

N.P. Mahalik

# Micromanufacturing and Nanotechnology



Springer

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With 300 Figures

 Springer

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Dedicated to all my

## **TEACHERS**

Especially to

**Sri Abhimanyu Mahalik**

**Smt Jayanti Mahalik**

**Er Babuchand Mahalik**

**Sri Prabhakar Barik**

**Professor P R Moore**

**Professor S K Lee**

and last but not the least

**Sri Tathagata Satapathy**

*(MP – Dhenkanal; Editor – The Dharitri)*

## Preface

Sophisticated miniaturised components and systems may indeed change all kinds of products and equipment in the most dramatic way. Methodology and design of miniaturisation represent a broad research topic with applications in fundamental physics, chemistry, martial science, computing methods, ultra-precision engineering, fabrication technology, micromachining, and many others based on the principles, characterization, modeling, simulation, sophistication, flexibility of state-of-the-art technology. Micromanufacturing and Nanotechnology (MaN), an advanced product and equipment design concept has emerged and caters to the need for miniaturisation. Technological research in the field of MaN is now expanding; its design phases appear to be highly complex and involve multi-physics and interdisciplinary approaches. The main objective of this book is to provide information on concepts, principles, characteristics, applications, latest technological developments and comparisons with regard to micro/nanosystems and technology. It incorporates research, development, tutorials and case studies. Academic and industrial research and developments in microengineering, micromanufacturing, micromechanics and nanotechnology are being carried out at many different institutions around the world. The technological trend in this domain (e.g., design and development methodology, current application scenarios, pros and cons, etc.) needs to be disseminated extensively so that the MaN revolution can spread to serve society. In particular, the book is intended to focus on describing the implicit concept of micromanufacturing and nanotechnology, multi-physical principle of microelectromechanical systems (MEMS) and micro-opto-electro-mechanical systems (MOEMS), design tips and hints, as much as the techniques and methodology.

Micromanufacturing and nanotechnology are two sides of a coin. There has been confusion and arguments on the terms microengineering, microsystems, ultra-precision engineering, micromachining, nanofinishing, micromechanics, microstructures and microsystems. The authors of the Chapters have attempted to clarify this confusion. The book will undoubtedly enable the readers to understand the underlying technology, philosophy, concepts, ideas, and principles, with regard to broader areas of micromanufacturing and nanotechnology such as application of laser technology, lithography, bulk and surface micromachining, nanofinishing, error compensation, MEMS, MOEMS, carbon nanotubes, micro energy chemical system, fuel cell, microstructure for space propulsion, biosensor, etc. Aspects of microsystems in terms of design process, practice, techniques, platforms, and experimental results have been presented in proper order. The

chapters include topical and general description as far as current research and technological developments are concerned. Fundamental methods, initiatives, significant research results as well as references for further study have been presented. Relative merits and demerits are described at the appropriate places so that novices as well as advanced practitioners can use the evaluation to guide their choices. All the contributions have been reviewed, edited, processed and placed appropriately in order to maintain consistency so that irrespective of whether the reader is an advanced practitioner or a new comer he or she can get most out of it. Since this book covers many aspects of interdisciplinary subjects, the importance of the book within the micro and nano domain is considered significant. The roadmap of the book is as follows.

Chapter 1 is a general introduction. Chapter 2 presents the principles of MEMS and MOEMS. Very precise definitions of different physical phenomena and their utilisation with respect to MEMS and MOEMS have been presented. Chapter 3 presents fundamental principles of application of laser technology in micromanufacturing. Geometrical compensation of high precision machine system is of paramount importance. Chapter 4 highlights the basic principle and experimental architecture of computer assisted laser interferometer based method for achieving compensation of errors. In this chapter the model of error and procedural method of its compensation is described. Chapter 5 discusses about the bulk micromachining processes, a fundamental process requirement for microsystems and equipment manufacturing. A step forward to this process is considered as surface micromachining. Chapter 6 adheres the principle of surface micromanufacturing. Chapter 7 discusses latest developments on microsystem conformant OVD (Optically Variable Device), a very demanding device that has long been used for document security applications. Various types of nanofinishing techniques, the important method in manipulating and describing not only micro- but the macrosystems are described in the Chapter 8. The role of micro- and nanotechnology in space applications is presented in Chapter 9. Carbon nanotubes and nanostructures are introduced in Chapter 10 and 11. It has been variously that the future of the computing world will be based on molecular computing. A comprehensive description of molecular logic gates based on fluorescence, absorption and electronic conductance is presented in Chapter 12. Chapter 13 provides some research outcome with regard to the design of microscale cantilever devices that can act as biological sensors. Transportation of micro-energy through microdevices is a challenging breakthrough and is referred to as MECS (Micro Energy and Chemical Systems). Potential applications are microelectronic cooling systems, chemical reactors, fuel processing and heat pumps as outlined in Chapter 14. Next, a detailed description of sculptured thin films is provided. The following two chapters discuss e-beam and optical nanolithography techniques, respectively. Chapter 18 provides some phenomenological description of nanotechnology vis-à-vis fuel cell applications. Derivatisation of carbon nanotubes with amine and chemical crosslinking in C<sub>60</sub> thin films are presented in Chapter 19 and 20, respectively.

The success story of this book ‘Micromanufacturing and Nanotechnology’ is in fact due to the direct and indirect involvement of many researchers, advisors,

technocrats, academicians, developers, integrators, designers, and last but not the least the well-wishers. Therefore, the editor and hence the publisher acknowledge the potential authors and companies whose papers, reports, articles, notes, study materials, etc. have been referred in this book. Further, many of the authors of the respective chapters gracefully acknowledge their funding agencies, without which their research could not have been completed. In particular persons such as M. Adrian Michalicek, Wassanai Wattanutchariya, Kannachai Kanlayasiri, Joseph Thomas, Hadi Hasan, Nitin Sharma, Patrick Kwon, Sharee McNab, David Melville, Conrad Wolf, Andrew Thompson, Alan Wright, Helen Devereux, Gary Turner and Mike Flaws and the following agencies, institutes, companies and journals are acknowledged.

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*Nitaigour Premchand Mahalik*

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## **7 Micromanufacturing for Document Security: Optically Variable Devices**

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### **7.1 Preamble**

By its very nature document security microtechnology is a subject much less able to be discussed in an open manner than many other areas of research and application. As well as the normal commercial in confidence issues, all companies, research groups and end users working in this area are mindful of the need to restrict the disclosure of information which might compromise the integrity of particular security devices being applied to protect official documents from counterfeiting. Not only are counterfeiting groups now much better organised in their activities, but they are also much more technology focussed in seeking to overcome new security measures. Holographic technology, foil embossing equipment, application processes and information associated with security device design is now being adopted by counterfeiters in their efforts to overcome the new security measures being introduced by the industry. However it is also important for the ongoing development of the industry that document security microstructure issues remain accessible to the research community. Only in this way can new ideas for improved security microstructures be developed and applied in order to stay ahead of the counterfeiters. With these issues and context in mind, this review will have a particular focus on the contribution of electron beam lithography to the development of particular optical security microstructures. It is this type of origination process, which is perceived by the industry to offer a higher level of counterfeit deterrence than the alternative hologram technologies.

### **7.2 Introduction**

The counterfeiting of banknotes and other financial transaction documents as well as visas, passports, ID cards, other official Government security papers and the

counterfeiting of software, pharmaceuticals and brand name products is now becoming one of the world's fastest growing areas of criminal activity. With the advent of colour photocopiers and digital scanning devices the traditional security printer's skill and craftsmanship is no longer sufficient to protect the integrity of high value documents (Fagan 1990). According to the International Chamber of Commerce Counterfeiting Intelligence Bureau over 5% of world trade consists of counterfeit product. The cost of this illegal activity amounts to over US\$350 billion annually and is growing. To counteract this rapidly evolving threat security printers and central bank issuing authorities have turned to new technology in the form of the diffractive Optically Variable Device (OVD) (Renesse 1994). Mass produced by embossing into hot stamping foil, these diffractive surface relief microstructures have proven to be a highly effective solution to the counterfeiting problem. The key security feature underpinning all optically variable devices is, as the name implies, the variability of the image with changing angle of view or changing angle of illumination by a light source. This image variability can even take the form of a switch between one artwork pattern to a totally different piece of artwork; from the image of a face to the number 50, for example. Because of this image change effect these devices cannot be copied by the usual photographic, computer scanning or printing techniques, and therein lies their attractiveness to security printers who have seen their traditional anti-counterfeiting technologies of intaglio print and watermarking undermined by the counterfeiters using the new computer scanning and copying technologies developed since the 1980's. In developing this discussion the intention is to first describe the origins of OVD technology as applied to financial transaction documents and then explore the history and influence of two particular high security developments in the fabrication of optically variable device (OVD) anti-counterfeiting technology for high security document applications. The focus will be on those features of two technologically competitive technologies, which are perceived by the security printing industry to be significant in reducing the counterfeiting threat to official documents. By comparing the security attributes of these competitive OVD technologies and their influence on different sections of the security printing industry from the early 1970's to the late 1990's, we will be able to draw some general conclusions about the suitability and uniqueness of particular OVD features and their suitability for future extension and development. The security value of the different OVD effects will be classified here according to the degree of difficulty in originating the device, the recognisability and uniqueness of their corresponding optical effects and finally by the degree of availability of these effects from alternative and less secure origination sources. In subsequent sections we will consider in more detail particular applications of the electron beam lithography origination process; the origination process regarded by the security printing industry as providing the most secure and controlled set of optical effects. By control here we mean the ability of the industry and its component suppliers to restrict the availability of these high security effects to high security printing industry applications only and in so doing prevent unscrupulous operators from gaining access to the technology. Finally we will consider the limitations of this current high-end origination

process and its corresponding foil based replication process and consider a new paradigm for addressing these limitations in a way that provides a future path for extended developments of the underlying core technology.

## 7.3 OVD Foil Microstructures

The first application of OVD technology as an anti-counterfeiting feature was the result of the adaptation of existing holographic technology to high volume manufacture by direct embossing onto foil and the application of that foil onto the security document by a hot stamping process. The security hologram was developed initially by the American Bank Note Company through its subsidiary, American Bank Note Holographics (ABNH) and was first adopted by MASTERCARD in 1982 in the form of a 2D/3D holographic foil image. Two years later VISA used a 3-D variation of the ABNH technology to protect its new credit card series (Fagan 1990). In both cases the use of the hologram resulted in a marked decrease in the rate of credit card counterfeiting and fraud.

### 7.3.1 The Security Hologram

In the years that followed many other variations of holographic foil images have appeared on various types of financial transaction cards. During the same period attempts were made to apply similar technology to paper substrates, including prototype banknote applications. It then became apparent that the hologram suffered from several serious problems, which reduced its effectiveness as a security feature when applied to these less robust substrates.

