum,* [web blog], https://www.holographyforum.org/wiki/DIY_Silver_Halide_Film#Hans.27_Diffusion_Post, (accessed 20 December 2018).

[180] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing,* pp. 37-43.

Figure 31. Hemisphere with chemical fogging.

In addition, overheating can not only cause chemical fogging but can also break the structure of the gelatin which later can cause the coating to break and peel off. This way the gelatin takes about an hour to melt, but it is a very gentle way to do it, not forcing the material and avoiding fogging and air bubbles. In the published recipe, Blyth stirred the gelatin for 20 min until melted. It was then filtered through a cotton handkerchief or nylon stocking to remove froth from the surface. He then stirred in the copper sulphate, to prevent chemical fogging, and added 4 ml of glycerol. As noted before, even though 4 ml glycerol is stated in the recipe, what actually goes into the gelatin is about 3,5 ml as glycerol is very viscous and some of it sticks to the glass. The glycerol is mixed in as it improves flexibility when coating onto curved surface. I tried the photo grade gelatin both with and without glycerol, and no difference was detectable, I decided to leave it out, as the hardener in the next step is made with glycerol anyway. If the coating seems to be very brittle, however, and is not flowing easily around corners, glycerol should be added. In that case it needs to be stirred in and air bubbles cannot be avoided. Once the bigger bubbles are removed simply with a spoon, the solution should rest for 30 minutes in the water bath, at no more than 40 degrees, and any bubbles settled inside come to the surface and pop, or can simple be taken off with the spoon. In summary both approaches of preparing the gelatin work, but using photo grade makes the process easier and the coating is more likely to be successful as less impurities are present.

The coating

For the coating, the gelatin is kept close to 40 degrees celsius. The glass object should be warm as well, but not too hot as they have to be touched directly. This is crucial, as only an even flow around the object can guarantee an even coating. A cold glass object makes the gelatin settle too fast. I explain the process of coating glass objects with the example of a hemisphere.

I pour a good part of the gelatin solution inside the hemisphere. At this point it is important that no drops fall on the hemisphere as they cool down quickly and create a bump in the coating. This might not seem too worrying, but wherever the gelatin is thicker than average, the chemistry works differently, mostly resulting in ugly stains that can ruin the hologram. After pouring the gelatin in the middle, the hemisphere is moved in a smooth, calm manner, not in a rush but not too slow for the gelatin to settle, and then I pour the rest of the gelatin gently, to avoid air bubbles, into a beaker or glass bottle for later use.

Figure 32. Coating of the gelatin by slowly moving it around in the hemisphere.

As mentioned before, it has to be kept at 40 degree celsius if more than one hemisphere is to be coated. The hemisphere is left on a grid with the opening facing downwards so excess gelatin can drip off. After ten minutes a fan is turned on to assist the drying process.

Figure 33. Drying of the coated glass objects.

If facing with the opening up, gelatin accumulates at the bottom, causing the same problems as noted in the edges later in the process. How to avoid or resolve these problems in the edges are discussed later in this chapter.

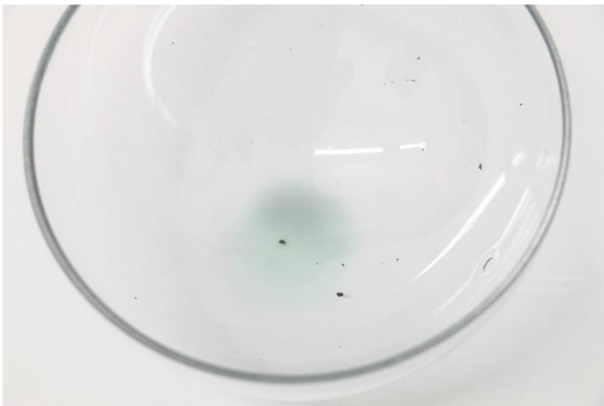

Figure 34. Gelatin stain that occurs, if the hemisphere is dried with the edges up.

The cold airflow now hardens the gelatin quickly and prevent more gelatin from running off, to ensure the coated layer is thick enough to distribute the silver halides later. A major advantage of the diffusion method, in contrast to emulsion making, is that the coating stage takes place in full light, as only the gelatin layer is coated and it is still not light sensitive. This makes it easier to control the coating process. To recap - when coating the glass object, there are three things that are important in ensuring a clean result:

1. For a clean hologram the coating of the gelatin layer has to be done as uniformly as possible. That can be a challenge depending on the shape of the object, as previously noted. The uniformity of the gelatin layer is very crucial to guarantee an equal reaction of the whole layer to the exposure and developing process. Uneven coating might result in the accumulation of chemicals in the thicker parts of the layer which may then lead to uncontrolled grain growth and fogging in those parts.

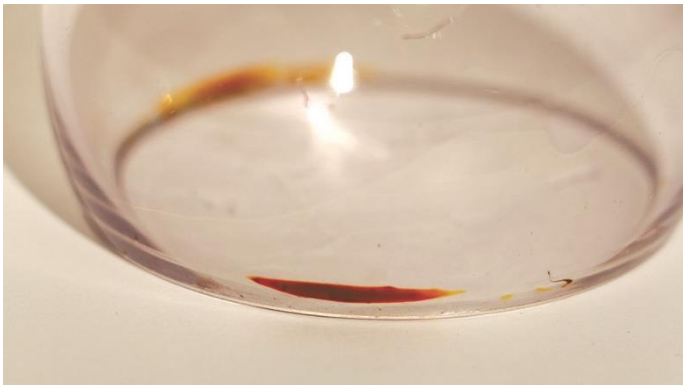

Figure 35. Stain in the edges of the hemisphere after processing due to thick gelatin.

Figure 36. Stains from left-over developer.

The gelatin can however be manipulated with heated de-ionized water. When coating hemispheres, prior to putting the hemisphere on a metal grid to dry, the edges have to be cleaned of the gelatin. As the hemispheres dry, gelatin runs towards the edges and accumulate there filling the gap created. In spite of having cleaned the edges before, this might still result in an excess of gelatin near the edges. It helps to bath the edges of the hemispheres in heated de-ionized water to thin the layer of gelatin repeatedly.

Figure 37. Cleaning the edges of a hemisphere from extra gelatin.

This technique requires some practice in observing the behaviour of the gelatin to know how many baths are necessary and to apply the bath in such a way that the rest of the coated area is not affected by the water vapour. It works best when done regularly, depending on the thickness of the gelatin, in the first 30 minutes after coating.

The second possible method is to clean the edges of the hemisphere after drying by melting the gelatin on the edges in a water bath. This results in edges free of gelatin and clean in the finished hologram, but, of course the hologram recording stops shortly before the edges as well. This is not a huge problem but rather a matter of taste and a choice of how the finished hologram should look like.

2. Secondly, it is important to avoid the occurrence of air bubbles while coating. Air bubbles are mainly produced when melting the gelatin through stirring or when pouring the melted gelatin too quickly and uncontrolled from the beaker into the bottle or the other way around. If air bubbles are in the gelatin, leaving the gelatin in water bath at 40 degree for a while helps to get rid of them. With

patience it is possible to use a spoon and get the air bubbles out but it is best to try to avoid the creation of air bubbles from the start.

3. And thirdly, when pouring the gelatin, the area of the object where no recording takes place (usually the outside of the hemisphere) should remain free from gelatin, as it is difficult to wash off afterwards. When coating plates this can be achieved by using a second glass plate, bigger than the plate that has to be coated. The plate is placed on the second glass plate and fixed with insulation tape completely around it. The two plates are held up at about 45 degrees and the gelatin is poured over it from one side to the other, like a curtain. Blyth describe this process in great detail.[181] There are, however, many different forms of plate coating. A Meyer Bar is often used and for bigger plates spin coating proves to be successful. When coating plates up to 20 cm x 30 cm I prefer to pour the gelatin as a puddle on the plate, which can then be moved carefully until the gelatin layer covers the plate equally. In my experience it is the cleanest and fastest method for plate coating.


Figure 38. Glass plate ready for coating.

[181] Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.' p. 85-86.

Figure 39. Gelatin is poured on a glass plate which is then slowly moved around.

As pointed out before, it is important to follow these steps to get a clean result. There is of course always the possibility of using those features, which are commonly perceived as errors, in a creative way and to incorporate them in the artwork depending on the artistic and visual goals of the project.

After coating, any remaining gelatin can be poured into a bottle and be reused, even weeks later. It simply needs to be heated in a water bath at 40 degrees celsius until liquid again.

Step 4: Hardener

Step one to three describe the cleaning and coating of the glass object. Step four starts with a coated glass object, which has cooled down and the gelatin is touch dry and jelled.

	Me	**Jeff Blyth**
3.	**Hardener:** 4 g chromium potassium sulfate $KCrS_2O_8$ in 100 ml de-ionized water + 4 ml glycerol $C_3H_8O_3$	**Hardener:** 4 g chromium potassium sulfate $KCrS_2O_8$ in 100 ml de-ionized water + 4 ml glycerol $C_3H_8O_3$

3a.	***Alternative Hardener:*** *1,5 g chromium (lll) acetate hydroxide* $(CH_3CO_2)_7\ CR_3\ (OH)_2$ *in 100 ml de-ionized water* *+ 4 ml glycerol* $C_3H_8O_3$	***Alternative Hardener:*** *1,5 g chromium (lll) acetate hydroxide* $(CH_3CO_2)_7\ CR_3\ (OH)_2$ *in 100 ml de-ionized water* *+ 4 ml glycerol* $C_3H_8O_3$

Table 5. Recipes of the possible solutions to harden the gelatin.

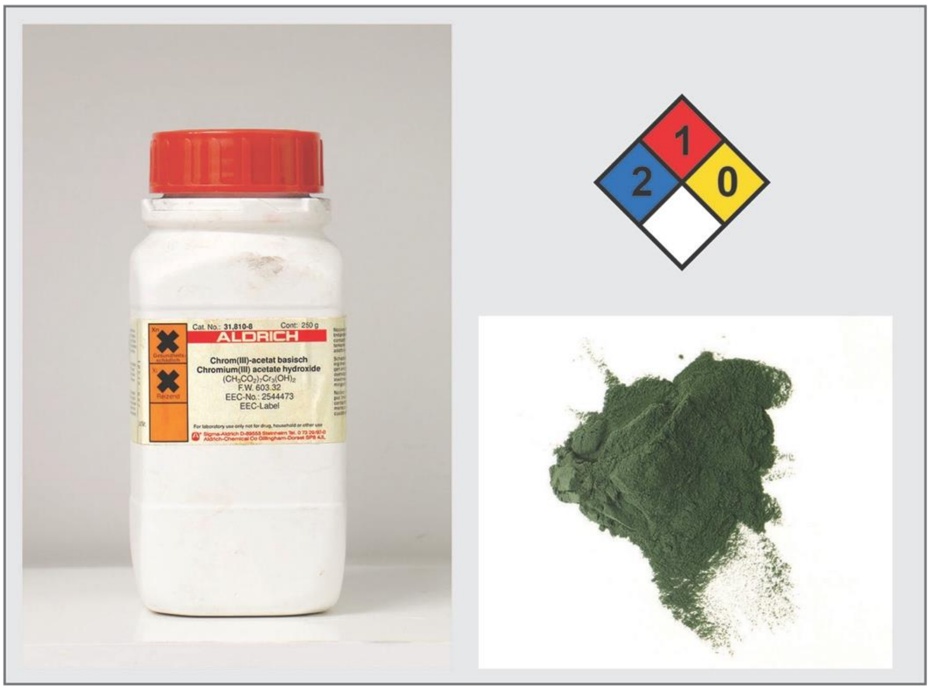

Figure 40. Chromium (III) acetate hydroxide. Used to prepare the *Alternative Hardener*.

Figure 41. Chrome Alum, used to prepare the Hardener solution.

Figure 42. Glycerol, a plasticizer to reduce brittleness of the gelatin layer and promote its flexibility.

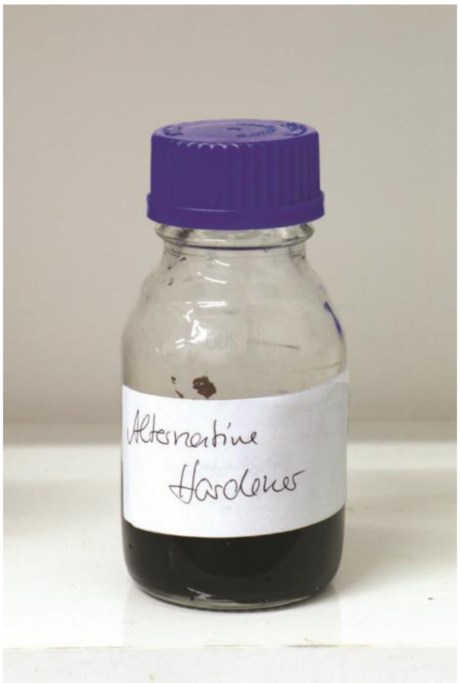

Figure 43. Solution for hardening the gelatin.

At this point, after coating and drying, the gelatin is quite soft and needs to be hardened, to make sure it does not get damaged when further processed. I have worked with the **Hardener** and the ***Alternative Hardener*** and both work fine.[182] The **Hardener** is poured inside the hemisphere and moved around for about 30 seconds and then poured back in the bottle for reuse.

Figure 44. Applying the hardening solution to the hemisphere to harden the gelatin layer by moving it around slowly and gentle.

[182] This is confirmed in Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing for Holography and Their Processing*, p. 43.

The hemisphere is cleaned from the outside and left on the grid for about two minutes. After two minutes it has to be checked for drops inside the hemisphere and the edges should be wiped clean. Like the gelatin the chromium accumulates there and might leave a purple (or green, depending on the hardener used) stain.

The original recipe states the chromium solution should be chilled at 5 degrees. In my experience, if the **Hardener** is too cold it seems to react with the soft gelatin and rupture it slightly, creating little holes in the coating. Using the **Hardener** at room temperature (17-20 degrees celsius) worked better, never creating any problems and it can still be stored for reuse. To make sure the hardening process takes place the hemisphere is left overnight, if possible in a cold air-flow. This is a cross-linking process, where bonds are formed to stabilize the gelatin. This can only happen, when the gelatin is in a dry and unswollen state. As this takes time, the original recipe gives an alternative process for speeding up the drying and puts the hemisphere in an oven. I cannot recommend it. After experimenting with it, the coating on hemispheres seemed to be easily damaged when processing it with further chemicals and wiping those off, a sign that the cross-linking has not been completely successful.

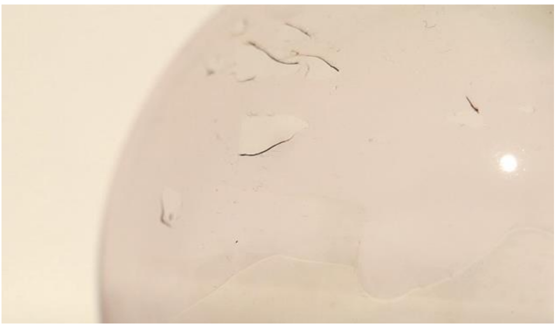

Figure 45. Scratching in the gelatin from wiping of chemicals.

In addition, this method recommends heating the oven at 50 degrees which might result in chemical fogging due to overheating, as explained earlier in this chapter.

After the hardening process, the hemisphere is rinsed thoroughly in de-ionized water. With the **Hardener** it is very likely that the coating changes its colour slightly too green or purple: rinsing should however result in a clear coating.

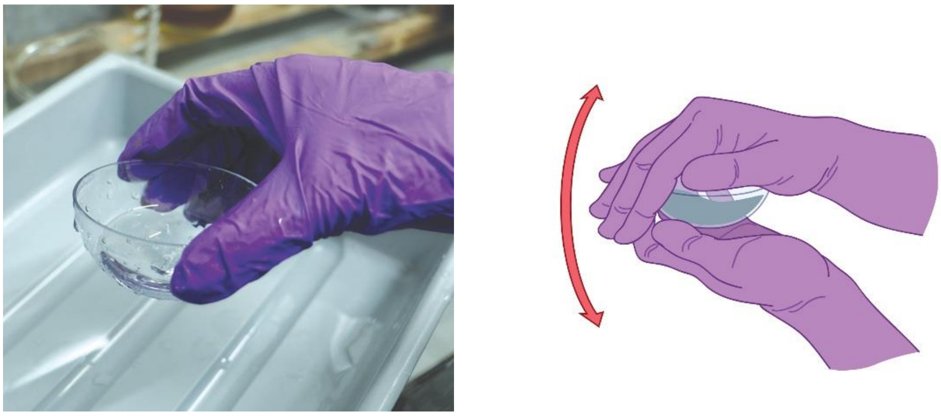

Figure 46. Cleaning the gelatin layer of the hardener solution by shaking it up and down, changing the de-ionized water three times.

Often after using the ***Alternative Hardener***, the coating looks more brittle and less soft after drying then when having used chrome alum. Both hardeners do the job of hardening the gelatin perfectly and the performance at the subbing stage is equally good. The difference appears when putting in the silver nitrate. With experience this becomes quite obvious. When putting in the silver nitrate, it behaves differently with the surface. If the coating is treated with chrome alum, the silver nitrate flows over it without any trouble, but when treated with acetate the solution forms dry patches and, it seems, is almost repelled at times. To make sure that the silver nitrate is dispersed in the gelatin layer, rinsing the gelatin coating in de-ionized water before putting in the silver nitrate helps. The surface should not be completely wet, but simply moist when the silver nitrate is put in. A rinse and a dry with a warm air flow works very well. The timings of both the rinse and the dry depend a lot upon the shape and size of the object coated. The gelatin should neither be touch dry nor soaking wet.

Chapter Five

Making the coating work

Following the steps explained in Chapter 4, the chosen glass object is now coated successfully with a thin layer of gelatin, either prepared for sticking to the glass by the previous step of subbing, or prepared without the subbing for an emulsion lift at the end of the process. Chapter 5 focuses on preparing the gelatin layer for the important step of diffusion in the silver nitrate and the silver nitrate bath itself. This is a pivotal chapter in my research, as the initial problems which affected the diffusion method are examined here: the improvements I made to resolve them and make the coating work are discussed at the end of this chapter.

Step 5: Sodium carbonate wash

After having rinsed the hardened coating, a quick wash of one to two minutes in sodium carbonate helps to make the coating slightly alkaline.

	Me	**Jeff Blyth**
4.	**Wash 1:** 0,1 g sodium carbonate Na_2CO_3 in 100 ml de-ionized water	**Wash 1:** 0,1 g sodium carbonate Na_2CO_3 in 100 ml de-ionized water

Table 6. Recipe for Wash 1 to make the coating slightly alkaline.

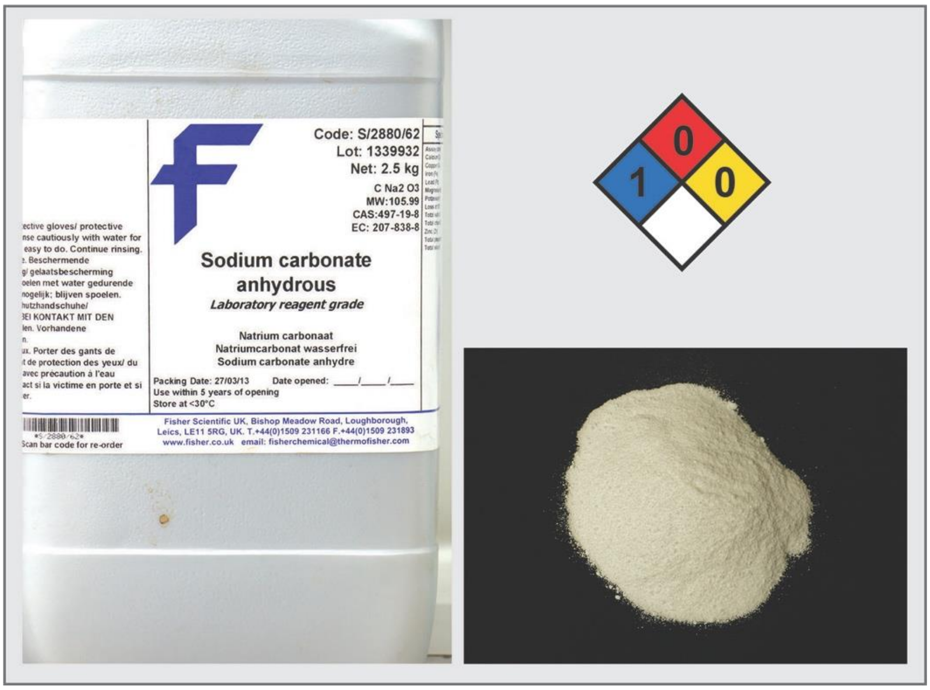

Figure 47. Sodium carbonate anhydrous, to make the gelatin layer slightly alkaline.

