From Art to Engineering

Sarah O'Hana[1*], Andrew J Pinkerton[2], Kalsang Shoba[3]
** Corresponding author*
[1]Laser Processing Research Centre,
School of Mechanical, Aerospace and Civil Engineering
The University of Manchester
Sackville Street Building, PO Box 88, Manchester, M60 1QD
United Kingdom.
E-mail: Sarah.O'hana@postgrad.manchester.ac.uk

[2]Laser Processing Research Centre,
School of Mechanical, Aerospace and Civil Engineering
The University of Manchester
Sackville Street Building, PO Box 88, Manchester, M60 1QD
United Kingdom.
E-mail: andrew.pinkerton@manchester.ac.uk

[3]TheVirtualCompany
City College Manchester
Whitworth Street
Manchester M1 3HB
United Kingdom
E-mail: kalsang@thevirtualcompany.co.uk

Abstract

This paper describes work which emerged through a need to understand more about the potential of laser surface engineering for use in the creative industries. The method of creation of contemporary jewellery pieces and the resultant 'Ocular' jewellery series are described from the points of view of an artist and an engineer. The work demonstrates how laser controlled oxide growth on commercially pure titanium under ambient conditions can be used as an artistic tool by producing even, defined colours or by reproducing a simulation of freehand drawings on a titanium surface. It also asks the question: how different are artists from scientists and engineers?

Keywords: jewellery, art, laser, titanium oxide

1. Introduction

The nature of an artist is one of enquiry and investigation. By continually looking for answers to the self-inflicted problems of design and execution, they experiment with and exploit the materials until they yield into place [1]. The search continues as outcomes often prove unsatisfactory. An extraordinary understanding of materials through years of research is gained in this way, making applied artists heavily responsible for the direct implementation of this knowledge. The accumulated material knowledge is applied together with much underrated practical expertise to create three-dimensional artefacts with awesome results [2]. <1st author>

The nature of a (research) engineer or scientist is one of seeking to understand and advance in a never ending cycle. Analysis is one dimension of their work, but the creation of a new process, protein, part, assembly, building, mathematical model or any other advancement all requires engineers and scientists to think beyond the purely analytical. For example, a turbine engine requires immense amounts of testing, analysis and painstaking assembly down to the tiniest detail, but who would argue that Frank Whittle and other pioneers of this technology were not men or extraordinary creativity and imagination? [3]. <2nd author>

It is easy to make superficial generalisations about either culture, but the lateral thought process that artists are renowned for is quite often the gateway that opens new territory and applications for emerging technologies. The work of Lynne Murray RCA with rapid prototyping [8] is a good example of this. A language that can be understood by the non-expert [4] helps to demystify the technology by bringing inside information out to new audiences, encouraging hybrid practices that can be extraordinary fruitful [5].

The work carried out in this research uses this dialogue and laser technology to create artefacts that prove the success of the art / engineering and art / science partnerships. Currently, it is rare to have this symbiotic state emerge as jewellery; far more common are the links made to science with fine art, photography and digital art [6,7].

2. Artistic and Scientific Techniques

2.1. Artistic Perspective

2.1.1 Background

The first author and contemporary jewellery artist Sarah O'Hana. has specialised in the promotion, support and implementation of new digital technologies, in particular laser processing, for the applied arts in the North West, UK. After initiating the only Professional Development Qualification (PDQ) that addressed these issues in the UK, she curated the resulting exhibition of 14 artists called In the Making [9], launched in the headquarters of Foment de les Arts Decoratives (FAD), Barcelona. This groundbreaking exhibition and resulting round table discussion 'Iniciatives de recolzament i projecció per a joves artistes i dissenyadors' caused the current research to be carried out into laser processing for the creative industries at The University of Manchester.