Some of these problems already existed in the case of the card applications. The key disadvantages included: (1) image blurring (and therefore reduced recognition) under extended light source illumination, (2) lack of image brightness, (3) very poor brightness and recognition after crumpling of the paper substrate and finally (4) lack of control over the origination technology which sometimes allowed unscrupulous operators to re-originate the security image or simulate the effects from commercially available foils with similar optical effects (Antes 1986).

While some of these problems were eliminated or reduced by the development of new origination processes such as holographic stereography and dot matrix technology (Souparis 1990), the results were usually perceived to be less than satisfactory from a security printer's point of view. This unfavourable perception was mainly due to the lack of a clear optical effects design philosophy as well as an inability to guarantee complete security with respect to the availability of specialised optical effects. In the following sections we shall show how these critical issues were resolved by the development of the first OVD technologies with optical effects exclusively reserved for security printing applications (Lee 1998).

### 7.3.2 The Kinegram™

Developed by the Landis & Gyr Corporation in the early 1980's, the Kinegram™ was the first OVD technology to be designed explicitly as a no compromise anti-counterfeiting measure exclusively reserved for banknote and other high security document applications. The Kinegram™ technology (Antes 1982, 1988; Moser 1996; Renesse 1994, 2004) represents probably the most advanced form of OVD microstructure written by laser interference techniques. An example of such a Kinegram™ microstructure is shown in Fig. 7.1. The photomicrograph shows some fundamental microstructure units of a Kinegram™ OVD. The small circular 60-micron diameter grating pixels have groove spacings and angles which vary throughout the device, according to the input picture information, thereby providing the means by which the macroscopic artwork of the Kinegram is made optically variable. The photomicrograph is taken from the Kinegram Saudia Arabia passport application of 1987. The initial stimulus for the Kinegram™ OVD development came from the Swiss National Bank and followed earlier work by Landis & Gyr on the development of machine-readable optical codes for banknotes. This work in turn drew on Landis & Gyr's still earlier work on optically coded pre-paid telephone cards. The expertise developed on these earlier projects, particularly in relation to the mathematical analysis of inverse scattering problems, provided the critical mathematical tools necessary for calculating the Kinegram™ microstructure configuration for particular optical effect designs. In conjunction with Gregor Antes' application of mathematical physics to the design of these unique optical effects, Landis & Gyr also developed a novel system for originating the required Kinegram™ microstructures. In order to satisfy the security requirements of the banknote printing industry, the Kinegram™ origination technology was (and still is) maintained as a single site process exclusively reserved for high security anti-counterfeiting applications. Fig. 7.2 shows some applications of the Kinegram OVD technology, including the Swiss 50 Franc and Finnish 500 Mark banknotes.

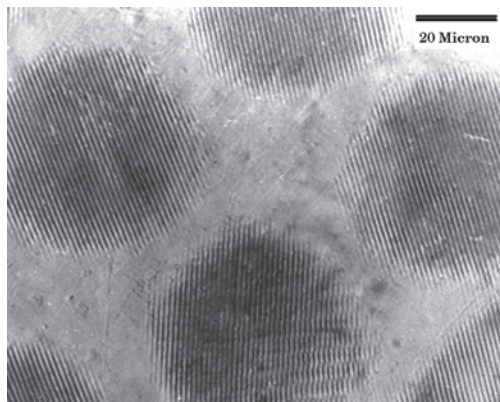


Fig. 7.1. Example of a Kinegram OVD microstructure



**Fig. 7.2.** Kinegram OVD applications, including the OK marketing Kinegram

Underlying this origination development work was a well-defined optical effects design philosophy, which drew heavily on a particular interpretation of the existing knowledge of the psychophysical aspects of visual perception. The two principal psycho-physical Kinegram<sup>TM</sup> design rules can be stated as follows: (1) use crisp sharp lines in an image to efficiently help memorisation, as shown for example in the 20 mm diameter Kinegram shown in Fig. 7.3 and (2) best memorisation of the variability of an image is achieved when the image change is accompanied by sudden and brisk changes of intensities. As well as these rules of perception, Kinegram<sup>TM</sup> images are also designed to have high brightness, be easy to observe under a wide range of illumination conditions and to be resistant to image degradation due to crumpling of the foil on the banknote. To complete this unique package of high security design and origination attributes, Landis & Gyr also restricted the availability of the Kinegram<sup>TM</sup> to banknotes and other official documents. This restriction on availability was intended to ensure that Kinegram optical effects would not be compromised in the way holographic optical effects had been compromised by their appearance on many commercial applications outside of security printing.

With such a powerful and tightly controlled set of security attributes, it is not surprising that the Kinegram<sup>TM</sup> quickly became the market leader in OVD protection for high security documents. Appearing first on the Saudia Arabia passport in 1987 and the Austrian 5,000 schilling banknote in 1990, the Kinegram<sup>TM</sup> later appeared on Finnish banknotes, the new Swiss currency in 1995, German banknotes in 1997 and finally the low denomination euro banknotes of 2002. Fig. 7.4.(a) shows the behaviour of the Kinegram on the Finnish 500 mark banknote. It should be noted however that not all of these projects conformed to the classical Kinegram<sup>TM</sup> design philosophy of sparkling opto-kinetic effects based on optically variable guilloche line artwork. The “moving 50” Swiss banknote Kinegram as shown in Fig.7.4(b) for example, is composed of arrays of diffractive tracks more reminiscent of an Exelgram<sup>TM</sup> microstructure than the juxtaposed micrograting elements of the other applications. The acceptance of the

OVD as an essential feature of modern banknote design (Lancaster and Mitchell 2004) has seen the emergence of competitors to the Kinegram<sup>TM</sup>. This is demonstrated by the selection of Hologram Industries' Moviegram<sup>TM</sup> for the higher denomination banknotes of the new European currency. Some of the competing products also show clear evidence of the adoption of the highly successful Kinegram design and optical effects philosophy. Companies such as ABNH of the US, AOT and De La Rue Holographics of the UK, Hologram Industries of France and the Toppan printing company of Japan are able to offer sometimes similar effects via alternative origination scenarios (Newswager; Aubrecht et al. 2004). While these companies have yet to create opto-kinetic effects of similar brightness to the Kinegram<sup>TM</sup> OVD it is clear that such improvements are only a matter of time.

With the increased availability and reduced control status of these Kinegram<sup>TM</sup> effects, there has developed an increasing interest in OVD technologies which offered additional optical effects unable to be produced by either holographic or opto-kinetic origination systems and which are able to be exclusively restricted to security printing applications. A particularly effective example of an alternative approach is provided by the electron beam lithography origination process as exemplified by the Exelgram<sup>TM</sup> OVD technology developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia.



**Fig. 7.3.** Characteristic opto-kinetic Kinegram OVD effects at three angles of view



**Fig. 7.4(a).** Optical behaviour of the Kinegram on Finnish 500 mark banknote

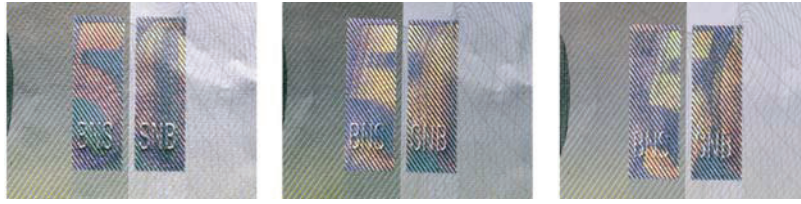


Fig. 7.4(b). The Swiss 50 Franc banknote Kinegram at three angles of view

### 7.3.3 The Catpix™ Electron Beam Lithography Microstructure

While the first examples of Exelgram™ technology did not appear until late 1993, the origins of the security philosophy which influenced the development of this OVD technology go back almost twenty years earlier to what was called the CNRD (Currency Note Research and Development) project in the early 1970's. The CNRD project was a joint collaboration between the CSIRO and Reserve Bank of Australia (RBA) and had the aim of developing a new high security banknote containing features that could not be copied by the coming generation of colour photocopiers (Hardwick 1990; Wilson 1998). In contrast to the optically variable guilloche philosophy, which drove the development program of the Kinegram™, the Exelgram™ traces its principal design influence back to the optically variable portraiture requirements of the RBA and similar influences from Bank of England studies during the same early 1970's period. Just as the opto-kinetic line art effects generated by Kinegrams can be regarded as optically variable versions of the complex guilloche effects used in traditional banknote design, so too can the positive to negative image switch of the American Express Centurion Exelgram™ incorporated into the new series of travellers cheques (Wood 1999; McHugh 1999) issued in 1997 be regarded as an optically variable example of the traditional portraits used on the majority of the world's banknotes. In this sense the Kinegram™ and the Exelgram can be regarded as alternative and complementary solutions to the same problem of protecting their common banknote heritage from counterfeiting. While portraiture was a critically preferred feature of the CNRD OVD, other design objectives also had to be met. These included the addition of optically variable graphics as well as a requirement that the diffractive properties of the device should be resistant to crumpling of the banknote surface. The final result of this work was the CATPIX™ grating concept developed by CSIRO in 1985–1987 (RA Lee, EP 0449 893 B1). This Catpix™ groove structure was used on the Captain Cook portrait OVD on the Australian 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 polymer banknote took the form of a 20 mm high schematic portrait of Captain Cook, two angles of view of which are shown in Fig. 7.5, and the underlying diffractive microstructure was written by a modified JEOL 5A electron beam lithography system. Interestingly this was the first electron beam lithography system to incorporate an oblique line writing capability as developed by CSIRO and

incorporated into the JEOL 5A system installed at the Reserve Bank of Australia note printing department in 1980. The OVD microstructure developed on this machine was designed in the form of a network of continuously connected curvilinear regions (catastrophe pixels) in order that the resultant diffraction pattern from the OVD would be less sensitive to banknote surface crumpling effects. Fig. 7.6 shows a small section of a curvilinear region of this type of OVD.

### 7.3.4 Structural Stability

As briefly discussed above, the crinkling and flexing of the banknote surface was an issue that arose very early on in the process of developing an effective security microstructure for anti-counterfeiting applications. Curving the rulings of the grating microstructure in an undulatory fashion was found, through earlier work on the mathematical and optical properties of catastrophe gratings (Lee 1983, 1985), to be an effective technique for generating expanded diffraction beams from small surface regions of the banknote OVD. This increased the observational stability of each diffracted beam because each expanded beam could be observed from a broader range of viewing angles than in the case of straight line grating structures, which produced unexpanded diffracted beams. Fig. 7.7 shows the first order Catpix grating Fourier plane diffraction pattern corresponding to the catastrophe grating (Lee 1983) ruling pattern shown in Fig. 7.6. While the Australian Reserve Bank Catpix<sup>TM</sup> technology shared a similar security philosophy to that of Landis & Gyr's Kinegram technology (unique optical effects, single source origination and controlled availability), there was a fundamental problem with the Catpix<sup>TM</sup> technology in that its portraiture capabilities were still very limited. Because optically variable greytone line art portraiture had still not been achieved, CSIRO initiated a new research project in late 1988 aimed at securing the optically variable portrait objective by using a radically different underlying grating structure to that used in Catpix<sup>TM</sup>. In the course of this work it was found that the modulated curvature geometry used to improve the observational structural stability of the Catpix OVD could also be adapted to solve the problem of creating a realistic OVD portraiture capability.