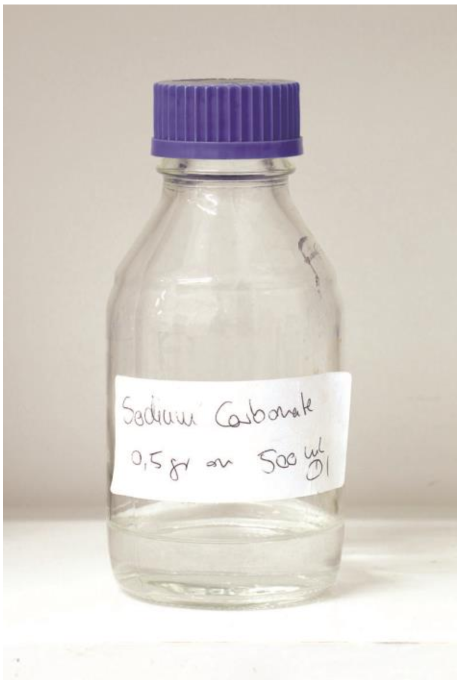

Figure 48. Sodium carbonate solution.

Blyth argues that this augments the acceptance of the silver nitrate later on in the process:

> The sheets are then left in a bath of 0.1 % sodium carbonate for about 1 to 2 minutes only and then briefly rinsed in DI. (Making the gelatin slightly alkaline contributes greatly to its ability to bind silver ions later).[183]

I made coatings both with and without this wash. I did not notice, however, any difference in the end results.

Step 6: Sodium nitrate wash

	Me	Jeff Blyth
5.		**Wash 2:** 10 g sodium nitrate $NaNO_3$ in 100 ml de-ionized water

Table 7. Recipe for Blyth's sodium nitrate wash, eliminated from the improved recipe.

I eliminated this step from the process, even though Blyth refers to this step as the defining step he was searching for to make the whole coating work:

> [...] it was found that the dreaded severe grain growth phenomenon was caused not by having too high a concentration of silver salt as was previously thought, but by low levels of chloride ion residing in the pre-coated gelatin film and that this could be prevented by first soaking the gelatin coating in a concentrated solution (soln) of potassium or sodium nitrate causing an ion exchange mechanism.[184]

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183 Blyth 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 87.
184 Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 79.

As noted previously, one distinctive thing about the diffusion method, as described here, is that it works with one halogen only: chlorine. We know that Talbot made his very first photogenic drawings on paper sensitized with table salt, sodium chloride, and that when the dry plate took over, emulsion making had evolved to use mainly the two halogens bromine and iodine. They were used together to increase light sensitivity. The percentage of iodine used would be very small and is used for the sole purpose of making the silver bromide crystals less perfect, which works as an open door for the light energy and sets the whole process of image forming in motion. Most of the holographic material today is made using the same principle. Using chlorine, as Blyth does, has been tried before, but it brings a new set of complications and problems. The main reason for using chlorine is due to the challenges of increasing light sensitivity while maintaining a small grain size. Blyth writes ‘AgCl is used because it was found that it was more than three times more photosensitive than AgBr in the recording process!’[185]

Even though holography has never sought the flexibility of a handheld camera solution such as photography, it is nevertheless extremely sensitive to the smallest vibration in the recording process, as vibrations destroy the interference pattern and consequently destroy the hologram. A relatively short exposure time is desired in holography, but with a small grain size as discussed at length in Chapter 2. Chlorine would seem to be the answer, if only pre-existing chlorides would not cause uncontrollable grain growth and therefore ruin the hologram.

Cleaning the coating with potassium or sodium nitrate, as Blyth suggests, is at variance with how photographic emulsions are made. When making an emulsion the manufacturer goes through considerable trouble to wash the emulsion clean of the byproduct of potassium nitrate, formed along-side the production of the silver halide. It is called double decomposition, in this case, with the equation for silver nitrate and potassium bromide:

$$AgNO_3 + KBr \rightarrow AgBr + KNO_3$$

[185] Blyth, ‘The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.’, p. 79.

The potassium nitrate should be washed away or it will crystallize on the coated plate. Baines describes it in *The Science of Photography:* 'The alkali nitrate is present in such concentrations that it would craze the emulsion by crystallising out when coated and dried on film or glass, [...]'.[186] Bjelkhagen makes the same observation when coating for holography: '[...] potassium nitrate, if not washed out, will craze the emulsion by crystallizing out when coated'.[187] In Blyth's diffusion method, potassium nitrate is not only produced through double decomposition but the coating is deliberately washed in a 10% solution of it, as described in his text:

> The sheets are then left for several hours or overnight in a 10 % soln. of pure potassium or sodium nitrate for the **essential** process of removing any chloride ions by a slow ion exchange mechanism. This time can be cut down to about an hour if the solution can be continuously mechanically agitated.[188]

For anybody who cannot agitate the solution for an hour, this is quite a time- consuming step. Blyth continues: 'The sheet is then rinsed well in DI and dried in a cold air flow so that it will be ready to allow silver nitrate to diffuse in'.[189] 'Rinsed well' is insufficient. The coating needs various washes to make sure the potassium nitrate is gone. With the hemispheres, as the gelatin layer tends to get slightly thicker close to the edges, avoiding crystallisation seemed almost a hopeless cause at times. It is important to mention that the coating works, however, without this step of washing with sodium nitrate, irrespective of whether food or photo grade gelatin had been used.

This paradox had been an issue for me since the beginning. The failure of the whole system finally eliminated it. I talk about this at length later in this chapter in the section *Troubleshooting and improvements* but before that, it is important to look at the next step regarding the silver nitrate, as they are all closely connected.

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186 Baines, *The Science of Photography,* p. 98

187 Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing for Holography and Their Processing*, p. 35.

188 Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 87.

189 Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 87.

Step 7: Silver Nitrate

	Me	Jeff Blyth
6.	**Silver nitrate solution:** 2,2 g silver nitrate $AgNO_3$ in 10 ml de-ionized water	**Silver nitrate solution:** 2 g silver nitrate $AgNO_3$ in 10 ml de-ionized water

Table 8. Recipe for the silver nitrate solution.

Figure 49. Silver nitrate

Silver nitrate has been used in photography from its very inception. To prepare the solution, the silver nitrate is easily mixed with de-ionized water. No magnetic stirrer is necessary: it can be done just by shaking the beaker with the hand. This is preferable, as it is very important not to contaminate the silver nitrate solution, which is easily done. The silver nitrate solution can be reused, but the moment the clear solution changes its colour to a light red or brownish colour, it will ruin the coating. The colour change is due to the formation of colloidal silver. Colloidal silver are small particles of silver that do not produce the silver halide needed, but instead forms a strong fog the moment the coating is put into the halide/dye solution. This is the next step, discussed in Chapter 6.

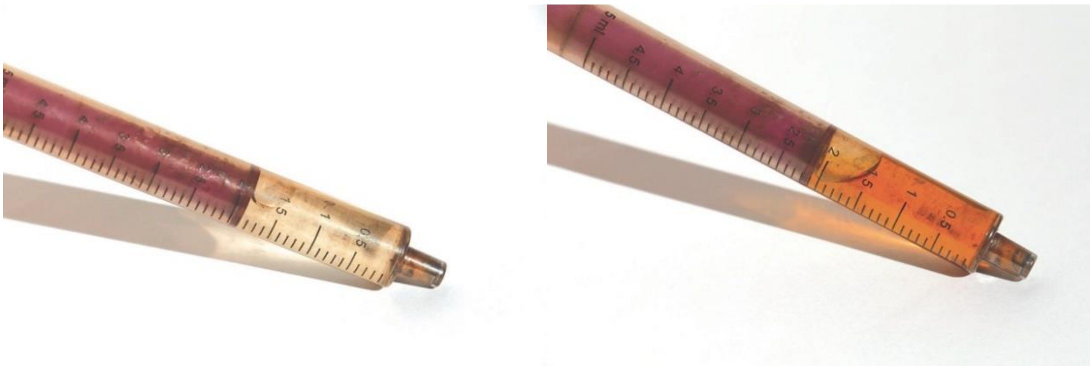

Figure 50. Pure silver nitrate in solution ready to use (left), contaminated silver nitrate in solution that will ruin the coating (right).

When putting the silver in, the use of a very warm, orange low light is recommended, as silver is slightly sensitive to the blue spectrum of the light. It is also important when putting the silver in, that the gelatin has time to absorb the silver nitrate. In alternative photography processes, a silver bath is often used, where the plate is submerged and left for a designated time. In the diffusion method the silver percentage used is high, consequently a high amount of silver would be necessary for a silver bath. It is more convenient to use the method proposed in Blyth's recipe:

> Using a clean syringe or pipette, I deposit a certain sized blob of silver nitrate soln. close to an edge of the carrier sheet. I then carefully place a cut piece of the gelatin coated on top of the blob so that about a half to one cm of the sheet protrudes over the edge of the carrier glass. The blob of silver nitrate soln then spreads evenly and easily over the gelatin film by capillary action except of course for the bit protruding over the edge of the thick carrier sheet. This overhang bit is useful for handling the sheet without touching the silver nitrate.[190]

The plate should be left there for two minutes. Blyth also recommends treating the carrier sheet with 'rain-x' which makes it easier to gather remaining silver nitrate solution. The solution can be regathered with a syringe and put back in the bottle. I

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[190] Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 88.

operate a two-bottle system and never mix used silver nitrate solution with freshly made, in case of contamination.

Figure 51. Two bottle system for making sure the silver nitrate solution stays clean. Silver nitrate, in forms of crystals or solution should be stored protected from light, in dark bottles, for example.

When coating glass objects such as hemispheres, the hemisphere itself is used to hold the silver nitrate solution. Blyth describes his method, when coating only one side of a wine glass, to prevent any waste of the expensive silver nitrate solution:

> Then use your gloved forefinger to wipe the silver solution only over that designated half of the glass. Spend at least two minutes gently wiping that solution over just that half of the glass.[191]

Here I disagree. It is more beneficial to use a bit more silver nitrate solution and spread it around by gently moving the wine glass or hemisphere, than wiping it in, as the risks of damaging the gelatin and contaminating the silver solution are considerable. In my experience moving the hemisphere gently around for about two minutes and making

191 Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 96.

sure the silver nitrate solution gets everywhere works successfully. Remaining silver nitrate solution can be gathered with a syringe and reused in the same way as excess solution from plate coating. The bigger the glass object is, the longer the time of agitating the silver nitrate solution in it should be.

Figure 52. Pouring silver nitrate solution into the hemisphere.

Figure 53. Moving silver nitrate around in the hemisphere slowly.

The silver nitrate solution is another point where the control the holographer has over the material proves useful. As previously noted, gelatin is often thicker closer to the edges and this can lead to dirty edges, as more chemicals are accumulated there, and this in turn leads, among other things, to grain growth. It can simply be avoided by not bathing the edges with the silver nitrate solution. That will result in clean edges in spite of a thick layer of gelatin. Blyth recommends only coating half of the wine glass with the silver nitrate solution. His motivation is to save cost on the expansive silver nitrate, and of course, this is a good idea for tests, but can be used creatively as well.

Once the silver nitrate is put in, it is extremely important that any traces of silver nitrate solution are wiped away very gently so as not to damage the gelatin. Any remaining silver nitrate on the surface causes grain growth and fogging later on.

Figure 54. Wiping the hemisphere gentle to make sure spare silver nitrate is gone.

After wiping the spare silver nitrate from the glass object, the coating needs to be dried under a warm (not hot) air flow. This has proven a definitive step in the process and is not emphasised enough in the original recipe. The warming of the coating ensures that the silver is diffusing into the coating. If it does not, it precipitates out later in the process and leave a white fog and ruin the hologram. Special care has to be taken with the edges, anywhere where the gelatin layer might be slightly thicker and the silver needs additional time to diffuse into.

Figure 55. Drying the hemisphere after wiping under a warm air flow.

When working with the halogen chlorine, it is very important to work with an extremely pure silver nitrate. Any little traces of chloride in the silver nitrate promote grain growth, once the dye with the chloride is introduced, to a point that may ruin the recording material.[192] The diffusion method does work as well with bromide, as Blyth describes in his article in 1999.[193] But the use of chlorine not only makes the plate three times more light-sensitive compared to when bromine is used, it also produces smaller grains, as noted in Chapter 2. These are advantages that make the challenges caused by the use of chlorine acceptable.

Troubleshooting and improvements

With a working coating system, we are now left with a gelatin coated substrate, slightly sensitive to light due to the silver nitrate dispersed in it, and ready for the next step: the sensitization. That, however, was not the case when I started to coat hemispheres. This part of my thesis gives a detailed account of the obstacles and problems I encountered, including quotes and photographs of my notebooks during the time, and discusses the improvements I made to the diffusion method to make it work for the coating of curved surfaces.

192 The chloride level of the silver used is 0-1 mg/kg.

193 Blyth, 'A diffusion method for making silver bromide based holographic recording material.'

One of the goals of my overall research objective - proving that handmade recording material with the diffusion method was a feasible new choice for the creative holographer - was to realise an actual project with such material. When the first two holograms in hemispheres had been successfully achieved, I decided to engage in my first artistic project to prove that it was manageable with hand coated material. In February 2017 I started to prepare *Space Bubbles* for the exhibition *Steampunks in Space* in November 2017 at the National Space Center. The annual event *Steampunks in Space* had released an open call to invite and commission five artists. I applied successfully. My proposal was to put holograms in globes to be hung from display stands in Steampunk design.

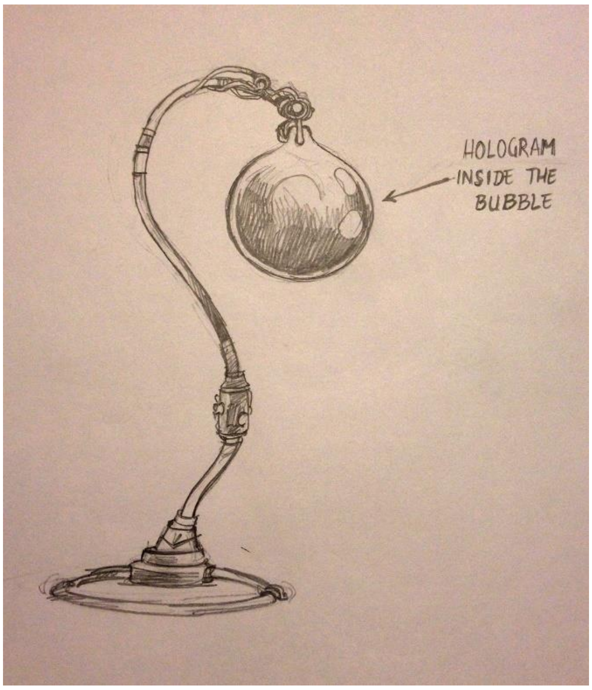


Figure 56. Proposal sketch for the exhibition at *Steampunks in Space*.

Moving from hemispheres to bubbles seemed to be the next logical step. The bubbles were glass globes bought from the internet, with a hole in one side, providing both an important access point for coating and for the presentational possibility of hanging.

Figure 57. Glass objects bought on the internet.

This was to be the new challenge to confirm the practical and creative application of the method, but even before I could focus on this, while continuing to coat hemispheres, the chemicals suddenly seemed to act unpredictably. The outcomes were milky blue coatings which did not record a hologram.

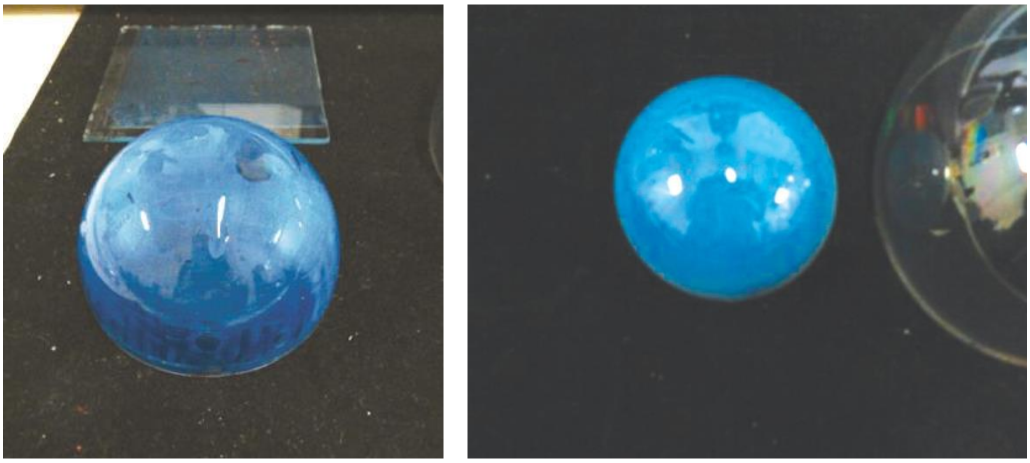


Figure 58. Blue milky hemisphere after the dye bath.

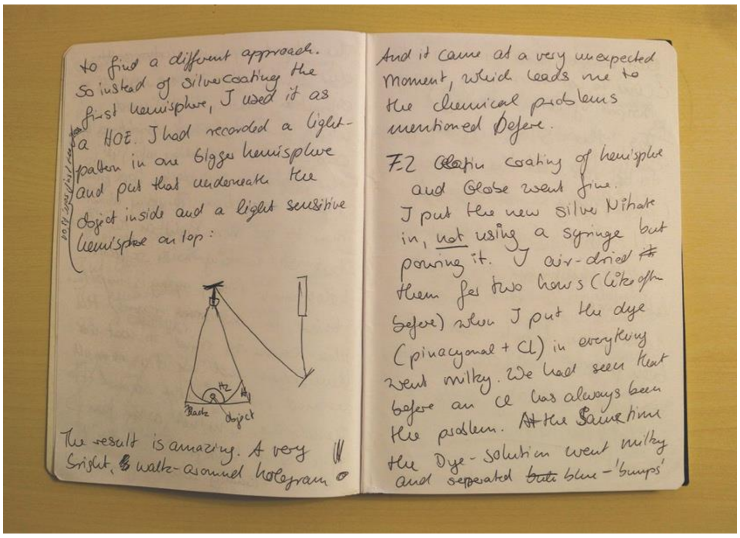
Up till this point, I had used the method as proposed by Blyth, following his recipe. Now I was forced to look closer and work out what suddenly had gone wrong and how to resolve it. This took me nine months. During that time I coated endless numbers of hemispheres and got to know the different steps of the process in detail as new problems kept occurring. When I had begun my research, it initially seemed that it would be easy to apply the diffusion method to art projects and my goal was to research how that changed the perception for the audience and how far I could experiment with the setup, while still being able to record a hologram. With the method not functioning, however, that goal had suddenly changed. The diffusion method as it stood was not feasible, but on the contrary, frustrating and time-consuming. The prejudices I had read about, and discussed in Chapter 1, against handmade recording material seemed to fulfill themselves. Giving up, however, was not an option. I had already experienced the creative potential and was convinced that times were changing and giving the artist a choice about the recording material would have a positive impact on creative holography.

Keeping in mind this new goal for my research, to make the diffusion method work again and be feasible for art projects, I began to experiment with the coating. It was not only the challenge of making it work again, but of understanding what had happened to derail the process and consequently preventing something like that from happening again to practitioners. In practice, the diffusion method was not as straightforward as it seemed to be in theory.

Figure 59. Fogged hemisphere after developing and bleaching.