Jewellery and objects in response to this research are predominantly made with laser coloured titanium surfaces. They have been exhibited at Heirlooms (St Botolphs Church, London) [10] as part of the Association for Contemporary Jewellery's (ACJ) conference of "Carry the Can" in London, July 2006. Recent work will be shown at Walking with Scientists in The Museum of Manchester, UK [11], 30th June – 2nd September 2007. Jewellery is unique within the design and visual arts in its demand to be 'finished' as a predominantly wearable art form; skill and ability in the making are important, even if the final aesthetic is chosen to be 'rough' or 'unfinished'. Observation of the everyday affects the final work. Engineering components, conversations with scientists or engineers, experiments by other researchers and the whole environment of life in the laboratory works its way, often subconsciously, into the design process.

2.1.2 Current Work

The finished series of three-dimensional work described in this paper is the Ocular Series 1-6. This series is based on the aesthetic of optical measuring equipment and relates to concepts of vision: 'seeing the bigger picture', 'clouded vision', 'seeing through tinted glasses', 'blurred vision'.... all expressions used in the English language that are linked to the problems of not seeing correctly because of an impediment, be it physical or psychological. Background research was done for this work in the area of optometry and the measuring systems that exist there in order to understand the process of eyesight correction which is also linked to a personal lifelong condition of hyperopia and astigmatism. Trays of optician's trial lenses including prisms and frames were acquired with the intention of creating a range of work based on seeing, observing, peering and clarifying vision. This is an analogy for the deficient situation existing between art and engineering that appears short sighted despite the current popular discussions that, interestingly, are usually initiated by the art and design culture.

The pieces include some unique features including fingerprints, marked by laser onto the acrylic portions of the pieces. These were included to add a dimension that simulates the reduction of distance between artist and workpiece, a concern rising from the increased use of digital technology that drives the laser.

Direct contact with material is important for the understanding of its properties [12], and drawing has become a prime ingredient that helps balance the regular shapes that appear on some pieces. In the attempt to render the technology transparent a more direct 'freehand' approach to laser processing is called for. Drawing is understanding and helps feed creativity. The link between drawing and making within the jewellery practice is perhaps obvious, although not always linear or calculated.

2.2. Engineering Perspective

In order to meet the requirements for the series is was necessary to be able to produce defined colours and recreate hand drawn shapes to predefined geometries on both sides of pieces of commercial titanium.

2.2.1 Background

Traditionally, a spectrum of colours can be achieved on titanium either by applying heat using traditional methods such as gas torches or more commonly by electrolytic oxidation (anodising). A titanium workpiece is immersed in an electrolytic solution as an anode and current is drawn. Oxygen generated at the anodic surface then combines with the titanium to form titanium oxide. As the oxide thickens it increasingly acts as an electrical insulator between the electrolyte and the anode until the point where there are too few OH- ions available to support further growth, The oxide thickness at which this occurs is primarily a function of the applied voltage but there have been a large number of studies on the properties of the oxide films [13-16], which have showed that the composition and microstructure of the anodic oxides are also strongly dependent on other factors such as electrolyte concentration, temperature and anodic surface conditions [17]. This means there are a lot of variables to control for an artist. Additionally the technique requires a high power supply and hazardous electrolytic bath and masking is difficult especially when detailed two-sided parts are to be created, as in this case.

The surface appearance of the workpiece after anodizing is due to the formation of a titanium oxide layer. Interference between light reflecting from the surfaces of the metal and oxide coating can be constructive or destructive as particular wavelengths depending on the oxide film thickness, meaning the frequencies of light reflected become a function of that thickness [16]. The oxide films grown on reactive metals in general have a higher refractive index than diamond which accounts for the brilliance of the colours seen.