**Fig. 7.5.** Two angles of view of the Captain Cook Catpix OVD; the first banknote OVD

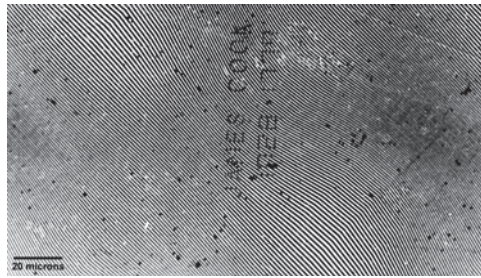


Fig. 7.6. Photomicrograph of a small section of the Captain Cook Catpix grating OVD

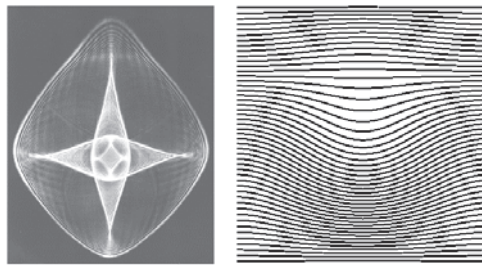


Fig. 7.7. Fourier plane diffraction pattern from a component of a Catpix grating OVD

### 7.3.5 The Pixelgram™ Palette Concept

An alternative and much more flexible approach to the design of OVD microstructures is based on the use of a palette of independent pixel grating functions of different line curvatures to represent the palette of grayscale or intensity values within a portrait image. The artwork to microstructure mapping process can then be thought of as part of a broader and more flexible mapping concept designed to allow for the conversion of any piece of artwork into optically variable form. The development of this diffractive microstructure palette technology was first implemented in 1989 via a new OVD technology (Lee 1991) developed by CSIRO called Pixelgram™. Each element of a Pixelgram palette is designed to be in one to one correspondence with the RGB palette used in the construction of the input artwork, e.g. as represented on a computer screen. The particular advantage of this microstructure palette concept is that it enables the electron beam lithography data file size to be minimised. In 1989 the data explosion problem was particularly acute for diffractive devices of areas of several square centimetres because in this case the electron beam lithography pattern file consisted of millions of micro trapezoids of different angles, widths and lengths. Converting this pattern file to binary on a Vax computer for the Leica EBMF series of machine took many hours of computer time and resulted in very large data files of several billion e-beam shapes. Disc storage devices at this time also could not very easily store the resultant multi-gigabyte binary pattern file.

Redefining the OVD image in terms of a palette of 10 or twenty micro grating files solved these problems. It was then only necessary to convert each micro grating file to binary and the resultant binary file for the palette was normally no larger than ten or twenty megabytes. In this new electron beam lithography writing format the image is defined by a special Job control data file consisting of a list of stage positions and exposure conditions for positioning and exposing each micro grating palette element according to the image layout in the original artwork file. A second key advantage of this palette-writing format is the ability to separate the macroscopic properties of the pixellated microstructure array from the microscopic properties of the system. In the case of the diffractive optically variable device this means that many different optically variable images can be constructed from the same microstructure palette. Each image simply corresponds to a different distribution of 30 micron X 30 micron or 60 micron X 60 micron diffractive microstructure palette elements. An example of a four-element diffractive microstructure palette and its corresponding RGB artwork palette is shown in Fig. 7.8 which shows four elements of a 16-element greyscale Pixelgram palette and its corresponding RGB greyscale palette. The diffractive microstructure pixels are 60 microns X 60 microns in size. An example of an optically variable portrait produced from such a palette is also shown at two angles of view. The characteristic OVD effect is a positive to negative tone image switch. Element 16 of the palette also includes a super high-resolution text message as an additional covert security feature. Fig. 7.9 shows a photomicrograph of a small section of an typical Pixelgram OVD.

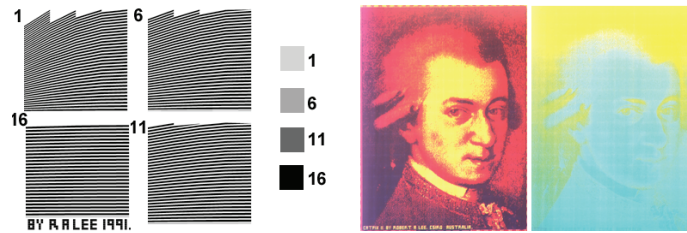


**Fig. 7.8.** Four elements of a greyscale Pixelgram palette and corresponding RGB palette

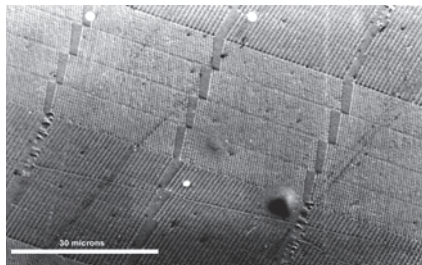


**Fig. 7.9.** Small section of a Pixelgram OVD showing pixels of different groove structure

The Pixelgram™ technology developed by CSIRO required the use of this new e-beam writing format, which was developed in collaboration with Leica Microsystems of the UK using data file structures developed by CSIRO Australia. The resulting specialised software package, called PATJOB, was implemented on a Leica EBMF 10.5 using a slight modification to some of the operating system routines. The implementation of this new e-beam writing configuration led to the rapid development of the Pixelgram™ OVD technology. All later OVD and security microstructure technologies developed by CSIRO have made use of this proprietary palette based electron beam lithography-writing format. More recently (in 2002) CSIRO and the Central Microstructure Laboratories of the Rutherford Appleton Laboratories in the UK developed an equivalent version of the palette based writing format for the Leica Vectorbeam VB6 series of electron beam lithography machines. This VB6 palette based data format, called PALTEK is a significant improvement over PATJOB as it has three times the resolution and ten times the writing speed of the earlier EBMF 10.5 version.

### 7.3.6 The Exelgram™ Track based OVD Microstructure

By early 1993 the size of the individual pixel gratings of the Pixelgram™ technology had been reduced to only 30 microns X 30 microns, providing greatly increased image resolution. However this reduction in pixel size also caused some loss in image brightness due to diffuse scattering effects from the edges of the pixel gratings. This diffuse scattering problem was solved by dispensing with the pixel based configuration of the OVD microstructure and replacing it with a surface relief structure based on a multiplicity of very thin diffractive tracks with continuous and smoothly varying groove angles and spacings (Lee, US patent nos. 5825547 and 6088161, 1997). This new alternative technology to Pixelgram™ was named EXELGRAM™, *exel* being the common term used to describe the fundamental exposure elements of the electron beam writing process. An example of how the diffractive microstructure palette concept can be used to generate application specific specialised optical effects is given for the case of optically variable greyscale portraiture. In this example the 16 greyscales of the input OVD artwork are mapped to 16 different microstructures of different grating groove curvature. Fig.7.10 shows an example of such a microstructure region. American Express US\$ and Euro Travellers cheques used Exelgram OVD microstructures of this type. In Fig. 7.10 the portrait dimensions are approximately 8 mm X 10 mm. Horizontal groove regions diffract the negative version of the portrait while sloping groove regions diffract light into angles where the positive version of the portrait can be observed, as shown above.

Fig.7.11 shows two views of the American Express Euro 50 Exelgram OVD at two different angles of observation. The application of the Exelgram to the Euro denomination cheques followed the highly successful application of the technology on the earlier US cheques (McHugh 1999; Wood 1999). These images illustrate the two channel switching capabilities of the technology as well as the highly accurate portraiture representations, which can be achieved. These images

are enlarged views. The actual long axis dimension of the foil on the cheque is 19mm. While optically variable portraiture, for example as illustrated in Fig.7.12, was the driving force behind the development of Exelgram, this effect is just one of many unique optical effects available within the Exelgram™ optical effects package. Most of these new effects relate to Exelgram's highly flexible optically variable graphics capability, which is due to the diffractive palette basis of the technology and the electron beam lithography basis of the origination process.

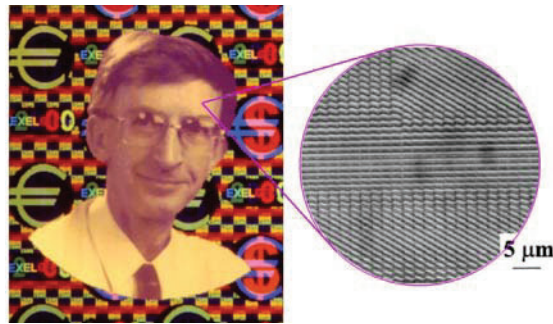


**Fig. 7.10.** Exelgram portrait OVD and corresponding diffraction grating microstructure



**Fig. 7.11.** American Express Euro Exelgram OVD at two angles of view



**Fig. 7.12.** Exelgram OVD showing two-channel switching and portraiture effects

For example the same curved line and variably spaced groove elements used for the portraiture effects can also be used to generate very fast switching two-channel effects. In this case two interlaced micro diffraction grating structures are produced in which one group of grating structures corresponds to the RGB mapping from one input picture while the second interlaced group corresponds to the RGB mapping from a second picture.

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 can be made to appear at quite different angles of view. Fig. 7.13(a) and Fig. 7.13(b) shows examples of the use of multi-channel microstructures (Lee 2000). In Fig. 7.13(a) the separation of the images is due to the different grating groove frequencies. This causes the different images to be diffracted at different angles of view to the OVD. By incorporating a slight degree of curvature into the individual groove elements much faster channel switching speeds can be obtained as well as less cross channel overlap. The Exelgram foils used on the Vietnamese bank cheques issued in 1996 used multi-channel effects of this type.

Examples of other high security Exelgram graphic effects can be seen on the new series of Hungarian banknotes issued in mid 1997. These banknotes contain an Exelgram™ foil stripe, which generates an image switch upon rotation of the banknote by ninety degrees.

