Development of optically variable devices for document security

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1. INTRODUCTION

Document counterfeiting has become a significant source of revenue loss in many industries, particularly in the banking and retail sectors. In addition to the direct economic losses in banknotes and financial transaction documents (estimated at ~$10-15 billion each year in the USA), the counterfeiting of visas, passports, ID cards and other official security documents has implications for national security. The ability to produce counterfeit documents of high quality has become widespread due to the availability of digital scanners and high resolution colour copiers. This equipment has reduced the effectiveness of traditional security features such as intaglio printing and complex design patterns in protecting the integrity of high security documents. As a result, various additional security features have been introduced in recent years. Nearly all of these security features have used visual or optically identifying keys in order to verify the documents. Security features have included optically variable inks, copy proof inks (spectrally difficult to detect by copiers), dot structure moiré, optically variable devices (OVDs), biometric devices and interference security image structures (ISIS) (multiple thin layers designed to create an iridescent image). In particular, the diffraction-based OVDs have become widely used as security elements to protect banknotes, cheques and high security documents against counterfeiting. As their name implies, optically variable devices are characterised by variations in optical effects with angle of observation or viewing. A basic feature of these devices has been a fine pattern of gratings of different line spacings and inclinations, designed to produce specific optical effects under varying conditions of illumination. The development of OVDs in Australia at CSIRO has been recognized as one of the leading document-security technologies in the world [1].

2. HISTORICAL BACKGROUND

The origins of the CSIRO OVD technology go back to the CNRD (Currency Note Research and Development) project in the early 1970's. The CNRD project was a joint collaboration between the CSIRO and the Reserve Bank of Australia (RBA) and had the aim of developing a new, high security banknote containing features which could not be copied by the coming generation of colour photocopiers. While portraiture was a preferred feature of the CNRD OVD, other design objectives included optically variable graphics and the requirement that the device should be resistant to crumpling of the banknote surface. The CSIRO introduced a program to develop foil-based diffractive optically variable devices which could be applied to banknotes.

The final result of this work was the CATPIX™ grating concept developed by CSIRO in 1985 -1987 [2]. The Catpix™ groove structure was used on the Captain Cook portrait OVD on the Australian commemorative ten-dollar plastic banknote issued in January, 1988. This was the first use of an OVD on a banknote anywhere in the world. The OVD on the 1988 banknote took the form of the schematic portrait of Captain Cook as shown in Figure 1. The OVD microstructure consists of a network of continuously connected curved regions (catastrophe pixels) designed so that the resulting diffraction pattern from the OVD would be less sensitive to surface crumpling effects of the banknote. Figure 2 shows a small section of a curvilinear region of this OVD. The Captain Cook banknote was issued with the OVD embossed onto a novel polymer substrate of bi-axially oriented polypropylene [3].

A further advance in OVD technology by CSIRO was implemented in 1989 as Pixelgram™ [4]. In this technology, the image was comprised of 30 x 30 μm or 60 x 60 μm pixel elements with the flexible allocation of a groove structure from a palette of fine gratings. Improved portraiture was among the technical capabilities of Pixelgram. By 1993, a new development of the technology was named Exelgram™ [5-7]. The prefix "*exel*" was derived from "*ex*posure *el*ement", a term devised to indicate that the diffraction pattern was written with the high resolution of electron beam equipment. Each Exelgram image was based on a very large number of gratings with the individual spacing of the grooves selected from a range of 10 different levels. The choice of groove spacing provided the corresponding iridescent colour in the individual 30 x 30 μm regions of the image.

3. EXELGRAM OVDs

Figure 3 shows an example of an optically variable greyscale portrait made up of a groove structure. When viewed at high magnification, the Exelgram OVDs are seen to comprise a series of extremely fine diffracting tracks (30 μm wide). The information required to construct a picture was encoded into the device by varying the individual groove angles and/or spacing (0.7-1.3 μm) continuously along each of the tracks.