When I started my research into the failure of the method, the obvious culprit was chlorine. The last two parts of this chapter have stressed the fact that chloride contamination ruins the attempt of a successful recording. While that is true, I found out that there is another factor which is highly important for the success of making recording material for holography: the drying in between the single steps of coating. It was a long journey of trial-and-error experimentation to reach that conclusion.

When the method broke down in the beginning of 2017, I went through the entire process step by step to see where the problem might be.


to find a different approach.
So instead of silvercoating the first hemisphere, I used it as a HOE. I had recorded a light-pattern in our bigger hemisphere and put that underneath the object inside and a light sensitive hemisphere on top:

The result is amazing. A very bright, walk-around hologram!!!

And it came at a very unexpected moment, which leads me to the chemical problems mentioned before.

7.2 Coating of hemisphere and Globe went fine.
I put the new silver Nitrate in, not using a syringe but pouring it. I air-dried them for two hours (like often before) when I put the dye (pinacyanol + Cl) in everything went milky. We had seen that before and Cl has always been the problem. At the same time the Dye-solution went milky and separated blue-'bumps'

Figure 60: Notebook C, 07.02.2017. The start of the breakdown of the system. On the left, I was still occupied with improving the setup: on the right, the first problem when coating appears.

I had run out of silver nitrate and was now using a new product. At the end of a very frustrating month, testing the new product and obtaining unsuccessful coatings, it seemed to be obvious that the failure of the coating was related to that. The new silver nitrate had to be the culprit. I now know that it was not. But at that point I bought silver nitrate from different suppliers, as the supplier we had used before had gone out of business. I have now settled on a product form Honeywell, distributed by Scientificlabs.[194] When the system had failed, I was sure that the change of silver nitrate would stabilise the method again and tried three different silver nitrates. None worked, of course, as the problem lay elsewhere.

When I revisit my research notes now, they reveal how frustrating this time was. Besides trying different silver nitrates, I experimented with how to put the silver in. I started by changing the method of handling the glass object after having put the silver in.

194 https://www.scientificlabs.co.uk/product/31630-25g, (accessed 15 June 2018).

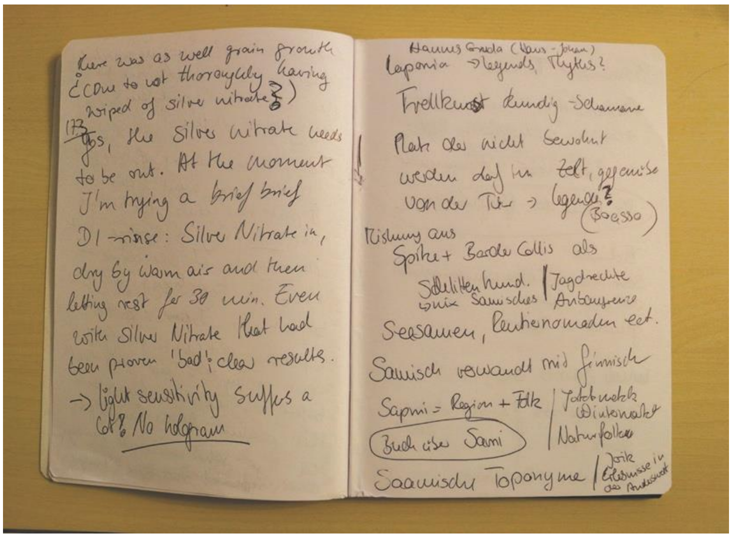


Figure 61. Notebook C, 17.03.2017

17.03.2017

Yes, the silver nitrate needs to be completely gone. Tried a brief DI rinse: silver nitrate in, dry by warm air, rest 30 min, brief rinse: NO hologram

When silver nitrate handled more carefully with syringe better results but still not perfect. Waiting for new silver nitrate.[195]

The rinse after the silver nitrate had been put in, of course, made the gelatin swell, and rinsed too much of the silver nitrate away. When wiping the surface only excess silver nitrate is removed, but by rinsing it, the silver nitrate already in the coating can also be removed. The silver nitrate needs to be removed from the surface - but that does not mean it has to disappear entirely. Quite the opposite, I had to ensure that the silver nitrate diffuses into the gelatin. Drying the glass object under a warm airflow for two minutes, directly after putting in the silver, avoids a lot of problems. I did not realise at the time that drying the glass object properly, immediately after the procedure, had actually been the solution, as I had gone one step too far with the additional rinse. It took me another two months and many more frustrating experiments, wasting perfectly good silver. My initial assumption had been that silver nitrate from a different supplier would make all the difference, but that was not the case, as my research notes reveal:

[195] Notebook C.

> 15.04.2017
>
> Desperation: Good, pure silver was finally delivered. It all went well at first, but I then ran into the same chemical problems. As soon as the dye touched the emulsion, a hard, white fog was formed.[196]

My suspicion at this point was chloride impurification. That was not good news. There seemed no way to solve the issue: I worked with the same degree of pure silver nitrate as we had done in the beginning. At this point the options seemed to be either to give up or to keep on trying and watching the system fail over and over again. Neither option was very tempting so I simply decided to move on from the belief or assumption that the silver nitrate was the problem and instead to believe that I would find the solution elsewhere.

As I mentioned before, I was never quite convinced with the potassium nitrate bath, as it went against everything I knew from photography with the problems it could cause. The noodling process invented in 1873, mentioned in Chapter 3, was specially designed to wash out the potassium nitrate. It was already known back then, that potassium nitrate could ruin a good result as it crystalizes out of the coating later in the progress, forming a fog that results in a dim recording or ruins the image completely.

In addition, the opportunity to omit the time-consuming bathing step with potassium nitrate was tempting, therefore I decided to try. My concern and supposition was that without the potassium nitrate bath, the extra chlorides in the coating would stimulate uncontrolled grain growth when the silver infused coating was put in contact with the dye bath, rendering the material unusable. That was, however, the same that was happening anyway.

Nevertheless, I coated four hemispheres, each with the same batch of gelatin made up from Blyth's original recipe. I was using the same mixture of chemicals, to have the least number of variables possible.[197]

---

[196] Notebook C.
[197] Notebook D, 08.05.2017.

1. The first hemisphere I coated as per the recipe instructions, applying **wash 1** and **wash 2.**
2. The second hemisphere I coated without applying **wash 1** or **wash 2.**
3. The third hemisphere I coated as instructed, but left out **wash 1.**
4. The fourth hemisphere I coated as instructed but left out **wash 2.**

All four hemispheres turned out clear. The two washes did not seem to make any difference at all. Instead I had been able to record four holograms for the first time since the method had failed. As the four different treatments did not give any dramatic or significant variation of result and they all turned out good, I decided to coat more hemispheres, sometimes with and sometimes without the **wash 2,** to test the concept. I knew the method was far from being stable and as suspected the problems came back. I repeated the coating as before and all four hemispheres turned out milky.

Figure 62. Fogged hemispheres from experimenting with Wash 1 and Wash 2.

Figure 63. Details of fogged hemispheres.

I continued coating, but became a little impatient, as I was producing a huge number of coated hemispheres that resulted in failure, but nevertheless, I had also experienced the system working again successfully.

Figure 64. Hemispheres.

At that point it seemed to all be down to random factors, unknown changes or nuances in the variables, or even simply to luck. This uncertainty let to a series of trial-and-error experiments, based on the looseness and often ambiguous character of the results of the preceding experiments. Allowing imprecision in the experiments and moving away from exact times and procedures but focusing more on the actual reaction of the material, the gelatin coating, ultimately resulted in a working emulsion. Experimenting with the potassium nitrate wash, my rhythm of coating was more or less like this: the two hemispheres which received the **wash 2** were left to soak in it overnight.

Figure 65. Hemispheres filled with sodium nitrate to be left overnight.

The next day I would treat the one that only received **wash 1**, and then rinse the three of them together, leave them a couple of hours to dry and then would put the silver in all of them. Putting in the silver was not a problem when it was pure silver. The problems happened when the object went into the dye bath after the silver. It would be a quick reaction which I could even see in the darkroom with only the safelight on. A solid white layer would form inside the hemisphere and ruin it completely. That was a very frustrating time. Nothing worked and I tried different things, such as cutting down the time of **wash 2**. I even changed the **hardener** to **alternative hardener** and back, when it did not make a difference.

At one point I tried to speed up the process to be able to do more hemispheres in a shorter time. I changed the drying method. For the longer drying periods, after the **hardener** and **wash 2,** I put the hemispheres in the oven at around 40 degrees celsius, as suggested in the original recipe:

> (An oven or warmer at 50 ^{0}C could be used instead to speed the slow process [of cross linking] up to about an hour, but the gelatin film must firstly be made relatively dry under a cold blower before being put in a warmer).[198]

I changed the drying after putting in the silver nitrate as well. The original recipe said to dry it in a cool air flow.[199] I put the hemisphere under a warm airflow for 3 minutes and then let it to dry under a cool airflow for at least 30 minutes. I did the same after the sensitizing step. The problems now seemed to be pushed down to the edges of the hemisphere with or without the two washes. A tiny breakthrough:

> 05.05.2017
> Maybe heat could be the solution. Some of them, to dry them faster I put in the oven for 2h. With the chromium, I didn't like it, because the gelatin got affected.

---

[198] Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 87.
[199] Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 88.

But only some of them (and none of them had problems with cl). Can this happen because of moisture? So, it's not the heat but the dryness that is important? [200]

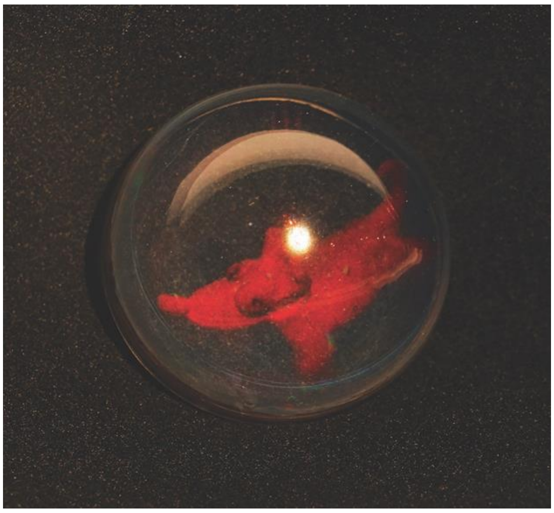


Figure 66. The first hemisphere that worked after the failure of the system. It has a diameter of 4,5 cm.

They worked for that batch, but the next one was again a failure. Looking back, I know that I was too focused on the heat, even though the notion that the dryness might be more important was emerging in my mind.

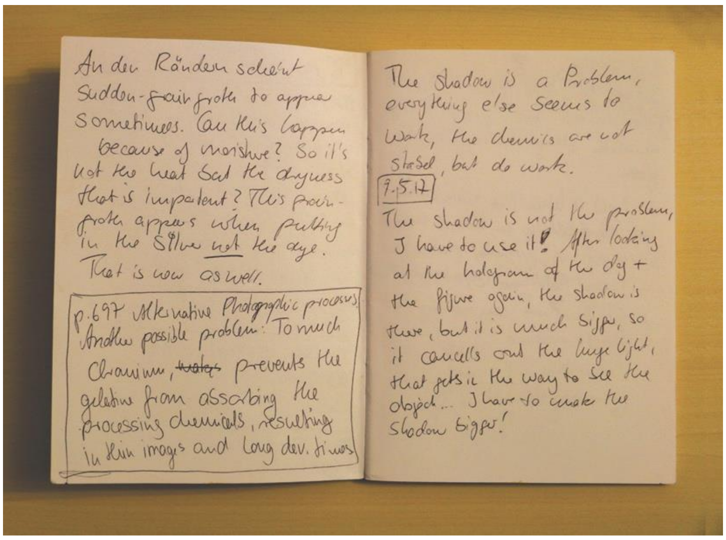


Figure 67. Notebook D, 09.05.2017

[200] Notebook D.

09.05.2017

Nothing seems to work anymore again. I'm back to Sodium Nitrate 2h.

Ging auch nicht. Das einzige was ständig wechselt: wipes!

(Doesn't work. The only thing that constantly changes are the wipes!)

It is not the wipes, same problem with the ones I used in the very beginning when everything was still working.[201]

Those were desperate times and I started to test different wipes, dry and wet, including the ones we had worked with before. Apart from the texture and the fact that wet tissues did not work as anticipated, there was no change. Consequently, special, expensive wipes are not necessary. Any tissue without a structure or additives will do.

Figure 68. Wipes used for cleaning the coating of extra silver nitrate and after the sensitizing step.

I continued coating as it seemed the only thing left to do. At that point I tested whatever it was possible to test. I started to doubt the quality of single distilled water, tried double distilled water and de-ionized water with no appreciable or transformative results at all.

10.05.2017

The ones that didn't work just now, were in the sodium nitrate solution overnight. A disaster. I had to change from sigma Aldrich nitrate to science lab nitrate. Might that be the problem?[202]

It was not.

[201] Notebook D.

[202] Notebook D.

> 10.05.2017
> Or, I also coated a small one, no sodium nitrate solution at all - clear! Why do the small ones work, but the bigger ones don't?
> Try now: 2h of NaNO3 und 30 min oven, to make sure they are really dry. Maybe I put the silver in to quick? [...]
>
> It still doesn't work!
> The problem just appears later and later, they were clear when I put them in the light tight box, when I looked an hour later, they were fogged. Box not light tight?? But it was up to now...[203]

What I did not realise in the heat of the moment was that it actually had worked. I had simply run into another, only seemingly related, problem: chemical fogging. This can happen for many different reasons in the process, possibly through heating the gelatin too much, and most likely would be my mistake by working too fast or not being focused enough. The heating in the oven after **Wash 2,** to make sure they are really dry, had been most likely the mistake leading to overheating of the gelatin. I used a mild oxidizer for the chemical fogging, which resolved it.[204]

Up to this stage the trial-and-error experimentation had been a very frustrating endeavour. It needed some time and analysis to realise and to understand the success of it. The holographic lab moved at that point to new purpose-built facilities in the same building, which necessitated abandoning the work in the lab for three months but gave me the opportunity to analyse and concentrate on reading. A few months later I looked at my work and notes again with fresh eyes. After moving into the new facilities and getting organised I started coating again and got my first results in October 2017. There were still problems, due to chemical fogging. It seemed like I had picked up my work exactly where I had left it. I used a mild oxidizer again and after processing, the hemispheres turned out milky blue with very dim holograms.

---

203 Notebook D.

204 Recipe for a mild oxidizer: 2 g EDTA, 2 g NaCl, 1 ml acetic acid in 100 ml water, bath for 1 minute, rinse.

I changed the sensitizing bath from Vit C to TEA with the hope to get a brighter hologram and reduced the exposure time as that quickly leads to milkiness in the developed hologram.[205] In the next hologram the milkiness was gone. Instead I had a bright hologram on a slightly too blue coating. Part of my developing process is a printout solution based on persulfate. After applying that the blueness of the coating was reduced to a tolerable level.[206]

Up to this point, in summary, the big fundamental problems were resolved. Everything was now quite positive apart from the chemical fogging. I suspected the chemical fogging appeared due to the heating in the oven for drying and stopped it. In the new lab facilities, a metal rack had been installed which was perfect for drying hemispheres, as a fan or cold air flow could be produced for drying them a lot more effectively than before:

Figure 69. Drying hemispheres before using a grid.

[205] Sensitizing baths will be discussed in Chapter 6.
[206] Print out and the chemicals involved will be discussed in Chapter 7.

Figure 70. More effective drying on a grid.

The chemical fogging was now gone and I regularly produced clear coatings. However, the holograms were still quite dim. I decided to go back to Vit C as a sensitizing bath, as I wanted the processed hologram not to have any colour changes. I could not change the dye concentration as I was already battling the blueness of the finished hemispheres. As a consequence, I augmented the silver concentration. Apart from that, after putting the silver in and wiping the hemisphere, I dried it for about 5 minutes under warm air, which I did again after the sensitizing bath.

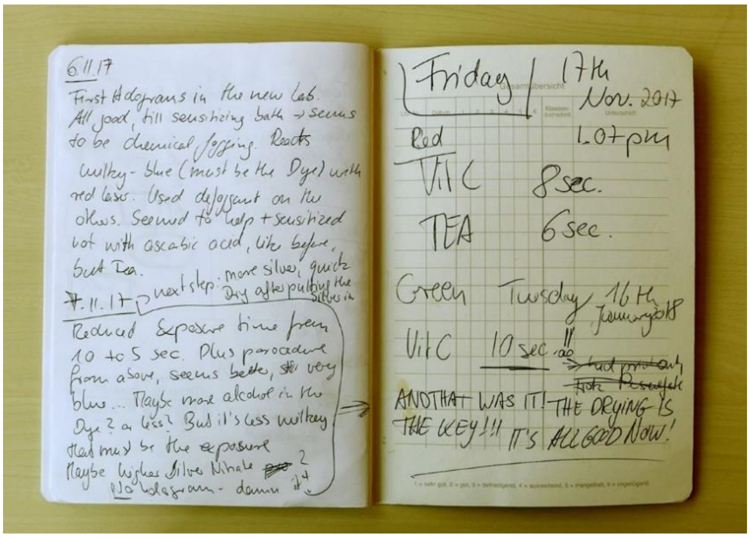


Figure 71. Notebook C, 07.11.17

07.11.17

Reduced exposure from 10 sec to 5 sec. Plus procedure from above, seems better, still very blue. Maybe more alcohol in the dye? But it's less milky. That must be exposure.

Next step: more silver, dry after putting the silver in. AND THAT WAS IT!

THE DRYING IS THE KEY! IT'S ALL GOOD NOW.[207]

17.11.2017

1.07 pm Red laser: Vit C (*Sensitizer)*: 8sec, tea 6sec, the perfect hologram![208]

Figure 72. The first hemisphere of a now stable system of the diffusion method.

I was now able to confidently reproduce red laser bright holograms and actually finish my holograms for the exhibition in the National Space Centre just in time. The chemicals were stable and the whole method worked fine. Drying the glass objects after Step 5 and Step 7 made all the critical difference. In retrospect, it all made sense.

[207] Notebook E.

[208] Notebook E.

When I had started to experiment with eliminating the washes, the first batch had worked. With the second batch the only change was the size: I had started the experiment with hemispheres with a diameter of 7cm and had then moved on to 10-12 cm. I had given them the same drying time, which was fine for the small ones, but not for the bigger ones. The problem had been that I had never given enough attention to the variability of drying times and the intensity of the drying. By luck sometimes it had worked out. But now I could control and adjust the times. An account on times is written down as part of the updated recipe in Chapter 6. Augmenting the silver concentration had been the second important step.

The next challenge was to change from the red laser to the green laser: To make successful red holograms in hemispheres, I had needed 1.5 years in total and a countless number of hemispheres to accomplish a good hologram. The first three hemispheres I exposed with the green laser were a disaster: milky, too orange due to the dye and very dim holograms. I analysed every hologram, went back to my notes and adjusted the chemicals and times. The 1.5 years of frustration now translated into an intensive learning time and paid off in January 2018, after having studied the diffusion method for two entire years.

16.01.2018
2.24 pm: green laser: Vit C, 10 sec.

Figure 73. The first green hologram in a hemisphere.

This chapter shows the importance of patience, commitment to constant experimentation and working practice in forming tacit knowledge. Only through constant observation and experimentation with the material did I achieve a successful result. From then on, through eliminating the second wash and spending more attention on the drying process, the method was stable. Variations in the visual outcome could now be easily analysed, often finding the problem in the thickness of the gelatin layer or contaminated silver. The next chapter focuses on the last steps in the process of making silver halide- based holographic recording material.

Chapter Six

Sensitization

Once the silver nitrate is put into the gelatin layer, silver halides need to be formed and the coating has to be made sensitive for the wavelength of the laser used. Those important steps are merged into one in the diffusion method as explained in this chapter. Furthermore, a final step of sensitization is discussed to increase the light sensitivity of the coating.

Light sensitivity of photographic and holographic emulsions has been considered previously in *The battle of grain growth and light sensitivity in the diffusion method*. The sensitization of the material is of course the most crucial part when making recording material. In terms of brightness, scattering and clearness, the quality of the finished hologram is determined now, and the first creative decisions are made to manipulate the eventual desired visual outcome.