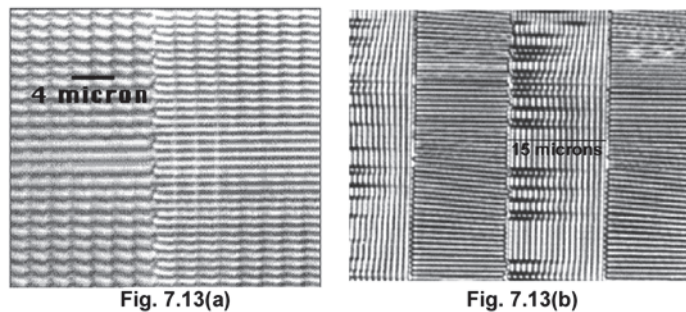


**Fig. 7.14.** Currency applications; Exelgram microstructures as an anti-counterfeiting feature

In this case the OVD image switches from the crown of Hungary to the letters MNB when the banknote is rotated by 90 degrees with respect to the normal. A

small part of the OVD microstructure used to achieve this right angle switching effect is shown in Fig. 7.13(b). Fig. 7.14 shows some sample Exelgram projects, including two Hungarian banknote denominations where the ninety-degree rotation image changes from the crown of Hungary to “MNB” on the foil stripe can be clearly seen. The effectiveness of Exelgram technology as an anti-counterfeiting feature is well documented.

### 7.3.7 Covert Image Micrographic Security Features

A unique advantage of the electron beam lithography origination process is its ability to fabricate complex non-diffractive anti-copy micrographic features and to integrate these features within the diffractive microstructure of the image. In this case the OVD image is designed to incorporate very small scale graphic elements consisting of combinations of alpha-numeric characters and other graphic elements such as logos and line drawings containing a range of feature sizes from 1 to 30 microns which act to diffusely scatter incoming light so that a palette of such micrographic elements can be used to form optically invariable macroscopic images of the greyscale or line-art form (Lee and Quint, PCT/AU98/00821). The Exelgrams used to protect the new Ukrainian passport/visa and the 2000 special edition New Zealand plastic \$10 millenium banknote include micrographic features of this type for enhanced protection against counterfeiting. Fig. 7.15(a) and Fig. 7.15(b) show examples of two types of micrographic elements based on a euro theme test. In Fig. 7.15(b) the micrographic doves forming the background wallpaper pattern are each 20 microns across. The first three letters of the word EURO shown here are comprised of the second type of micrographic element, an enlarged view of which is shown in Fig. 7.15(a). A typical Exelgram OVD of this type may contain up to 100,000 individual micrographic elements embedded within a background diffractive microstructure. Particular advantages of such hybrid diffractive/ micrographic OVD microstructures include; (1) easy microscopic forensic authentication of the smallest piece of embossed substrate, (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.

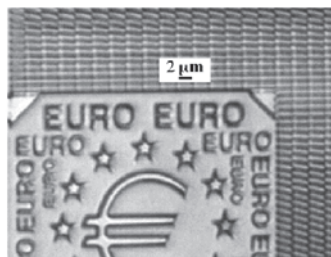


Figure 15a



Figure 15b

Fig. 7.15. Micrographic doves forming the background



Fig. 7.16. CSIRO high security electron beam lithography laboratory established in 1993

### 7.3.8 Kinegram™ and Exelgram™: Comparison

The foregoing comparison of the attributes of the Exelgram™ and Kinegram™ technologies shows a very high degree of agreement with respect to satisfying security printing industry requirements. Both technologies are based on high cost single source origination systems and each technology generates its own unique set of tightly controlled optical effects. A summary of Kinegram and Exelgram optical effects and security attributes is shown in Table 7.1. The above discussion relating to the particular advantages of using electron beam lithography in the fabrication of specialised diffractive microstructures for anti-counterfeiting applications shows that this technique has much greater flexibility, resolution and geometric precision than previous techniques based on laser interference or holographic imaging. This is particularly true in the case of fast switching graphic effects, optically variable greyscale and line art portraiture and complex anti-copy micrographic effects. The origination of these effects is not possible using the earlier optical techniques. The mathematically defined input structure functions combined with the polygon based sequential writing mode of the EBL origination technique offers an almost unlimited range of possibilities for the generation of security microstructures that can be applied to security documents as specialised “inks”, by direct embossing or as embossed hot stamping foils.

### 7.3.9 Vectorgram™ Image Multiplexing

As a further example of the versatility inherent in the electron beam lithography method for the micromanufacturing of optical security devices we will now discuss the technique of image multiplexing. The Vectorgram™ multiplexing concept (Lee, US patent 6,342,969) is best understood by considering a Pixelgram™ or Exelgram™ microstructure palette as a set of optical field generators. For example a typical palette of 26 elements might consist of two main groups. By element here we mean a 30 micron X 30 micron pixel containing a miniature diffraction grating of curved or straight grooves. Exelgram pixels are

constrained by the requirement to smoothly connect to other pixels vertically above or below in the image. Elements 1 to 10 in a typical palette might consist of horizontal grooves of different spatial frequency; element 1 being of the lowest frequency and element 10 of the highest frequency. These elements are used for the generation of kinematic effects within the image. Elements 11 to 26 on the other hand might have a fixed spatial frequency, but varying degrees of groove curvature between the different elements. This group of 16 elements can therefore be used for positive to negative switch portraiture effects. Two channel effects can be produced by putting pixels of different spatial frequency next to each other in the image or by splitting the pixels in half and using different spatial frequencies in each half pixel. Micrographic effects can be produced with other palettes by putting little pictures into each 30-micron pixel. Different degrees of diffuse scatter between the different micro pictures can be used to generate optically invariable image effects. A two channel Pixelgram or Exelgram palette using split pixels can be regarded as a multi-component pixel palette because each pixel is a generator of two different optical fields.

**Table 7.1.** A summary of Kinegram and Exelgram security elements and optical effects

| Security elements and optical effects | Kinegram™                                                                       | Exelgram™                                                                                         |
|---------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Single source origination             | Yes                                                                             | Yes                                                                                               |
| Origination technology                | Analogue by proprietary laser exposure system                                   | Digital by vector scan electron beam lithography                                                  |
| Technology availability               | Tightly controlled                                                              | Tightly controlled                                                                                |
| IP protection                         | Yes, various patents                                                            | Yes, various patents                                                                              |
| Origination costs                     | High                                                                            | High                                                                                              |
| Microstructure geometry               | Arrays of 60 micron diameter pixels or 60 µm wide lines                         | Based on arrays of 15 or 30 micron wide diffractive tracks with internal groove angle modulations |
| Image resolution                      | 60 micron                                                                       | 30 micron                                                                                         |
| Image brightness                      | Very high                                                                       | High                                                                                              |
| Kinematic effects                     | Yes, observed by rotating OVD about axis perpendicular to the plane of the OVD. | Yes, observed by rotating the OVD about an axis within the plane of the OVD.                      |
| +/- greyscale portraiture             | No                                                                              | Yes                                                                                               |
| Greyscale effects                     | No                                                                              | Yes                                                                                               |
| Sharp colour effects                  | Limited                                                                         | Yes, sharp and highly visible                                                                     |
| Multichannel effects                  | Yes                                                                             | Yes                                                                                               |
| Channel switching speed               | Slow                                                                            | Very fast                                                                                         |
| Diffuse scattering effects            | No                                                                              | Yes                                                                                               |
| Microtext                             | Yes                                                                             | Yes                                                                                               |
| Micrographic effects                  | No                                                                              | Yes                                                                                               |
| Covert image effects                  | Yes. Fourier plane covert image observed under laser illumination               | Yes. OVD plane image observed through coded transparent screen.                                   |

While the total image field generated by the two channels Exelgram may be regarded as a vector object, the local image field (i.e. the image field observed at a particular angle of view) is not a vector object because the two channels are not overlapping at the observer's eye. This is a preferred requirement as it is usually desirable to avoid cross talk between channels so as to generate a fast and clean switch from one image in channel 1 to another image in channel 2. However sometimes it is desirable to deliberately maximise cross talk between channels in order to create new types of optical effects. This multiplexing of optical fields to generate new types of optical effects is the key idea behind the Vectorgram™ process.

The process of arranging different types of optical microstructure elements within a Vectorgram™ pixel in order to cause a combined optical effect at the observer's eye is analogous to the process of combining the elementary directional aspects (Vector components) of a physical field to produce a resultant directional effect (Vector); hence the name Vectorgram™. Two examples of optical effects, which can be generated by this process, are described.

By splitting each pixel of a pixellated diffractive device into three areas corresponding to the red, green and blue components of a full colour image of a face or scene it is possible to create a device, which under point source illumination, generates a reproduction of that face or scene at one particular angle of view. The input artwork here involves three pictures corresponding to the red, green and blue components of the image. Fig. 7.17 shows a small section of a Vectorgram OVD with this type of structure. The area inside the black square represents a pixel of dimensions 30 microns X 30 microns. Each triplet of tracks contains diffraction grating structures of three slightly different spatial frequencies so that a red, green and blue triplet of spectra is allowed to overlap at one angle of view of the observer. The intensity of the red, green and blue components is controlled by varying the width of the pixel tracks according to the intensity required by the input artwork pixel.

In the optically variable device known under the trademark Pixelgram portraiture effects are achieved by mapping the greyscale palette of an image into a palette of miniature diffraction gratings (e.g. each of size 30 microns X 30 microns) where the grating rulings are curved in such a way as to modulate the intensity of the diffracted light in accordance with the level of greyness in the original portrait artwork. Lighter shades of grey correspond to greater degrees of groove curvature and more expansion of the diffracted beam. In the case of the Exelgram technology the modulation of the diffracted light intensity is achieved by varying the angle of the grooves within each grating track.

By combining both groove modulation techniques it is possible to generate optically variable portrait effects with increased brightness and a higher degree of variability in the transition from positive tone image to negative tone as the angle of view is changed. Fig. 7.18 shows a small section of the microstructure of such a Vectorgram portrait structure. A photograph of a corresponding example Vectorgram OVD at one angle of view is also shown. As can be seen from the micrograph, the combination process is a result of interlacing columns of Pixelgram type grating structures with Exelgram type microstructures. Fig. 7.19

shows a comparison of Exelgram positive to negative switching portraiture effects with the corresponding Vectorgram equivalent. Note the increased brightness of the Vectorgram positive tone image when compared to the Exelgram version. In each case the OVD size is 22mm X 22mm.