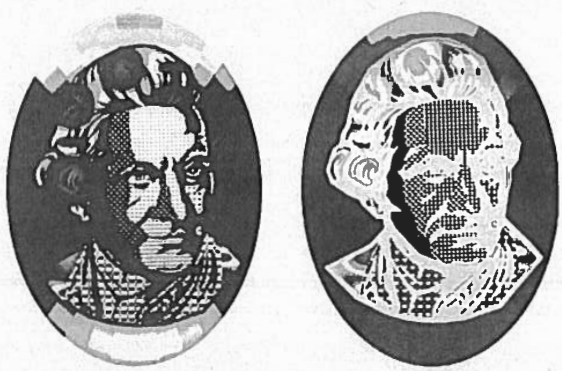

Figure 1. Two angles of view of the Captain Cook Catpix OVD; the first OVD to be used as an anti-counterfeiting device on a banknote. The height of the ellipse on the banknote was ~20 mm.

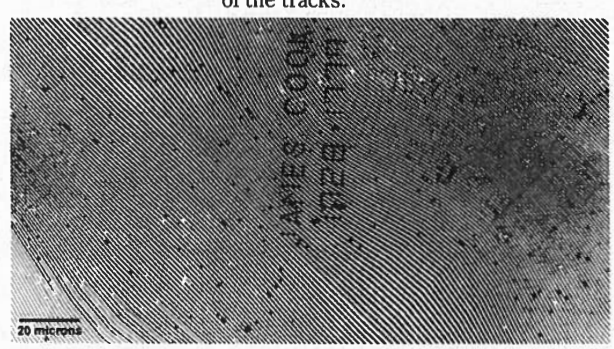

Figure 2. Small section of the Captain Cook Catpix grating OVD. The grating structure was overwritten in parts with 7 μm high micro-lettering.

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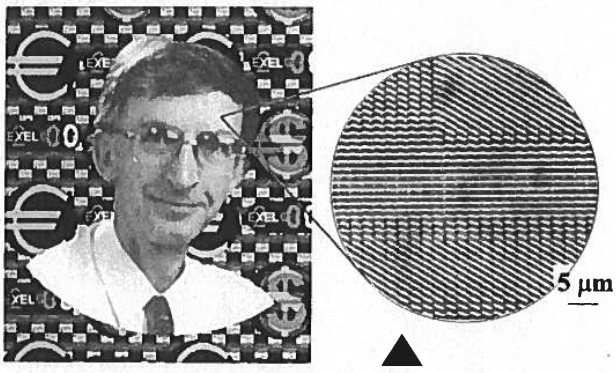

Figure 4. American Express Euro Exelgram OVD at two different angles of view.

Figure 3. Photograph of Exelgram portrait OVD (R.A. Lee) and a corresponding small section of the underlying microstructure comprised of diffraction gratings. The dimensions of the portrait are ~8 mm x 10 mm. The regions of horizontal grooves diffract the negative version of the portrait while regions of sloping grooves diffract light into angles to give the positive version of the portrait (as shown above).

Exelgram OVDs of this type were used in American Express US and Euro traveller's cheques. Figure 4 shows two views of the American Express 50 Euro Exelgram OVD at different angles of tilt. The application of the Exelgram to the Euro denomination cheques followed on from the highly successful use of the technology on the earlier US cheques [8]. These photographs illustrate the capability of the technology to provide a fast switching effect between two different diffractive images as the image is tilted. The images in Figure 4 are enlarged views. The long axis dimension of the foil on the cheque was 19mm.

The switch between the two images was achieved by dividing each image into vertical tracks of width 30 μm. The first input picture occupied one set of vertical tracks and the second picture corresponded to the alternate tracks. By arranging the groove angles and/or spacings of the two sets of microstructures to be quite different, the resultant diffractive images generated by the OVD were made to appear at quite different angles of view. Figures 5 (a-c) show examples of the use of interlaced microstructures [9].

