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Electrical Colour – The Impact of Anodising on the Early Use of Titanium and Aluminium by Studio Jewellers

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Colour features strongly in her work. Her practice involves continual experimentation, developing new techniques for producing pattern on titanium and working with knowledge of the behaviour of the metal derived from her PhD research completed at the University of the Arts, London (2010).

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Front cover:

Sculpture by Lynne Bartlett 2011, commissioned by the Materials Department at Imperial College, London in honour of the late Professor Harvey Flower, anodised titanium tubes (39cm in length) in an acrylic frame.
Aluminium spiral cuffs. Jane Adam, 1999. Photo by Joel Degen.

Electrical Colour – The Impact of Anodising on the Early Use of Titanium and Aluminium by Studio Jewellers

LYNNE BARTLETT

The introduction in the twentieth century of the colourable-metals , titanium and aluminium, significantly expanded the possibilities for jewellery design which were enthusiastically exploited by the growing band of studio jewellers in both Europe and the USA.

In particular the availability of increased volumes of titanium led to collaboration in the UK between industry and academia and Ann Marie Shillito produced the first piece of designed titanium jewellery at Birmingham in 1967.

Both titanium and aluminium owe their colourability to the creation of a durable oxide surface by anodization. The anodising process operates differently for each metal with direct colour created by interference on titanium while for aluminium a porous surface is produced which can then be decorated in an infinite variety of ways as demonstrated by Jane Adam.

This article outlines the history of the use of titanium and aluminium and their establishment as regular materials for creative jewellery design.

Introduction

In early societies 'found' objects such as shells, seeds, feathers and coloured stones were used as adornment and examples have been found dating back to 75,000 BC in South Africa (Vanhaeren et al. 2013: 500).While such diverse materials have been used and continue to have a place in jewellery design, metals have played a central role both for their own properties and as frameworks for construction of wearable jewels. The precious metals, gold and silver and their copper alloy simulants have been wrought and cast into wires and sheet forms, embellished by engraving, chasing and repoussé to produce ornamented surfaces, but the colour palette of metals is limited to white, yellow and red. The majority of metals, including the established jewellery metals such as silver, platinum and palladium are white. Gold is the only yellow metal and although it can be alloyed to give white, green and red shades these are subtle variations. Copper is the only elemental red metal but it has mostly been used in alloyed variations such as bronze or brass to imitate gold. Other colours in design, for example blue, purple and green, are supplied by additional components. A brief survey of the use of colour in jewellery (Bartlett 2017:55) outlines many of these materials from diverse historical and geographical locations. The most commonly used are gemstones and vitreous enamels but the range also includes various natural or manmade substances including glass, wood, ceramics and plastics.

The colour range for design using metals was transformed by the introduction to jewellers in the mid-twentieth century of two new metals, titanium and aluminium. Both are silvery lightweight metals and each permit, using diverse techniques, the design of multicoloured durable patterned surfaces giving jewellery makers a completely new design approach.

This paper comments briefly on the discovery, early extraction and properties of these metals and their paths to their current positions as standard jewellery metals. Both elements are widely distributed in the forms of their oxides and other compounds but were not isolated as pure metals for many decades after their discovery.

The emerging studio jewellery sector in America and Britain in the post war decades was greatly expanded and encouraged by changes in the training and education of individual jewellers, providing a fertile ground for the exploitation of new metals. The expansion of the design scope due to the introduction of titanium and aluminium and the associated nineteenth century technical process innovation of anodising is discussed. Major emphasis is placed on the introduction and development of the use of titanium, which was first used for designed jewellery in Britain and contrasted with the use of aluminium: two women designers, Ann Marie Shillito and Jane Adam, played important roles in the exploitation and early use of these new jewellery materials. The paper concludes that both metals are now acknowledged in all sectors of jewellery manufacture as standard metals.

Titanium

History of discovery and early manufacture

Although the existence of titanium was established in the late eighteenth century it was not isolated as a pure metal until the early twentieth century. In 1791 William Gregor, a Cornish cleric and amateur mineralogist, published his discovery of the presence of the oxide of an unknown metal, which he called *menaccanite*, during his experiments on the black beach sands of Cornwall (*ilmenite*). In 1795 Martin Heinrich Klaproth, a German chemist, isolated a similar oxide from 'red schorl' (*rutile*) from Hungary. He acknowledged Gregor's prior discovery but named the new metal element present in the oxide, titanium:

> Wherefore no name can be found for a new fossil [element] which indicates its peculiar and characteristic properties, in which position I find myself at present, I think it is best to choose such a denomination as means nothing of itself and this can give no rise to any erroneous ideas. In consequence of this, as I did in the case of uranium, I shall borrow the name for this metallic substance from mythology, and in particular from the Titans, the first sons of the earth. I therefore call this metallic genus, titanium. (Barksdale 1966)

Over 100 years later, in 1910, M.A. Hunter, working for General Electric in the United States of America isolated the pure metal (McQuillan 1956) but an industrial process for its production was not developed until 1932 in Austria by Dr Wilhelm Kroll.

Titanium may have remained an interesting curiosity for metallurgists had not the metal's unique combination of properties, light weight and high strength been needed by the United States aerospace programme in the 1950s. The huge technical and financial resources required to produce significant volumes of the new metal were made available by the potential foreseen for its application in the highly technically demanding and expanding aerospace industry. Such concentrated, focused effort meant that production of titanium was scaled up from laboratory sample to commercial production, at a rate of *ca* 1000 tons/annum, in less than ten years (Clapham 1957: 84). This compares with the new metal of the nineteenth century, aluminium, which took fifty years to reach the same level of development, and iron and steel, which have been in continuous development for centuries.

The British manufacturer of titanium from the 1950s was Imperial Metal Industries (IMI), the metals division of Imperial Chemical Industries (ICI), and the excitement created in the scientific industry by the introduction of a metal with the toughness of steel and the light weight of aluminium is exemplified by the numerous articles about titanium published in its house journal:

> Until a few years ago few people had even seen it; it is not yet a common metallurgical commodity, and few metallurgists have experience of it or know much about it. This, therefore, is the justification for referring to it as a new metal, which it is, inasmuch as we are just now witnessing its industrial birth. (Cook 1954:2)

The cancellation of the American aerospace programme and consequent drop in demand in 1958 caused a significant fall in price (Lippert 1970:6). Large volumes of titanium became available for new markets and the chemical and other process industries were able to capitalise on the corrosion resistant behaviour of the metal that had been noted in the laboratory.

Fig. 1.
Titanium sponge set in silver pendant, 1963, Malcolm Green, Collection of Worshipful Company of Goldsmiths.

These applications were so successful that by 1977 about half the titanium produced was used in non-aerospace industrial engineering applications. The metal went from curiosity to commodity in ten years but has subsequently suffered a cyclical demand pattern common to many metals.

