ROYAL AUSTRALIAN MINT AND COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION (CSIRO)

NEW METHOD OF PRODUCING OVD COINS

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Introduction

Hologram coins have become one of the most technically advanced forms of numismatic product. In these silver or gold coins, a relief microstructure designed to provide a diffractive image has been impressed into a selected area of the surface. In most cases, the holograms have comprised an array of small, dot-shaped or "dot matrix" diffractive elements which were generated by laser interferometry. The interference lines contained within each of the dots have been created with a fixed period and orientation by configuration of the laser beams. The resulting hologram coins have been characterized by a bright, iridescent colour with the display of either a 2 dimensional artwork image or a 3 dimensional holographic object.

The Royal Australian Mint has issued three hologram coins, each highlighting a theme of national significance. The first issue in 2001 was the Centenary of Federation "Finale" Coin which commemorated the foundation of the Australian nation. The coin featured a unique switch effect between two images with change in viewing angle of the coin [1]. This was the first example of an OVD (optically variable device) coin using the complex and finer microstructure generated by electron beam lithography. The image switch in the OVD was encoded using a two channel effect in the fine diffracting grooves in the structure [2]. Other advantageous features of the optically variable device have included a sharper definition of shapes than with a hologram and the ability to assign specific iridescent colours throughout the image. The second OVD coin issued by the Royal Australian Mint was a celebration of the "Year of the Outback" (2002) and featured the Olgas Mountain range in Central Australia. The OVD in this coin was designed to mimic the legendary change in colour of the mountain range and sky during the passage of daylight as simulated in the coin by altering the viewing angle. The third issue of an OVD coin was a commemoration of the "Year of the Volunteer" (2003). In the Volunteer Finale coin, the OVD image has depicted the role of service groups in the Australian community and also featured an optical switch. All three coins have used the OVD origination process developed by CSIRO in which the diffraction pattern was written with the high resolution of electron beam (e-beam) equipment.

In this paper presented at the XXIII MDC, we describe the "Kangaroo" OVD coin which has been produced in an aluminium bronze alloy. The manufacture of the "Kangaroo" coin has used a unique new method developed by CSIRO and the Royal Australian Mint. This method has enabled the application of an OVD onto the surface of non-precious or base alloys.

Diffraction in OVD Coins

The surface relief structure in an OVD was comprised of a series of very fine diffracting grooves. The image or picture has been encoded into the OVD by varying the individual groove angles and/ or spatial frequency between the 30 μm wide tracks. In particular, the spacing of the grooves was selected from a range of 10 different levels in order to give distinctive colours in the diffracting image. Figure 1 has shown an example of a groove structure which was typical of the OVD image in the coin.

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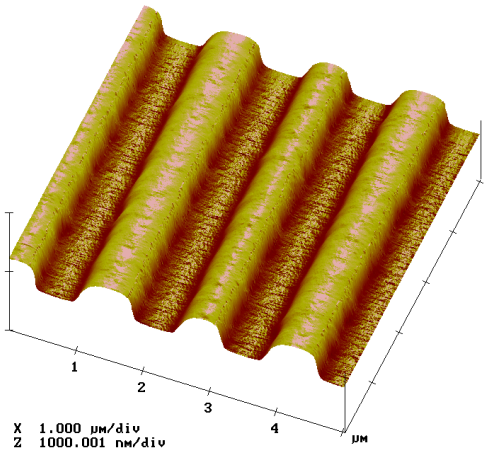

Figure 1. Example of the groove structure in the OVD image as characterized by scanning probe microscope.

A beam of light incident on the surface of this type of grating has produced phase reinforcement at path differences equal to a whole number of wavelengths, λ. The angle of diffraction was determined by the order, m, and groove spacing, d. The diffraction orders were increased in sequence around the undiffracted light beam termed the zero order, z = 0. For the first order, or the brightest diffracted beam, the angle θ for intense diffraction has been given by the grating relation $\sin \theta = \lambda/d$. For gratings with each of the 10 distinct spacings, an intense first order diffraction beam occurred at a different viewing angle and displayed a specific colour.

Production of the OVD

The colour features in the OVD for the "Kangaroo" coin were introduced at the stage of the initial artwork. During this stage of design, an artwork layout was prepared within the format of an Adobe Photoshop file. The entire image was made up of sub-fields of 30 x 30 µm, each of which was assigned a colour from the palette grouping of 10 elements developed by CSIRO. The precise colour within this 10-element group corresponded to a particular spacing of the gratings within the range of pitch 0.75-1.5 µm. The first 9 of these elements have been reserved for single indexed colours and the tenth was allocated to micrographic or non-diffractive, geometric patterns. The palette elements have been designed to give distinctly different colours in order to create an optical variation in the image when viewed at different angles.