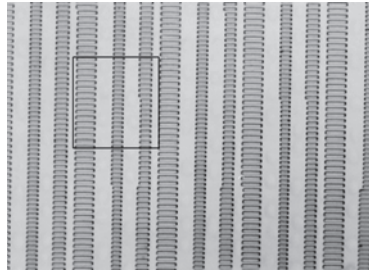


**Fig. 7.17.** Micrograph of a small section of a Vectorgram OVD

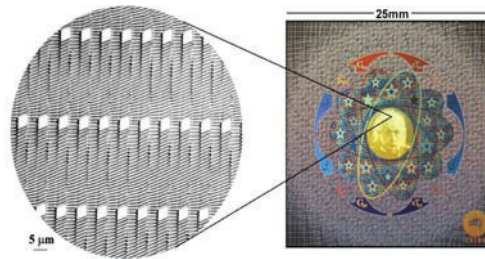


**Fig. 7.18.** Vectorgram microstructure for producing high brightness dynamic portraiture



**Fig. 7.19.** Comparison of Exelgram images (A , B) and Vectorgram images (C , D)

### 7.3.10 Interstitial Groove Element Modulation

In the Pixelgram, Exelgram and Vectorgram scenarios, the techniques for image modulation of the input artwork include groove frequency modulation, groove angle modulation, curvature modulation and combinations thereof. In all of these cases the fundamental modulation unit is the pixel palette element consisting of a fixed number of diffraction grating grooves of particular angles, spacings and

curvatures. However it is also possible to extend the resolution of the modulation unit by considering modifications to the diffracted wavefront due to the “doping” of individual pixel palette elements with particular groove elements. The principle idea (Lee PCT/AU99/00520) here is the concept of using a continuous background groove pattern to generate a diffracted carrier wave and then to modulate this carrier wave with optically variable information by “doping” the background groove pattern with a multiplicity of interstitial groove elements to modulate both the spatial frequency and amplitude from each interstitial groove region according to the requirements defined by the optically invariable input picture information. In particular, the angles of diffraction from any particular interstitial groove are given by the local spatial frequency in that region and this is related to the number of parallel interstitial groove elements in that region. The intensity of diffracted light from the particular interstitial groove region under consideration is proportional to the length, angle, shape and degree of curvature of the interstitial groove elements. Hence the interstitial groove element concept provides a possible mechanism for modulating both diffracted light intensity and diffraction angle at a much higher degree of resolution. Fig. 7.20 shows a small section of an OVD microstructure of this type.

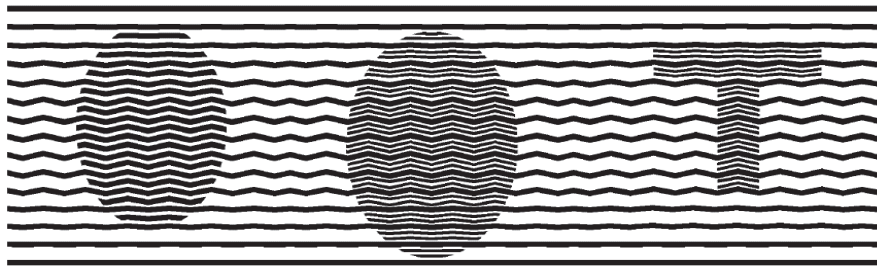


Fig. 7.20. Small section of an interstitial groove element optical security microstructure

## 7.4 Generic OVD Microstructures

The high security foil microstructures described in the previous section can be characterised as belonging to a class of optically variable devices ideally suited to high volume banknote type applications. High volume means volumes greater than 40 million units; all formed using the same OVD image. For these application volumes the high origination costs of the master plate, typically of the order of US\$40,000, can be amortised over the production run resulting in a unit foil price of much less than 1 US cent. For lower volume applications the Kinegram or Exelgram solution is much less cost effective and there is therefore a need for much lower cost solutions outside of the security compromised dot matrix hologram technologies. Three different approaches to this low volume and high security requirement are described.

### **7.4.1 Optically Variable Ink Technology**

One method for increasing flexibility, while retaining security through optical variability, involves the development of liquid media or inks containing microscopic flakes or pigment particles, which are in themselves individually optically variable.

#### ***7.4.1.1 Multilayer Thin Film Pigments***

The US company Flex Products has a long history in the development of products of this type; in particular products based on microscopic thin film flakes which change colour (e.g. from red to green) with changing angle of view due to the cancellation of particular wavelengths and the reinforcement of other wavelengths as the incoming white light is partially reflected and partially transmitted at the boundaries of different layers of different refractive index within each flake (Phillips and Bleikolm 1996). Optically variable pigments of this thin film interference type can be distributed within a transparent liquid to produce a range of optically variable inks. Optically variable inks of this type are used on a wide range of banknotes throughout the world. While the optically variable effect is much simpler (being just a colour change), less pronounced and much more subtle than for conventional security foil patches, the ability of the ink to be used within standard offset printing processes with complete in-house artwork freedom and at relatively low cost (when compared to security foil technology) is a big attraction of the technology for printers with both high and low volume security printing requirements.

#### ***7.4.1.2 Diffractive Ink Pigments and Micrographic Powders***

An alternative optically variable ink technology to the above multilayer thin film pigment can be produced by replacing the multilayer flakes with microscopic flakes in the form of miniature surface relief diffraction gratings. In this case the optical properties of the ink are determined by the diffraction of light from the groove patterns contained within the ink flakes. Arranging the groove spacings within the flakes to have predefined spacings, and also arranging the groove spacings to vary according to some modulation function can control the optical properties of the ink controlled to a much higher degree than with thin film devices (Lee, US patent no. 5912767; Argoitia and Chu 2004).

This higher degree of flexibility is due to the fact that the ink flake microstructures can be varied to an almost unlimited degree by using electron beam lithography to originate the master embossing plate for production of the diffractive flakes. The concept of a security ink based on diffractive flakes or pigments incorporating novel diffraction grating groove patterns originated by electron beam lithography was first proposed several years ago by CSIRO in Australia. More recently the idea has been further studied in the context of printable holograms (Argoitia and Chu 2004).

On a broader front it can be seen that not only are diffractive ink pigments able to be constructed in this way, but also ink flakes or powders based on the incorporation of microscopic micrographic elements as described earlier. This provides a basis for the production of low cost multi-element micrographic powders and pigments suitable for a range of security and track and trace applications. Mixing together two or more single element micrographic or diffractive powders selected from a palette of 26 or more individual single element powders can be used to create a range of personalised powders for scattering on documents or products to link the item to the owner or user. For example, imagine a micrographic powder palette consisting of 26 elements, where each micrographic element is a letter of the alphabet approximately 3 microns in height. For each letter (e.g. "A") a master embossing shim (comprising a repeating pattern of the letter, e.g. "A", over a fixed area) is produced by electron beam lithography and electroplating. The embossing shim is then used to emboss 6 or 7-micron diameter polymer beads in a roll or stamping type embossing press with an area of polymer powder particles being impressed with the letter (e.g. "A") via the rolling or stamping process. When this process is repeated with each of the 26 letters of the alphabet we will have 26 powders to use as the basis for the construction of the multi-element powders. The number of possible multi-element powder combinations is very large. In fact a little mathematical analysis shows that a micrographic powder palette of N elements can generate  $2^N - 1$  combination powders. The Table 7.2 shows examples of combination powders for the alphabet micrographic palette. Hence a 26 element micrographic powder palette can produce more than 67 million individual combination powders; enough to service over 67 million customers with their own micro ID signature for protecting their documentation and assets. Optical pigments constructed in this way can also be used to trace particular types of dangerous materials such as explosives.

**Table 7.2.** Micrographic powder combinations for the alphabet micrographic palette

| Palette elements | Micrographic elements | Powder combinations                                          | No. of powder types       |
|------------------|-----------------------|--------------------------------------------------------------|---------------------------|
| 1                | A,                    | A                                                            | 1                         |
| 2                | A, B                  | A, B, AB                                                     | 3                         |
| 3                | A, B, C               | A, B, C, AB, AC, BC, ABC                                     | 7                         |
| 4                | A, B, C, D            | A, B, C, D, ABCD, AB, AC, AD, BC, BD, CD, ABC, BCD, CDA, ABD | 15                        |
| 5                | A, B, C, D, E         | .                                                            | 31                        |
| .                | .                     | .                                                            | .                         |
| 26               | A, B, C, ..., Z       | .                                                            | $2^{26} - 1 = 67,108,863$ |

#### 7.4.2 Diffractive Data Foils

Foil based data storage systems for financial transaction and other types of applications have been in use around the world for many years now. Every credit

card carries on its reverse side a 1 cm by 9 cm magnetic foil stripe containing information pertaining to the user so that financial transactions can be carried out within the retail sector and for financial transactions at automatic teller machines (ATM) and electronic funds transfer point of sale (EFTPOS) terminals. The problem is that unscrupulous operators using hand held “skimming” devices or other more sophisticated data retrieval systems easily copy the information on the magnetic stripe. Once the information is collected it can be used to construct counterfeit credit cards for use in electronic theft and ID fraud applications. Because of this data-counterfeiting problem there is a need for more secure personal data storage technologies, which are both user friendly and open to network applications. Various innovative concepts have been proposed to increase the level of counterfeit difficulty. Some of these new technologies, including Valuguard<sup>TM</sup> and Xsec<sup>TM</sup> aim to increase security by making use of the inherent properties, such as noise and data jitter, within the mag stripe. Other proposed solutions make use of the security characteristics offered by OVD microstructures. Two of these OVD based data protection solutions are described.

#### **7.4.2.1 Holomagnetic Data Storage**

One such OVD technology based solution is the holomagnetic stripe technology developed by the company American Bank Note Holographics of the US and Leonhard Kurz GmbH. Holomagnetics uses a special machine readable holographic overlay on top of a magnetic stripe. The distribution and registration of the holographic pattern is unique to each card and is read and represented by a characteristic number stored on the magnetic stripe. A special reader can read the holographic pattern and calculate a corresponding pattern and compare with the number stored. Only when a match is confirmed is the financial transaction allowed to proceed via the normal magnetic stripe reading and comparison process.

#### **7.4.2.2 Pixelgram Optical Pulse Sampling (POPS)**

POPS is a secure data storage technology that unlike the magnetic stripe component technologies discussed above, uses diffractive microstructures for both the data storage process and the authentication process (Lee, US patent no. 5811775). POPS uses the concept of continuous foil patterns of Pixelgram and Exelgram diffractive microstructures which, under laser illumination, generate unique diffractive signature beams that can be machine read by photodetectors programmed to recognise and accept only beam intensity profiles of a unique predetermined envelope structure. Data is encoded into a POPS foil stripe by erasure (e.g. by laser ablation) of the diffraction grating microstructure within small cellular areas across and down the strip. This has the effect of sampling the diffracted light pulses in a manner characteristic of the information stored within a pulse. The highly unusual diffraction signatures determine the security value of the POPS system or pulse shapes which can be generated by novel diffraction grating microstructures fabricated by the electron beam lithography process. For

example a typical POPS data storage palette might consist of a set of 8 Exelgram type-grating microstructures of different groove slopes. Three elements of this type of palette are shown in Fig. 7.21. Micrograting structures such as those shown in Fig. 7.21 can be used to control the intensity of the diffracted light. Intensity is measured by a photodetector positioned to collect light from a straight line grating of the same underlying spatial frequency as the micrograting palette elements.



**Fig. 7.21.** Examples of POPS palette elements

Fig. 7.22 shows how a palette of such microgratings can be used to design 8 bit pulse shapes into which binary data can be encoded by the erasure (by laser ablation) of particular pulse palette elements. The data readout system for the POPS system is shown schematically in Fig. 7.23. Greyscale areas represent microgratings of particular groove curvature. Fig. 7.23(b) is an example of a pulse signature grating structure. Micrograting areas can be as large as required and the data storage capacity is a function of POPS stripe length and data redundancy required.