Titanium is a very reactive metal and combines with elements in the atmosphere, such as oxygen and nitrogen immediately the surface is exposed to air. The seeming paradox of a reactive metal being used as a corrosion-resistant element is explained by the fact that a thin protective oxide layer forms on the surface of the metal within minutes of its production, unless it is in an inert atmosphere such as that of argon gas. Surface oxides on titanium exhibit a wide range of colours and, as colour has always fascinated the artist, undoubtedly the colour exhibited by oxidised titanium was attractive to jewellers.

There is anecdotal evidence to suggest that simple pins and earrings had been fabricated by workers in titanium plants from the early days of its manufacture. An example, in a more sophisticated setting, is the silver pendant by Malcolm Green, hallmarked 1963, set with titanium sponge in the collection of the Worshipful Company of Goldsmiths (fig. 1).

The late isolation and exploitation of titanium, as described above, could be taken as an indication that it is a rare element but this is not so. Titanium is relatively abundant at 0.6 % of the earth's crust and it is also present in the atmosphere of the sun and in interstellar space. It is the ninth most common element and the fourth commonest metal after aluminium, iron and magnesium. However titanium is very reactive and, unlike gold, silver, copper and iron, is never found as a pure metal. This very reactivity is why it is so difficult to isolate and process as a pure metal. Even today a modified Kroll method is used which makes production relatively slow and expensive. Much effort has been expended to develop a continuous process, without success.

Introduction to Jewellers

The initiative for the use of titanium as a medium for jewellery manufacture came from industry in Britain. It is unusual for an industrial company to be responsible for the development of a completely new jewellery material and its processing but this is what happened in the case of titanium.

As part of the IMI research effort based at Witton near Birmingham, UK, J.B. Cotton had a large team working on the new metal (fig. 2). Or rather as one of the team members, Peter Hayfield, said '… playing with the possibilities of titanium'. Cotton published several papers on metal colour and in particular the potential of titanium (Cotton 1958:68).

Gerald Whiles, one of the tutors at the nearby School of Jewellery in Birmingham, recalls being approached by Cotton in 1963 with the idea that titanium would be an interesting material for the students to explore (Hunt 1990). A group of silversmithing students visited IMI and were given samples of titanium sheet, wire and tube (fig. 3). The technical staff at IMI provided advice on process techniques, including colouring by anodising. All the metal forming techniques were tried including some, such as forging, that the technicians at IMI thought would be difficult or dangerous. Observing the exciting experiments by the silversmiths, the jewellery design students, one of whom was Ann Marie Shillito, asked to be included in the project (Bartlett 2009:16): the belt buckle (fig. 4) that she made in 1967 is the earliest designed piece of titanium jewellery to have been identified. The buckle was milled and pierced from a thick sheet of metal and coloured by anodising.

While it is probable that industry hoped for high-value, volume outlets it was in the sphere of studio jewellery that titanium made its initial impact. Studio jewellers, working from independent workshops, producing unique pieces or limited editions, are one of the categories of jewellery manufacture in Britain described by Janice West:

> There are four general categories of jewellery. The most precious, often commissioned is referred to as fine jewellery; studio or contemporary jewellery has been the area of avant-garde developments and experimentation; high-street jewellery, which at best tends to consist of watered-down versions of fine jewellery, usually silver or low-carat gold; the fourth category might be described as unwearable wearables and is perhaps more an idea about jewellery than jewellery as such. These works rarely exist outside galleries and museums.
> (West 1998:10)

To understand the impact made by the arrival of a new metal in a largely traditional craft area it is important to appreciate the conditions of the jewellery industry in Britain at the time. Most of the jewellery manufacturing facilities had been adapted for the production of strategic engineering parts during the Second World War and thus there was a hiatus in jewellery making for several years. After the war the extremely high purchase tax on luxury goods such as jewellery made it very difficult for new designs to enter the market (Bide 2008:56). It was also not particularly easy

Fig. 2.
J.B. Cotton (front centre) and his team at IMI Research *ca* 1971. Image courtesy of Peter Hayfield.

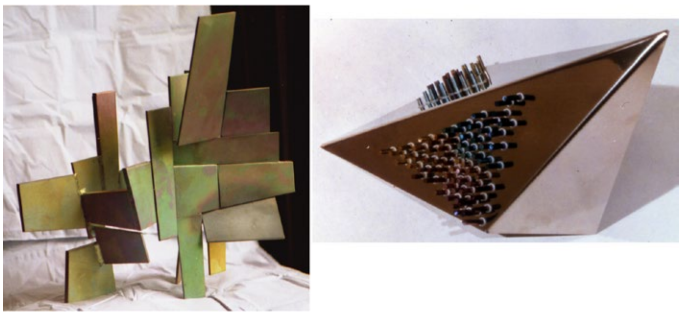

Fig. 3.
Two sculptures made by silversmithing students at Birmingham 1964/5 using titanium sheet and rod, (major dimensions *ca* 50 cm) property of Peter Hayfield.

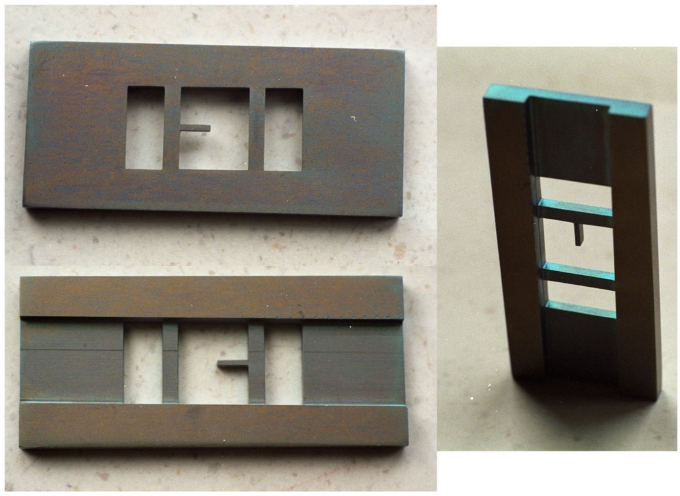

Fig. 4.
Belt buckle machined from a thick sheet of titanium and coloured by anodising (three views). The differing colour on the face of the buckle and on the edges can be a feature of anodised titanium. Ann Marie Shillito 1967.

Fig. 5.
Copy of page from *Vogue* magazine (1970), showing a model wearing a multi-coloured titanium collar. The text read 'Titanium collar by Alan Wright' but the fashion magazine has chosen to illustrate it in black and white and focus on the model's hairstyle as the major feature of the image.

to obtain precious metals and a licence to purchase gold was still necessary until the early 1970s. The situation had a stifling effect on jewellery design and manufacture in Britain throughout the 1950s. Designs were often copied from the nineteenth and early twentieth centuries and the training of the jeweller continued to follow a traditional apprenticeship system with emphasis on special skills and technical excellence and expertise. But the next decade saw an amazing growth in the sector and in the early 1960s two major events resulted in radical changes in design and making.