In general, there are two different kinds of sensitization: chemical and spectral sensitization. Chemical sensitization, as we have seen before, is utilised to increase the light sensitivity of the silver halide crystals. When bromide-iodide emulsions are produced, the sensitivity is increased through the ripening, the growing of the grains and the introducing of 'sensitivity specks'[209] - irregularities and defects in the crystal surface, which makes it easier for the light energy to be absorbed. The diffusion method has no interest in growing the grains or in producing a variety of grain sizes. For a good working holographic coating a lot of very fine grains are advantageous. In contrast to the double jet method in which the halides and the silver are mixed into the emulsion at the same time, in the diffusion method, the silver nitrate is already dispersed in the gelatin when the halides are introduced together with the dye for spectral sensitization. Spectral sensitization can be achieved by different dyes for different wavelengths and has been discussed in Chapter 3.

[209] Richardson and Wiltshire, *The Hologram*, p. 103.

Step 8: The formation of silver halides and spectral sensitization

In this step the silver halides are formed and the coating is made light sensitive to a specific wavelength at the same time. Therefore, from now on, a safelight has to be used. Silver halides are slightly sensitive to the blue spectrum of the light, which is why a green safelight is used when the spectral sensitization is done for a red laser and a red safelight is used for working with a green laser. A panchromatic coating has not been created yet for use with the diffusion method: when that is the case, a dim orange safelight is a good choice.

Figure 74. Different safelights.

	Me	Jeff Blyth
8.	**Dye Solution:** 100 ml of **Stock dye solution 1** is mixed with 2 ml of **Stock dye solution 2.**	**Dye Solution:** 100 ml of **Stock dye solution 1** is mixed with 2 ml of **Stock dye solution 2.**
8a.	**Stock dye solution 1:** 41 g sodium chloride NaCl in 334 ml de-ionized water + 666 ml ethanol C_2H_6O or methanol CH_3OH (de-ionized water: alcohol in relation 1:2)	**Stock dye solution 1:** 41 g sodium chloride NaCl in 334 ml de-ionized water + 666 ml ethanol C_2H_6O or methanol CH_3OH (de-ionized water: alcohol in relation 1:2)

8b.	**Stock dye solution 2:** For red laser light: 0,3 g pinacyanol chloride $C_{25}H_{25}ClN_2$ + 100 ml ethanol or methanol For green laser light: 0,5 g acridine orange $C_{17}H_{19}N_3$ + 100 ml 1:2 de-ionized water: alcohol	**Stock dye solution 2:** For red laser light: 0,3 g pinacyanol chloride $C_{25}H_{25}ClN_2$ + 100 ml ethanol or methanol For green laser light: 0,5 g acridine orange $C_{17}H_{19}N_3$ + 100 ml 1:2 de-ionized water: alcohol

Table 9. Recipe for the dye bath for red and green laser.

After the silver is put into the coating and the coating has been dried thoroughly, as discussed in *Troubleshooting and improvements*, the glass object can now be treated with the **Dye Solution**.

Figure 75. Dyes used in the diffusion method.

Figure 76. Dyes in solution, as stock and ready to used, diluted with the Stock dye solution 1.

Figure 77. Methanol

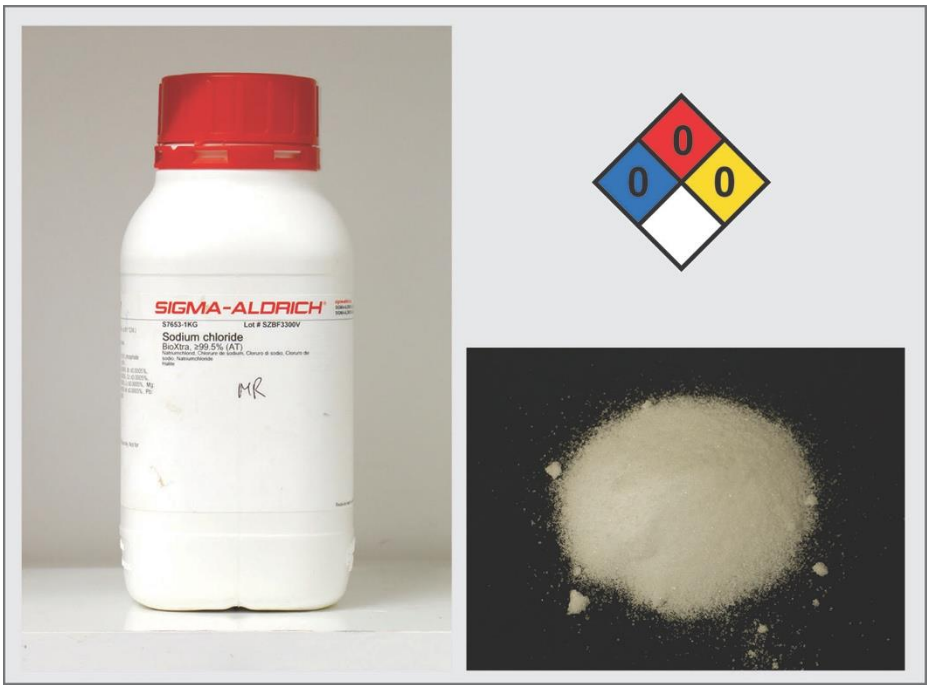


Figure 78. Sodium chloride (common table salt).

Figure 79. Stock dye solution 1.

The choice of the dye is, as with the choice of the safelight, dependent on the laser that is used. No matter which dye is used, the method is the same. In the case of a plate, it is put into the dye bath and constantly agitated for 45 seconds. The method when coating a hemisphere is similar: the hemisphere is filled quickly with the dye bath and agitated for 45 seconds.

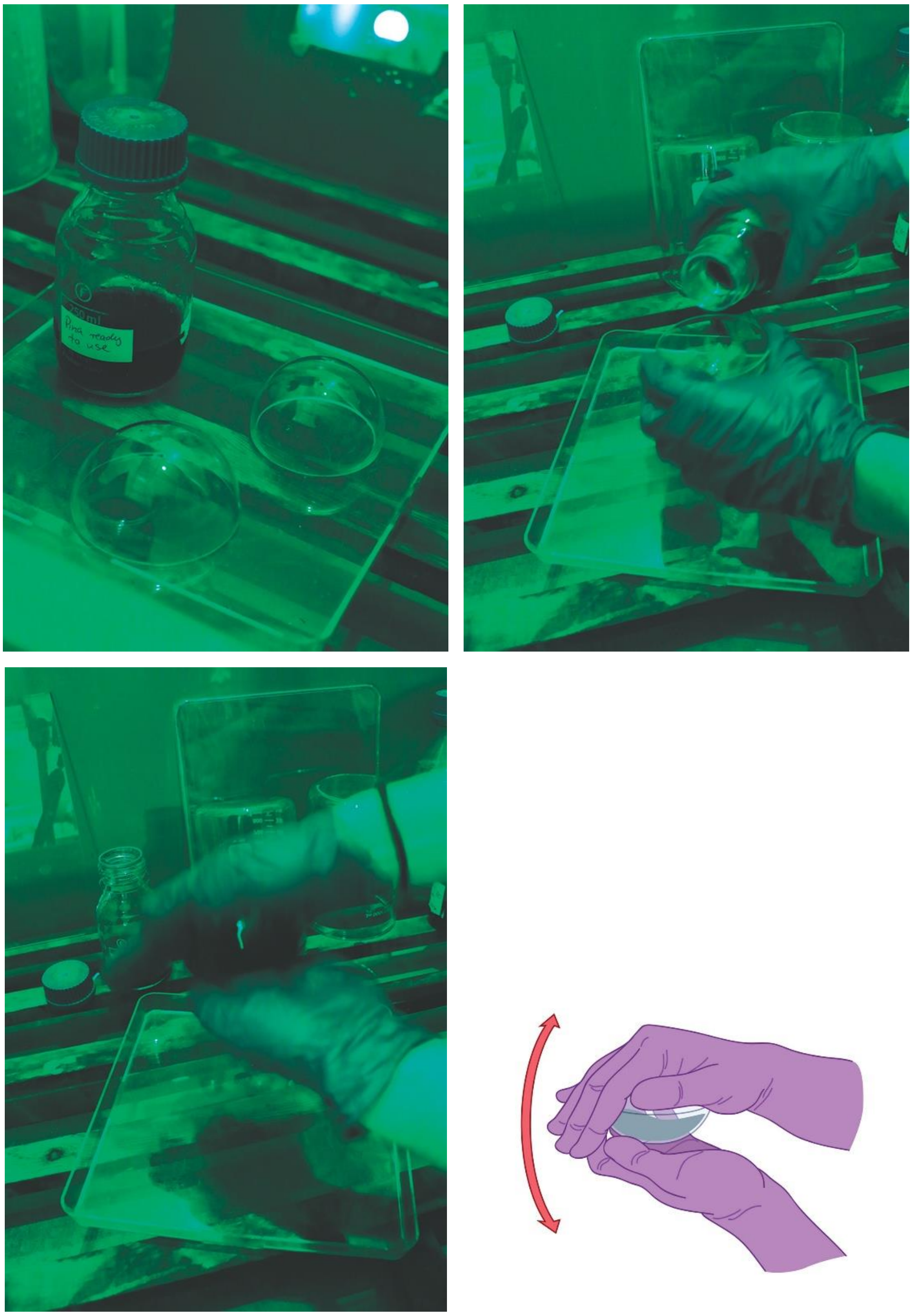


Figure 80. Applying the dye bath, by after pouring the solution in the hemisphere, shaking it up and down to make sure the solution touches the whole gelatin layer evenly.

This is the time when the silver chloride is formed and the dye wraps itself around the grain, as described in Chapter 3. After the 45 seconds the dye bath is poured out into a beaker or glass bottle for later re-use and the hemisphere is now put into cold, running tap water. The water bath at this point is not only to stop the reaction of the sodium chloride solution, but to prevent grain growth that would ruin the coating, as Blyth puts it: 'To stop the reaction of the sodium chloride solution, the glass is filled rapidly with running tap water and left in the water for several minutes.'[210]

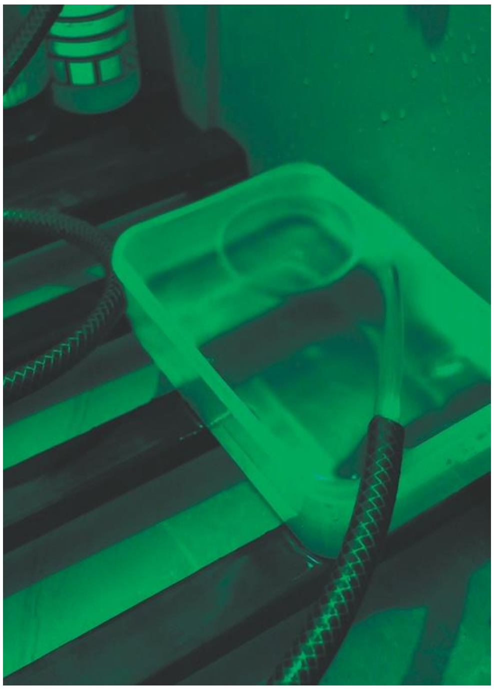


Figure 81. The important step of washing the coating in cold running water after the dye bath.

This is a more important step than it might seem, as the hemisphere is cleaned of all unnecessary chemicals. The dye bath is the moment in the diffusion method when double decomposition takes place:

$$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$$

Sodium nitrate is formed as a byproduct to silver chloride. As pointed out in Chapter 5, it is highly important to wash the coating clear of any sodium nitrate or it crystalizes out

[210] Blyth, 'The new Blyth diffusion method for making silver halide holograms on glass plates and wine glasses.', p. 97.

later. Apart from sodium nitrate, any other spare chemicals washes out as well and therefore cannot cause any problems later on. This wash is as important as the drying after the putting in the silver nitrate. A good wash under cold running tap water for seven to ten minutes, depending on size of the object and thickness of the gelatin, gave me good clean results. The coated glass can be dried and stored at this point or the last sensitizing step, described in the next part of this chapter, can be done without having to dry the hemisphere in between.

Any sudden grain growth would occur at this point and make itself visible by obvious scatter and stains. Grain growth is more likely to occur in parts where the gelatin is thicker which is usually close to the edges and can therefore be ignored if the edges are not part of the final hologram.

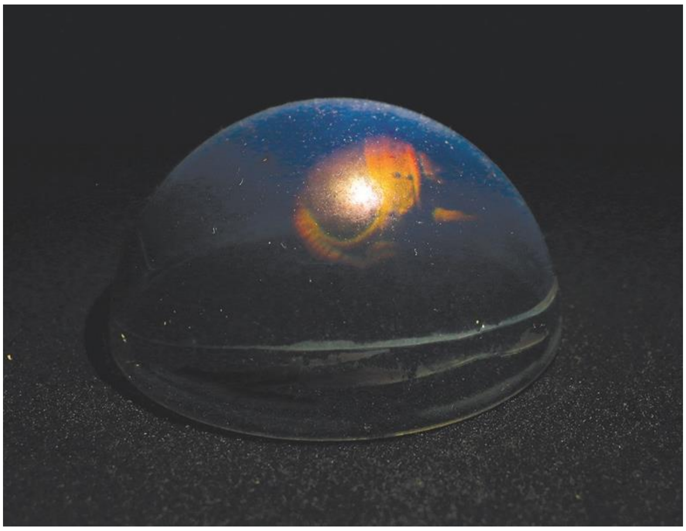


Figure 82. Lines of grain growth due to thick gelatin.

A major part of the dye bath is alcohol. This is important as the dye, especially pinacyanol, does not dissolve in water. The dye solution should therefore be covered shortly after its use or the alcohol evaporates: this was one of the unrelated problems I ran into previously when the whole method broke down.

> 07.02. 2017:
> Gelatin coating of hemisphere and globe went fine. I put the new silver nitrate in, not using a syringe but pouring it. I air-dried them for two hours (like often before). When I put in the dye (pinacyanol chloride) everything went milky. I had seen that

> before and chloride had always been the problem. At the same time the dye-solution went milky and separated blue 'bumps', there was as well grain growth.[211]

I increased the alcohol content and the problem was solved.

It is important to check if the coating is clear after the bath. If there is any fog or crystallization, impurities have been in the coating and are reacting with the silver nitrate. If this is the case, there is no point in carrying on but instead it is advisable to start anew. With a clear coating we can go on to the last step.

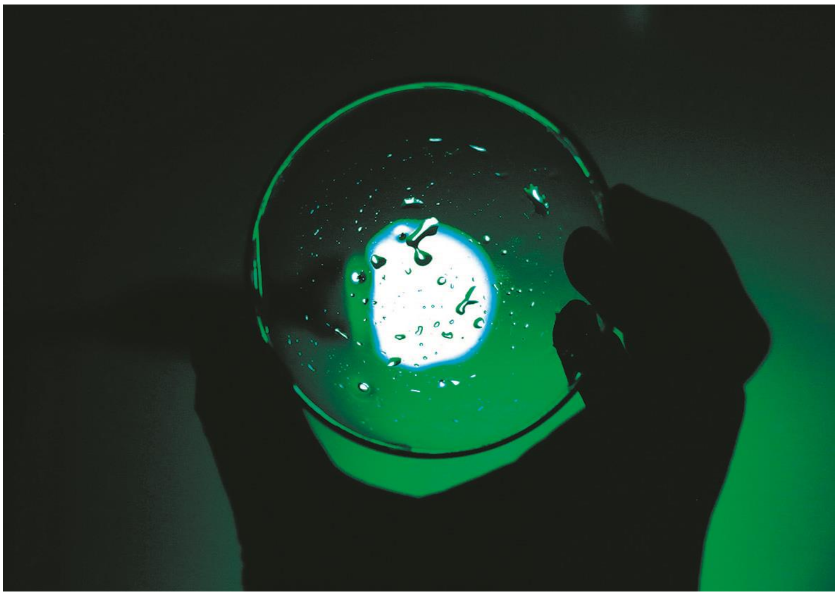


Figure 83. Checking if the hemisphere is clear after the dye bath.

Step 9: Final Sensitization

If the hemisphere stays clear and no grain growth or fogging is happening, it can be sensitized. This step increases the coating's light sensitivity and is very common in holographic practice. As mentioned before, this is, after choosing the colour of the laser and therefore the colour of the hologram, another step where creative and practical choices can be made by using different sensitizing solutions.

[211] Notebook C.

	Me	Jeff Blyth
9.	**Sensitizer:** 2 g ascorbic acid $C_6H_8O_6$ + 100 ml de-ionized water + sodium hydroxide NaOH until pH is at 4,5 or 5	**Sensitizer:** 2 g ascorbic acid $C_6H_8O_6$ + 100 ml de-ionized water + sodium hydroxide NaOH until pH is at 4,5 or 5
9a.	**TEA:** 15 % triethanolamine in de-ionized water	**TEA:** 15 % triethanolamine in de-ionized water

Table 10. Recipes for different sensitizing solutions.

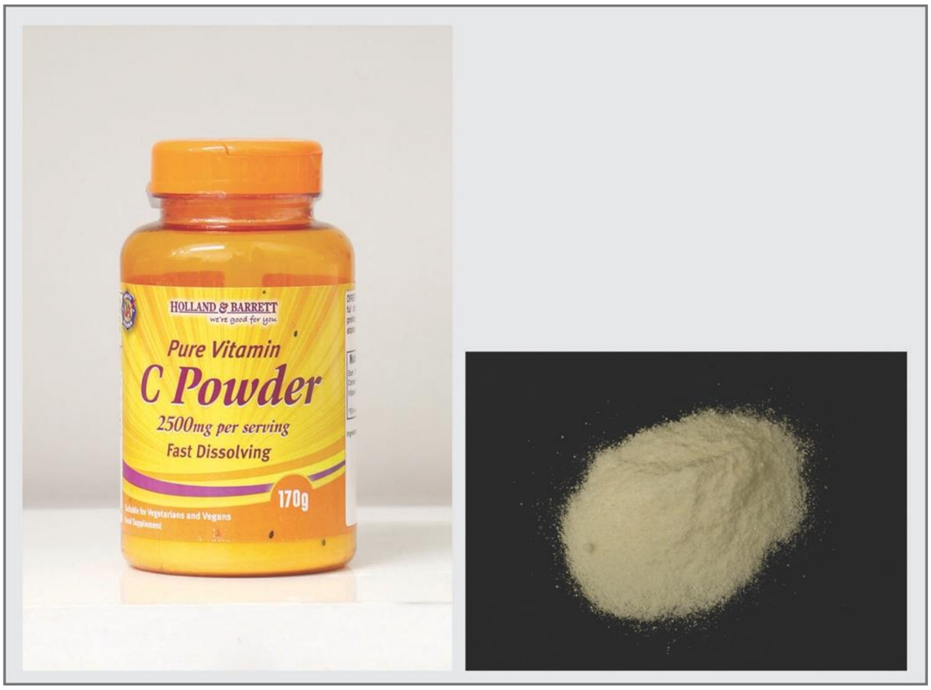


Figure 84. Vitamin C (Ascorbic Acid).

Figure 85. Sodium hydroxide.

Figure 86. Ascorbic Acid Sensitizer.

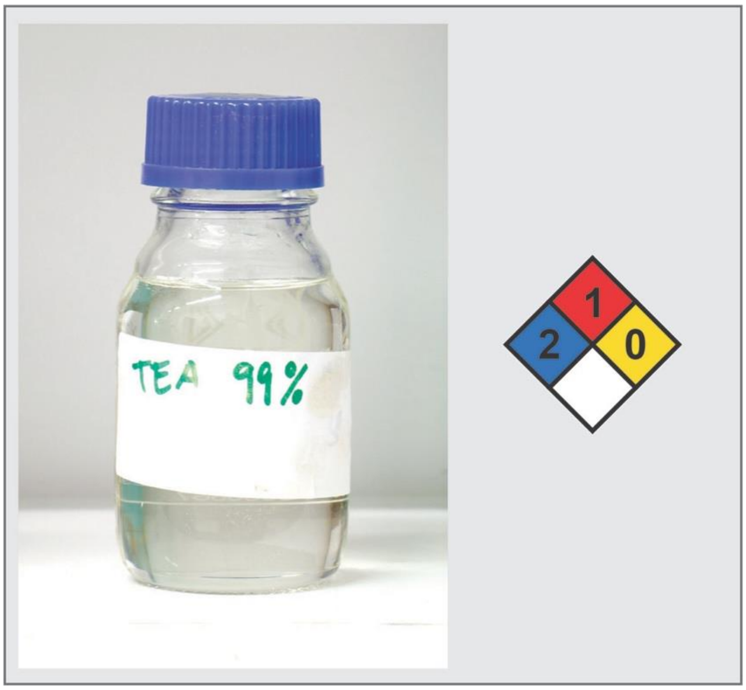


Figure 87. Triethanolamine (TEA).