Langdale et al [18] treated commercially pure titanium with a pulsed Nd:YAG laser (2-17 kHz frequency, 2-50 mm/s traverse speed) in ambient air. The authors found a range of titanium oxides and concluded that although the layer thickness may have an effect, the different colours they observed corresponded to different titanium oxides. A similar study by Perez del Pino et al [19] (Nd:YAG laser, 30 kHz frequency, 56.7 W mean power, 25-300 mm/s) confirmed these results; additionally a greater range of oxides was found to form at higher specific energies. However, a later study by the same authors [20], comparing the colours obtained from anodizing and laser treating titanium, concluded that light interference phenomena within an upper TiO_2 surface layer were the mechanism in both cases. The additional oxides created during laser treatment were said to be part of a deeper layer which was not significant for appearance. Carey et al

[21] drew attention to the potential of lasers in the Jewellery industry, but Bartlett noted the unpredictability of the evenness of colours developed in this way, attributing it to 'flower oxides' [17].

2.2.2 Current Work

The base material was commercially pure titanium plate; it was initially cut into the required shape for the final piece using a 35W Nd:YAG laser (100ns, 680mJ pulses at 20Hz pulse frequency) with argon gas shroud. The shaped piece was then placed on a honeycombed bed and a Universal X-660 Laser Platform fitted with a pulsed 60W CO_2 laser used to treat the surface. This free-standing unit comprises the laser, an X-Y beam positioning system with 0.81 × 0.46 m work area, interchangeable focussing optics and computer interface. The laser beam was focussed by a 2.0" (50mm) focal length lens in an enclosed lens cartridge to a spot of diameter 0.15 mm at the workpiece. The pulse frequency was varied in proportion to speed in order to maintain a constant spatial distribution of pulses on the surface; for this work it was set at 1000 pulses / dots per inch.

In order for artistic designs to be created on the workpiece by the system two different control methods were used.

- Where an area of even, predefined colour was required, the laser scanning parameters and area were pre-programmed with the help of Adobe Illustrator and Corel Draw software packages. A series of parallel beam traces performed in a raster pattern on the required area in ambient air was then used to form a titanium oxide film on the surface. The relationship between the laser parameters and final colour were obtained through experience. Existing literature in the field can provide a guide but many factors are difficult to predict. For example the specific energy parameters used by Pérez del Pino et al [19,20]and Fedenev et al [22] to produce comparable results differed by orders of magnitude because of different surface absorptivity, heat conduction at the workpiece and other effects pointed out by Fedenev et al.
- Where rapidly varying colour was required, the same CO_2 laser was driven by a bitmap obtained from a digital graphics package such or scanned drawing. The intensity of laser flux delivered to the workpiece surface at each position was based on the bitmap. The resulting marks on the titanium surface replicated the original drawing and appeared to have been applied by hand quite spontaneously. The exact colours obtained were however less predictable than those obtained by the former method.

After completion of a part, surfaces were tested by non-destructive methods. The samples were photographed under natural light using a Canon EOS digital camera set to maximum resolution. Images with no colour correction were transferred directly to microcomputer and treated areas analysed using Adobe Photoshop software for colour balance. This is a considerably simpler method of characterising the surface appearance than the spectrophotometry-based techniques used by previous researchers, but as the relationship between visible appearance and TiO_2 layer thickness is now well established [20,23] it was not necessary to repeat that analysis. The surface produced by one set of laser parameters was also tested for phase composition with a Phillips X-Pert MPD diffractometer using Cu Kα radiation (λ = 1.54 A) measuring using a thin film method. The incidence angle was approximately 0.7°.

3. Results and Discussion

3.1. Artistic Perspective

Figure 1 shows Ocular no 5. This object was made with the intention to hold rather than wear. Thumb and index finger prints of the author's have been marked onto acrylic holding points, directly informing the viewer about where to hold the piece. The lens, reclaimed from a camera, distorts the vision. The colours and order of the pattern applied are the author's aesthetic choice which are based, as all this work, on the original experiments done by CO2 laser on the titanium. Figure 2 shows the laser process parameters used to produce the upper and lower surfaces of this piece.

