Some Considerations on Color Hologram Trial Techniques Using $He\text{-}Cd^+$ Laser with Coherent Blue-White Light

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Optical holography technology is now firmly established as a special display medium as well as a useful tool for scientific and engineering studies. It has found a remarkably wide range of applications such as color holography, holographic interferometry, and computer-generated holograms.

A hollow cathode $He\text{-}Cd^+$ laser with coherent blue-white light is now available in place of a He-Ne laser and an Ar^+ laser. A simple optical setup for the separation of RGB primary colors is proposed from the viewpoint of making the practical color hologram in this study.

The deterioration of visual appearance of reconstructed images owing to the cross talk is discussed in connection with the recording materials with high resolution and wide spectral characteristics.

1. Introduction

Optical holography technology has found a remarkably wide range of applications such as color holography, holographic interferometry, holographic optical elements and computer-generated holograms together with the research and development of various lasers and recording materials.

An idea of a multicolor image with 3-D real appearance was first pointed out by Leith and Upatnieks [1]. The multicolor image can be produced by a special color hologram recorded with three suitably chosen wavelengths. Note that the color hologram is recorded on a special film or plate by means of triple-exposure. It looks like the monochromatic hologram in appearance, but the optical process for making and reconstructing the hologram differs from in contrast to the conventional holography techniques.

A special laser such as $He\text{-}Cd^+$ laser and a unique recording material are used in connection with an optical setup arrangement in the color holography. The resulting hologram can be considered as three incoherently superposed holograms. When the color hologram is suitably illuminated once again by using light with three different and independent wavelengths, each of light for reconstructing the original object is diffracted by the hologram.

As a result, the superposition of these three images results in a multicolor image under the limited

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condition. But, there are several practical problems such as light sources for color holography, recording materials, and the deterioration of reconstructed images, though an idea of the multicolor holography was demonstrated in the early 1960's.

On the other hand, the unique techniques for making quasi-color holograms have been studied by many researchers [2].

These special holograms may be simply reconstructed with general white light such as an incandescent lamp. For example, there are the rainbow hologram, Lippmann hologram, image hologram, emboss hologram, etc. [3].

In this study, some considerations on color holography techniques using a new developed He-Cd^+ laser with coherent blue-white light are checked from the experimental results. A new separation technique of RGB primary light sources for making color hologram is proposed. The deterioration of visual appearance of reconstructed images owing to the cross talk is discussed in connection with the recording materials with high resolution and spectral characteristics of three different wave-length sensitivity.

2. Hollow cathode He-Cd^+ laser with coherent blue-white light

A hollow cathode He-Cd^+ laser with coherent blue-white light is developed by Koito Manufacturing Co., Ltd., and is now commercially available [4]. The structure of a He-Cd^+ laser tube is shown in Fig.1. In contrast to a conventional He-Cd^+ laser (only blue light) which uses the positive column plasma as the laser medium, this new laser uses the negative glow plasma. The negative glow plasma can be generated in the center of cathode pipe. Both electron density and energy of the negative glow plasma become very high. In addition to blue light, it is possible to obtain red and green components of light from a single laser tube. This laser can oscillate simultaneously at red (636.0 nm and 635.5 nm), green (537.8 nm and 533.8 nm), and blue (441.6 nm) in a single tube. The output power characteristics of the white-blue light laser are mainly affected by He pressure, discharge current, Cd^+ vapor pressure corresponding to an anode voltage, etc. The vapor pressure of Cd is an important parameter which determines the output of the laser. To keep it constant, the outside of reservoir was surrounded by a heater so that the temperature of the Cd reservoir was controlled. The vapor pressure of Cd in the laser tube is 10 [Pa] (7.5×10^{-2} [Torr]). Total output power of the three colors was about 34 [mW] (red power : 6 mW, green power : 8 mW, and blue power : 20 mW). After the operation of about 600 [h], each output power became about 3.4, 3.2, and 13,3 mW, respectively. The life time can now exceed more than 1,000 [h] without refilling of