In 1961 Graham Hughes organised the International Exhibition of Modern Jewellery at Goldsmiths' Hall. The work, featuring innovative design, displayed in distinctive showcases, had an enormous impact on the jewellery world in Britain (Phillips 2000:118).

The other notable event of the early 1960s was the publication of the Government's Coldstream Report (Coldstream 1960) which resulted in major changes in education in the art and design fields with the introduction of degree-level course in areas such as jewellery. New colleges and courses set a framework for the rapid adoption and exploitation of new materials especially in the growing sector of studio jewellery made by individual designer/makers.

The School of Jewellery at Birmingham was part of the expansion across Britain of courses where students were encouraged to think about and experiment with materials other than precious metals and gemstones. Tutors from other creative disciplines fostered a cross-fertilisation of ideas. In 1965 the new metal, titanium, was introduced into this highly energised and creative environment (Hunt 1990). Subsequently its use spread through the close-knit jewellery school network of the late 1960s (Turner 1996:9) as tutors and students saw pieces incorporating the new metal in degree shows.

Little written evidence is available from this period but interviews with selected jewellery students from 1960s to 1980s are recorded as part of a survey of practitioners from these years (Bartlett 2009, appendix). Eric Spiller recalls using titanium at the Central School of Art and Design, London (Central) in 1968 and Alan Wright notes that samples of titanium from IMI were brought into class at Central in 1969. A bronze, blue and green necklace that he produced was one of the first pieces of titanium jewellery to be featured in a mainstream magazine. It was illustrated in *Vogue* in 1970 but ironically only in black and white (fig. 5). The text stated 'Titanium collar by Alan Wright' but the image of the model was mainly illustrating a hairstyle.

Moving from Birmingham, Shillito continued her experimentation with titanium at the Royal College of Art (RCA) from 1968 and it is possible that her arrival there may have encouraged other students to experiment with the new metal. In 1969 Professor Robert Goodden, Head of the School of Silversmithing and Jewellery at the RCA noted that:

> … some students experimented in the use of titanium as a jewellery material. The metal has several properties to recommend it for the purpose; it has the strength of steel but only half the weight; its air-formed surface film of oxide can be dissolved and re-crystallised by thermal etching to give a faceted, granular appearance; and the transparent film of oxide can be increased by electrical

> anodizing in a variety of acids to a range of thicknesses which give rise to colour by interference without the use of colouring agents. The colours are soft and beautiful – much 'greyer' than those of soap bubbles for instance. (Goodden 1969:10)

By the early 1970s titanium had become a regular product used in jewellery courses. James Brent Ward's graduate show from the Central in 1973 included titanium pieces (fig. 6) as reported in *Design Journal:*

> Some materials are easier to work, others more of a challenge. James Brent Ward found the latter was true of titanium. Unlike silver, it can[not] be soldered except in a vacuum, and it takes up to three days to polish satisfactorily. It is coloured by being dipped into an electrolytic solution and having a current passed through it, the different colours being dependent on different voltages. James used both polished and unpolished titanium, but feels he is still at the experimental stage. (Hughes Stanton 1973:61-8)

This contemporary quotation highlights the experimental approach to titanium that was still current in the field of titanium jewellery in the early 1970s. Several of the jewellers who had experimented with titanium on undergraduate courses continued their studies at the RCA and developed their work there. One of the students who came to the RCA from Hornsey in the late 1970s was Clarissa Mitchell. As well as using titanium to create colourful frames for sunglasses (fig. 7), she also researched the use of titanium sputtering on other materials (Mitchell 1981).

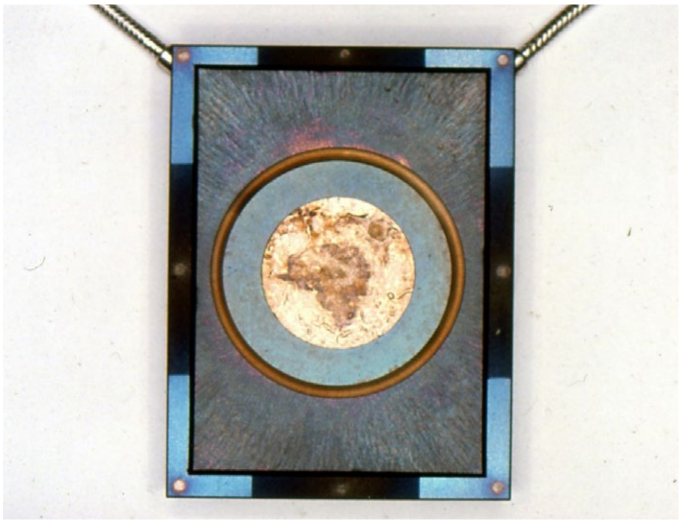

Fig. 6.
James Brent Ward pendant from late 1970s, titanium frame and insert with gold amalgam centre and gold rivets, image courtesy of J.B. Ward.

Fig. 7.
Titanium sunglasses by Clarissa Mitchell, 1981. Image courtesy of the Royal College of Art.

Titanium jewellery development

For the majority of jewellers 'the temptation of colour', to quote Marjan Unger, was the most alluring feature of the new metal (Unger 2016:151). Limitations on workability were accepted initially in order to explore the exciting new design possibilities that could only be achieved by using titanium.

Industry, as described above, had discovered that colour on titanium could be produced by heat oxidation in air, or electrochemically, by anodising in an aqueous solution. Jewellers therefore had to grapple with the oxidation procedures and devise their own pragmatic solutions to the application of these processes. The limited range of coloured metals, produced by alloying, had been purchased from specialist suppliers but with titanium, jewellers needed to devise their own methods for colouration to produce specific designs.

Electrical processes, such as the plating of a silver or base metal artefact with gold, although familiar to jewellers are usually carried out by specialist craftsmen but anodising titanium to produce surface oxides, and hence colour, is such a crucial part of the design process that jewellers had to familiarise themselves with the electrical equipment and the inorganic solutions used as electrolytes. The use of heat to generate an oxide layer on titanium was a more familiar process for the jeweller but came at a radically different stage in the procedure. Heating to produce colour is the final or penultimate step in the creation of a titanium jewellery item rather than part of the initial production as is the case when working with precious metals.

The challenge of working with titanium produced two broadly different responses. Some jewellers found titanium worth the effort for the creative possibilities given by the colouring of the surface while others just used pieces of coloured titanium in a similar way to gemstones or enamelled plaques with a silver frame. The first Loot exhibition in 1975, organised at Goldsmiths' Hall, included several such titanium pieces. Perhaps because they are the easiest colours to produce, many jewellers coloured titanium various shades of blue, making it a natural sky backdrop to scenic pieces.