To sensitize the coating, the chosen **Sensitizer** is poured into the hemisphere, or the plate is put into the bath, and agitated gently or left soaking for about two minutes, using the sensitizer described in *Step 9*, or for about one minute only when using the sensitizer described in *Step 9a*.

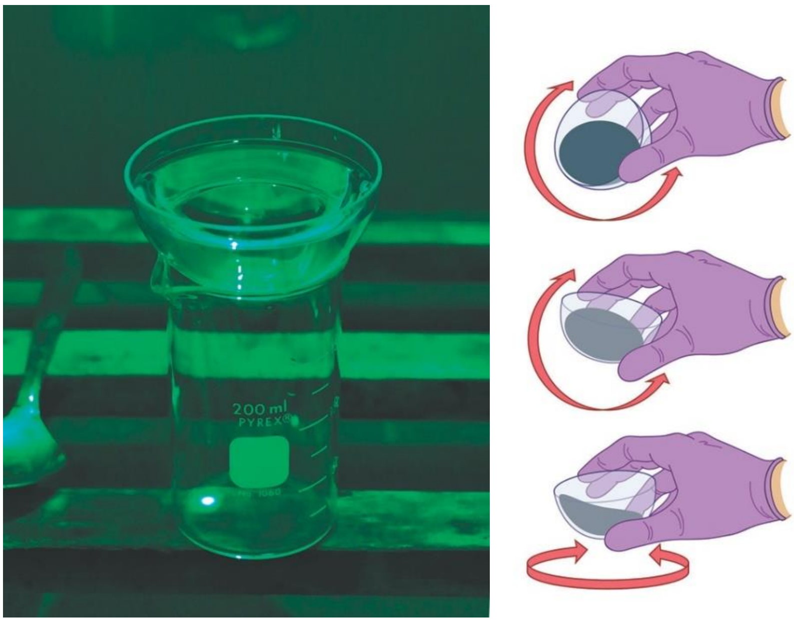


Figure 88. Hemisphere with sensitizer. The hemisphere can either be left with the sensitizer or, if there is not enough solution to fill the hemisphere to the top, be moved gently.

After that the hemisphere, or the plate, is wiped carefully, as the gelatin is very easy to damage at this point, and left to dry into a cold airflow, after having been dried for two to five minutes under a warm airflow. No rinsing in distilled water, as mentioned in the original recipe, is necessary.

With the sensitizing solution described in *Step 9*, the light sensitivity is enhanced without a colour change and the wavelength of the laser is replayed in the hologram. This is used to produce master holograms. Master holograms work in holography as negatives do in photography: they are reproducible, they can be copied. The important feature is that in order to make a copy, the hologram needs to be very bright when replayed in the wavelength of the laser it was recorded with.[212]

Another possibility is, of course, the well-known treatment with triethanolamine, better known as TEA, if a colour shift is desired.[213] To achieve a bright green hologram, when using a red laser, the coating should be immersed in the 15 % TEA solution for one minute and then be treated in the same way as with the ascorbic acid sensitizer. This method is known as pre-swelling of the emulsion. Different percentages of the triethanolamine give different colours in the finished hologram. John Kaufman experimented with this technique with great success producing *pseudo colour holograms*.[214] Another option for colour manipulation is the post swelling with citric acid, as Blyth discovered.[215] Holograms tend not to finish as bright as when treated with TEA, however, as the swelling is done after processing the hologram: if one is not happy with the colour obtained, the colour effect can be easily removed by giving the hologram a wash in tap water.

After the sensitizing step with ascorbic acid or TEA, the recording material is set to dry. This drying time depends entirely on the size of the coated area and the shape of the

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212 This will be explained in greater detail in Chapter 7.

213 J. Kaufman, 'Previsualization and Pseudocolor Image Plane Reflection Hologram', *Proceedings of the International Symposium on Display Holography,* Lake Forest College, 1982, pp. 195-208; Jeff Blyth, 'Pseudoscopic Moldmaking Handy Trick for Denisyuk Holographers', *Holosphere 8*, No. 11, New York, Museum of Holography, 1979, p. 5.

214 J. Kaufman, 'Life in the Lab – A Working Visit to a Holography Studio', *Leonardo*, vol. 25 No.5, 1992, p. 487-502.

215 Jeff Blyth, 'Blyth Colour Tuning', 12 May 2013, *holographyforum*, [web blog], https://holowiki.org/wiki/Blyth_Colour_Tuning, (accessed 15 June 2018).

glass and thickness of the gelatin layer. Previous experience of the whole coating process with the object will give a good indication of how long is necessary. There are many variables that influence such decisions: size, shape and thickness of the coating, room temperature and humidity are all factors in calculating optimum or appropriate timings. Practicing and learning the craft, in other words experience, guides those decisions: observation and experimentation are the keys to success. Important discoveries that changed the future of a medium have been made through practice and observations: 'Daguerre's discovery of the latent image is presented as the result of tacit experience rather than fortunate accident'.[216]

This step of sensitization concludes the production of the recording material. The last three chapters have explained the method in detail by going through it step by step. This is important to understand the changes that have been made and the importance of the practice-based approach for the forming of tacit knowledge which ultimately made the coating work. To have a clear understanding of the changes made, I summarise them now, in the last part of this chapter and give an updated recipe of the diffusion method

Conclusion and vital changes in the recipe

First of all, I started to use de-ionized water throughout the process. This goes hand-in-hand with the change of the quality of the gelatin. The diffusion method relies on a clean coating without impurities, above all traces of chloride. Ensuring that the process is clean from the beginning by rigorously cleaning the glass plate saves the artist from later troubles and a very time-consuming washing process. The use of de-ionized water throughout the process through to the point when the coating was put into the dye bath and sodium chloride was introduced into the coating, kept the possibility of chlorides being introduced prematurely to the process low.

The slight increase of silver nitrate is responsible for a brighter finished hologram.

[216] Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. iii.

These changes are all important, but what ultimately made the coating effective and the process of experimentation and research successful was tireless repetition of the coating and observation of the material. The process of discovering what went wrong, described in length in *Troubleshooting and improvements*, is a process typical for developing and learning a new skill. Knowledge is produced through slowly-gathered experience by making. In *Ways of Making and Knowing*, Butters compares this process with the analogy of a comb-maker:

> The comb-maker possessed an empirical knowledge born of the manual craft he had practiced over many years. This knowledge was generalized and transferable insofar as he made combs that worked, and it was particularized insofar as he claimed he learned something new from making each one of them, by bringing into being something that had not existed before.[217]

It is clear that every coating, especially when put onto different shapes but even on conventional substrates, can show different characteristics each time and teach something new. Although I can generalise and pass on my knowledge formed over the last few years - and I do that in the next part of this Chapter with the updated recipe - there is the part of the tacit knowledge that cannot be transferred by text. Robinson gives those things that can be discovered only through the constant careful act of making another very fitting name:

> The information given is based on many years' practical experience, but even so it is not possible to indicate all those little points which can only be learnt by continued experiment, and which may be called "tricks of the trade".[218]

To make and to discover new knowledge through making requires an open mind and determination. From the start, when reading a recipe, it is necessary to read between the lines, knowing for sure, that even there the *tricks of the trade* are not necessarily revealed. Failure when starting out is almost guaranteed. Nevertheless, working in a craft context and working in an analogue medium present the rewarding opportunity of discovering something new or fresh from the actual working experience, as Butters

[217] Smith, Meyers and Cook (eds.), *Ways of Making and Knowing* p. 49.
[218] Robinson, 'The Techniques and Material Aesthetics of the Daguerreotype', p. iv.

notes, when talking about *Skill, Improvisation, and Innovation*: 'Whether intended or not, deviations from norms produced new and interesting results.'[219]

The updated recipe is the consequence of this kind of experimentation, of working with an open mind, sensitive to the subtle or sometimes dramatic changes which can result from different calibrations of critical variables. The final result is a clean coating, the outcome of constant practice, constant slight adjustments to all aspects of the coating environment and process and, of course, the engagement of the practitioner, the human agency.

Recipe: diffusion method for the practitioner

	Diffusion Method for the practitioner
1.	**Whiting formula:** 80 g whiting + 100 ml water + 20 ml grain alcohol
	The glass object should be clean, without any dust, dried water drops or streaks. After pouring Gelatin 1 the objects should rest for about 10 minutes before put in the oven.
2.	**Gelatin 1:** 5 ml dissolved gelatin 2 + 5 ml stock chromium in 100 ml de-ionized water
	The glass object can be coated directly with Gelatin 2 when coming out of the oven, as the Gelatin 2 flows more evenly, if the object is warm. A couple of minutes delay is recommended though, as the objects are quite hot out of the oven.
3.	**Gelatin 2:** 10 g of granulated gelatin (photo grade) in 100 ml de-ionized water
	The gelatin layer needs to set before the hardening step until touch try. In addition, now is the time to work variations in coating thickness.

[219] Smith, Meyers and Cook (eds.), *Ways of Making and Knowing,* p. 60.

4.	**Hardener:** 4 g chromium potassium sulfate $KCrS_2O_8$ in 100 ml de-ionized water + 4 ml glycerol $C_3H_8O_3$
4a.	***Alternative Hardener 2:*** *1,5 g chromium (lll) acetate hydroxide $(CH_3CO_2)_7$ CR_3 $(OH)_2$ in 100 ml de-ionized water* *+ 4 ml glycerol $C_3H_8O_3$*
	The glass object is washed thoroughly to obtain a clear coating. Wash 1 can be applied without drying the coating before.
5.	**Wash 1:** 0,1 g sodium carbonate Na_2CO_3 in 100 ml de-ionized water
	This is a highly important drying step. The coating has to be completely dry before the silver nitrate is put into it. If the gelatin is still swollen, the silver does not move into the gelatin layer but stay at the surface and cause problems later.
6.	*step eliminated*
7.	**Silver nitrate solution:** 2,2 g silver nitrate $AgNO_3$ in 10 ml de-ionized water
	The silver nitrate is put in and spare silver nitrate is gently wiped from the surface. It now is very important to de-swell the moist and therefore swollen gelatin. Even though this is a quick process, I found that a quick dry under a warm airflow is not enough. I recommend at least 4 minutes with extra care to areas where the gelatin layer is thicker. The glass object should then rest for at least 30 minutes before the next step.
8.	**Dye Solution:** 100 ml of **Stock dye solution 1** is mixed with 2 ml of **Stock dye solution 2.**

8a.	**Stock dye solution 1:** 41 g sodium chloride NaCl in 334 ml de-ionized water + 666 ml ethanol C_2H_6O or methanol CH_3OH (de-ionized water: alcohol in relation 1:2)
8b.	**Stock dye solution 2:** For red laser light: 0,3 g pinacyanol chloride $C_{25}H_{25}ClN_2$ + 100 ml ethanol or methanol For green laser light: 0,5 g acridine orange $C_{17}H_{19}N_3$ + 100 ml 1:2 de-ionized water: alcohol
	After the dye bath, the glass object should be rinsed thoroughly in cold de-ionized water for ten minutes or longer. This is an important step, as formed potassium nitrate is washed out.
9.	**Sensitizer:** 2 g Ascorbic Acid $C_6H_8O_6$ + 100 ml de-ionized water + sodium hydroxide NaOH until pH is at 4,5 or 5
9a.	**TEA:** 15 % triethanolamine in de-ionized water
	The surface is gently wiped clear and the coating is dried under a warm airflow for more or less 5 minutes. To ensure the coating does not move when recording the holograms, it needs to be completely dry. This depends on the size of the object. Usually 30 minutes are enough.

Table 11. Complete recipe of the diffusion method for the practitioner.

The entire process from cleaning the glass to the processed hologram can be achieved with this improved version of the diffusion method in two working days, inclusive of one night ‘resting’ needed when the hardener is working. In addition, glass objects can be coated and stored at any step of the way. It is easiest and safest to store them after the hardener. I can then put the silver in and sensitize the coating in the morning and shoot the hologram by midday. With the elimination of the potassium nitrate wash, a second, long waiting period, often another night, has been taken out of the process, making the procedure a lot quicker and cleaner, as the crystallization of the sodium nitrate is not an issue anymore. A clean work with a higher quality gelatin, and taking the drying and the washing stages seriously, results in clean bright holograms with this version of the diffusion method.

Chapter Seven

Recording and Processing

The last three chapters examined the making of silver halide-based recording material with the diffusion method in detail. Following the production of the material, this chapter focuses on the actual recording of the hologram.

There are many different ways, called setups, to record a hologram.[220] To explain in detail different setups for the recording goes beyond the scope of this research. As holography is a medium affected by many variables and making a silver halide-based light sensitive emulsion is a complex task in itself, variables in the setup are limited at this stage. It is, however, a future task to try different setups on different glass objects to create new holographic visual outcomes. The failing of the diffusion method in the beginning of my research and the resulting need to refine and improve the method made it necessary to keep the setup simple.

Setup

For my thesis I employed two different setups. Both setups produce white light single beam reflection holograms. White light refers to the fact that the hologram can be replayed with a spotlight that does not have to be a laser. Single beam indicates that the laser beam has not been split and *reflection hologram*, in contrast to *transmission hologram*[221], indicates the following setup. A beam of laser light is shot in the darkness: with mirrors, the beam is directed through a lens to be expanded and illuminate a light sensitive glass object, the place where the hologram is recorded and replayed for the audience to contemplate. Through the glass object and light sensitive coating, the expanded laser beam finds the object from which it is reflected back. The beam meets itself in the light sensitive gelatin layer, coated on the glass object and the two beams

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[220] For example: Saxby, *Practical Holography*; George W., Stroke, *An Introduction to Coherent Optics and Holography,* New York – London, Academic Press, 1966; Abramson, Nils H., *The Making and Evaluation of Holograms,* London, Academic, 1981; Unterseher, F., Hansen, J., and Schlesinger, B., *Holography Handbook, Making Holograms the Easy Way,* Berkeley, Ross Books, 1982.

[221] Transmission Hologram: 'Any hologram in which the reconstruction beam is incident on the side of the hologram opposite to the viewer.' Saxby, *Practical Holography,* 4th ed., p. 632.

form an interference pattern and store the information of the object. This kind of reflection hologram is called a Denisyuk Hologram, named after its inventor.[222]

Apart from this quite simple setup of a reflection hologram there are numerous other possible setups to achieve the recording of different types of holograms. However, research into the nature and problems of the lighting for 360° holography (for instance the hemispheres) such as Ryuichi Hioki's and Takeomi Suzui's research paper *Reconstruction of Wavefronts in All Directions*[223] is the exception. Wider research is still scarce.

The first setup I used was a single beam setup for Denisyuk recordings, typically used for so-called tabletop holograms.[224] Tabletop holograms are shot with the expanded light beam being reflected from a mirror at 45°.

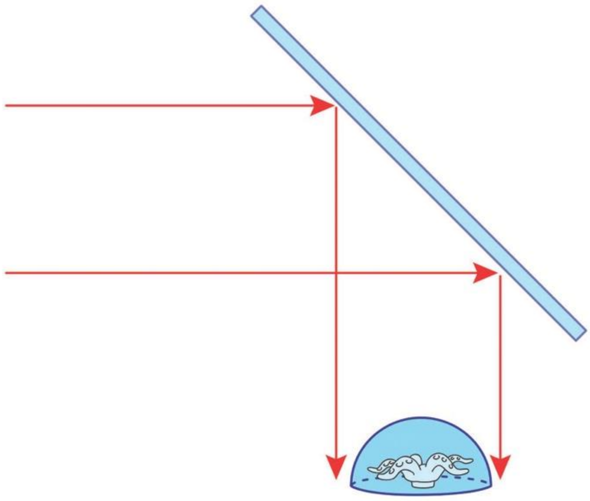

Figure 89. Setup for a tabletop hologram with the mirror at 45 degrees.

Saxby describes five different setups for different kinds of 360° holography, this being the first. It was the same setup which Blyth used for plates and the wine glass

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[222] A wide range of different setups and the difference between reflection and transmission holograms are explained in all four editions of Saxby's *Practical Holography.*

[223] R. Hioki and T. Suzuki 'Reconstruction of Wavefronts in All Directions' in Bjelkhagen and Caulfield (eds.), *Fundamental Techniques in Holography,* SPIE, 2002, pp. 122-123.

[224] Denisyuk, 'My way in Holography', p. 426; For technical drawing of the set-up see: Saxby, *Practical Holography,* 4th ed., p.149.

holograms I began my research process with, being sure it would work just as successfully with the hemispheres. However, when I started with hemisphere holography, I had trouble generating a hologram of an object. I was using the first setup described and shown in Figure 81. While this setup had worked with the wine glass, the hemispheres very often did not produce a hologram at all. If there was a hologram it was very dim.

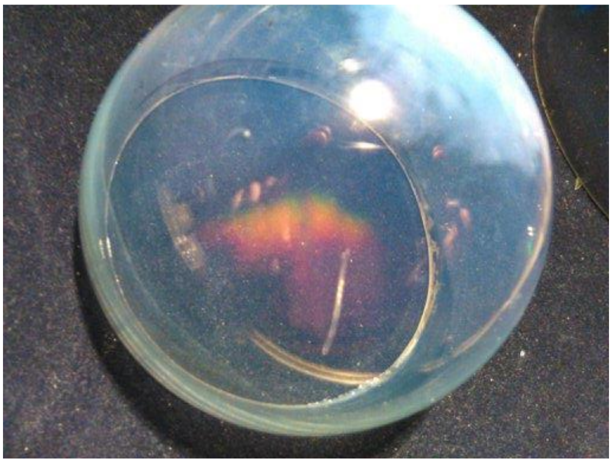

Figure 90. A dim hologram made with a tabletop setup.

At that time, I did produce clear coatings and was sure that the problem lay in the setup. I decided to try the transfer method which can create holograms that float in front of the recording material by making a hologram of a hologram. When viewing a hologram, the virtual image is seen behind the glass. If the glass is flipped around, the pseudoscopic image, displays as an inverted, but real image in front of the glass. This real image is used when making a transfer hologram. The holographic real image is replayed in laser light and recording material is placed where the real image is, recording it.[225] The hologram acting as the object is called the Master hologram or H1 and the new hologram produced, the copy, is referred to as H2. I used one of my first hand coated plates, sensitized in ascorbic acid, and therefore replaying the wavelength of the laser perfectly.

[225] Transfer hologram: 'A hologram made using a holographic image as object.' Saxby, *Practical Holography,* 4th ed., p. 632. Pseudoscopic image: '[…] In holography, the term is extended to describe an image in which full parallax is present but reversed, so that a shift in viewpoint to the right reveals more of the *left* side, that is, the image is reversed front to back'. Saxby, *Practical Holography,* 4th ed., p. 628. Real image: An image formed by light waves that actually pass through the image space. A real image can thus be viewed on a screen or recorded by an optical sensor. Saxby, *Practical Holography,* 4th ed., p. 628.

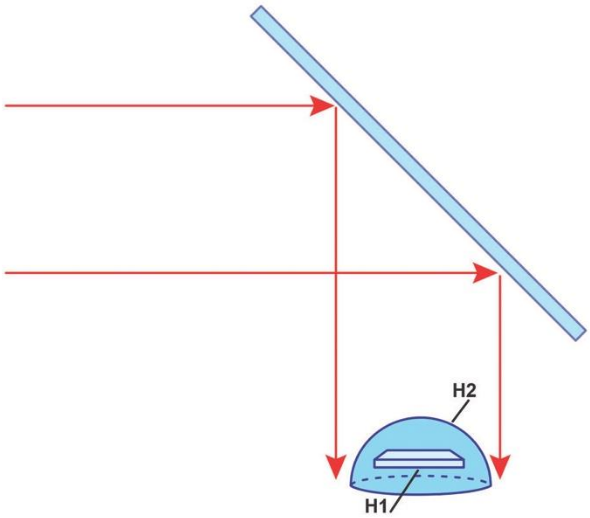

Figure 91. Tabletop setup for a transfer reflection hologram.