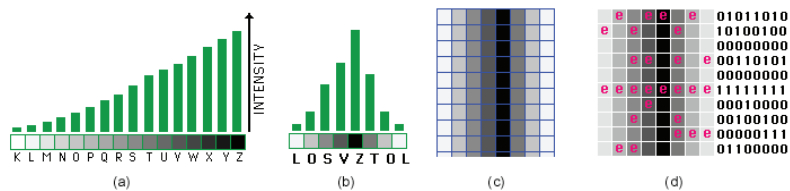


**Fig. 7.22.** (a) POPS palette (b) Example of a pulse signature grating structure (c) Section of unencoded POPS strip. (d) POPS strip and 8 bit byte structure after data encoding by laser erasure in cells labelled “e”

In this arrangement the POPS stripe replaces the magnetic stripe on the back of the credit card and the laser scanning system is built into the Automatic Teller Machine (ATM) or the point of sale card. This carding reading requirement creates a problem, which applies, not just to the POPS system, but also to all alternative technologies to the current magnetic stripe system. This is the problem of embedded infrastructure; that is, the current installed base ATM machines, etc. Changing the data storage technology on the card also requires a change in the card reading infrastructure and this is a significant cost barrier to the introduction

of new technology. The inherent security characteristics of this optical data storage system is determined by the unique pulse shapes or signatures which can be constructed using micrograting palette elements incorporating grating groove structures of very unusual configuration. These grating structures can only be originated using electron beam lithography origination systems and this origination technology by nature of its complexity and expense acts as a further barrier to the counterfeiter wishing to emulate the characteristics of the POPS system.

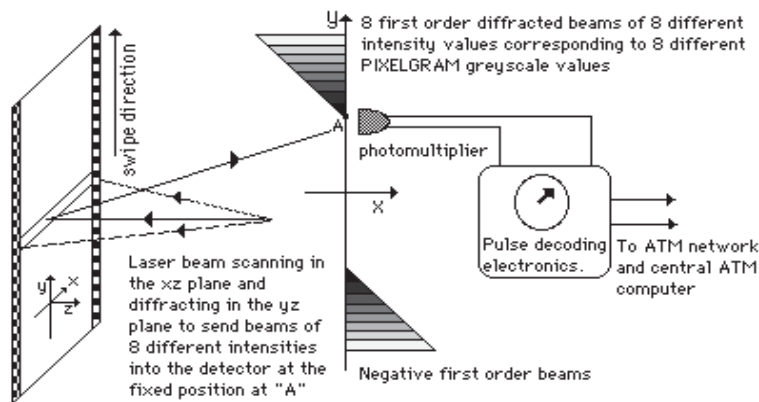


Fig. 7.23. POPS data readout system

### 7.4.3 Biometric OVD Technology

While the problem of ID fraud due to the counterfeiting of personal identification documentation has always been with us, this issue is now receiving much more attention from document issuers and law enforcement agencies due to the rapid escalation of financial losses related to this area of criminal activity. For example, in the UK, ID fraud costs more than 1.3 billion pounds per year with over 100,000 people directly affected in the process. Furthermore, multiple or false identities are used in more than a third of terrorist related activity and in organised crime and money laundering (www.standards.com.au, 2003).

In Australia, the situation is similar with financial losses due to ID fraud in 2002-2003 amounting to over \$1.1 billion. There is therefore a need for improved levels of security for documents related to the legitimate identification of individuals for travel, access control and other purposes. Current ID document protective technologies include the traditional features of intaglio printing, watermarked paper, screen angle modulation printing as well as some relatively recent technologies such as the use of optically variable devices in the form of hot stamping foil patches or transparent overlays. While the use of OVDs in these two forms has certainly improved the security of ID documents, there is still a risk

associated with altering the identity information without changing the other security features (e.g. by temporarily peeling away the transparent OVD overlay and replacing the photograph of the ID document holder with that of another individual).

The linking personal biological information associated with the ID document holder (e.g. iris scan information, fingerprints, etc. (Ashbourn 2003) to the document in a much more secure fashion is of course possible using electronic data storage methods such as chip cards. However this method requires machine authentication of the document and this requirement limits the utility of this method for protecting the document; e.g. on the spot visual authentication by field personnel is not possible without field portable equipment. As well as issues associated with expensive authentication infrastructure and equipment, there are also issues here related to individual privacy and the safeguarding of the document holder's biometric information and ensuring that this information is not made available for other purposes outside of its intended ID document use.

With the above background in mind, it can be seen that there is a need for an ID document solution, which links the visual image of the document holder to an OVD solution, which is unique to that individual. While this is possible using current OVD technologies such as Exelgram, the cost of such an application would be prohibitive in the extreme because an OVD origination would need to be produced for each document holder. However there has recently been developed an alternative and much lower cost method for achieving a similar result.

In its simplest form the biometric OVD concept (Lee 2004; McCarthy 2004) involves firstly originating a generic diffractive microstructure consisting of only two different groove spatial frequencies. This is illustrated in Fig. 7.24 for the case of a track based OVD such as Exelgram. In this case every even numbered track contains a grating microstructure of a fixed spatial frequency, while every odd numbered track contains a grating microstructure of a different spatial frequency to the even numbered tracks. This generic micrograting array forms the blank OVD canvas. After production of the corresponding embossed hot stamping foil, the security documents are prepared by hot stamping individual generic foil patches onto these documents. In this way all ID documents can be prepared prior to the inclusion of the ID information. The encoding of the image data into the blank OVD canvas to produce a two channel OVD now takes place via the following procedure. First, a portrait of the document holder is obtained and converted into a gridded and binary dithered image as shown by the example in Fig. 7.25 (A). Then a similar procedure is used to prepare the image chosen for the second channel of the OVD as shown by way of example in Fig. 7.25(B).

Finally the two binary dithered images are interlaced into a set of tracks where the even numbered tracks contain the dithered image of the document holder and the odd numbered tracks contain the image data of the second channel image. The resultant image pattern is shown in Fig. 7.26. The preparation of this two channel image data is carried out by special software and is effectively instantaneous following the image capture of the ID document holder's face.

The encoded two channel image data file is now used to control the operation of a laser exposure or ink jet printing system which scans the blank generic OVD

canvas on the ID document and modifies the reflectivity of the grating pixels at selected locations according to the form of the image data file. The resultant OVD produces an image of the ID document holder at one angle of view and also replays the second channel image at a different angle of view corresponding to diffraction from the second set of micro grating pixels. These two images are shown in Fig. 7.27. Fig. 7.28 shows an example of an experimental biometric OVD produced in the manner described above. Note that the method described above for producing a diffractive biometric OVD structure involves an in-register modification of the diffraction properties from pre-selected micro grating pixels aligned in parallel tracks.

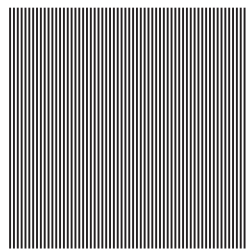


Fig. 7.24 Biometric OVD canvas

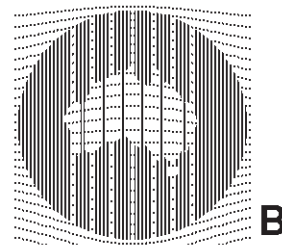
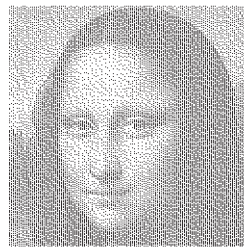


Fig. 7.25 Channel 1 input image (A) and channel 2 input image (B)

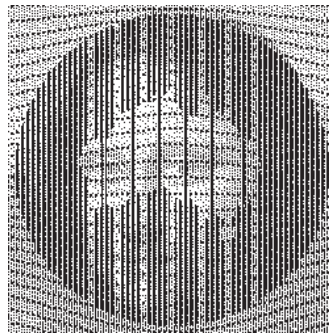


Fig. 7.26. Combined channels input data file for biometric OVD



Fig. 7.27. Biometric OVD image at two different angles of view

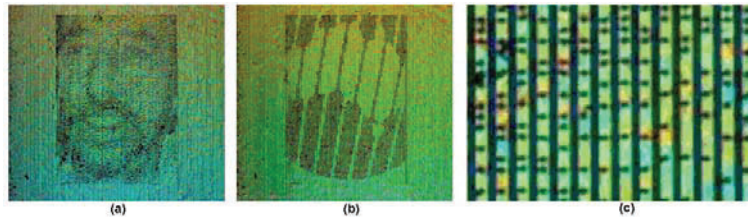


**Fig. 7.28.** Experimental biometric OVD image (of size approx. 6 mm X 10 mm) at two different angles of view (a), (b) and a magnified view of the laser ablated Exelgram track structure (black spots) for one of the channels (c). The black stripes in (c) correspond to the second channel, which diffracts at a different angle of view.

Using this structure the interlaced double image information is initially scrambled by the data encoding process and then decoded or unscrambled by the two angle micro grating array. The method can be regarded as a subtractive OVD origination method in contrast to current diffractive origination methods where both the OVD microstructure and the project specific artwork or image information is required to be originated within a single process. By separating the optically variable microstructure information from the project specific artwork information into two processes involving a generic microstructure origination step and a low cost data-encoding step a personalised OVD imaging process can be achieved. Personalizing the microstructure by subtractive modification of individual micro grating pixels by laser ablation or ink jet printing is the low cost per unit part of this process. Origination of the generic two channel OVD canvas and the production of the corresponding embossed hot stamping foil is of a similar cost to conventional OVDs.

## 7.5 NanoCODES

All of the optically variable device technologies described in sections 1 to 3 above have one thing in common. They all use embossed hot stamping foil as the transfer medium for attaching the optical microstructure to the security document requiring protection from counterfeiting. However foil based OVD technology, while in standard use throughout the world today on more than 70 different types of banknotes, is not regarded by security printers as the most preferred protection measure for security documents.