In the catalogue for the second Loot exhibition in 1976, Graham Hughes, the Art Director at Goldsmiths' Hall, noted the use of 'a new metal and new colour' in the pieces exhibited (Hughes 1976). Eleven of the three hundred and thirty exhibitors showed work that incorporated titanium. One of these was Scilla Speet who had started working with titanium as a student at Birmingham in 1968 and while at the RCA (1970-3), produced pieces that involved inserting titanium rod into solid silver (fig. 8). The Loot exhibition in Minneapolis in 1978 featured a significant number of titanium pieces and subsequent workshops given in the USA by British jewellers carried the use of titanium across the Atlantic (Winkler 1980).

The first exhibition to be devoted entirely to titanium was held at the Electrum Gallery in London in October 1976, and featured three students from the RCA, Ed de Large, Kevin Coates and James Brent Ward. De Large developed his own techniques to produce exquisite cloudscape brooches. Figure 9 illustrates one of his brooches from 1978 showing what could be achieved in terms of design by painstaking anodising techniques :

Fig. 8.
Two silver bangles with titanium rod inserts (one coloured by paintbrush technique, where the work is connected to the anodiser and the electrolyte is carried on a brush) by Scilla Speet, 1972.

Fig. 9.
Brooch. Titanium set in a silver frame. Cloudscape with optical illusion. Ed de Large, 1978. Image courtesy of Ed de Large.

Fig. 10.
Titanium and 18ct gold 'Magpie' brooch, Kevin Coates, 1974, image courtesy of the Royal College of Arts.

Fig. 11.
Laser cut titanium brooches with integral pins, Ann Marie Shillito, 1991.

Fig. 12.
Titanium forged bracelet with bronze hinge by Brian Podschies, 1985.

> Titanium is hardly malleable, it is impossible to solder, and it is extremely difficult to form using normal silversmithing methods. This last limitation was perhaps fortuitous, in that it encouraged me to suggest a third dimension in my pieces where none existed (they are all flat). I don't draw or engrave lines on titanium, rather, I use stencils to define areas in the composition, creating the illusion of different planes by juxtaposing highly iridescent satin planes with matt and velvety sandblasted ones, achieved with wet and dry emery papers, glass-fibre brushes and small grinding wheels. The varied surface textures dramatically affect the appearance of the colours, which gives the actually simple, organised composition a complex appearance, with the play of light altering the atmosphere of a piece from, say, bright and cheerful, to menacing. (De Large 1979:22)

For Coates, titanium was just one of many materials chosen for visual impact and his work with titanium and gold was considered noteworthy by the Head of School, Philip Popham (fig. 10):

> Kevin Coates, a second-year student, is designing very exciting jewellery combining 18K gold and coloured titanium. He has perfected by genuine research, a difficult and ingenious process developed to suit his own requirements. Suitably shaped pieces of titanium (which cannot be soldered) are secured by modelled wax and then embedded in plaster for lost wax casting. The plaster holds the titanium in place while the wax is burnt away and molten gold poured into the recesses so left which, on cooling, permanently unites both metals. (Popham 1974:16)

Encouraged by Peter Gainsbury, Technical Director at the Goldsmiths' Company, Brent Ward undertook a structured programme of research into the use of titanium while at the RCA between 1974 and 1977. The resulting paper, based on this research, was published by the Worshipful Company of Goldsmiths as a technical bulletin entitled 'The Colouring and Working of Refractory Metals' in 1978 (reissued in 1982) and became the standard guide for jewellers on working with refractory metals (Brent Ward 1978).

In the late 1970s Shillito became aware of the use of titanium for surgical implants and devised integral ear wires, hand cut, for titanium earrings. Her experiments in the late 1980s with laser cutting, in collaboration with Heriot-Watt University, Edinburgh, produced brooches with integral pins (fig. 11).

Brian Podschies, another Birmingham student from 1973-77, after trying the standard colouring procedures developed a hot-forging technique (fig. 12). This novel technique produced quite different results from those developed by fellow jeweller and designer, David Poston in 1983 when he began hot forging the metal to produce finished grey/black pieces (fig. 13).

For the first decade of its use, up to the mid-1970s, titanium was regarded as a special material used principally by designer/makers such as Shillito, De Large, Coates and Brent Ward to produce one-off or limited-edition pieces. The second half

Fig. 13.
Titanium four-part hot-forged bracelet by David Poston, 1984.

Fig. 14.
Titanium earrings (acid etched and anodised) by Prism 1980s. Image courtesy of Prism.

of the 1970s and the early 1980s saw production move to a more industrial scale. Barry and Sally Milburn, who both studied at Central in the late 1970s, were inspired by the work of Ed de Large but saw titanium jewellery as a way to achieve their ambitions for a volume jewellery manufacturing business, Prism (fig. 14). A substantial volume of simple, inexpensive pieces began to appear in the windows of high street jewellers. Commercial companies such as Simbol, Prism and Dust (co-founded by Brent Ward) opened small factories and concentrated on producing simple multi-coloured jewellery for the mass-market; the perception of titanium changed.

Students in the early 1980s were often inspired by the intricate images created by Ed de Large. One of these was Debby Moxon who went on to develop her own particular method of heat-colouring titanium. Using precise geometric scoring and a fine flame she created a deceptively simple style, whose complexity only becomes apparent with knowledge of the behaviour of the metal (fig. 15).

Inevitably during the late 1980s the use of titanium in standard high street pieces reduced its special appeal for the more design-led jewellers; artist/craftsmen found it difficult to sell their individual designs as customers became accustomed to the inexpensive products available in many high street stores for £10-20. Only the most committed makers continued to use it. A notable example is Brian Eburah who studied at Central 1973-6 and continues to feature titanium in combination with silver and gemstones in his work today (fig. 16).

The light weight of titanium, so important in industry, has been seen as a disadvantage in a jewellery market where, for historic reasons, related to the use of precious metals, value has been connected with weight. Writing in the *Financial Times* in 2002, Vivienne Becker disparages 'tinny titanium'. The possibilities offered for larger scale wearable pieces, which have to some extent been realised with aluminium have not been exploited for

Fig. 15.
Titanium brooch by Debby Moxon from 1982/3, illustrating her sophisticated use of heat-colouring.

Fig. 16.
Titanium, gold and silver brooch with topaz by Brian Eburah, 2005.

Fig. 17.
Open University mace entirely made with titanium, 1972.