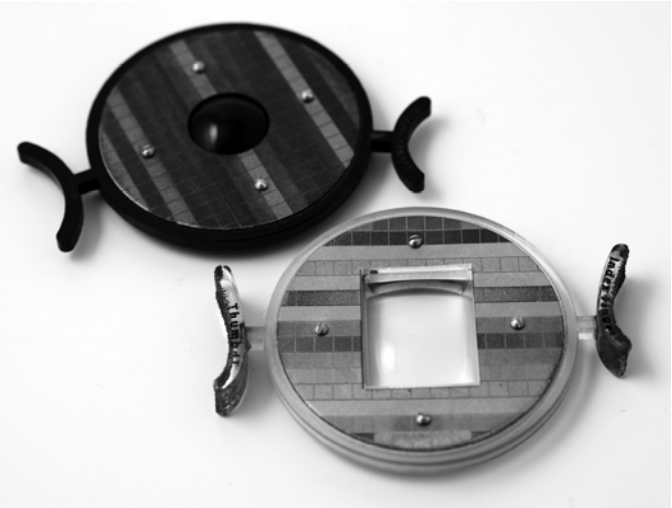
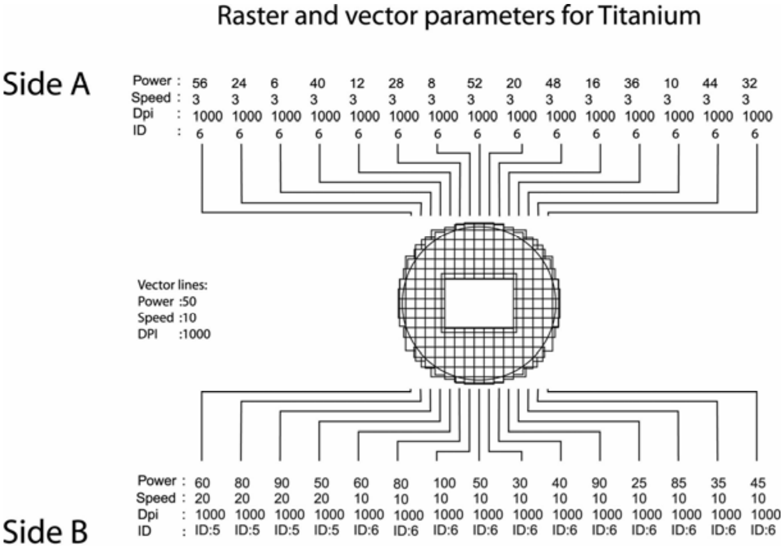


Figure 1: Ocular no. 5. The colour visible on the titanium is controlled by different laser parameters shown in Figure 2



Side A

Power :	56	24	6	40	12	28	8	52	20	48	16	36	10	44	32
Speed :	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Dpi :	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
ID :	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

Side B

Power :	60	80	90	50	60	80	100	50	30	40	90	25	85	35	45
Speed :	20	20	20	20	10	10	10	10	10	10	10	10	10	10	10
Dpi :	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
ID :	ID:5	ID:5	ID:5	ID:5	ID:6	ID:6	ID:6	ID:6	ID:6	ID:6	ID:6	ID:6	ID:6	ID:6	ID:6

Figure 2: Laser parameters for Ocular Series no. 5. (power and speed are given as a % of the maximums of 60 W and mm/s repectively)

Figure 3 shows Ocular 2, containing a square lens. The author's thumbprints and other fingerprints are an important feature of this piece. Prints were taken using indelible ink then scanned. Various techniques in Photoshop were then used to manipulate the resulting image with added text in layers that were sent through to the laser for marking in different stages. The position of the fingerprints indicates the manner in which the viewer should hold the piece to look through the lens which has also been recovered from a camera and greatly distorts the view.