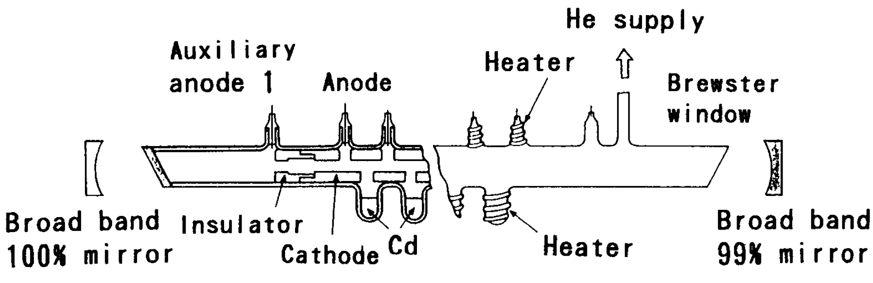


Fig. 1 Structure of hollow cathode He-Cd^+ blue-white laser light

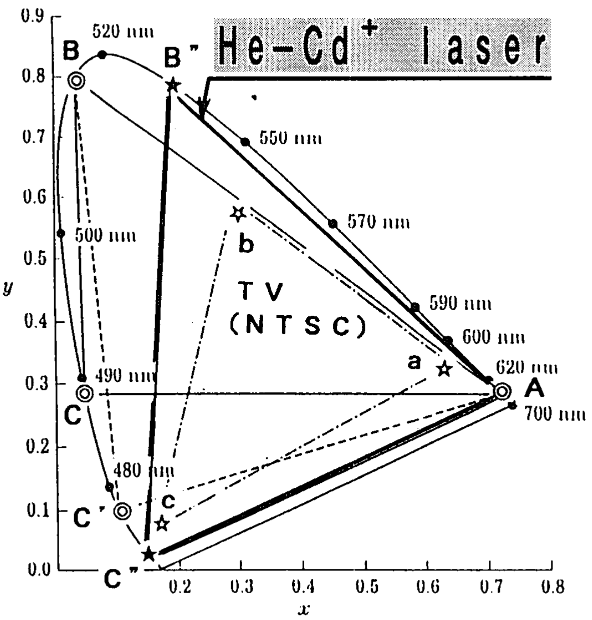


Fig. 2 Color gamut on CIE chromaticity diagram

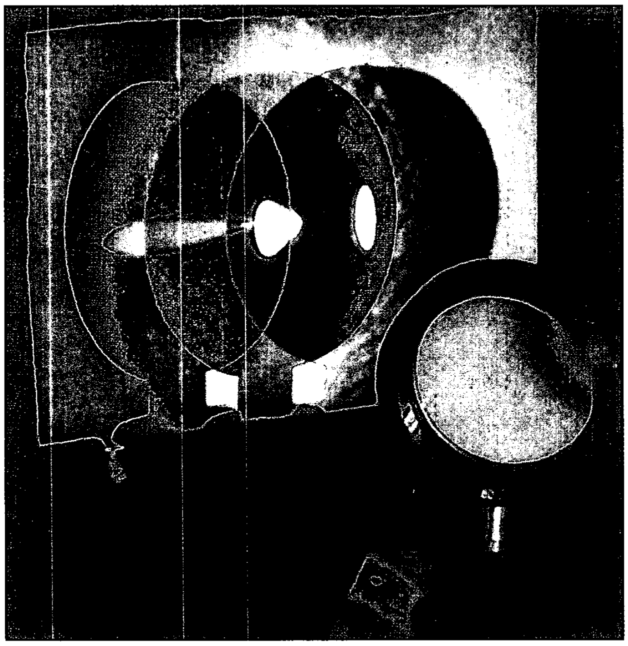


Fig. 3 Separation of RGB primary colors from the He-Cd+ laser by using two dichroic mirrors

the He gas and Cd from the outside.