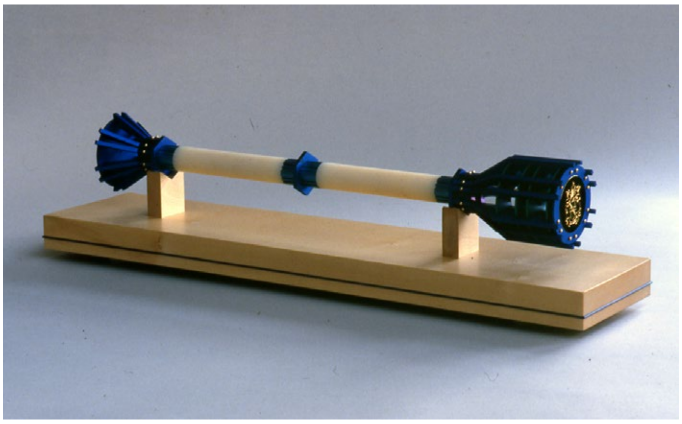

Fig. 18.
Birmingham Polytechnic mace, nylon shaft with titanium fittings, Terry Hunt, 1988. Image courtesy of T. Hunt.

Fig. 19.
Articulated ring with tsavorites and diamonds set in titanium and white gold fitting by G (Glenn Spiro) made for Beyonce and donated by her to the Victoria & Albert Museum 2014. (Photo Lynne Bartlett)

titanium. The benefit of the lightness of titanium has, however, been successfully used in maces or ceremonial staffs which were increasingly needed for the newly created Universities. A notable example is that for the Open University, which was commissioned by ICI, designed by Eric Clements and made at Birmingham by Hamish Bowie, shown in figure 17. Titanium was also used, appropriately, for the Birmingham Polytechnic mace, designed and made by Terry Hunt in 1988 (fig. 18).

Since the 1980s and during the1990s uncoloured titanium has been widely used for its strength and light weight, particularly for sports equipment and spectacles. The popularity of body piercing and the biocompatibility of titanium have been combined to produce a range of mass-produced titanium body jewellery. A wide range of titanium rings, often inlaid or combined with precious metals and diamonds are now offered and the 'industrial' image of the metal is being successfully marketed to men.

Since the 1990s more and more use has been made of titanium in the fine jewellery sector as exemplified by the 'papillon' ring made by G (Glenn Spiro) for Beyonce and donated by her to the Victoria and Albert Museum (Accession number M.1-2018) (fig. 19).[1] Observation of the piece shows that both piercing and casting have been used to create mounts for pave-set diamonds and other gemstones. The lightness of titanium has seen it increasingly used to produce larger diamond set pieces and the potential for alternative background colour in terms of the setting metal has broadened the design scope in this area.

Titanium, over fifty years since it was introduced as a jewellery metal, is now just one of the materials in the jewellers' repertoire, albeit for some a special metal. Many students are encouraged to use titanium while studying but relatively few continue to explore and exploit its properties after graduation.

1 https://www.vam.ac.uk/articles/papillon-ring-by-glenn-spiro

Aluminium

History of discovery and early manufacture

In common with titanium, the existence of aluminium was known in the eighteenth century but it was only produced as a pure metal in the mid-nineteenth century. Also, as with titanium, the strong affinity of the metal for oxygen made the isolation of the pure metal very difficult. Sir Humphrey Davy, although he failed to isolate the pure metal from its principal oxide, alumina, did name the metal (Britannica). The name is derived from one of its salts, alum, but whether it should be aluminum or aluminium remains a matter of debate.

The credit for the first isolation goes to Oersted who produced aluminium in powder form in 1825 but it was Wohler in 1827 who produced metallic aluminium. A potential commercial production method was developed by Sainte-Claire Deville in 1850 and small ingots of the purified metal were shown at the Paris exposition in 1855. The price of aluminium was greater than that of gold and the silvery lightweight metal was treated as a novel jewellery material set in gold mounts (Bury1991; Phillips 2000:14). It is perhaps not surprising that the modernising nephew of Napoleon Bonaparte, Napoleon III, ordered the fabrication of aluminium utensils and is reported to have eaten from an aluminium plate in preference to a gold one, as aluminium was the more costly metal (Venetski 1969).

The extraction of metallic aluminium from its ore using an electrical current was demonstrated by both Bunsen and Deville but it was only viable as a method for commercial production after the invention of the dynamo in 1872 and the consequent reduction in electricity supply costs (Adam 1985:2). Both Heroult in France and Hall in America patented processes for the electrolytic extraction of aluminium from its ores in 1886 (Wernick 1956:3) and factories were set up in Germany and the USA.

Aluminium developed quickly during the late nineteenth and early twentieth centuries and went from being a special material to an inexpensive industrial metal. It was valued for its light weight and corrosion resistance, high thermal and electrical conductivity and high ductility. The disadvantages of softness and low strength were overcome by judicious alloying with a wide range of other metals. Cast alloys were produced for direct castings using different casting methods and wrought alloys were first cast into ingots, also known as billets, which were subsequently mechanically formed into sheet or wire.

The increasingly abundant lightweight metal found many outlets in the construction industry and the growing aeronautical industry and was also used for a wide range of domestic wares such as saucepans and commercially produced jewellery. Today it would be hard to imagine life without aluminium cans and aluminium foil. In the 1950s high purity aluminium was used to manufacture inexpensive cast jewellery items that were processed to have the appearance of gold (Wernick 1956:15) and were sold for just a few pounds.

Adoption by studio jewellers

Aluminium found a ready outlet in the mass-produced jewellery market as a lightweight substitute for other non-precious jewellery metals from the 1950s. The studio jewellery movement in the US with its emphasis on design above material value can be traced back to 1940s New York (Turner 1996:6). As Ralph Turner documents, the studio jewellery movement that existed in America received an impetus from the changes in education across the States in the 1960s paralleling the developments in that decade in Britain noted above with respect to the use of titanium.

Many studio jewellers in America started to use aluminium in their practice in the late 1970s, initially incorporating ready produced, coloured pieces in their work. In a monograph one of these artists, David Tisdale, suggests that jewellers in America were introduced to the technique of aluminium anodising in the workshop by Arline Fisch who had seen it used at the Bezalel Academy in Jerusalem in the late 1970s (Tisdale 1985:27).

Fig. 20.
Anodised and dyed aluminium earrings Jane Adam *ca* 1995.

Tisdale studied the process of anodising aluminium for use in jewellery and completed his MA thesis on the topic in 1981.

Also in America David LaPlantz started using painted aluminium in his studio pieces in 1980 in preference to titanium, the new colourable metal, which was becoming popular in the USA at that time. But around 1984 he switched to anodising aluminium and published a book in 1988 as a workshop manual for jewellers (LaPlantz 1988). The techniques recommended involved obtaining a single even colouring on a piece and provided advice on pattern production by use of multiple anodising steps.