Firstly the foil basis of the technology requires a separate foil production facility and this reduces security, due to the risks associated with the transporting of the security foil to the security printing plant, and adds to production costs because of the need for specialised equipment for hot stamping the foils onto the security document. Secondly, and more recently, a new problem has arisen due to the inherently uncontrolled nature of holographic and diffractive OVD technology and some of its optical effects. Counterfeiters can now buy sophisticated dot matrix (Lee CK et al. 2000) master plate origination technology off-the-shelf so to

speak and can also buy the necessary foil embossing and hot stamping technology from other sources. Thirdly the diffraction grating basis of OVD foils has an inherent problem due to the periodic nature of the grating groove structures in most of these devices. The more periodic the grating structure the greater the possibility of holographic copying (McGrew 1990) of the microstructure using holographic contact copying techniques. Counterfeit banknotes are already starting to appear with counterfeit OVD foils attached (Holography News, 2004; Renesse 2004). While the quality of these counterfeits is at present very poor, it is only a matter of time before more sophisticated versions appear. These new threats have given impetus to the search for much more sophisticated diffractive optical security microstructures and more sophisticated origination technologies. Electron beam lithography origination is now the increasingly preferred fabrication process (Tethal 2004) because of the more complex and secure specialised optical effects able to be produced by this process and the increased resistance to holographic contact copying due to the ability of these systems to produce curved and variable spaced grating groove structures. Holographic systems are unable to create microstructures, which generate these more specialised optical effects preferred by the security printing industry. However there is a view within the industry that a more fundamental change is required in order to provide a much greater degree of document security. This view includes a preference for a new OVD technology which eliminates the need for foil, is well differentiated in optical effects from the diffractive foil technologies and has sufficient microstructure depth to allow for more cost effective direct printing of the OVD microstructure onto the security document using an in-line printing process. Importantly, associated with the above required paradigm shift in thinking is a further requirement that any new origination process must involve technology which is much less accessible to the counterfeiters.

In this section we will address these issues by describing a new approach to the design of optically variable devices (OVDs) for anti-counterfeiting applications. In particular we shall address the range of problems related to improving the security and differentiation of OVD optical effects, in-line replication of the resultant image and lowering the overall cost of the OVD replication process while at the same time creating an origination process much less accessible to organised counterfeiting groups. In order to accommodate the broadest possible range of optical microstructure types, including the pre-existing diffractive types discussed above, as well as new reflective and refractive mechanisms and combinations of reflective and diffractive versions thereof, we will introduce a new umbrella term which also defines the principal area of application of these devices as relating to document security. The term NanoCODES (Nanofabrication of Cellular Optical Device Encryption Surfaces) is the proposed generic descriptor for this new approach as it emphasises that the main objective of this type of research is to find mechanisms for the coding of easily recognisable images into an optically variable form in a manner which is both secure from copying and simulation and easily recognisable by the general public as an authentication feature. One particular subset of NanoCODES devices of course relates to the diffractive devices

discussed in previous sections. The second subset, which we will discuss, is based on devices consisting of arrays of micromirror optical elements.

### 7.5.1 The Micromirror OVD

The most important step change underpinning the new OVD approach is the replacement of micro diffraction grating elements within the OVD architecture by arrays of micro mirror elements (Lee, patent application no. PCT/AU02/00551). Optical micromirror array devices will be shown to offer the best hope of creating OVDs with sufficient microstructure depth to allow for direct printing onto the document substrate via the use of specialised reflective inks. The objective here is to do away with the current practice involving the costly intermediate step of producing an embossed hot stamping foil as the carrier of the OVD microstructure.

In the case of diffractive OVDs the diffraction grating groove spacings must be of the order of the wavelength of light in order for diffraction effects to take place. The depth of the grooves is related to the spacing by nature of the origination process, whether by electron beam lithography or laser interference techniques, and this limited groove depth capability (usually much less than 1 micron) is the main reason diffractive OVD microstructures are unable to be printed by normal printing techniques. The roughness of the substrate surface is normally of much greater depth than the surface relief of the diffractive microstructure. Micro mirror devices on the other hand are not so limited in their microstructure depth characteristics. For example a micro mirror array of 60 micron square micro mirror pixels inclined at an average angle of 30 degrees to the horizontal would have an average microstructure depth of  $60\sin(30) = 30$  microns. It is this greatly increased depth characteristic that holds out the promise of being able to produce OVD microstructures which can be directly printed. The development of passive micro mirror arrays with the above dimensional requirements can be achieved by combining the palette based cellular origination process used for diffractive OVDs with the well-known techniques of greytone lithography.

Greytone lithography is a technique for producing high-resolution microstructures with quite complex surface profiles and significant depth dimension. The process starts with the production of a variable transparency mask by electron beam lithography techniques. This mask is then typically used in an optical projection system to transfer the variable transparency distribution into a variable exposure distribution on a thick optical resist layer. Development of the exposed resist then yields a surface relief microstructure with a depth distribution corresponding to the distribution of transparency on the mask modified by the transfer function of the optical projection system and the exposure characteristics of the optical resist. The greytone lithography technique has been successfully applied to the fabrication of many different types of complex 3D high-resolution microstructures (Purdy 1994; Reimer et.al. 1997; Gimkiewicz et al. 1999; Kuddryashov et al. 2003). Examples include Fresnel lens array structures, blazed

gratings, micropism arrays for optical interconnects and greyscale structure formations in general.

The graytone lithography technique can also be applied within a cellular array format to create palette based imaging structures. Because the set of fundamental microstructure elements of the cellular array is finite in number it can be regarded as a palette of greytone elements in an analagous manner to the RGB palette of a computer graphic image. Because of this analogy with the elements of a conventional colour palette this extended greytone lithography technique has been given the name “Colourtone Lithography” (Lee 2002). Further, investigations into this new colourtone lithography technique have been carried out by Leech and Zeidler (Leech and Zeidler 2003) with the aim of understanding the optical lithography exposure conditions required for increasing the depth of the microstructures. Recently further work has been undertaken to investigate the optical reflection and imaging properties of cellular greytone structures and to investigate the direct printing capabilities of these novel cellular array microstructures (Lee 2004).

### 7.5.2 Origination of a Micromirror OVD

A typical micro mirror array OVD microstructure may contain up to one million micro mirrors of dimensions 60 microns X 60 microns or less with each mirror arranged at a predetermined angle according to the input picture information.

The procedure for producing a micromirror OVD involves two main phases – production of an image specific mask by electron beam lithography and the use of that mask within a photolithography exposure system to produce the required micromirror surface relief structure within a thick optical resist layer. The micromirror printing die is then formed by the electroplating of this optical resist layer to produce a hard nickel tool. The details regarding this origination process may be described as follows.

#### 7.5.2.1 Greytone Palettes

The simplest type of greytone palette is one where each palette element corresponds to a fixed “shade of grey”. The mask element corresponding to each palette element in this case consists of a uniform distribution of micro apertures with the micro aperture sizes varying between the greytone palette elements to give the different exposures. However a much more versatile lithography concept can be conceived by allowing each greytone palette element itself to have a variable microaperture distribution within the greytone pixel area. This is the basis of the “Colourtone Lithography” concept mentioned previously. In analogy to the standard greytone technique this new process involves the fabrication of a variable transparency mask by electron beam lithography and wet or dry etching followed by the use of this mask to profile a photoresist surface by means of a photolithography process. However in contrast to a greytone mask the “Colourtone Mask” is a pixellated array of individual mask pixel elements, where

each mask pixel is typically of size 30 microns X 30 microns or 60 microns X 60 microns, and is a member of a finite set of mask pixels (“Mask Palette”) of different transparency distribution. Secondly the distribution of mask pixels within the pixellated array is controlled by a colour coded input “Picture File” where each colour coded pixel or “RGB Pixel” of the picture file is a member of an “RGB Pixel Palette” and each member of the RGB palette is in one to one correspondence with each mask pixel of the mask palette. An example of an RGB picture palette and corresponding 3D microstructure palette is shown in Fig. 7.29. Not shown in Fig. 7.29 is the intermediate phase variable transparency mask palette, which generates the 3D pixel elements through exposure of the mask elements in an optical lithography system. This process modulates the optical transparency distribution of each mask palette element by both the transfer function of the optical system and the exposure properties of the optical resist. Hence calculation of the required mask palette for a given 3D pixel palette involves a similar functional relationship in the optics and resist technology to that used in conventional or non-palette greytone lithography. The colourtone lithography concept can therefore be seen to allow for the fabrication of complex microsurface structures containing a finite set of elemental 3D microsurface structures. An example of a four-element artwork palette, mask palette and corresponding microstructure palette, which can be used to construct a micro mirror device, is shown in Fig. 7.30.

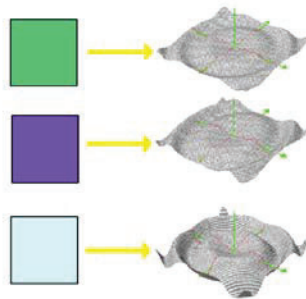


Fig. 7.29

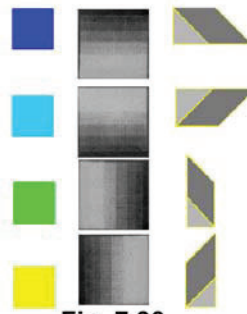


Fig. 7.30

### 7.5.2.2 Micromirror Two Channel Switch Effect

As an explicit example of the use of the colourtone lithography technique to construct an optically variable micro mirror array, consider the artwork sample shown in Fig. 7.31. To create an optically variable microstructure version of this artwork we simply map the interlaced rows of light and dark pixels, representing the euro and “50” symbols respectively, into corresponding interlaced rows of micro mirrors of different slopes. Then when the surface relief microstructure is rotated about an axis parallel to the rows of interlaced micro mirrors the euro or “50” symbol will alternatively reflect light to the eye depending on which set of micro mirrors is aligned for maximum reflection.

To construct the device the artwork of Fig. 7.31 is converted into a corresponding pixellated greytone mask element array by palette based electron beam lithography techniques whereby each light and dark artwork pixel is replaced by the corresponding mask palette elements shown in Fig. 7.30. For the background area in Fig. 7.30 the artwork pixels are mapped into a mask pixel element (not shown in Fig. 7.30) corresponding to a diffuse scattering microstructure element. ZEP 7000 is used as the electron beam resists and the pattern is exposed at 35 microcoulomb/cm<sup>2</sup> in a Leica EBMF 10.5 electron beam lithography system. After development of the plate a mask is produced by reactive ion etching in a Cl<sub>2</sub>/O<sub>2</sub> plasma.

The variable transparency colourtone mask corresponding to Fig. 7.31 is then placed in a one to one mask aligner and used to expose a 30-micron thick layer of optical resist to the variable exposure pattern created by the mask. After development the optical resist surface is electroplated to produce a highly reflecting hard nickel surface replica of the device. Fig. 7.32 shows an optical micrograph of a small section of an experimental micro mirror microstructure produced in this way. Rows of micromirrors of opposing slopes can be seen here. In this particular case each micromirror has a dimension of 30 microns X 30 microns and therefore the total width of the micrograph is approximately 165 microns. Fig. 7.33 shows experimental images of the optically variable switch effect produced by the artwork shown in Fig. 7.31.