Fig.2 shows the CIE chromaticity diagram which contains four kinds of color gamuts. The whole color gamut, i.e., a triangle AB"C", of the hollow cathode $He-Cd^+$ laser becomes wide in comparison with that of the green and blue light ($\lambda = 514$ [nm] at point B, and 488 [nm] at point C) from an Ar^+ laser, and the red light ($\lambda = 633$ [nm] at point A) from a He-Ne laser. The broken line shows the extended color gamut, on condition that the blue primary is replaced by $\lambda = 477$ [nm] at point C'. The chain line encloses the range of colors which may be reproduced by a typical colortelevision display. The result of the separation of RGB primary colors of $He-Cd^+$ laser is shown in the case of two dichroic mirrors in Fig.3. A combination of RGB primary colors looks like white color because of the additive mixture of light.

3. Optical setup for making color hologram

An optical setup used by Friesem and Fedorowicz is shown in Fig.4 in order to record three-color images of diffusely reflecting object [5]. The green and blue light from an Ar^+ laser was mixed with the red light from a He-Ne laser. One beam is used to illuminate the object while the other is used as a reference beam, and the resulting hologram is recorded in a special material with photographic emulsion. The ideal recording material for color hologram should have a spectral sensitivity well matched to available laser wavelength and high resolution characteristics. It is very difficult to make the recording material having the uniform and flat spectral characteristics over the range of visual light. In addition, the recording materials are not recyclable and relatively expensive. Silver halide photographic emulsions are widely used as the recording materials for monochromatic holography. Recently, some makers stopped the production of recording material, because there is

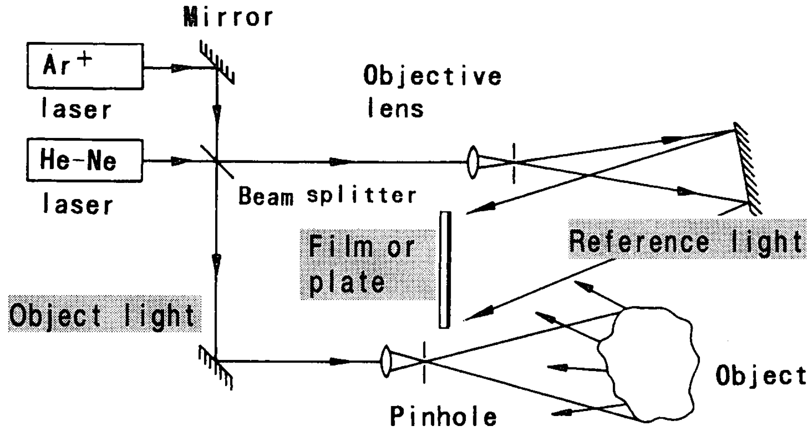
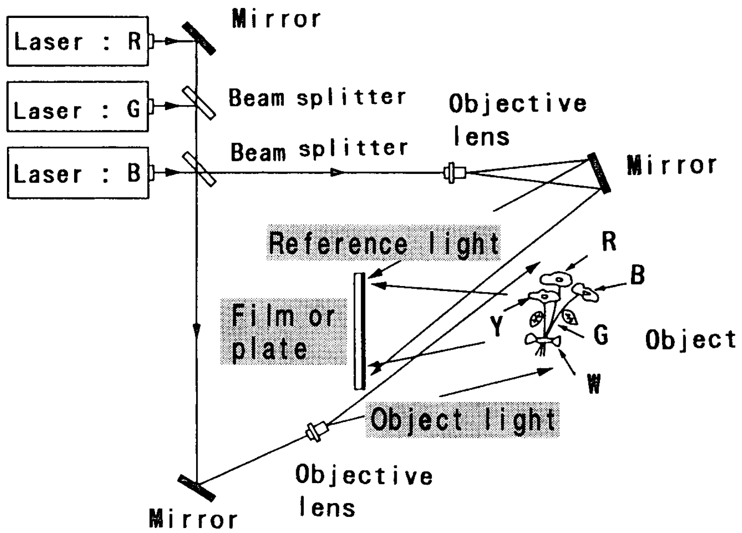
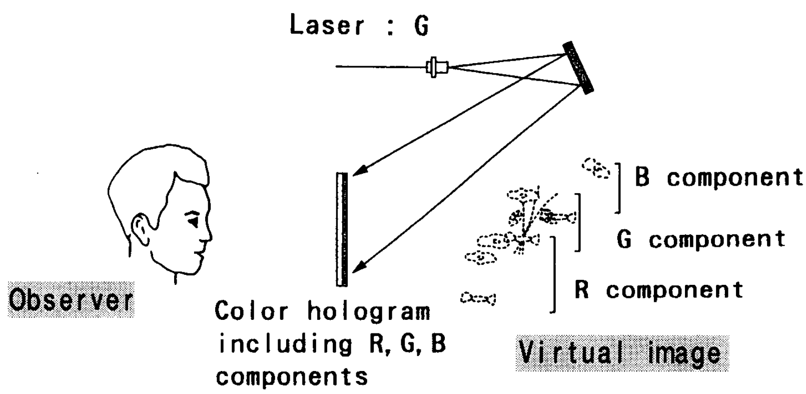