In Figure 5(a), the separation of the images is due to the different line-spacings of the gratings. This caused the images to be diffracted at different angles of view to the OVD. In the case of two channel images, each with distinctly different spacings, the first order diffraction beams appeared at different viewing angles and exhibited distinct colours.

In terms of fine-scale structure, the switch effect resulted from the different arrangement of groove spacings for the two channels or tracks. Figure 6 (a) shows an example of adjacent parallel channels with different groove spacings seen on either side of one pixel grating. In Figure 6 (b), a higher magnification view of the grooves shows the channel interface with coarser structure in the upper part of the image and a finer structure was present below. Also seen in Figure 6 (b) was a change in orientation of the grooves at the interface.

There have been several examples of the commercial use of Exelgram OVDs

Figure 5. Example of an Exelgram OVD demonstrating both i) a switching between two images (CSIRO logo and face of early Governor John MacArthur) and ii) a positive tone to negative tone image change as observed at three different angles of view.

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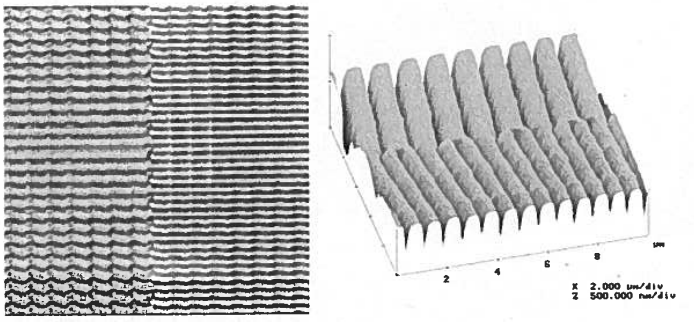

Figure 6. Grating structure of an Exelgram image viewed by (a) optical microscope and (b) atomic Force Microscope showing the change in spacing between two switch regions at the channel boundary.

Photograph by Mark Fergus of CSIRO

Figure 7. Examples of currency applications which have included Exelgram microstructures as an anti-counterfeiting feature.

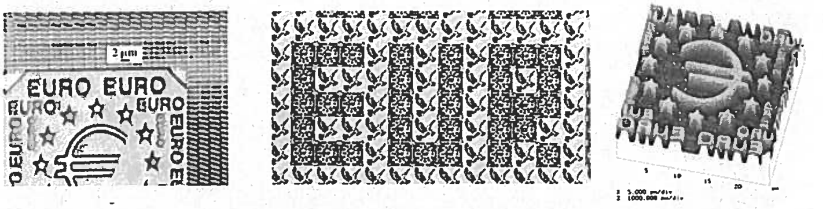

Fig. 8. Examples of micrographic elements based on a Euro test theme showing views of the same region at varying magnification.

including the Vietnamese (1996), Hungarian (1997) and New Zealand (2000) banknotes, Amex US and Euro security documents (1997, 1999) and the Australian "opal" stamps (April 1995). Figure 7 shows a selection of currency applications including two Hungarian banknote denominations where, under a 90° rotation of the banknote, the image changes from the crown of Hungary to "MNB" on the foil stripe.

4. MICROGRAPHIC SECURITY FEATURES

For additional protection against counterfeiting, OVDs have included graphic elements on a very small scale. These elements have been "micro-sculptured" using the finely focused electron beam. The graphic elements have consisted of combinations of alpha-numeric characters as well as logos and line drawings containing a range of sizes (1-30 μm) [10]. The areas in the OVD image covered in micrographic elements have been integrated with the surrounding diffraction grating regions. In terms of optical effect, the micrographic elements have acted to diffusely scatter the incoming light. The Exelgrams used to protect the new Ukrainian passport/visa and the special edition New Zealand plastic $10 millenium banknote have included micrographic features of this type.