Fig. 7.31

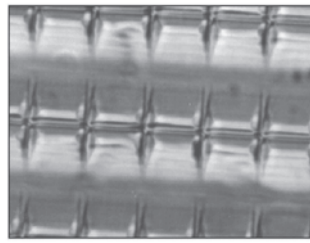


Fig. 7.32

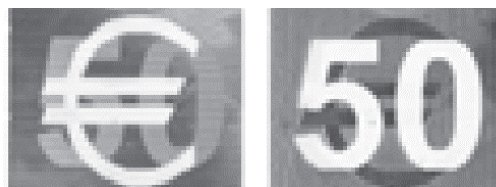


**Fig. 7.33.** Images of an experimental micromirror optically variable device at two angles of view showing the corresponding images embedded into each channel using the artwork configuration of Fig. 7.30 and the micromirror palette shown in Fig. 7.31

This example shows that two channel image switching is readily achieved within a micromirror framework by forming the individual channel images from micromirrors of different slopes and then interlacing these columns or rows of

differently sloping micromirrors so that both images overlap each other within the same OVD area. Image separation is then achieved by the different reflectances of the two groups of micromirrors as the angle of view or the angle of illumination of the device is changed.

### 7.5.2.3 Optically Variable Portraiture using Micromirror Arrays

In the case of portraiture effects a micromirror mechanism is needed which modulates the degree of brightness of a micromirror pixel within a portrait image as a function of position within the portrait in accordance with the greyness value of the corresponding pixel within the input artwork. There are two possible mechanisms for achieving this variable intensity pixel behaviour. The first possibility is to fix the average slope of the micromirror pixels corresponding to the portrait image while also varying the curvature of the micromirror pixel surfaces so that the light is reflected into an expanding cone of light, only part of which is intercepted by the eye at any one angle of view. In this scenario variable degrees of surface curvature represent the different shades of grey within a portrait image. In practice this type of intensity modulation mechanism is very difficult to achieve because of the inherent difficulty in the micro sculpturing of such small surface areas using greytone lithography techniques. An alternative, and much simpler technique is to modulate the reflected light intensity by varying the area of the micromirror surface. Fig. 7.34 shows 4 elements of a 16-element portraiture mask palette corresponding to a 16-element grayscale portrait palette. White areas correspond to the areas of greatest light transmission within the mask elements. Therefore the top parts of the mask pixels will generate the greatest intensity of exposure during the photolithography part of the origination process. The corresponding areas on the photoresist will therefore have the greatest depth after development and the resulting micromirror pixels will consist of micromirrors sloping downwards from bottom to top (using the orientation of the pixels shown in Fig. 7.34). By interlacing these portrait type micromirror pixels with a different image comprised of micromirrors sloping in the opposite direction we can create a two channel micromirror OVD with a portrait image in one channel. Fig. 7.35 shows a photograph of an example of such a micromirror OVD.

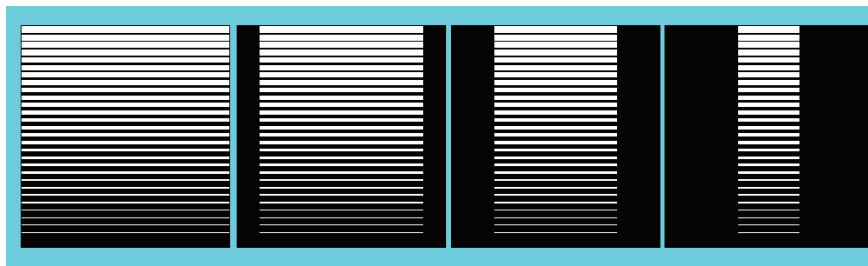


**Fig. 7.34.** 4 mask elements of a 16-element micromirror portrait palette used for modulating the reflected light intensity within micromirror portrait image OVD

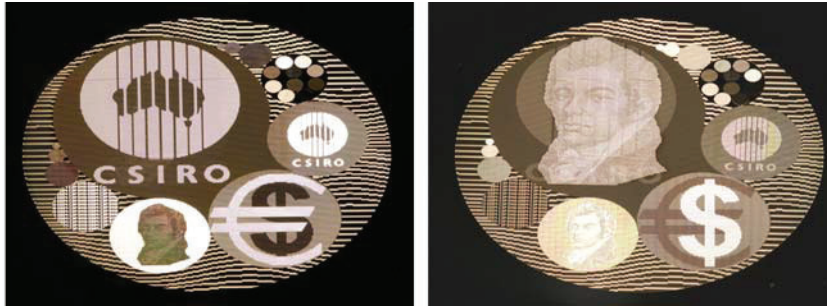


**Fig. 7.35.** Photographs of the images generated by a nickel shim containing a two-channel micromirror OVD with a grayscale portrait image in one channel. The diameter of the OVD is 36 mm

### 7.5.3 Summary of Micromirror OVD Optical Effects

From the above examples it can be seen that micromirror optically variable devices can generate various other optical effects. In fact it can be shown that there exists an isomorphic relationship between diffraction and reflection effects generated by diffractive and reflective OVDs respectively. In both cases the diffracted or reflected optical fields are described by gradient mapping equations with respect to the optical phase function generated by the microstructure. The main differences between the two systems relates to the presence of the wavelength and order number parameters in the diffractive case. Diffractive OVDs differ from reflective OVDs through the presence of colour effects and multiple diffraction orders. Except for these differences we can map all of the usual optical effects associated with diffractive OVDs into an equivalent set of optical effects produced by reflective OVDs. Table 7.3 compares and summarises the different mechanisms for achieving particular optical effects within the two OVD scenarios. A particular advantage of the micromirror OVD concept relates to the relatively large angular separation between channels (sometimes of the order of 120 degrees). Since there is only one propagating order for each channel in the micro mirror case, micro mirror OVDs are likely to be far less sensitive to crumpling of the paper surface in comparison to diffractive OVDs where the degree of cross talk between different channels due to both multi order propagation and relatively small angular differences (e.g. 30 degrees) between channels often causes the individual channels to be separately unobservable after crumpling of the paper surface. Another interesting aspect of this type of security microstructure is its ability to be used as an embossing tool for transparent substrates; such as polymer banknotes. In this case the micro mirror structures become micro prism arrays and the image becomes an optically variable watermark in transmission; that is, looking through the transparent substrate at a light source we observe an image switch as we move the transparent device from above the light source to below the light source.

It is also clear from the above discussion and the isomorphic relationship between the optics of diffractive and reflective pixellated arrays that the micromirror OVD concept easily lends itself to the creation of generic OVD substrates for application in the area of biometric OVD technology. A diffractive version of this technology was described in section 7.4.3 above. If we replace the two channel Exelgram structure by a generic two channel reflective micromirror structure then all other aspects of the biometric OVD concept can be carried over to the micromirror case (including the laser written data encoding process) with the result that a personalised direct print version of the technology can be created.

It can be seen from the example described in the previous section that the biometric OVD concept can also be applied to the storing of bar code data in a very secure manner. Since a bar code is simply a picture of black and white bars of different widths organised into a particular sequence, we can imagine using two different bar code images as channel 1 and channel 2 images encoded into an interlaced sequence according to the method described earlier. The bar code reader is then presented with two bar codes to read at two different angles of view and modified software within the reader correlates the two pieces of bar code data to determine the authenticity of the object carrying the two channel bar code. For example, an ID card or passport could include both a biometric OVD image of the document holder for visual authentication and an OVD bar code containing other data pertaining to that individual. In both cases the data is written onto the document at the time of issue using the subtractive data encoding method described in the previous section. In a similar manner to the biometric OVD case it can be seen that the micromirror origination process can also be used to produce a reflective version of the POPS data storage system discussed in section 7.4.2. In the case of micromirrors the data palette is constructed from micromirror pixels of variable micromirror width and the signature pulse reflected from the printed micromirror strip is constructed from sets of 8 micromirror areas of different reflectivity corresponding to different micromirror widths. The data encoding process in this case is similar to the diffractive case in that destroying the reflectivity of particular micromirror areas by laser ablation creates a binary "1", the unerased areas being binary "0"s.

In concluding this section it should be mentioned that, while we have focused the discussion on the use of a generic micro mirror array as the underlying OVD microstructure, similar biometric OVD and personalised data encoding techniques can be applied when the underlying generic OVD microstructure takes the form of a transparent film embossed with a generic micro mirror surface relief structure to create arrays of micro prisms corresponding to different angles of refraction of the transmitted light. In this case the images are viewable in transmission at two different angles of view, thereby creating an optically variable watermark effect. In this case of course no reflective ink need to be applied to the substrate to view the images. It can be seen that the encoding of the data onto this film substrate can be carried out using similar in-register laser ablation techniques in order to modify the refractive properties of individual prism pixels. In fact, in this case of course, the laser ablation process changes the individual micro prism pixels into diffusely transmitting pixels.

**Table 7.3.** Comparison of diffractive and reflective OVD optical effects

| Optical property              | Diffractive pixel OVD                                                                                                                                                                            | Reflective pixel OVD                                                                                                                                                                                        |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Resolution dependence.        | Determined by diffractive pixel dimensions                                                                                                                                                       | Determined by micro mirror pixel dimensions                                                                                                                                                                 |
| Palette structure             | Comprised of a finite set of diffractive pixels of different grating groove spacings, modulations, curvature and groove orientations.                                                            | Comprised of a finite set of micro mirror pixels of different mirror angles, curvatures and orientations.                                                                                                   |
| Multi-channel image switching | Produced by using adjacent diffractive pixels of different spatial frequency                                                                                                                     | Produced by using adjacent micro mirrors of different mirror slope angles.                                                                                                                                  |
| Microtext                     | Produced by constructing letters out of diffractive pixels of the same type                                                                                                                      | Produced by constructing letters out of micro mirror pixels of the same angle slope and orientation.                                                                                                        |
| Right angle effects           | Produced by using adjacent diffractive pixels with grooves orientated at 90 degrees to each other.                                                                                               | Produced by using adjacent micro mirror pixels with mirror slopes orientated at 90 degrees to each other.                                                                                                   |
| Covert image effects          | Produced by interlacing a positive and negative version of the same image, where the positive image diffractive pixels have different groove curvature to the negative image diffractive pixels. | Produced by interlacing a positive and negative version of the same image, where the positive image micro mirror pixels have different mirror curvature or width to the negative image micro mirror pixels. |
| Movement effects              | Produced by filling adjacent areas of the OVD with diffractive pixels of different special frequency.                                                                                            | Produced by filling adjacent areas of the OVD with micro mirror pixels of different micro mirror angle.                                                                                                     |

## 7.6 Conclusions

In this chapter we have reviewed the specialised area of micromanufacturing and nanotechnology as applied to the fabrication of optical security microstructures. In particular we have discussed in detail the specific area of optically variable devices and the advantages offered by the electron beam lithography method of manufacturing these devices. While the growth of development and adoption of foil based OVDs during the 1990's has certainly resulted in improved protection against counterfeiting, the need for more application specificity, particularly in the

ID document area, reduced costs in both origination and replication and 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 producing 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 organised and more technically focussed we can expect security printers and their associated technology suppliers to become much more R&D focussed in meeting this evolving threat from the counterfeiters. Current thinking within the industry now accepts the need to upgrade document security on a regular five-year basis and therefore we can expect that micromanufacturing and nanotechnology R&D for document security will become a growing area.

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