At about the same time in Britain Jane Adam started experimenting with anodised aluminium with a particular emphasis on its potential for multi-coloured design. Although initially anodising her own metal she moved to explore the design possibilities that could be achieved by using the ready anodised but unsealed sheet material that was available from industrial anodising companies. Over a period of around four years she conducted a series of detailed experiments to determine the optimum materials in terms of inks, dyes, resists and how these could be combined by the artist/jeweller to produce the desired design outcome. The results of this work were presented in her MA dissertation at the Royal College of Art in 1985 (Adam 1985). She not only used the materials very successfully in her own workshop practice (fig. 20) but passed on her knowledge to other practitioners by teaching and lecturing in Britain and worldwide. Continuing her experimental approach in the use of anodised aluminium for her innovative jewellery Adam has gained global recognition with pieces in many prestigious collections, including the Victoria and Albert Museum.

Anodised aluminium enables the jeweller to use an almost unlimited range of marks and colours. As the colourants are fixed in the thin adherent oxide layer on the surface of the metal, they are very durable. The lightweight of aluminium and the broad range of decorative possibilities (fig. 21), incorporating both abstract and figurative designs, have made it a significant jewellery material especially in the field of contemporary jewellery. The availability of ready-anodised aluminium sheet and the comparative ease of colouring with simple inks and dyes have enabled jewellers to produce colourful, inexpensive jewellery items which, for example, can be sold below £100.

Fig. 21.
Dyed anodised aluminium annular brooch with silver pin, showing texture from net curtains Lynne Bartlett *ca* 2000.

Anodising

History and development

The common process that links the production of surface colour on both aluminium and titanium is anodising, which can be regarded as a form of electrolysis. Electrolysis, which may be described as a chemical reaction driven by an electric current, was first performed by Nicholson and Carlisle in 1800. The procedure involves the passing of an electric current between two electrodes suspended in a liquid bath. Sir Humphrey Davy used electrolysis to isolate metals such as sodium and potassium (Shukla and Prem Kumar 2008:31). The nomenclature for the process and the component parts of the system commonly in use today was proposed by Davy's assistant at the Royal Institution, Michael Faraday, who coined the term electrolysis for the process and electrolyte for the liquid in the bath. Faraday's Laws of Electrolysis published in 1883 and 1884 provide a basis for all subsequent work in electrochemical science and technology (Walsh 1991:481-4). His first law states: 'Chemical action or decomposing power is exactly proportional to the quantity of electricity which passes'. Faraday was also involved in naming the two poles placed in the electrolyte and the charge bearing entities within the solution, which he called ions. The positive pole where the electrical current enters the system is termed the anode and the negative pole where it leaves is the cathode.

Anodising as a method of creating an oxide layer on a metal surface was observed by Heinrich Buff in 1857. Working with aluminium in an aqueous electrolyte he noted the thickening of the naturally formed oxide layer as the negatively charged oxygen ions reacted with the aluminium anode. The thickened oxide layer created by this reaction protected the metal and acted effectively as a lubricant (Buff 1857:265-384). However this method of protecting an aluminium surface was not used extensively until the early twentieth century.

Fig. 22.
Chain necklace made using ready-dyed aluminium links, Lynne Bartlett 2004.

Anodising Aluminium

The disadvantages of the softness and reactivity of aluminium were overcome by the formulation of a wide variety of alloys. As the alloying metals often reduced the natural corrosion resistance of the pure metal the alloys needed protection from corrosion and many processes were developed to protect the metal surface. These methods included various coatings such as paints, lacquers and varnishes but also electrochemical methods such as plating and, probably the most successful method, that of anodising. Anodising is used to thicken the natural aluminium oxide surface on the metal and provide a durable hard surface layer. The process patented by Bengough and Stuart in 1923 (Jenny and Lewis1950:90) used a chromic acid electrolyte and produced a grey film. Their objective was to provide protection from corrosion of aluminium seaplane parts. Aluminium knitting needles with a characteristic grey finish are everyday examples of this type of coating (Adam 1985:12).

Other electrolytes were tested for use in the anodising process and the use of dilute sulphuric acid produced anodised surfaces that were very useful for decorative purposes (Wernick and Pinner 1956:223). The film produced using sulphuric acid as the electrolyte is clear, transparent, colourless and, more importantly, is porous and capable of absorbing dyes. This thin layer is receptive to colouring agents, particularly inks and dyes, and a wide range of patterning techniques can be used to produce what is effectively a coloured metal surface. Once colour has been applied to the oxide layer the surface is sealed by immersing the piece in boiling water or by steaming. This process causes the aluminium oxide layer created by the anodising process to swell and trap the colorant within. Anodising in sulphuric acid and subsequent steaming has been the preferred method for use in jewellery design as described above. Whether the artist anodises the aluminium prior to decoration or whether he or she purchases ready-anodised metal the transparent porous surface layer provides a ready canvas for artistic expression.

As Adam describes, a combination of solvent-based inks and water-based dyes permit complex designs using painting, drawing, printing and other surface decorating techniques. Although much work has been produced using sheet metal it is possible to form 3-D shapes and extrude wires that can be subsequently anodised and dyed to produce more complex designs. Commercial companies also offer ready dyed wires in a variety of colours and thicknesses (diameters) (fig. 22).

In summary anodising of aluminium produces a transparent oxide surface layer on the metal which requires the further application of inks and dyes to produce the appearance of coloured metal. In complete contrast no ink or dye is required to achieve the appearance of colour on titanium, as discussed below.

Anodising Titanium

The colour on titanium is a manifestation of thin film interference which is commonly seen with petrol on a wet road. No dyes or pigments are involved and the colour depends on the thickness of the oxide layer developed on the surface of the metal.

Anodising can be used to thicken the naturally formed oxide layer on titanium and although the film is transparent the interference phenomenon allows the development of a permanently coloured surface when the metal is oxidised. Oxidised titanium exhibits interference colours when the oxide layer on the surface of the metal is within the range 20 - 300 nm thick. The colours observed range from a dull reddish yellow through purple to blue and then through yellow, orange, pink, mauve and blue to green. This surface coloration can be manipulated by artists to produce many different effects giving new and exciting design possibilities.

Titanium may be oxidised by heat or by anodising and these two processes are described in the video produced to mark the twentieth anniversary of the Association for Contemporary Jewellery (ACJ) in collaboration with the Goldsmiths' Company (ACJ 2017). Because of the poor heat conduction of titanium, heat oxidation tends to produce patchy colouring but anodising, as recommended by IMI technicians and described in Cotton's paper (Cotton 1975:354), can produce a homogenous surface colour appearance, giving the jeweller more control over the design.

Anodising units specifically for titanium were developed in the 1970s and a wide variety of electrolytes were used, including Coca-Cola, but the solution recommended by IMI, namely 10% by weight ammonium sulphate in water is still in use. The voltages needed to produce specific colours vary with the surface of the metal and its preparation but the sequence followed is that established by Newton and exemplified by the phenomenon known as Newton's rings (Newton 1730).