Figure 3: Ocular Series no. 2. The colour visible on the titanium is controlled by different laser parameters shown in Figure 2

Figure 4 shows Ocular 3, with chain and random marking. The design for this piece is grounded in the aesthetic of instruments used for optical measuring as well as in a fundamental need to get away from the predictable digital appearance of laser processed work. For this reason the marks are taken directly from original drawings which were scanned into digital form (Figure 5). This is an important strand of on-going practice as it is essential to understand form, shape and colour. For a maker of objects this is logical although the link between drawing and making is obvious but not always straightforward and linear. The simultaneous advance of the multi-stranded animal that is art practice is in constant evolution. It is a question of harnessing the resulting energy into considered shape and form.

Figure 4: Ocular Series no 3. Titanium marked on the basis of the bitmap file shown in Figure 5

Figure 5: Drawing converted to bitmap for control of laser surface oxidation of titanium

3.2. Engineering Perspective

The range of colours created on the titanium surface in Ocular mo. 5 were analysed as described in section 2.1. Results of the optical analysis are shown in Tables 1 (constant speed, variable power) and Table 2 (variable speed, constant power).

Table 1. Laser treated titanium surfaces – parameters and effects at constant traverse speed

Mean power (W)	Speed (mm/s)	Colour	R	G	B	TiO_2 depth (nm) *$_*$
10	30	Golden	137	102	64	35
20	30	Deep blue	28	45	71	60
30	30	Green-blue	81	109	110	80
40	30	Pale green	124	130	118	95
50	30	Pink-brown	132	119	111	130
60	30	Brown	84	81	72	190

*by matching colours to the results of [20,23]

Table 2. Laser treated titanium surfaces – parameters and effects at constant laser power

Mean power (W)	Speed (mm/s)	Colour	R	G	B	TiO_2 depth (nm) *$_*$
100	10	Grey	70	89	96	200+
100	30	Brown-Grey	62	61	56	190
100	50	Dull green-red	110	95	88	180
100	80	Pink-brown	114	116	94	130
100	100	Mid green	82	89	81	100
100	150	Blue-green	34	52	62	70

*by matching colours to the results of [20,23]

Figure 6 shows the results obtained from grazing incidence X-ray diffraction analysis of the surface treated at 60 W and 100 mm/s and appearing dull green in colour. The four significant phases highlighted were hexagonal α-Ti, cubic TiO, tetragonal rutile TiO_2 and hexagonal Ti_2O titanium oxides. The reference peak positions of these phases are shown on separate spectra for clarity.

Peaks corresponding to the underlying α-Ti are very strong, evidencing the very thin nature of the surface layer that had developed. They also provide an almost perfect match to reference angles of diffraction giving good confidence in the accuracy of the measurements. There is evidence for the presence of TiO, although as can be seen from Figure 6(b), the diffraction peaks are smaller than the reference values by increasing amounts on moving from left to right. This indicates a slightly larger lattice parameter than expected which could have been caused by a gradual transition between phases. Indeed, it can be seen that a number of the peaks are quite broad which can be indication of a graded phase structure.

Rutile TiO_2, which is normally obtained at high temperatures such as $800^{\circ}C$, and held by most authors to be responsible for the interference colours seen on the surfaces is clearly present. Gyorgy et al [24] concluded that during pulsed (300 ns) Nd:YAG laser irradiation of Ti under ambient conditions, oxidation proceeds from TiO present in the early stage of the irradiation, through Ti_2O_3, until the formation of the TiO_2 rutile phase at high number of pulses. In this case each part of the surface received only 6 pulses (1000 dpi surface coverage, spot diameter 0.15 mm) so it is likely another mechanism was responsible for this phase. No Ti_2O_3 or anatase TiO_2 was detected in this investigation.

The third oxide found was the hexagonal Ti_2O titanium oxide. This is of the same lattice structure as the underlying α-Ti and probably formed lower in the surface layer, partly integrated with it. In all the XRD results are in agreement with the theory of a graded surface layer progressing from an outer layer of TiO_2 to lower layers of more Ti rich oxides [20].