The tabletop technique worked successfully when making reflection transfers and I produced my first bright hemisphere.

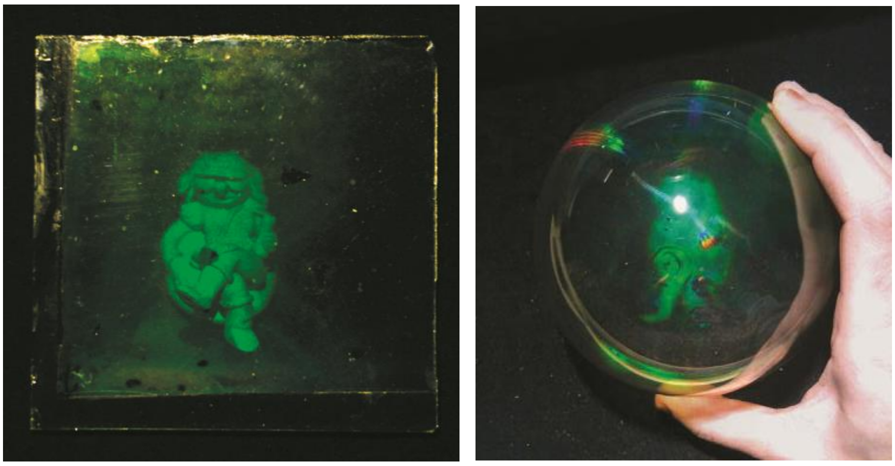

Figure 92. H1 (left) and the copy H2 in a hemisphere (right).

Therefore, in the beginning it seemed that the hemispheres work best as a copy from a master hologram. The object replays nicely, due to the glass plate of the master, and a diffraction grating is produced which gives the transfer hologram more brightness and colours. Nevertheless, I wanted to create a hologram of an object on a hemisphere and decided to read up on possible solutions, which then led me to the new setup of *conical holograms.*

For the hemisphere holography I employed a setup which Saxby describes as a setup for *single-beam conical holograms.*[226] In this setup the laser is directed to illuminate the object directly from above.

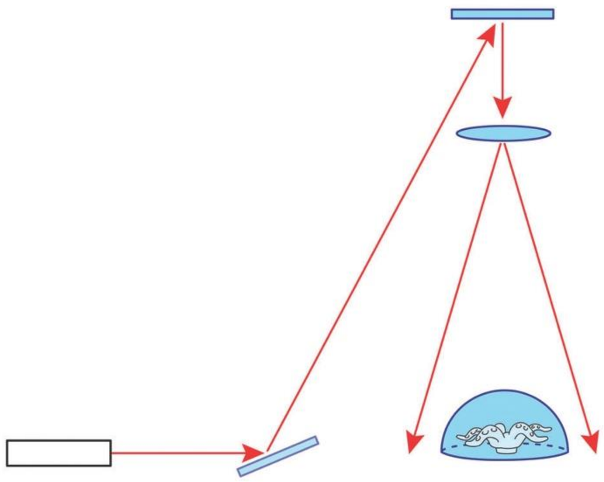

Figure 93. Overhead setup for the recording of holograms of objects.

Saxby used the setup to make conical holograms by cutting holographic film and forming it in the shape of a cone. The setup was excellent for hemisphere holography. Saxby described the use of a quarter-wave plate as a solution for problems with polarization. I never encountered similar problems and used the setup without the quarter-wave plate and this worked fine for the hemispheres. Over time, I used slightly different setups, minimizing the loss of laser power and stray light, by using smaller mirrors.

[226] Saxby, *Practical Holography,* 4th ed., p. 150.

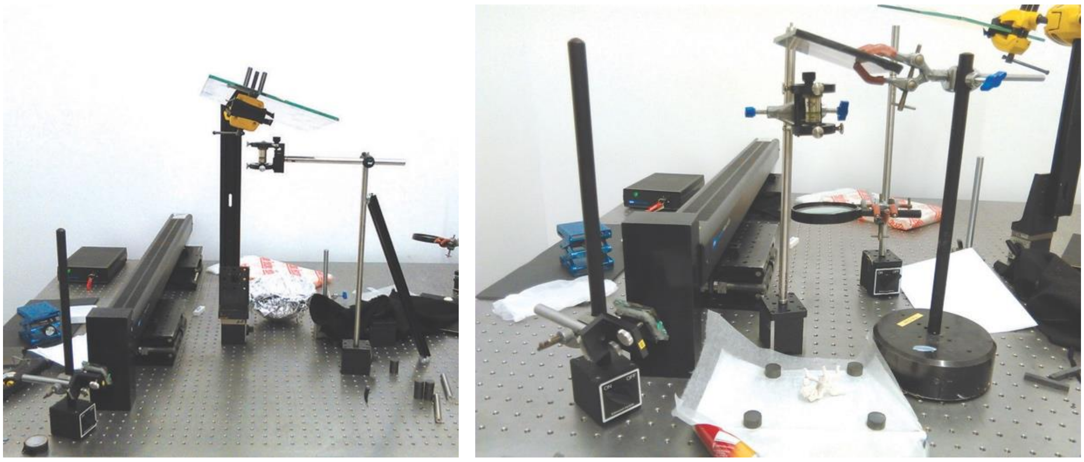

Figure 94. The first overhead setup to record holograms in hemispheres.

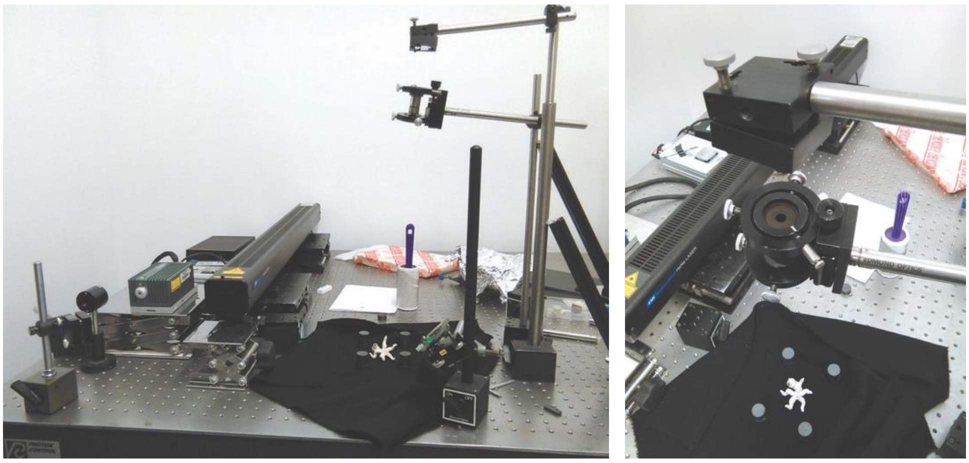

Figure 95. The second overhead setup to record holograms in hemispheres.

To stabilise the system, an overhead structure was developed and built.

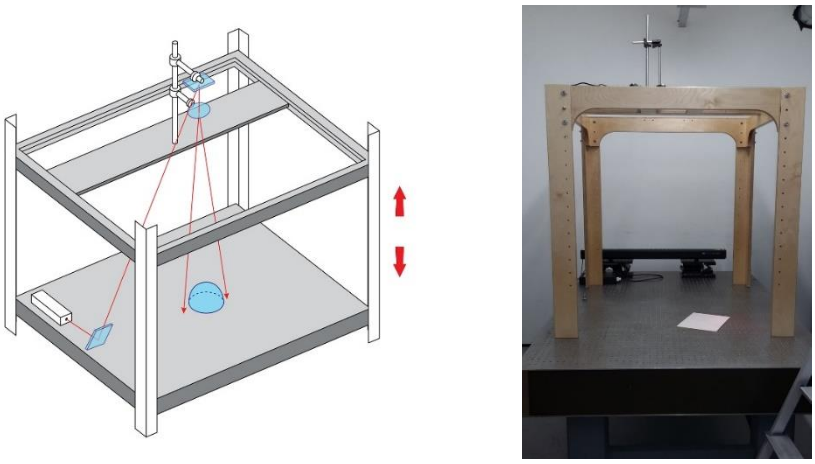

Figure 96. Overhead recording system for the recording of Hemisphere Holography.

Subject matter

In my research I focus on holograms of objects in contrast to using light and its characteristics as the subject matter. When working with light as subject matter like holographic artists such as Rudi Berkhout, it very often leads to a more complex setup, while the recording of a subject through the method of a Denisyuk-setup is straight forward and shows the quality of the coating.

Holography does not only have high demands on the recording material, but its subject matter as well. To produce a bright hologram, especially working with reflection holograms, it is beneficial to have a highly reflective object. In addition, due to holography's sensitivity to vibrations, the objects need to be solid and stable, as any movement may result in black spots.

Figure 97. Hologram of a tadpole with movement in the tail.

Margaret Benyon's series on holograms on the different stages of bread while becoming stale proves this:

> A series of holograms of a loaf of bread taken over a number of days showed the bread looking dramatically rotten when it was actually fresh, and looking fresh when it had become rock-hard and solid enough to record.[227]

[227] Margaret Benyon, [website], http://www.art-in-holography.org/papers/benyon.html, (accessed 1 May 2018).

When the bread is fresh it moves during exposure and therefore disappears from the record.

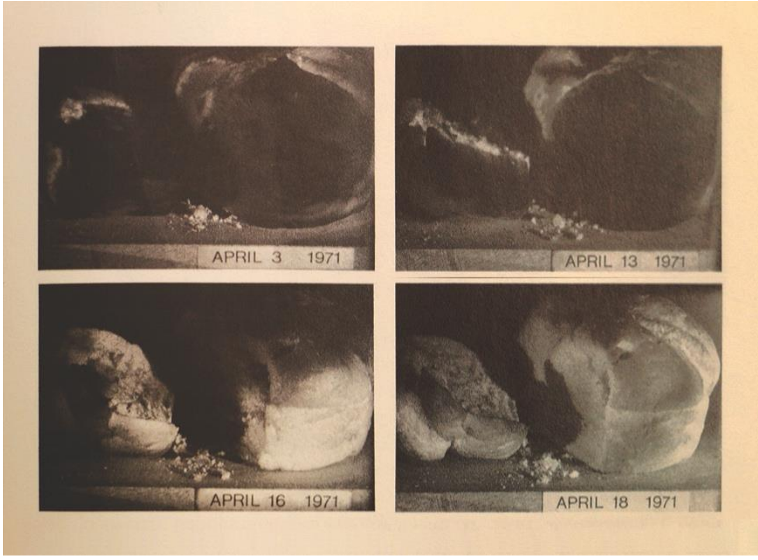

Figure 98. Margaret Benyon, *Bread*, 1971.

Mundane and trivial items are, unfortunately, a significant feature of holographic subject matter. These often result in images which highlight the technological aspect of holography rather than presenting meaningful content. This is, however, not the focus of this research. Therefore, apart from the holograms for the exhibition, my main preoccupation was not to use objects ubiquitously recorded as holograms, simply because they were solid and shiny, such as hammers, flutes, screws or coins. Quickly I made the choice to create my own subject matter out of plasticine, working alongside a sculpture artist.[228]

[228] Gustavo Vargas, https://artefactop.wixsite.com/gustaffo/plasticine (accessed 9 March 2019).

Figure 99. Plasticine subject matter used for the research.

Figure 100. Details of the plasticine figures.

I had been told that making holograms of plasticine objects was not possible, as it would move during exposure much like the loaf of bread of Margaret Benyon. None of that happened. To be on the safe side I brought my plasticine objects to the lab to acclimatise a day before I would record the holograms. Once they were acclimatized to room temperature and humidity, the chance that they would move, even marginally or imperceptibly, was reduced. When setting up the recording of a hologram, once the object and recording material have been put in place they are left for a certain time span, known as settling time. With a settling time of 15 minutes, the plasticine usually did not move.

There are, however, two further possibilities to secure the immobility of plasticine objects even further, particularly if working under conditions where vibrations are a known problem. The teapot and the cup in Figure 91 are silver sprayed plasticine objects. By spraying the objects (silver, or gold, or white), the layer of spray paint hardens, further restricting any movement from the plasticine. The downside is, however, that fine details, which makes plasticine such an attractive subject matter, might get lost.

The second possibility to hold the object in place securely is magnets. By prepping the object with a piece of metal it then sticks to any magnet presented.

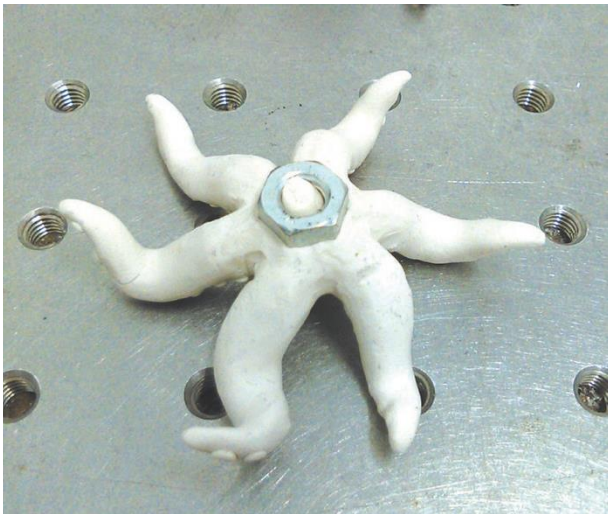

Figure 101. Plasticine figure with metal ring to secure the object from moving with a magnet.

Exposure

Nowadays it is possible to make not only monochrome holograms, but also full colour holograms, through the combination of three lasers: blue, green and red.[229] Consequently holographic recording material should be capable of recording all of these colours. During my research I had the opportunity to use a green laser, with the wavelength at 532 nm, a red HeNe Laser with the wavelength at 633 nm and a blue laser with the wavelength at 457 nm, all of them continuous wave lasers. Unfortunately, the blue laser was only available for a few hours. A small test, however, was possible and turned out successful, with a dim register of blue light identifiable. More research is necessary in the future especially in terms of scattering and noise in the finished blue image. The red and green recordings are generally very bright and noise and scatter free. A next step in the research will be to do a two colour hologram, with the red and green lasers.

As my thesis concentrated on the coating, in terms of setup there is still a lot of room for experimentation and further research. For me, it was important to limit the variables. To make sure the setup worked, I used commercial plates from Colour Holographic and made a test hologram, before exposing my hand coated objects. In this way I knew that, if anything went wrong, it was not the setup.

When exposing material produced with the diffusion method, it is important not to overexpose. Overexposure leads to a thick fogging of the plate when developed. I had the best results with an exposure time from 7 to 10 seconds. If that leads to developing time longer than one minute, again fog is produced. If that is the case, there are two possibilities to increase the light sensitivity of the plate itself: increasing the silver nitrate percentage slightly or increasing the pH in the sensitizing solution if using the ascorbic acid sensitizer, but not higher than 6.

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[229] Reconnaissance Holography News, *Optoclones of Russian State Treasures*, [website], 2018, https://www.reconnaissance.net/holography-news/issues/february-2018/ (accessed 13 February 2019).

Processing

Once the recording material and the object have been exposed by the laser light, the latent image has to be developed and processed.

A lot of research has gone into the processing of holograms. It is a very important stage in the creation of a hologram, which can even, in the worst cases and under certain circumstances, destroy the hologram all together. Despite the research, the importance of the process has been or still is ignored at times due to the seeming similarity to photography. As photographic recording material had been used, the conclusion seems to be obviously that photographic processing chemicals can also be used, even though that is not necessarily the case.

While holography and photography function on the same fundamental principle of recording light through silver halide-based material, after understanding the different priorities of each medium and the resulting differences in the recording material, it is not surprising that there are differences in the processing as well.

This is pointed out and explained in key texts such *Practical Holography* by Saxby and *Silver-Halide Recording Materials* by Bjelkhagen. In his first edition, Saxby remarks that: 'The progress of holography as a display medium was held up for a number of years by preconceived ideas about processing technique derived from practices in photography.'[230] Saxby returns to this concern in the subsequent editions of his book, and in the third editions, he writes:

> Even now, on studying scientific paper where the experimental work has involved holography, you may often notice that the researchers have processed their holograms using commercial photographic developers (such as Kodak D-19) that unsuitable for holography, resulting in feeble images.[231]

And in his last edition in 2016, Saxby further underlines his concern:

[230] Saxby, *Practical Holography,* 1st ed., p. 70.
[231] Saxby, *Practical Holography,* 3rd ed., p. 59.

> It is a sobering thought that even today, some optics lab workers know so little about the needs of holographic processing that they continue to use commercial photographic developer and fixers, resulting in feeble images, even though suppliers of materials for holography usually recommend and/or sell chemical sets designed specifically for processing those materials.[232]

These quotes show once more, that research in the darkroom has either not been carried out on a big scale, as it is the case with the recording material, or is simply ignored, because of the assumption holography and photography work with the same mechanisms.

Before the name holography was used widely, in Britain the technique was often called 'wavefront reconstruction', which describes the process quite accurately. The fundamental characteristic of holography is to replay the whole information of a recorded wave front and therefore create a three-dimensional image. To be able to do that an interference pattern is created, recorded and developed. In comparison to photography where the amplitude of light is fixed in the emulsion, in the holographic process a negative image of the interference pattern is developed and then bleached to fringes that replay the image through refraction. This mechanism only works if the grain size of the silver halides is small enough. Small grains mean lower sensitivity of the coating, while bigger grains are more sensitive to light. This is a difficulty in holography and it is not easy to balance or control, especially when using inappropriate chemicals such as photographic developer and fixer for the processing of holograms, as pointed out by Saxby:

> Unfortunately, some of the complexing effects [...] [in photographic developer] have a deleterious effect on the very tiny silver halide crystals in holographic emulsion; for example, small amounts of sulfite, and even the chlorides present in mains water, can have a considerable solvent effect on the developing grains.[233]

[232] Saxby, *Practical Holography,* 4th ed., p. 80.
[233] Saxby, *Practical Holography,* 4th ed., p. 83.

The next three parts of this chapter, give the recipes for the developer, bleach and print out solution for successful processing, when using recording material produced with the diffusion method. It has to be pointed out, that this thesis, due to the large extent of the research in the field, does not explore different processing options. The aim is simply to give a method for successful processing at this point. Future work will experiment with the method and different processing options.

Developer

The development stage in holography is, as it is in photography, a reduction process. The silver in the gelatin is reduced to metallic silver, turning black in the process. One of the reasons why photographic developer cannot be used is that it often uses so-called preservatives; chemicals that make the life of the developer longer, but also affect the very small grains in holographic recording material. Photographic developer is often stored in a dark bottle and can be reused. Holographic developer is stored in two different bottles and only mixed together when needed. Without the preservatives, the solution quickly turns brown as air and light oxidizes it making it useless. However, if a developer is covered in between use, it can be used for quite a while, until it gets very dark brown.

The developer used for the diffusion method is a quick-reacting fairly common holographic developer.

Part A

6 g metol (4-methylaminophenol sulfate) dissolved in 1 litre of de-ionized water. Once the metol is completely dissolved, 40 g of ascorbic acid is added.

Figure 102. Metol.