Fig. 4 Optical setup used for recording a multicolor hologram of diffusely reflecting object



(a) Simple optical setup for recording color hologram



(b) Cross talk in the case of reconstruction of hologram

Fig. 5 Basic color holography by means of primary colors : R•G•B no great demand for holography and its applications in the future.

Fig.5 shows the optical arrangement for making color hologram by means of three different lasers, and an example of setup for observing the virtual image by the use of a green laser [6]. A problem in multicolor holography is that each hologram or multi-exposure hologram diffracts not only light of the wavelength used to record it, but light of the other two wavelengths simultaneously. As a result, a total of nine primary images often called virtual images and nine conjugate images are reconstructed in principle. Three of these give rise to a full-color reconstructed images at the specified position originally occupied by the principal object. The remaining images diffracted from a component hologram are formed at other different positions. The main image overlaps with the remaining images each other. The result of the overlap degrades the visual and real appearance of multi-colored images. Several methods have been tried to eliminate or decrease the cross talk images.

Fig.6 shows a simple optical setup for making color hologram in this study. The hollow cathode $He\text{-}Cd^+$ laser with coherent blue-white light is used as the coherent light source, and original light is separated by using two dichroic mirrors, because the optical path length must match between objective light and reference light each other.

As a film or plate for recording a color hologram, BB-PAN plate (made in Germany) is used [7]. This plate has a special spectral sensitivity characteristic which is sensitive to each light of