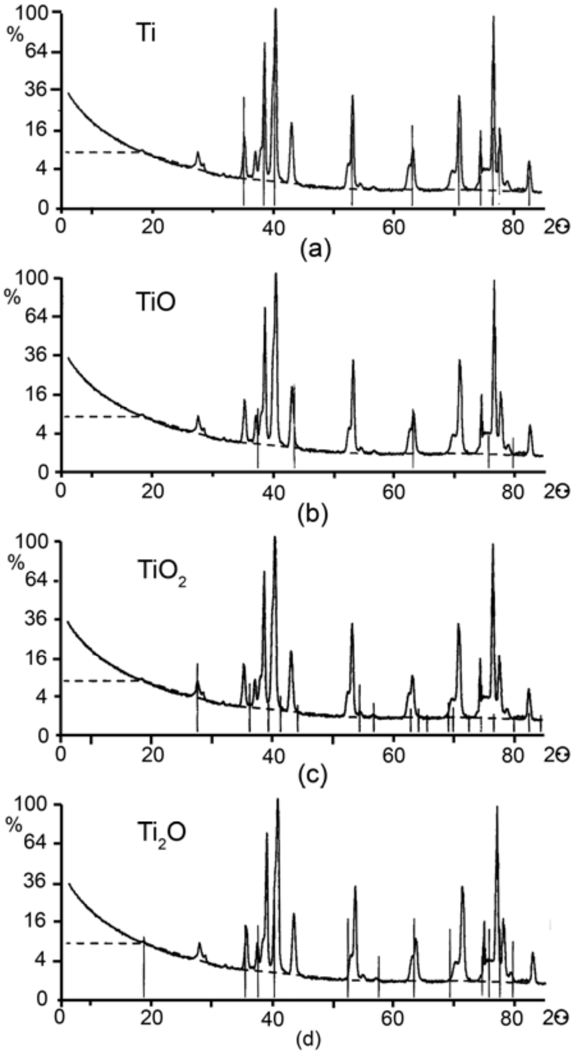


Figure 6: Grazing incidence X-ray diffraction spectrum from the surface of a laser treated titanium sample (60 W, 100 mm/s)

4. Conclusion

A moderate power (60 W), pulsed CO_2 laser directed via an X-Y beam positioning system within an integrated system and interfaced with commercial graphics software has been found a very efficient tool for creation of controlled and even areas of colour and of designs that appear spontaneous on the surface of commercial purity Titanium plate. Rutile nitrogen oxide, TiO_2, usually considered to form an outer surface layer and be responsible for interference colours, plus TiO and Ti_2O titanium oxides were detected on the surface. Results are consistent with the theory of a graded surface layer progressing from an outer layer of TiO_2 to lower layers of more Ti rich oxides.

The artefacts shown in this paper are an illustration of how the tools and techniques used by researchers in science and engineering can be adopted by the creative industries. The exhibition at The Manchester

Museum that this paper accompanies is also a demonstration of how art can help the public understanding of a particular discipline that can seem remote and alien. An alloy of two different cultures has been reached by mutual collaboration, demonstrating how both stand to gain much from each other.

5. Acknowledgement

The authors would like to thank Professors Andrew Gale and Lin Li of the School of Mechanical, Aerospace and Civil Engineering at The University of Manchester for support throughout this project and for providing facilities for the work. Thanks also to Manchester Material Science Centre, specifically Judith Shackleton and Richard Moat, for assistance with X-ray diffraction analysis and useful discussions on the results and to Dr Marc Schmidt of The Laser Processing Research Centre for assistance with laser cutting of samples.

6. References

[1] O'Hana, S. (2003) ¡Ojo! An exhibition of Spanish Contemporary Jewellery. pp.19

[2] Cheung, L., Clarke, B., Clarke, I. (2006) New Directions in jewellery II. Black Dog Publishing.