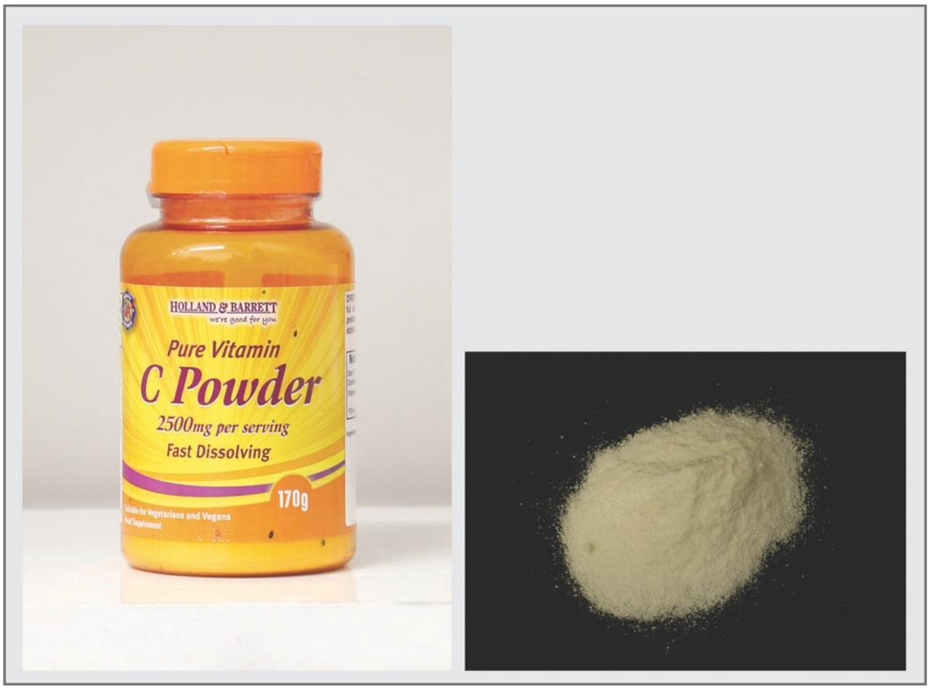

Figure 103. Vitamin C (Ascorbic Acid).

Part B

100 g of sodium carbonate anhydrous and 30 g of sodium hydroxide are mixed in 1 litre of de-ionized water.

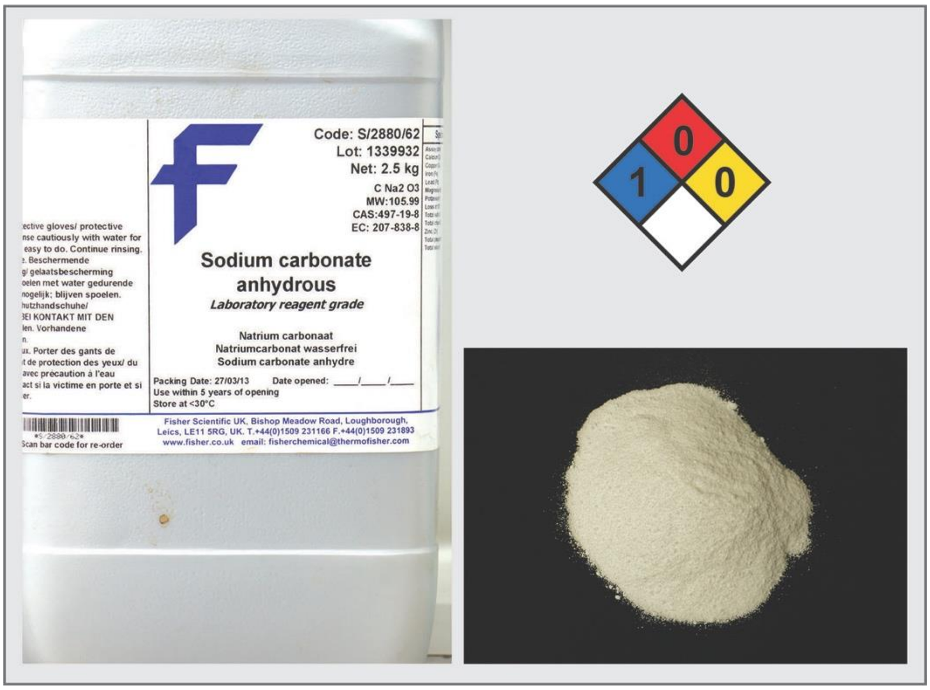

Figure 104. Sodium carbonate anhydrous.

Figure 105. Sodium hydroxide.

Part B is highly alkaline as a developer only becomes active in an alkaline solution. Only when Part A and Part B are mixed together in equal quantities will the developer work efficiently.

Figure 106. Part A and Part B of the developer.
Part A will get darker in time.

The developer is designed to react fast and not to interfere with the shape of the silver grains in the gelatin. Enough exposure time should be given to have a developing time of between 20 and 40 seconds, not longer.

To develop the hologram, the coated area is submerged quickly, to cover the whole area more or less simultaneously, in the developer and agitated. In the case of the hemispheres, the hemisphere is 3\4 filled with developer and is then moved rapidly up and down.

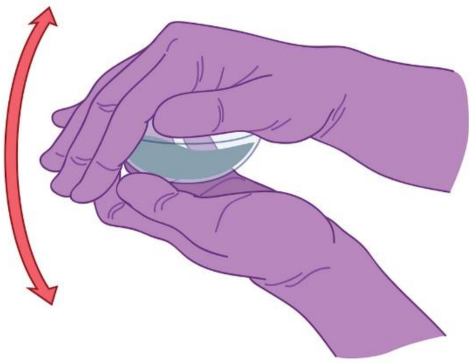

Figure 107. Developing the hemisphere by shaking it repeatedly.

The development is done when the exposed area has turned from clear to middle grey. The coating should be rinsed in tap water to stop the reaction and can then be bleached.

Bleach

I have worked with two different bleaches when processing material made with the diffusion method. Both bleaches are *rehalogenating* bleaches as opposed to *reversal*, also called *solvent*, bleaches. During the bleaching process, the recording material changes back to transparent. Rehalogenating bleaches reconvert the developed silver to silver halides, while solvent bleaches remove the developed silver and leave the undeveloped silver halides.[234] The main objective of the bleach bath is to build the fringes, the diffraction pattern, which creates the holographic image when lit.

The following recipes have proven to be successful for the holograms recorded on coatings made with the diffusion method:

40 g ethylenediaminetetraacetic acid iron (111) sodium salt (EDTA)
60 g potassium bromide
70 ml acetic acid
Dissolved up in 1 litre of de-ionized water

[234] Saxby, *Practical Holography,* 4th ed., p. 613.

Figure 108. EDTA.

Figure 109. Potassium bromide.

Figure 110. Acetic acid.

A second bleach is recommended by Blyth which is very fast acting due to the copper sulphate, but shrinks the gelatin layer slightly, which changes the replayed wavelength:

Figure 111. Copper sulfate.

Figure 112. Potassium bromide.

Figure 113. Acetic acid.

20 g copper sulphate

80 g potassium bromide

70 ml acetic acid

Dissolved up in 1 litre of de-ionized water

Both bleaches work fine for the diffusion method.

Figure 114. EDTA Bleach and Copper Bleach.

After the bleach, a good wash is necessary, to wash out the chemicals. 10 minutes in running tap water is recommended.

Print out

Print out is a term used in photography and best known in the context of printing out papers (P.O.P) in contrast to developing out papers (D.O.P). The difference being that developing out papers create a latent image, which then is developed. In printing out papers, by contrast, the image appears during exposure.[235] Printing out paper needs to be fixed after the exposure, to make sure the image stays and the whole paper does not turn black in time. The term *print out* in holography refers to the fact that, as with photographic coatings, holographic recording material may darken in time, for the simple reason, that in holography the silver, unlike in photography, stays in the coating.

[235] Hirsch, *Photographic Possibilities*, p. 123-124; Newhall, *The History of Photography,* p. 126.

While the print out effect can reduce scattering in the image and therefore can even be a positive effect up to a point, there are ways to make the coating more light-stable.[236]

In my experience this is a very successful print out bath for the coating of the diffusion method with the additional advantage to remove residual stain from the dye.

Figure 115. Bleaching of the dye stain with persulfate.

The solution of the following recipe can be reused until it is no longer a clear solution.

40 g sodium persulfate (or potassium persulfate)
40 g sodium hydrogen sulfate
1 litre of de-ionized water

[236] Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing*, p. 208.

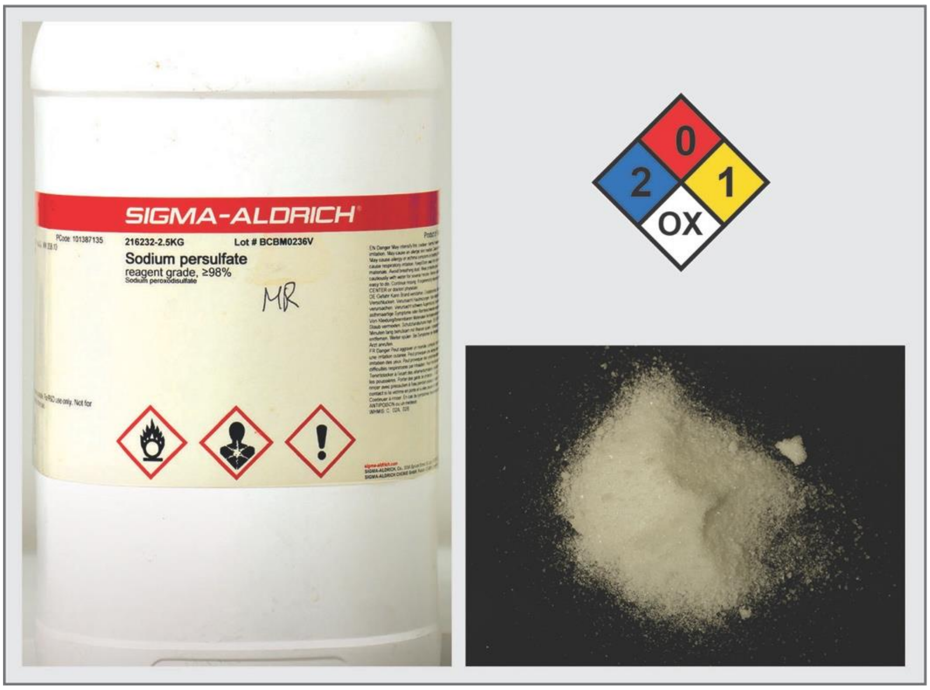

Figure 116. Sodium persulfate.

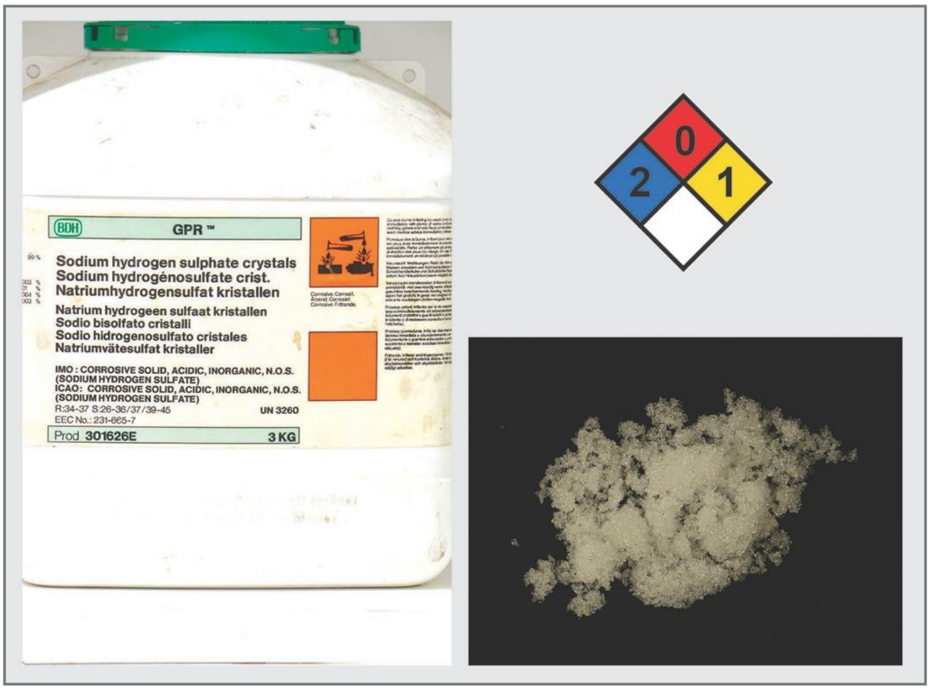

Figure 117. Sodium hydrogen sulphate crystals.

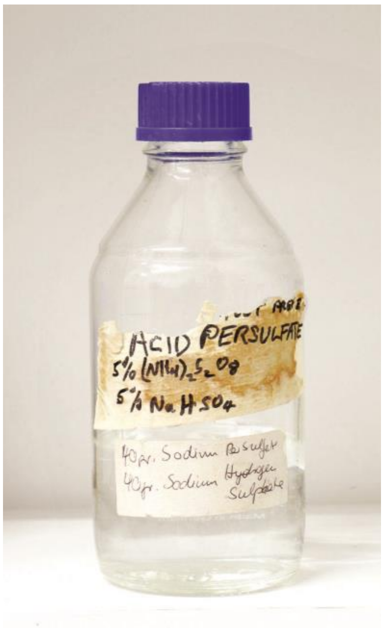

Figure 118. Print out solution.

After this last step, the hologram only has to be washed from 20 to 30 minutes depending on the size, and then dried. When letting the hologram dry, it is important, to wipe of water drops, as they can cause colour changes in the finished hologram. To avoid that and other mineral deposits due to the use of tap water, a last bath in de-ionized water with a wetting agent is recommended. I used Photo Flo form Kodak. A few drops are sufficient.

Figure 119. Photo-Flo as a last wash, leads to a cleaner finish of the hologram.

This processing system works very well for the diffusion method. There has been, however, a lot of research in developer and bleach solution for holography, which provides a future platform for experiments with different processing solutions to perhaps achieve an even brighter hologram. The diffusion method is in its first steps and improvements in the future are clearly possible.

This chapter completes the making of silver halide-based recording material and recording and processing the hologram. The next chapter, to conclude my research, focuses on the future of the diffusion method in holographic practice.

Chapter Eight

Conclusion and the perfect hologram

At the beginning of this research I set out to examine the potential of silver halide-based holographic material as a creative tool by hand-coating it on glass objects. I explored and experimented with the diffusion method to consider its viability, for both the artistic practitioner as a means for greater autonomy and expressiveness and also for a wider holographic audience. Early in my research it became clear that the diffusion method itself needed significant adjustments and this led to an intensive process of exploration in the laboratory. I began a series of trial-and-error experiments, informed both by explicit knowledge from texts and by the tacit knowledge I gathered during my time observing and working with the diffusion method. I had started to engage more with the working and thought processes involved in this approach and the actual experience of assimilating tacit knowledge. Through careful consideration of the chemicals and through the continual act of practising the coating process, my awareness of a growing tacit knowledge played a major part in the eventual success of producing hand-coated recording material.

Figure 120. A selection of hemispheres produced during the research.

The innovative ideas and holographic exploration by creative holographic practitioners highlighted in this thesis show that creative holography has successfully escaped the traditional gallery context for fine art photography and wall-bound two dimensional display modes many times in its short history. The strong desire to abandon the 'wall for holography' and explore radical display possibilities clearly suggests that the diffusion method could emerge as a powerful tool, amplifying the possibilities for the holographic practitioner.

This thesis shows that promoting holography as a skill and a craft, which can be practised and learned, rather than as a complex science, makes it more accessible to a future generation of art holographers. Suzanne Butters remarked that '[...] one should bear in mind that before the eighteenth century the word art meant 'skill' and it referred to any expertise that could be learned'.[237] This research, with its investigation into the hand-coating of silver halide-based holographic material explores one important way to inspire and forge a new community of skilled artists. It follows the rising interest in the actual recording material, described in Chapter 1, and defines the production of recording material by the practitioner as an important skill for a new form of creative holography.

Alone or in collaboration, the Creative Holographer, being artisan and artist, creates new knowledge through the experience of actual *making*, as occurs when coating plates. This permits the Creative Holographer to find new ways of expressing artistic ideas. Practising and crafting can result in an intimate knowledge of the material worked with, with every piece made being unique. Martina Margetts stresses that point in her essay *Action Not Words:* 'The maker has the freedom and control: the role of making is to create new ways of thinking, through engagement with the materials, techniques and ideas.'[238] From my own experience of coating glass objects in the lab, I know that the possibilities are endless. This thesis is the first step in a whole new world of creative possibilities of holography as virtually *any* object becomes a possible substrate for

[237] Smith, Meyers and Cook, (eds.), *Ways of Making and Knowing,* pp. 49-50.
[238] Martina Margetts, 'Action Not Words', in *Power of Making: The importance of being skilled*, London, V&A Publishing, 2011, p. 43.

holography and the creative process starts with the coating material and not late in the process with the setup and subject matter.

Hand-coating material opens doors for many potential visual outcomes: with the diffusion method the practitioner now has the choice to work either with silver halide-based material or the DCG process. Whichever method chosen, a hands-on environment is crucial. My research has also shown that the learning of recording material-making has to be practice-based in a clear and comprehensible way. This calls for a change in both the educational approach of holography and in the opportunities for practice-based development and exploration of the medium.

Up until now, the perfect hologram has been measured by the *perfect* three-dimensional true colour holographic replica. A hologram has much more to offer than being simply visible and bright. While the diffusion method is able to produce bright holograms, the hologram most observed in my exhibition at *Steampunks in Space*, for example, was the one that was the least clear: an octopus in a glass bubble.

Figure 121. *Steampunks in Space* exhibition.

Figure 122. Close-up: Hemisphere Holography.

Figure 123. Bright holograms produced with the diffusion method for the exhibition *Steampunks in Space*.

Figure 124. Hologram of an octopus in a glass bubble.

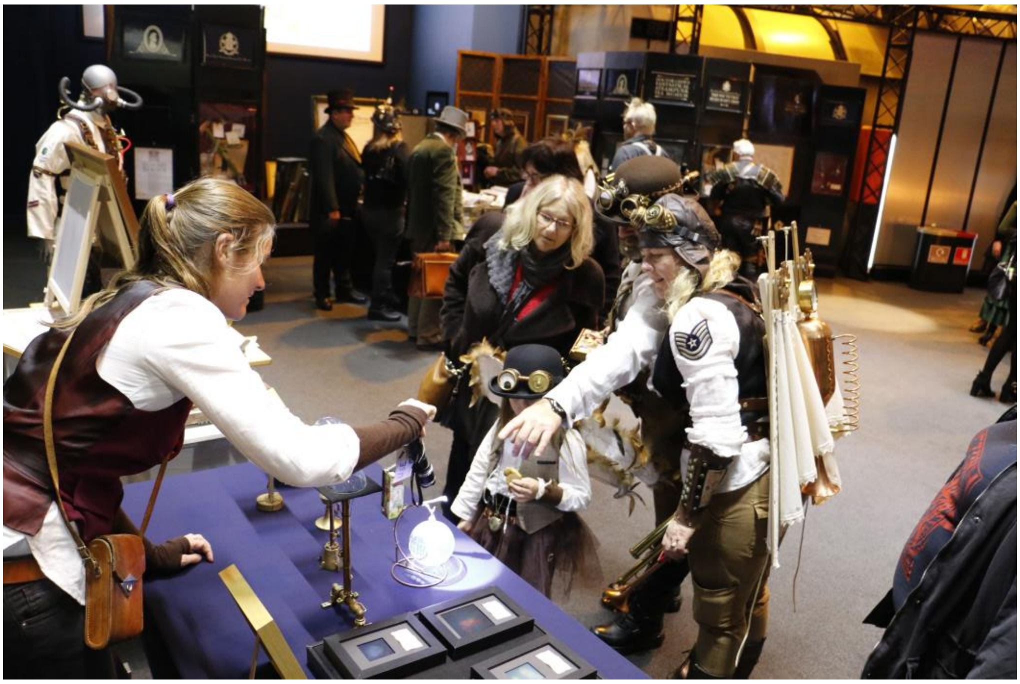

Figure 125. People searching for the octopus.

People would stand around and talk about it, and whoever actually had seen the octopus which was inside was said to be fortunate. I think there is a lot more to the idea of the perfect hologram. Errors can be used. When coating recording material there are a lot of steps on the way that can be used to create a unique visual outcome, once the concept of the clean hologram being the perfect hologram has been overcome.