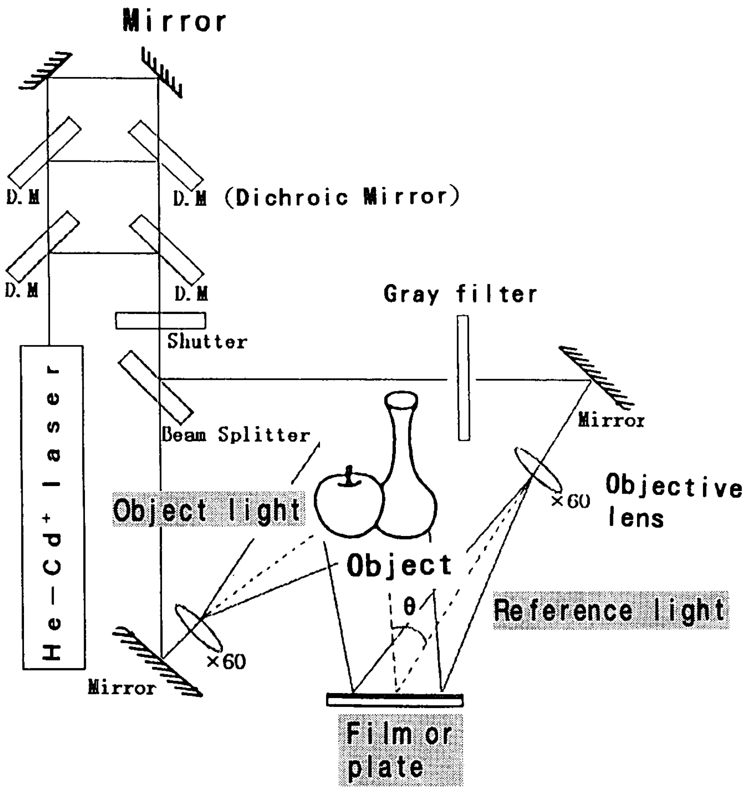
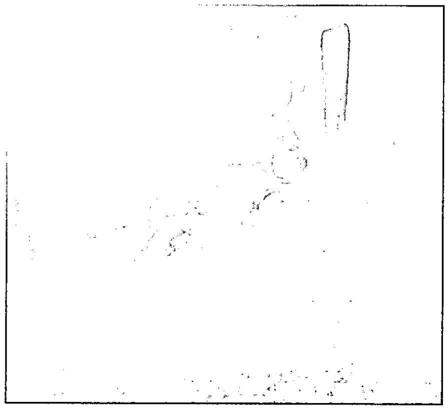
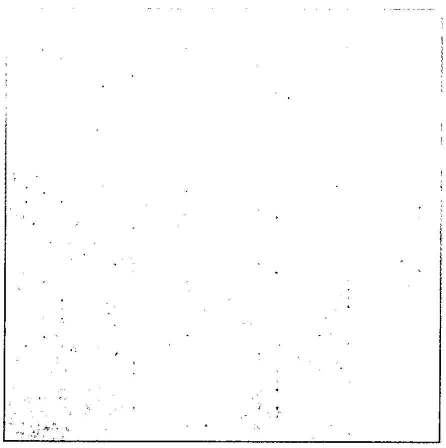


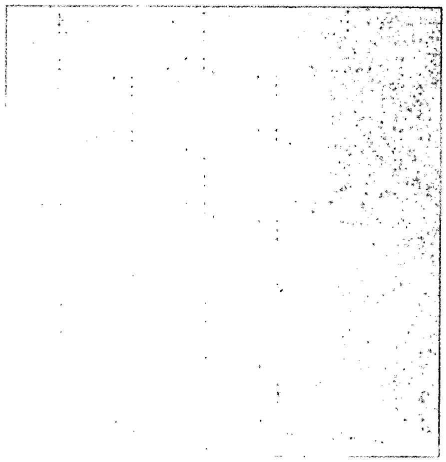
Fig. 6 Optical setup for recording a multicolor hologram by using $He\text{-}Cd^+$ laser



(a) Red light ($\lambda = 636$ nm)



(b) Blue light ($\lambda = 442$ nm)



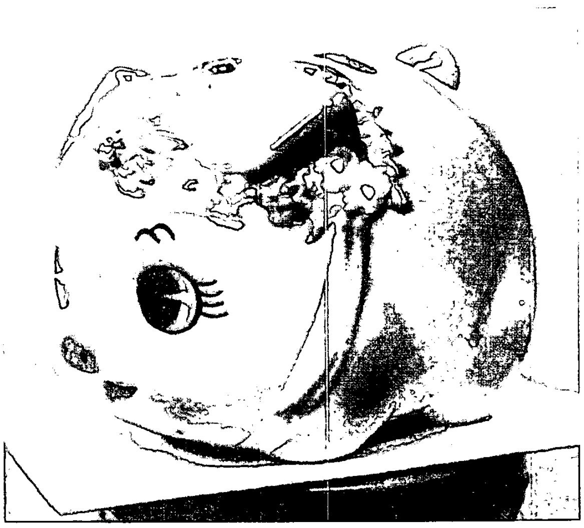
(c) A combination of RGB light (blue-white light)