[3] Golley J, 1997, Genesis of the Jet: Frank Whittle and the Invention of the Jet Engine, Crowood Press

[4] Broers, A. (2005) The Triumph of Technology, Reith lectures, BBC Radio 4

[5] Coode-Adams, B. (2005) Cross Pollination. Artists Newsletter. June. Pp 18-19

[6] Kemp, M. (2005) From science in art to the art of science. *Nature*. Vol. 434, pp 308 – 309

[7] Reidy, H, Art of steel, (re Antony Gormley), *Professional Engineering* 20(10), PE Publishing, London.

[8] Murray L K, 2007, Pavement Schmuck, *Proceedings of the Inside Out:11th Ars Ornata Europeana symposium*, Manchester, UK.

[9] Grainger J, O'Hana S, Hare-Duke B, Rose N and Gaspar M, 2003, In The Making Foment de les Arts Decoratives, Convent dels Angels, Barcelona.

[10] Callinicos E, 2006, Heirlooms, an exhibition of rings, St. Botolphs. London. Buckinghamshire Chilterns University College.

[11] O'Hana S, Shoba K, Gale A W and Bond B, 2007, Walking with Scientists. Between Two Cultures: A dialogue in Jewellery, The Museum of Manchester, Manchester, UK.

[12] McCullough M, 1998, Abstracting Craft: The Practiced Digital Hand, The MIT Press.

[13] Armstrong N R and Quinn R K, 1977, Auger and X-Ray Photoelectron Spectroscopic and Electrochemical Characterization of Titanium Thin-Film Electrodes, *Surface Science* 67(2), 451-468.

[14] Lausmaa J, Kasemo B, Mattsson H and Odelius H, 1990, Multitechnique Surface Characterization of Oxide-Films on Electropolished and Anodically Oxidized Titanium, *Applied Surface Science* 45(3), 189-200.

[15] Delplancke J L and Winand R, 1988, Galvanostatic Anodization of Titanium .1. Structures and Compositions of the Anodic Films, *Electrochimica Acta* 33(11), 1539-1549.

[16] Sharma A K, 1992, Anodizing Titanium for Space Applications, *Thin Solid Films* 208(1), 48-54.

[17] Bartlett L, 2006, An unusual phenomenon observed when anodising CP titanium to produce coloured surfaces for jewellery and other decorative uses, *Optics and Laser Technology* 38(4-6), 440-444.

[18] Langlade C, Vannes A B, Krafft J M and Martin J R, 1998, Surface modification and tribological behaviour of titanium and titanium alloys after YAG-laser treatments, *Surface & Coatings Technology* 101(1-3), 383-387.

[19] Pérez del Pino A, Serra P and Morenza J L, 2002, Coloring of titanium by pulsed laser processing in air, *Thin Solid Films* 415(1-2), 201-205.

[20] Perez del Pino A, Fernandez-Pradas J M, Serra P and Morenza J L, 2004, Coloring of titanium through laser oxidation: comparative study with anodizing, *Surface & Coatings Technology* 187(1), 106-112.

[21] Carey A M, Steen W M and Watkins D, 1998, Laser Surface Ornamentation, International Conference on Applications of Lasers and Electro-Optics (ICALEO), LIA, Orlando.

[22] Fedenev A V, Alekseev S B, Orlovskii V M, Tarasenko V F, Tkachev A N, Shulepov M A and Yakovlenko S I, 2003, Oxidation of titanium surface under laser irradiation, *Proceedings of the Proceedings of SPIE - The International Society for Optical Engineering*, Wroclaw, Poland, 713-716.

[23] Goldsmiths, 1984, Coloured Refractory Metals for Jewellery, Issue 11, The Worshipful Company of Goldsmiths, London.

[24] Gyorgy E, Del Pino A P, Serra P and Morenza J L, 2004, Structure formation on titanium during oxidation induced by cumulative pulsed Nd:YAG laser irradiation, *Applied Physics A (Materials Science Processing)* A78(5), 765-70.