Although anodising produces a more uniform colour appearance than heat, it can show unexpected variations and research into this problem (Bartlett 2009) in collaboration with Imperial College succeeded, by means of Transmission Electron Microscopy (TEM), in demonstrating the difference in structure of the oxide layers created by the two methods. The structures of the oxide layers were clearly observed and accurate measurements of the layer thicknesses made. Although some difference in structure between the two layers had been expected, the actual result was astonishing. The anodised layer (fig. 23) is mostly a sandwich structure of relatively uniform thickness (139 nm +/- 4 nm) along its length but showing the presence of random voids within the oxide layer. In complete contrast to the

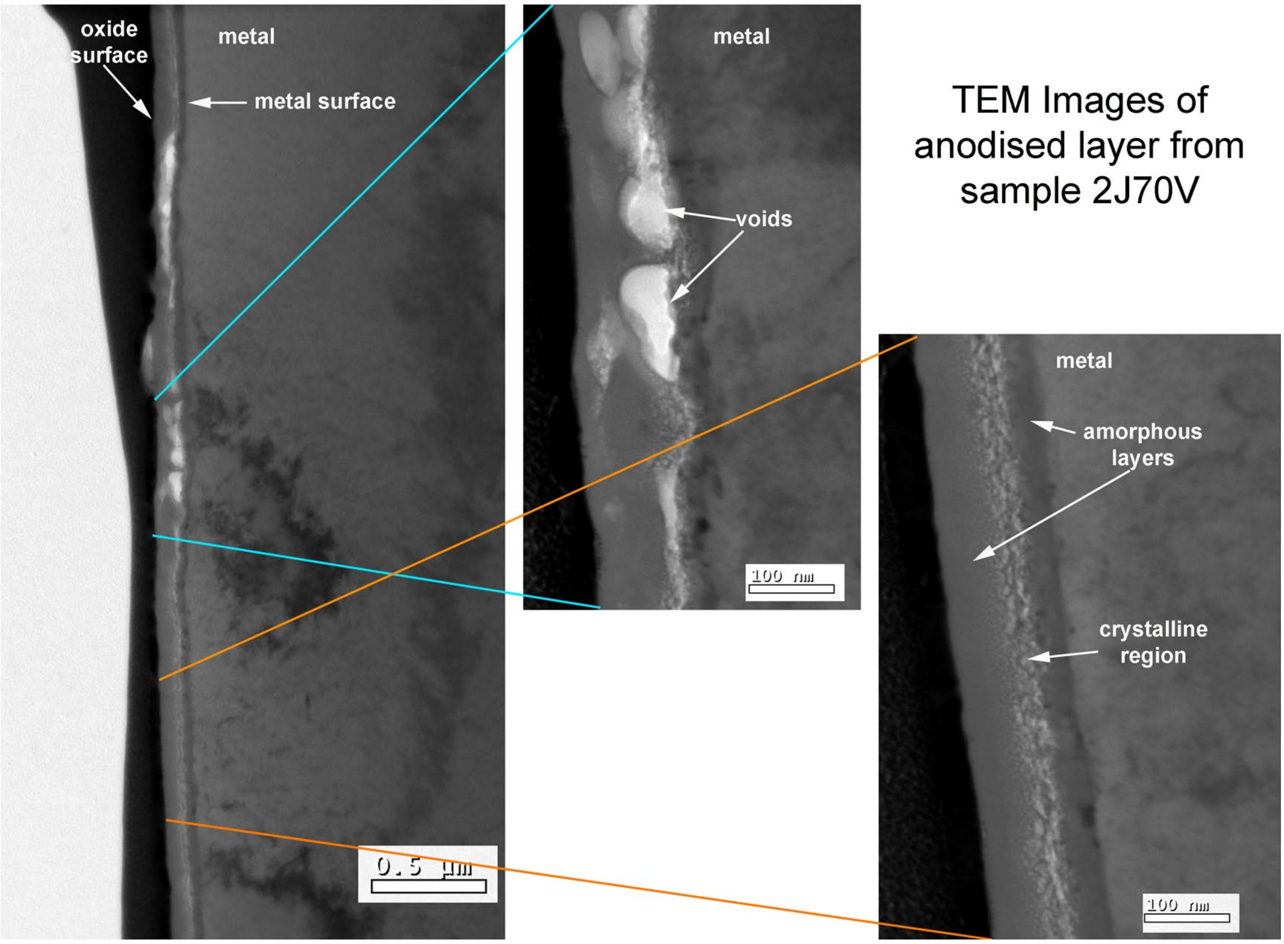

Fig. 23.
Transmission Electron Microscope (TEM) images of an anodised titanium sample showing the thickness of the oxide layer created by anodising at different magnifications in nanometres.