Figure 8 (a-c) shows examples of two types of micrographic elements based on a Euro test theme. In figure 8(b), the micrographic doves forming the background wallpaper pattern were each 20 μm across. The first three letters of the word "EURO" shown here were comprised of the second type of micrographic element, enlarged views of which are shown in Figure 8 (a and c). A typical Exelgram OVD of this type may contain up to 100,000 individual micrographic elements embedded within a background of grating microstructures. Advantages of micrographic OVD microstructures include: (1) ease of microscopic forensic authentication of the smallest piece of embossed foil, (2) extremely high security against attempted holographic copying and (3) reduced metallic appearance of the OVD foil due to diffuse scattering from the micrographic elements.

5. THE PRODUCTION OF AN OVD

The sequence of production of a grating-based OVD has comprised three stages: a) artwork development, b) conversion of artwork to electron beam format and c) fabrication of the master image plate. During the design stage, artwork was prepared as an Adobe Photoshop file using a palette developed by CSIRO with 26 different elements. The group of 10 colour elements in the palette was used to define the switch effect in the Exelgram image (for example, Figure 5). Each colour within this 10 element group corresponded to a particular pitch of the tracks in the range 0.7-1.3 µm.

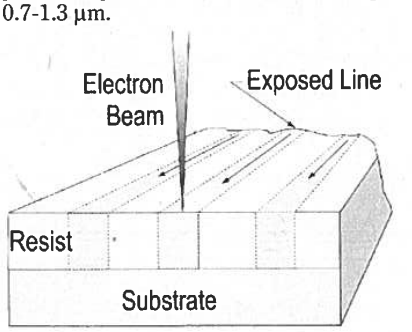

Figure 9. Schematic illustration of the finely focused electron beam exposing a grating pattern in resist.

The OVD pattern was exposed into a layer of electron-sensitive resist using a finely focused beam of a Leica EBMF 10.5 e-beam lithography system (as schematically shown in Figure 9). The master plate for the exposure consisted of a quartz base (12.5 x 12.5 mm) overlaid by a thin layer of Cr and a film of resist. The electron beam was exposed across each of the 30 x 30 µm sub-fields in the images on the plate.

Following the exposure, the layer of resist was developed in a standard solvent to reveal the fine structure of grooves. The OVD array was then copied from the Master plate as a nickel shim. The shim was produced by an initial sputtering of a thin film of Ni (~ 100 nm) followed by the electroplating of a thicker layer (~ 150 µm) in a nickel sulphamate bath. The nickel shim has been used as a die plate in the mass production of embossed foil. The metallized foil comprised multiple polymer layers including a lacquer coat, a metal coating and an adhesive layer. The image was embossed into a polymer layer using a rotary embossing process. The embossed polymer was then vacuum metallized with aluminium and coated with adhesive on the metallized side. The multilayered foil is then separately transferred onto the document by a "hot stamping" process which involves various combinations of heat, pressure and dwell time.

In recent years, Exelgram OVDs have also been applied into the surface of Australian coins [11]. In these coins, the presence of the diffractive structure was intended primarily as an enhancement of the colour and iridescence rather than as a security feature. This method has been limited to commemorative coins because of the shallow grooves in the OVD and the excessive wear of circulating coins. The transfer of the fine structure of grooves into the silver or gold was achieved by use of an intermediate nickel shim which acted as a stamping die [12].

6. MICRO-MIRROR OVDs

The OVDs described in the previous sections have been produced as grating structures which were hot embossed into metallized foil. Although the foil OVDs are in standard use throughout

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the world (currently on more than 70 different types of banknotes), this technology has several limitations. Firstly, it is expensive when compared with traditional security print technologies such as intaglio and watermarking. The application of the foil requires a separate production facility, thereby adding to production costs because of the need for specialized equipment to hot stamp the foils onto the security document. Secondly, counterfeiters can buy the technology for the origination of master plates from one source and the necessary foil embossing and hot stamping technology from another source. Counterfeit banknotes with attached fraudulent OVD foils are already appearing [13]. While the quality of these counterfeits has been very poor, it is only a matter of time before the emergence of more sophisticated versions.