Fig. 7 Comparison of celor images reconstructed by using He-Cd^+ laser

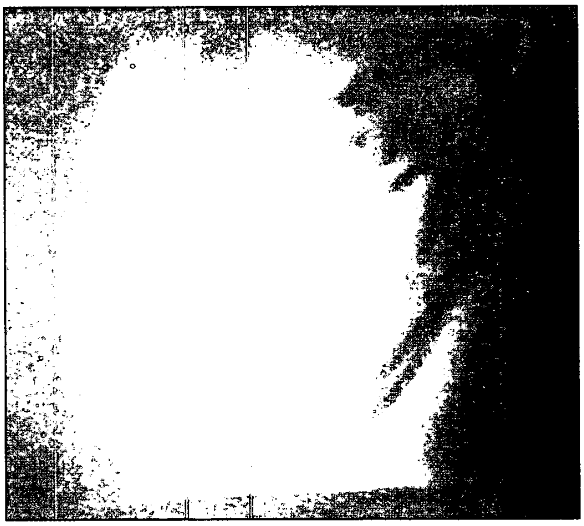
RGB primary colors. But, the exposure of this plate is very long in contrast to that of a general film or plate for monochromatic holography.

Fig.7 demonstrates the result of three reconstructed color images. The image is reconstructed from the monochromatic hologram by using He-Cd^+ laser. Note that the monochromatic hologram is recorded with the red light component of the He-Cd^+ laser. In Fig.7(c), the visual appearance of the reconstructed image becomes bad owing to the cross talk caused by a combination of three different wavelengths of the He-Cd^+ laser.

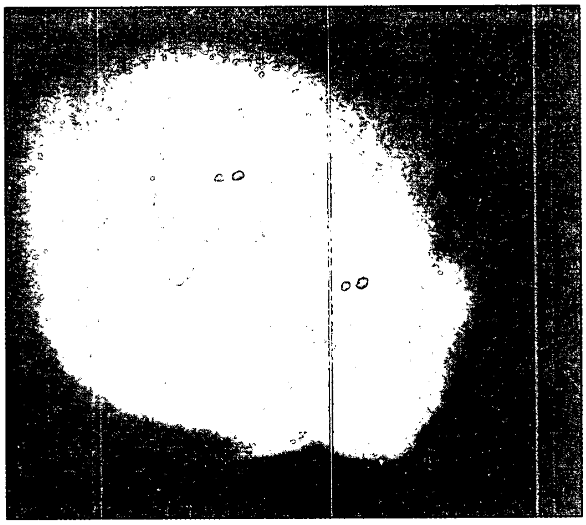
Fig.8 demonstrates the results of 3-D original color object and reconstructed color images after the computer process of the output of a digital still camera. In this case, it should be noted that the three color holograms are independently recorded by the use of three hologram plates and three R, G, and B primary colors separated from the He-Cd^+ laser. There is no problem on the cross talk, because a combination of three wavelengths is not used in the reconstruction process.



(a) Original image



(b) Red image : $\theta=45^\circ$



(c) Green image : $\theta=60^\circ$

(d) Blue image : $\theta=60^\circ$

Fig. 8 Original image and comparison of three color images reconstructed by uisng He-Cd$^+$ laser

4. Discussions

We have a lot of problems on color holography techniques [8]. First, an optical setup and its suitable arrangement must be considered together with a combination of the coherent laser light or a separation of RGB primary colors in advance.