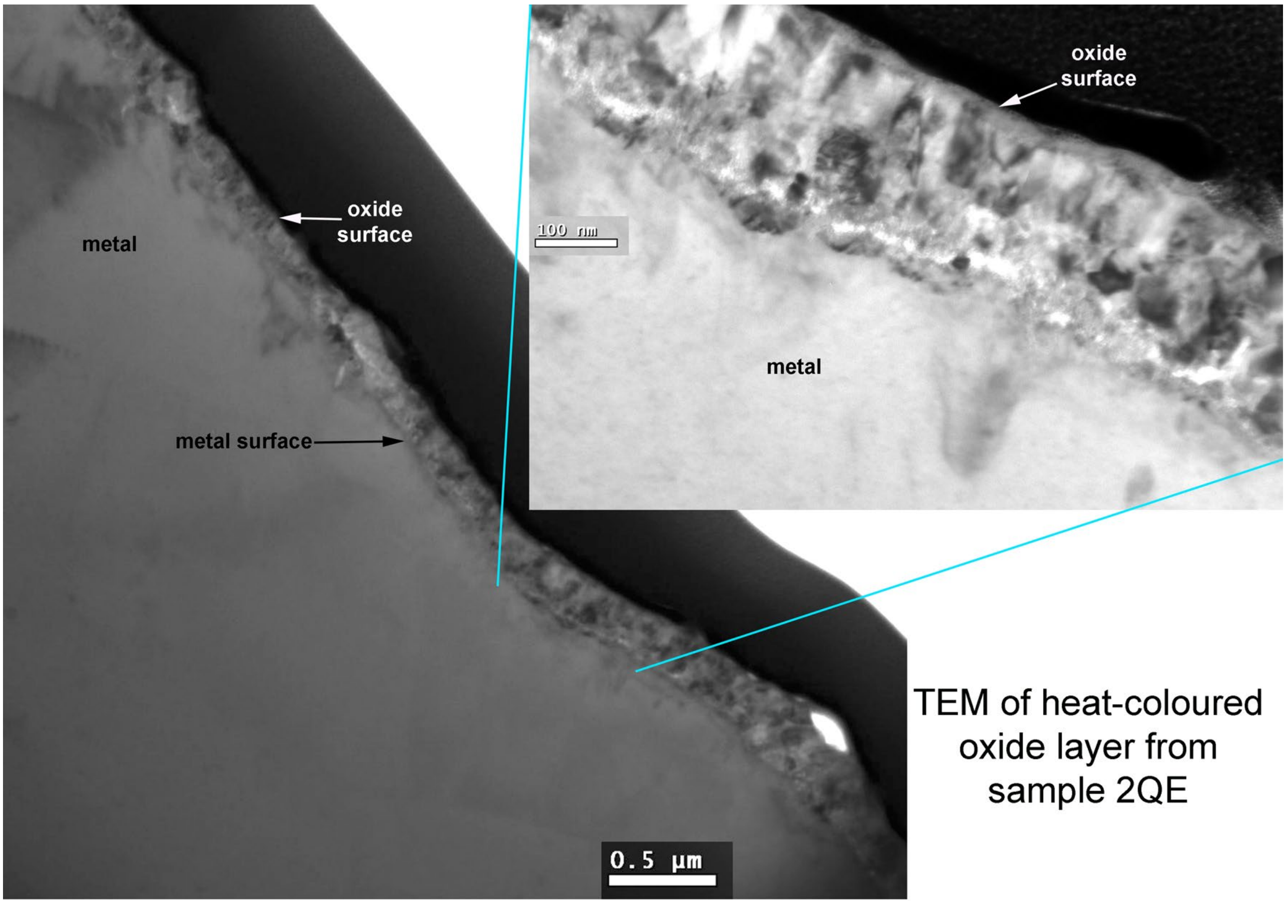

Fig. 24.
Transmission Electron Microscope (TEM) images of a heated titanium sample showing the thickness of the thermally created oxide layer at different magnifications.

anodised layer, the oxide layer created by heat (fig. 24) is entirely crystalline with variable thickness increasing along the length of the sample from 135 nm to 255 nm. The structure of the heat-generated oxide layer explains why these surfaces are more robust in jewellery wear than anodised surfaces.

Historically the titanium surface was prepared using a hydrofluoric acid etch but this is now largely confined to industrial production because of the dangers of hydrofluoric acid. For the workshop jeweller (see above for types of jeweller) alternative methods must be used to homogenise the surface. The most reliable is abrasion but great care needs to be taken to thoroughly clean the surface after each grade of grit so that contamination is minimised. The use of freshly prepared titanium, supplied protected with a polymer film, also minimises contamination when compared to the factory off-cuts which were used in the past.

The experimental confirmation that different surfaces colour at different rates gives the jeweller many possibilities for both controlled and spontaneous pattern making. Anodising at a specific voltage will give different colours on the same piece of metal for differently prepared surfaces.

Laser cutting of titanium has been used for jewellery since the 1980s and in 1998 Ann-Marie Carey noted both laser oxidation and ablation (the removal of the created oxide) in her research at the RCA (Carey et al.1998). Sarah O'Hana also explored

Fig. 25.
Laser patterned titanium bangle, Sara O'Hana 2007, (image courtesy of Sara O'Hana)

the decorative potential of the use of lasers to create coloured pattern on titanium. The interesting and subtle effects produced are shown in figure 25. As an alternative to building up the oxide layer by use of laser the developing technique of laser ablation shows promise for future design development. Relatively low powered lasers can cut through and thin an oxide layer already established by anodising to reveal a different colour (fig. 26). The success of this procedure gives the designer/maker added possibilities for surface manipulation.

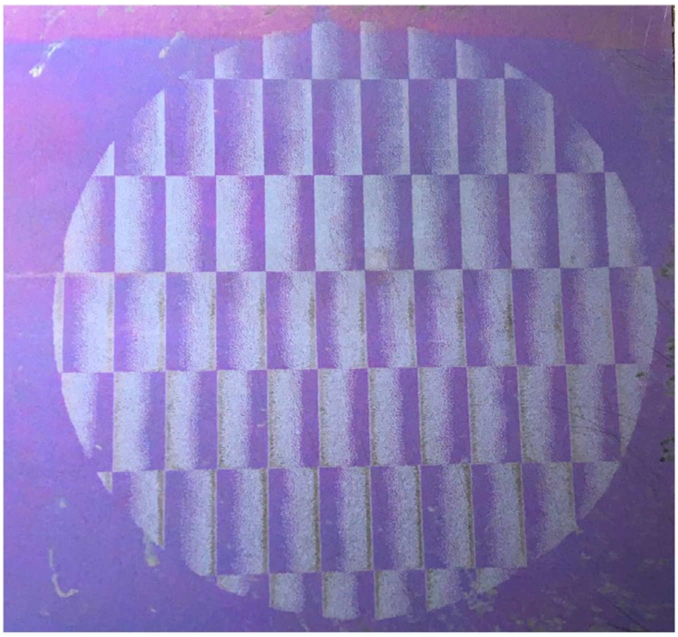

Fig. 26.
Trial laser-ablated titanium panel (*ca* 6cm square), Lynne Bartlett 2016.

Conclusions

As has been demonstrated, the possibilities for jewellery design in the twentieth century in Britian, USA and Europe were significantly expanded by the introduction of two new metals with the shared property of colourability. The growth of the studio jewellery movement during the 1960s, 70s and 80s both in Europe and America provided a fertile ground for experimentation with new non-traditional materials and techniques (Turner 1996) and both aluminium and titanium were taken up by artist jewellers and designer/makers particularly in light of the surface colour and pattern that could be achieved. Although, as shown, both metals allow the production of durable, coloured surfaces by the use of anodising the techniques and mechanisms are very different. Anodising aluminium is a lengthy process which uses a range of toxic and caustic chemicals, such as sulphuric acid and caustic soda, but produces a porous surface that can be decorated in an infinite variety of ways. Titanium by contrast is anodised in relatively safe and easily handled materials but is difficult to control in terms of design outcome.

However, both metals have now become established as regular materials for creative jewellery design and manufacture, used by the contemporary jeweller in the workshop, by industrial producers and even in fine jewellery.

The extensive research effort expended by IMI in the 1960s to develop new outlets for the then novel metal titanium did not produce significant sales volumes. The desire of the new entrepreneurial designer/makers to differentiate their work from their competing fellow graduates by using new materials and techniques was at odds with the commercial needs of the industrial companies. Titanium usage for all types of jewellery has increased but the volumes remain relatively low and no statistics are given for that category of use. But whatever the intentions of IMI it was through their efforts that titanium became firmly established as a jewellery metal.

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