A new OVD approach has been the replacement of gratings within the OVD architecture by arrays of micro-mirrors. The objective has been to eliminate the current practice involving the costly intermediate step of producing an embossed hot stamping foil as the carrier of the OVD microstructure. The micro-mirror array devices have sufficient depth to allow for direct printing onto the document via the use of specialized reflective inks. Micro-mirror devices with 60 μm square pixels inclined at an angle of 30° to the horizontal give an average depth of microstructure of ~30 μm. This greatly increased depth holds out the promise of being able to produce OVD microstructures which can be directly printed. In comparison, grating based OVDs cannot presently be printed by normal techniques because of the limited groove depth (« 1 μm). The roughness of the substrate surface (e.g. paper) is usually much greater than the surface relief of the diffractive microstructure.

A typical OVD microstructure comprised of a micro-mirror array (Figure 10) may contain up to one million mirrors of dimensions 60 x 60 μm or less. Each mirror is arranged at a predetermined angle according to the input picture information.

The procedure for producing a micro-mirror OVD involves three main phases – i) production of an image specific mask by electron beam lithography, ii) UV exposure through the mask to produce the required micro-mirror surface relief structure in a thick layer of optical resist and iii) electroplating of this resist layer to produce a hard nickel tool.

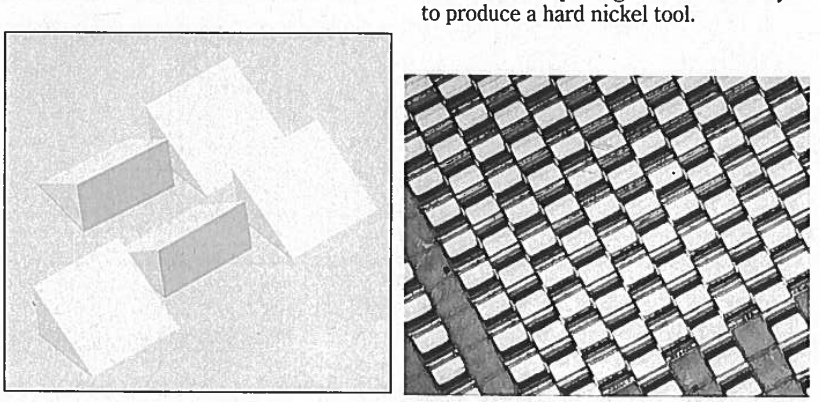

Figure 10. Optical micrograph of an experimental micro-mirror structure. Rows of micro-mirrors of opposing slopes can be seen here. In this particular case, each micro-mirror has a dimension of 30 x 30 μm.

Figure 11. Example of artwork to be converted into an optically variable micro-mirror microstructure.

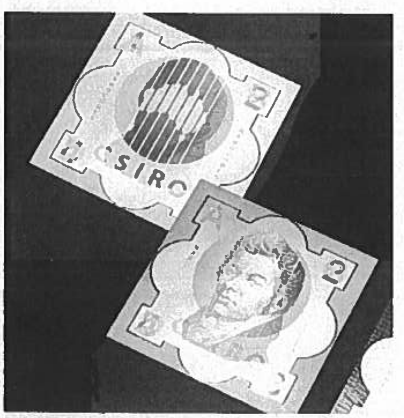

Figure. 12. Images of an experimental micro-mirror optically variable device at two angles of view showing the corresponding images embedded into each channel. Micro-mirrors of opposite slope have been used to reflect the two images into two different viewing directions.

The process starts with the production of a variable transparency mask by electron beam lithography. In this process, the sloping micro-mirrors have been produced using "greytone" lithography. A mask with 30 x 30 μm or 60 x 60 μm pixels was exposed as an array of apertures by electron beam lithography. Each pixel was exposed as very small apertures of varying size (~1 μm) which create a gradation in greyscale across the pixel. In this way, micro-mirrors with different inclination, orientation and depth can be designed in the mask. An example of a four element artwork palette, mask palette and corresponding mirror slope that can be used to construct a micro-mirror device is shown in Figure 11. Recently, Lee has extended the capabilities of greytone lithography by the introduction of a palette-based imaging format [14]. A unique feature of this format has been the capability of a continuous variation in the pattern across each palette element or cell. Using this format, each image was comprised of a finite set of greytone palette elements analogous to the RGB palette of a computer graphic image. Because of the analogy with the elements of a conventional colour palette, this extended greytone lithography technique has been given the name "Colourtone lithography" [14].