> In these early writings by Pethick, the experimentalist view emerged that there were no wrong ways to make a hologram as long as something played back & it was even OK to break the rules. For instance, you could create color compositions resulting from the "spectral smear" from using a non-coherent reconstruction source to illuminate a laser transmission hologram.[239]

Just as the sand table overturned the belief that without a heavy table holography was not possible, hand-coating material can re-define the perfect hologram. Producing recording material frees the artist from standardized material and the holographic image from the wall and can create a sense of control and autonomy from commercial recording material. The artistic process is now less limited and more liberated.

[239] Crenshaw, 'Jerry Pethick: The Missing History of the Sand Isolation Table', p. 5.

Appendix A

Paper published in Conference Proceedings of ISDH 2018 in Aveiro, Portugal

Hemisphere Holography

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ABSTRACT

In the paper I introduce my research regarding a unique coating process, using Silver Halide, which enables the recording of holograms within glass hemispheres as a potential advance for Display Holography. The paper details the first exhibition of Hemisphere Holography at the National Space Centre based in Leicester, UK, in November 2017. Furthermore it discusses the audience reaction to Hemisphere Holography in comparison to Holograms on glass plates.

Keywords: Hemisphere Holography, Recording Material, Emulsion Production, Silver Halide, Self-Coating

1. INTRODUCTION

Traditionally Holograms are recorded on plane surfaces, either glass-plates or film. With the means of self-coating holographic material after the Jeff Blyth Method [1], this paper challenges the idea of recording holography as a 3D-image-making medium exclusively on an essentially two dimensional surface. It looks into and tries to prove the new, alleged, visual potential of holograms on glass hemispheres by putting Hemisphere Holography to a practical test as part of an exhibition.

2. HEMISPHERE HOLOGRAPHY IN EXHIBITION

The National Space Centre in Leicester, UK called for artists at the end of 2016 and, as I was a successful applicant, commissioned me to create a piece of new artwork for the event "Steampunks in Space". This is an annual event in the National Space Centre that runs for one weekend. As it is always very well attended it seemed a good place to test Hemisphere Holography on an audience. The Steampunk community is known for original design. Steampunk is an alternate timeline of the eighteenth century with its origin in England. This leads to a Victorian-style design, to a love for the idea of the 'mad' scientist and the fearless explorer and an appreciation for the analogue, the unknown and the uncanny. These characteristics make it easy to place Holography, with its sometimes almost arcane aesthetics, in this environment. Ghostly images, analogue, with a profound scientific background, sometimes transmitting a feeling of ephemeralness, met a highly curious audience with the desire to explore. Not surprisingly these factors contributed to the success of the exhibition.

The proposed theme for the artworks was the space race of the 1960s, which gave all the invited artists room for imaginative creativity. The creative premise for my contribution was that the Luna 1 spacecraft - part of the Soviet Luna Programme in 1959 and meant to land on the moon to send back data - was now *not* on the moon, but instead orbiting the sun and sending back images in the form of holograms. These visual messages are the holograms I displayed.

Fig.1 Display of Holograms at “Steampunks in Space 2017”.

Fig.2 Two of the Hemisphere Holograms in close-up.

The exhibition includes plane holograms and hemispherical ones, and this was due to two reasons. The first, and the decisive one, related to the difficulties I encountered in actually producing the recording material for Hemisphere Holography. Silver Halide emulsion has not been used before as we see it in the exhibition. Accordingly, figuring out how to apply the coating successfully was a big part of the research and production of Hemisphere Holography. When the holograms *finally* decided to appear, the exhibition was only a week away. By then I had recorded some traditional holograms, just in case. Fortunately, with the subject matter ready to go, I was able to produce six curved holograms as well. The decision to exhibit both types of holography arose from seeing both of them next to each other. This gave an ideal opportunity to compare audience reactions immediately - the outcome of which I will discuss later in in the paper.

Another challenge was the replay of the recorded wavefront. As the holograms were part of a bigger exhibition and event, delicate lightning requirements were not a priority. The lightning was very broad, coming from a high ceiling, with no possibilities for spotlights. I decided to let the audience do the job of lighting the holograms themselves with torches I provided.

Fig.3 Hemisphere Holograms with torches.

I first put the torches on the table without the signs seen in the picture, thinking that visitors would use them because they were there. Inevitably, no-one picked up the torches, when I wasn't there to show how it worked. The big instructional signs helped a bit. Still it worked best when I was there to get people engaged by handing them the torches while explaining what to do with them. Margaret Benyon commented on a similar problem in one of her exhibitions in an interview with Sean F. Johnston:

I always put down that exhibition as a complete failure, because most people never got to see the holograms unless I was there to show them, even though I had put arrows etc, because they didn't know what to expect; they had no idea. I had to teach them how to see the holograms. [2]

Contrary to Benyon I wouldn't call this a failure. Even though people had to learn how to look for the hologram, and maybe a few even left without having seen anything, I got the feeling that once engaged, once they had the torches in their hands and had seen the first hologram, the joy of discovering took over, children and adults alike. People came to the table to discuss certain holograms because they would see them differently, of course, from different perspectives and from playing with the torches, or the spotlight of their smartphones. For me, rather than a failure, this is an interesting starting point for further research in how holograms are perceived by the audience and if and how the experience changes by changing the form of the object that contains the hologram.

3. HEMISPHERE VS. PLATE: AN ANALYSIS ATTEMPT

Most of the subject matter of both exhibits, the hemispheres and the plates, are fantasy creatures you would find in the Steampunk space universe. In both cases the observer would not be able to recognize the object as something he had seen before. This turned out to be an extra challenge, appreciated by the audience, as it gave a lot of room for imagination and discussion. In general people would find the holograms in the plates faster and easier than the ones in the hemispheres. This seemed to make the moment of the discovery more intense and more desirable. The challenge of finding, I believe, and Margaret Benyon has mentioned this before, has to do with expectations. People would stand with a torch in front of the hemisphere not knowing what to do next. We expect to see an image when we look at a two dimensional surface, framed and put on the wall. Andrew Pepper comments on this matter in his paper 'Holography without frames: sculptural installations incorporating 'drawn' elements' stating that:

Viewers bring with them an acquired (subliminal) knowledge of how to view 'art' on walls, which includes an understanding of where the work stops (the edge of the frame), orientation (we know where the top and bottom are), the nature of completion (the work is deemed 'finished') and spatial location through the definition of the picture plane (the surface contains the visual illusion of volume). [3]

Pepper goes on and translates this idea into the universe of holography:

Unfortunately, when holograms are framed in a format which makes them ‘appear’ like flat pictures, but display stored holographic volume, a visual and perceptual conflict occurs. [4]

In the case of Hemisphere Holography, the trained eyes of the audience are thrown out of their learned experience of looking at a flat image and the illusion of a three dimensional space. This is not only because of the *visual and perceptual conflict*, as Pepper puts it, but also because of the unusual form that holds the image. The eye tries to find and make sense of non-planar image, in a place, floating in thin air inside boundaries of glass, where there really shouldn’t be an image, but the object itself. I was curious if the fact that the audience isn’t looking at a plane surface might dissolve this *visual and perceptual conflict,* but quite the opposite seemed to be the case, which brings me back to the expectations I mentioned before. As the spectator is searching for an image, floating in thin air inside a glass hemisphere, visually speaking, he was left quite alone. To translate what we learned about how to look at and especially for images, *our post-Renaissance understanding of the depiction of volume on a flat surface* [5] into Hemisphere Holography was challenging, as the surface wasn’t flat and the connection between the substrate and the image is very loose. The process of the image-making is hidden without any further knowledge about how a hologram is produced. In a way the substrate loses its significance.

This presents an interesting thought process for the audience. The hemisphere must have meaning but it can’t be seen by a quick glance. The question I was asked the most, was where the image came from, as it was obviously not the light, which the viewers controlled themselves. Furthermore, I could observe that, the rounder the glass object was, the most interesting it seemed to be as an object. The one that was almost a closed Bubble was the hologram people spent most time with. It was at the same time, the hologram hardest to find and the audience got obsessed with it. The object itself is very intriguing, and as mentioned before, people wouldn’t expect anything to be in there. But turning the torch and being proven wrong, even, in some cases, without actually recognizing the object, drew the audience to the glass bubble. Not being able to see anything but being told by other observers, that there actually was something to see, spiked the interest even more. A second factor was that this bubble obviously had a direct connection to the hologram, as with the grid it actively kept something inside. The connection of the substrate with the image seemed to have a certain importance.

Fig.4 Bubble Hologram with audience and as close-up.

4. CONCLUSION

Based on my experience in the lab, preparing the Hemispheres, and how they were received in the exhibition, the hand coated material bears great possibilities to present holograms in new ways. The evidence that holography should consider the possibility to leave its framed home on the walls and embrace its interactivity and visual expressiveness has been long given. Works like '*Coexistence*' by Ray Park, Martina Mrongovius' '*Jellyfish*', Andrew Peppers theoretical and practical work and David Warrens '*Hololuja; A one kilometer Art Hologram'* are only a few of successful examples of holography having left its static place to maximize its interaction with the audience. Once one is able to coat one's own material and become independent from what plate suppliers can offer, Hemisphere Holography can be nothing else than just the first step towards new possibilities of visual expression and experience.

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Appendix B

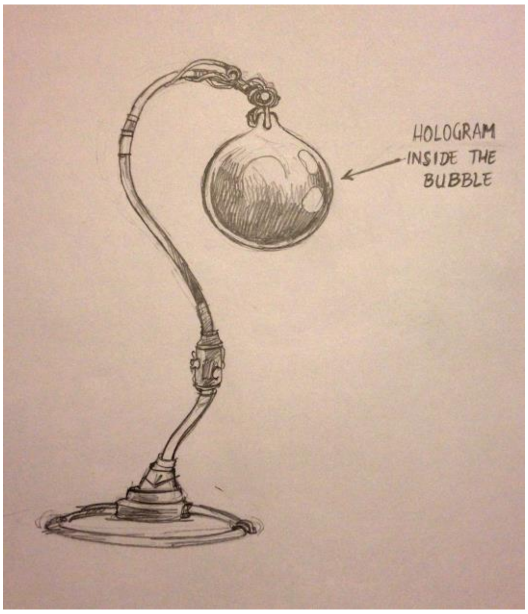
Proposal for *Steampunks in Space* Exhibition, National Space Centre, UK

Working Title: Luna One

Brief description:
As part of the Space Race between the United States and Soviet Union, the Soviet Union launched their Luna Programme - a series of un-manned spacecraft designed to impact on the moon in order to explore and send back data. Because of a 'malfunction', the first spacecraft ever sent, Luna One, passed by the moon and left the earth orbit and entered the heliocentric orbit. Being the first spacecraft to not only achieve escape velocity from the earth and to enter the heliocentric orbit, but also to explore the solar wind, Luna One was affectionately renamed *Mechta*, the Russian word for Dream. It is believed that *Mechta* is still orbiting the sun, but unable to send back messages: the last contact happened on the 5th of January 1959, only 3 days after its launch.

*Mechta'*s silence continued until 1962, when Scientist and Professor Dr. Sonenhof claimed to be 'catching' messages from Luna One. She further claimed that the messages were transmitted by light with the help of a heliograph and, caught in a device she calls 'Spacebubbles', appeared as holograms.

The exhibition will show 4 to 6 of those holographic messages (Bubble diameter: 8 to 15 cm). The holographic messages will be anything from pictures of the sun to objects floating in space deemed worth watching at by *Mechta*/Luna One, as interpreted by Dr. Sonenhof.



Display requirements:

There will be drawings of Luna One in the 'Steampunk Universe' and the notes of Dr. Sonenhof plus the holographic messages. So, a wall to hang drawings and a table to put the items would be needed.

Holograms are best lit with LEDs from diagonal-above. It would be good to have the table free standing in the room so the audience can move around it, as the holograms change when looked at from different angles.

Name: Tine Barkmann
Email: barkmannt@gmail.com

The story . . .

During the space race the Russian government launched their *Soviet Luna Programme.* Luna 1 was launched and intended to land on the surface of the moon and send back data. Due to an error in the rocket's burn time Luna 1 never made it to the moon. It flew right past it, left the geocentric orbit and entered the heliocentric orbit, as the first man-made object ever, and was therefore called a 'new planet'. After sending back observations and data, never captured before, about the solar wind and the magnetic field of the moon among other things, the new planet, now renamed *Mechta* (Dream), eventually fell silent. Or so it was believed.

Years later, when *Mechta was* now a distant memory in space history, a young scientist, Josephine R. Wood, was interrupted at her evening meal, when she heard a rather unpleasant noise from her bathroom window. Believing a poor bird had once more been distracted by the terribly bright lights her neighbours used these days, and found its short life ended on her bathroom window, she got up with a deep sigh and a last look at her dinner, now doomed to be eaten cold many hours later that evening. Or so she believed. Minutes later she would have forgotten about her dinner or why she got up in the first place.

Outside, there was no trace of a bird, not a single feather. Josephine had a closer look around, finally concluding that there was no death to mourn this particular evening. On her way back to her dining room she couldn't shake the feeling of something having changed and without controlling her steps she found herself in front of her bathroom door. When she opened that door, her life changed. There was no sign of a bird, but a bright red image, of what she now believes was a 'carte de visite' of the moon impactor Luna 1, floating on her bathroom window.

After this first, memorable evening, more messages arrived out of nowhere. *Mechta* had started to communicate once more, sending new observations. Now, without any mission to worry about, *Mechta* seemed to just analyse its environment. Josephine pondered that maybe, all alone and forgotten in space, the new planet had got bored and lonely and rather than lose every connection to its old home, earth, it started to send images.

Eventually Josephine grew tired of collecting and preserving these messages: she had to cut, not only the bathroom window, but the dining room and kitchen window as well. The cold airflow would run through the whole house. She therefore created a message-catching device which she put up around the house, capturing the images before they bumped against her window. It also helped her sleep better, as the noise, as mentioned before, was rather unpleasant. Now she was able to trap the floating signals into little glass-hemispheres, to sleep well again and to finally start her investigation into the mystery – an investigation which is still, admittedly, in its very early stages.

The first step for her was to figure out how *Mechta* sends these signals. Scientifically, the most common sense theory to date is that *Mechta* uses some kind of a giant, natural heliotrope, benefitting from reflections from lake or ice surfaces on planets on the way to earth.

After proving this theory, responding to *Mechta* will be the next big task...

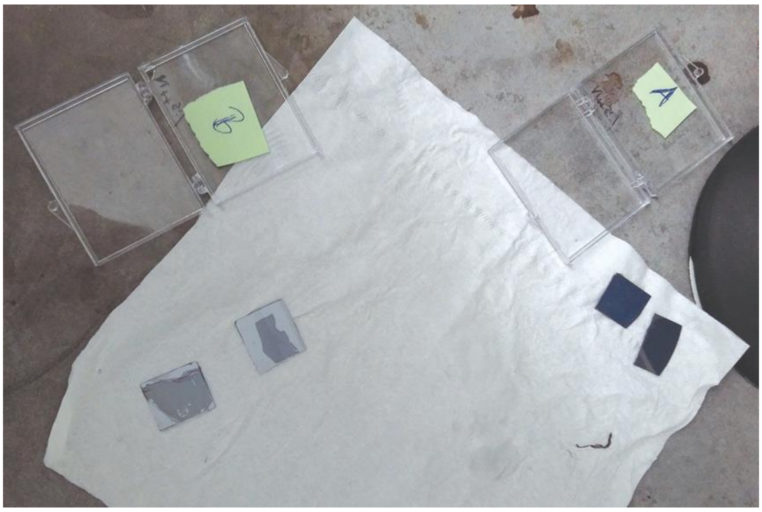
Presentation of the story in the exhibition:

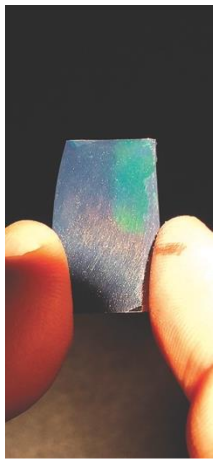
Pictures of the whole exhibition are in the paper, presented as Appendix A.

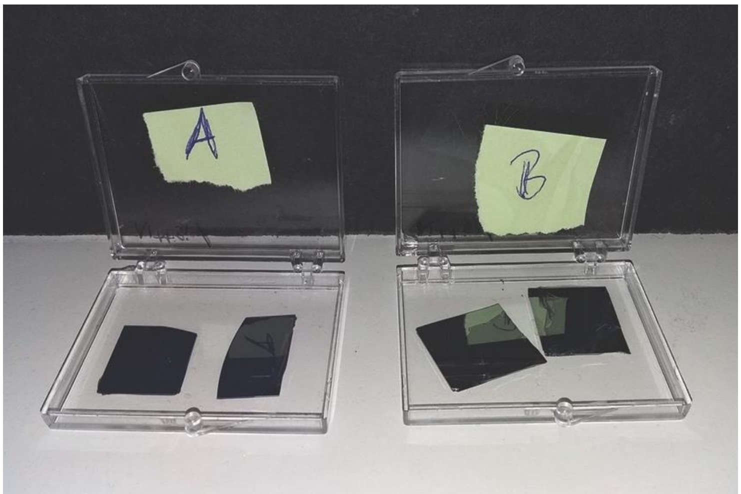
Appendix C

Notes on grain size measurement and other analyses

The establishment of specific and measurable explicit knowledge about the diffusion method was one of several aims of my overall research process. In particular, I hoped to complete a detailed evaluation and measuring of grain size, as it plays a critical role with regard to light sensitivity and 'clearness' in the holographic recording process. Having arranged for the use of an electron microscope at De Montfort University, I prepared several silicon wafers by executing an emulsion lift (see images below) of a recorded hologram, in preparation for analysis under the electron microscope.

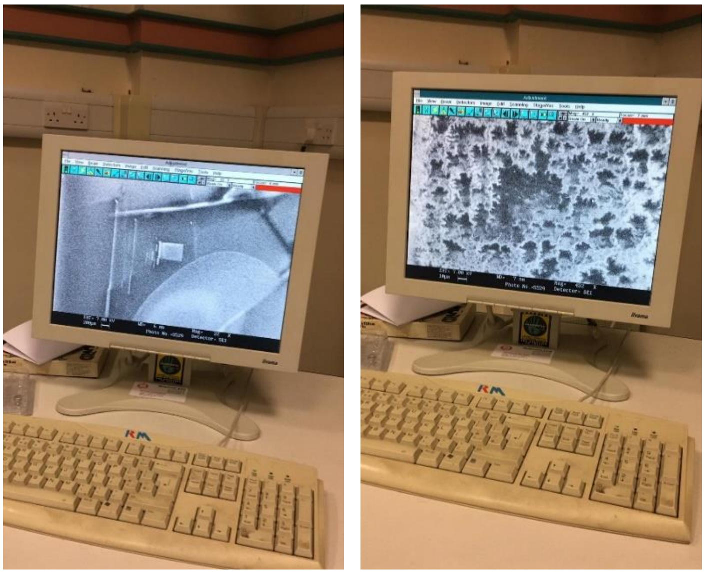






Holograms on wafer silicon, prepared by emulsion lift, ready to analyse for grain size.

Unfortunately, no meaningful results were achieved. Further intended tests included the measurement of the gelatin layer and diffraction efficiency. These analyses are therefore still outstanding due to a variety of factors such as damage to the coating in the microscope analysis process (as shown in images below) and time management of the collaborating parties. Nevertheless, the coating in question had worked successfully in practice, as proved by the bright holograms recorded, and the principal goal of my research and work - a recipe for a feasible diffusion method - was achieved.



Results from the analysis of the coating for grain size.

Although it would have been desirable to be able to have measured these aspects of the holographic process, ultimately they were neither the main focus of my research nor, in essence, reliable indicators. As noted before in relation to hand coating material, characteristics such as the gelatin layer, grain size and diffraction efficiency may change from coating to coating. Ultimately the important issue was to achieve bright holograms and this was done successfully with a coating exposed with red, green and blue lasers.

Future research and work, however, should continue to analyse these aspects of the holographic process and examine them on an empirical measurable basis. Coupled with the tacit knowledge gained through practical working experience, a greater explicit understanding of the issues and ideal parameters relating to the gelatin layer, grain size and diffraction efficiency will reinforce the validity, practicality and feasibility of the diffusion method in making successful recording material.

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