Second, it is very important to clear up the characteristics of the practical recording materials for recording the color hologram and chemical photographic process. Generally, a silver halide recording film or plate demands a special chemical developing material. We can not easily obtain dichromated gelation, photo-resists, photo-polymers, photo-thermoplastics, photo-refractive materials, etc. in Japan. Many recording materials are not commercially available at present and inexpensive from the viewpoint of the wide spread of color holography. The ideal recording materials for color holography should have a spectral sensitivity well matched to an available laser wavelength, and a high resolution with 2000～3000 [lines/mm]. In addition, they should be

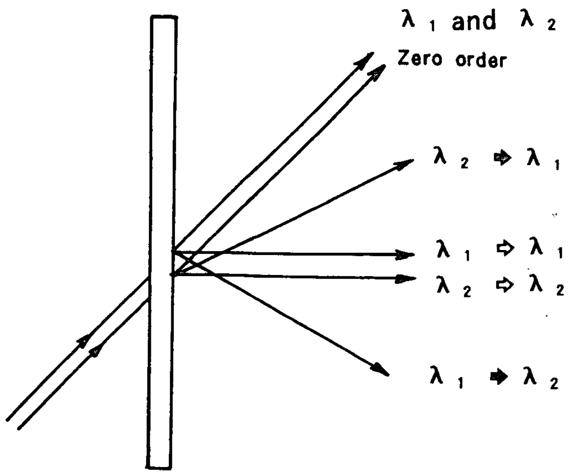


Fig. 9 Aspect of reconstructed (or diffracted) beams from a two-color hologram

indefinitely recyclable or reused in practice. The silver halide materials for color holography, i.e., 749 F (USA), BB-PAN (Germany), Holotrend PFG-03 C (Russia) are useful now. But, the exposure time of the silver halide materials for color hologram is very long in contrast to that of a monochromatic hologram. It is troublesome to perform the chemical process by using a lot of combination of chemicals. Because of the relatively low diffraction efficiency of the amplitude holograms, general holograms are often processed to yield the phase holograms, which have much higher diffraction efficiency by the use of bleach techniques.

Last, we must solve the cross talk problems of color holography as a matter of the practical principle, i.e., color holograms for 3-D displays. In order to overcome the above drawbacks, the rainbow hologram, image hologram, Lippmann hologram, etc. have been studied and developed in place of the conventional color holography techniques [9].

Fig.9 shows the aspects of reconstructed or diffracted beams from a two-color hologram. Four types of color images diffracted by two kinds of wavelengths : λ_1 and λ_2 are demonstrated as $\lambda_2 \rightarrow \lambda_1$, $\lambda_1 \Rightarrow \lambda_1$, $\lambda_2 \Rightarrow \lambda_2$, $\lambda_1 \rightarrow \lambda_2$, respectively. For example, the symbol "$\lambda_1 \rightarrow \lambda_2$" stands for the occurrence of the beam : λ_2 diffracted by using the incident beam : λ_1 in the case of reconstruction process of two-color hologram. In this case, two different types of the cross talk images are inevitably produced owing to the symbol : $\lambda_1 \rightarrow \lambda_2$ and $\lambda_2 \rightarrow \lambda_1$. In general, a K beam hologram produces the K^2 images in the case of the reconstruction process. The K^2-K images are undesirable. A three-color hologram after the multiple exposure of three times would produce nine images simultaneously, out of which six would be unwanted. As a result, an observer sees a combination of the reconstructed color images with much deterioration.

5. Conclusions

It is possible to record the red component hologram with a He-Ne laser or a He-Cd^+ laser after the separation of RGB primary colors, while the green and blue component holograms are obtained by using the He-Cd$^+$ laser in place of an Ar$^+$ laser.

It is very difficult to carry out the practical reconstruction of multicolor images without the crosstalk, whenever a set of color holograms containing three RGB components is recorded in principle.

Hereafter, we would like to carry out an another approach, i.e., an idea of multicolor rainbow hologram or Lippmann hologram. These special holograms are built up from the independent exposures on two different films or plates.

The quasi-color images will be easily demonstrated from the specific hologram by means of the white light such as an incandescent lamp or a halogen lamp.

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