The mask is then exposed in an optical projection system to transfer the variable transparency distribution into a layer of resist (~30 μm thickness) [15]. The gradation in grey level within each of the pixels in the mask results in a variable exposure of the thick resist and formation of an array of micro-mirrors. This method has been used to construct an optically variable micro-mirror array which switches between images as it is tilted. Consider the sample of artwork shown in Figure 11. To create an optically variable microstructure version of this artwork we simply map the alternating rows of artwork elements, representing the CSIRO logo and portrait images respectively, into corresponding interleaved rows of micro-mirrors of different slopes. Then, when the image is rotated or tilted, either the CSIRO logo or portrait images will reflect light to the eye according to which set of micro-mirrors is aligned for maximum reflection. Furthermore, mapping different shades of grey within the portrait image into micro-mirrors of the same slope, but different width, enables one to vary the brightness of these portrait pixels.

A photograph of the associated switch between portrait and non-portrait images produced by the micro-mirror array is shown in Figure 12. This effect was obtained by forming the individual channel images from micro-mirrors of different slopes and then interleaving these columns or rows of differently sloping micro-mirrors, so that both images overlapped each other within the same OVD area.

7. CONCLUSIONS

In this paper we have reviewed the fabrication of optical security microstruc-

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tures for protecting official documents from counterfeiting. In particular, we have focused on the specific area of optically variable devices and the advantages offered by the electron beam lithography method of manufacturing these devices. In contrast to the parallel exposure process of holography, the sequential writing method of electron beam lithography provides a means of creating optical effects which are both easily recognizable by the public and highly secure against counterfeiting, because of the inability of these effects to be reproduced by the readily available holographic technologies available to counterfeiters. The growth of development and the adoption of foil based OVDs during the 1990's has certainly resulted in improved protection against counterfeiting. However, the need for more application specificity, particularly in the ID document area, for reduced costs in both origination and replication coupled with the ongoing need to stay ahead of the counterfeiters as they attempt to undermine the latest developments, has led to a demand by security printers for more innovative technologies. There is a need for better differentiated optical effects, lower costs and better control on the availability of the underlying core technologies. In CSIRO we have responded to these industry challenges by initiating new research activities to develop biometric-specific OVD microstructures as well as optical microstructures which can be directly printed onto the security document without the costly intermediate foil phase. As the counterfeiters become better organized and more technically focused we can expect security printers and their associated technology suppliers to become much more R&D focused in meeting this evolving threat from the counterfeiters. Current thinking within the industry has now accepted the need to upgrade document security on a regular five-year basis. We can therefore expect that micro manufacturing R&D for document security will become an area of growing importance.

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This paper was presented at the Victorian Section Technical Meeting on May 16th, 2005

LETTER TO THE EDITOR

Dear Ian,

In reference to the recent letter from Mr. Hill (June 2005 issue of Surface Coatings Australia), I wish to clarify observations he made regarding changes in the FSCT governance.

While it is fair for Mr. Hill to say that the FSCT is undergoing significant changes, it should be noted that direct election by the membership only extends to positions of Board Director, not the Presidency. The President of the FSCT will continue to be elected by the Board of Directors. Also being proposed is a radically smaller Board, reduced from 36 to just 11 members, including Officers. Radical indeed(!), but considered very necessary in the world in which we now live and do business.

We thank Mr. Hill for his good wishes for success (despite his stated "pessimism") and hope that these steps taken by the FSCT toward democracy will provide for growth and prosperity in the future.

We, in turn, extend to SCAA and its membership our best wishes for a most successful Expo 05 Conference — and beyond.

Sincerely,
Bob Ziegler
Executive Vice President
FSCT — USA

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