The OVD image for the "Kangaroo" coin was circular in shape with a diameter of 25 mm. A prominent feature of the image was a series of five kangaroos with a progressive increase in size from the upper to the lower part of the coin. The Kangaroos also differed in their individual orientation, colour and posture. Other features of the OVD image were the symbol and lettering for the 1 dollar designation and a vertically striped

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background with a different colour in each segment. After assigning a colour to each area of the artwork image, the files were merged with palette element files, which converted each sub-field into a specific grating structure. The choice of the microstructures and their allocation to each region in the artwork was designed to give a sense of movement of the kangaroos with tilt in the viewing angle of the coin.

The OVD pattern was exposed onto a layer of electron sensitive resist using a commercial e-beam lithography system with a finely focused beam. The master plate for the exposure was comprised of a quartz base (12.5 x 12.5 mm) with a thin layer of Cr overlaid by a film of EBR-9 resist. The electron beam was exposed across each of the 30 x 30 μm sub-fields in the images on the plate. Following the exposure, the layer of resist was developed in a standard solvent to reveal the fine structure of grooves.

An array of 3 x 3 of the OVD images was exposed onto the master plate as shown in Figure 2. Each of the OVDs in the array was accurately spaced and located by the use of registration marks. A higher magnification view of a single OVD has been shown in Figure 3. The two photographs corresponded to different tilts in relation to the camera in order to alternatively capture the first order diffraction from the five kangaroos in Figure 3(a) and the striped background in Figure 3(b).

Figure 2. Array of “Kangaroo” OVD images.

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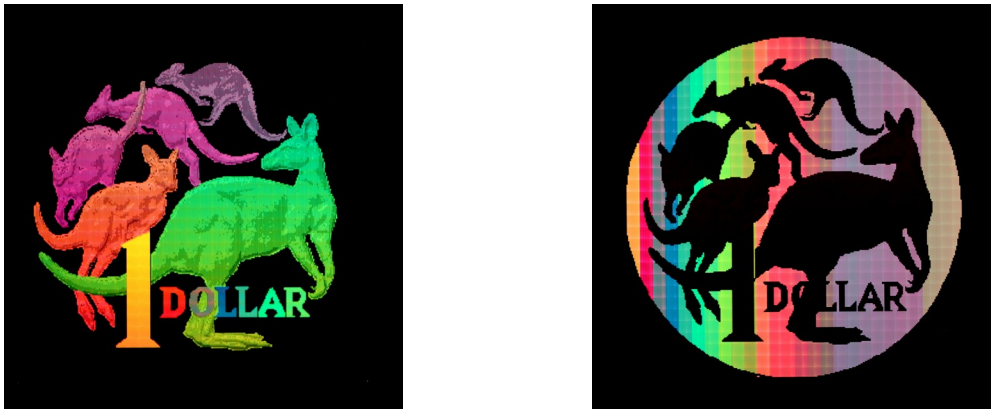

a) b)

Figure 3. A single OVD image showing the diffracted colours in a) the series of five kangaroos and b) the vertically striped background.

Manufacture of the Coin

At this stage of the process after the e-beam writing of a Master plate, an array of 3 x 3 OVD images had been formed in resist. A copy of the OVD array was then fabricated from the Master plate as a nickel shim (with dimensions of 12.5 x 12.5 mm). The shim was produced by an initial sputtering of a thin film of Ni (~ 100 nm) followed by electroplating of a thicker layer (~ 150 μm) in a nickel sulphamate bath. The 3 x 3 array of OVDs on the surface of the nickel shim was then further copied by moulding as an elastomeric stamp. A liquid mixture of the elastomer pre-polymer was immersed over the nickel shim and allowed to cure while the surfaces remained in contact. The separation of the nickel shim from the cured elastomer then resulted in the formation of a flexible stamp containing all of the fine details of the OVD structure. From the block of elastomer which contained a 3 x 3 array, the individual stamps were detached with each containing a separate OVD as shown in Figure 4.

Figure 4. Elastomer stamp with “Kangaroo” OVD.

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The individual stamps were then aligned as a 4 x 4 matrix in a plastic nest in which a recessed ridge had been precisely machined to control the height and orientation of the OVD image. At the same time, a configuration of 4 x 4 of the aluminium bronze blanks was arranged in a separate plastic holder. The dimensions of the holder accurately matched the nest containing the stamps. The rims of the coins were slightly protruding above the upper level of the holder to enable a complete contact with the stamp around the full perimeter of the coin. The transfer of the relief pattern onto the coin then proceeded by contact between the stamp and a liquid resin which was introduced onto the face of the coin blank. The curing of the liquid resin and removal of the elastomeric stamp then resulted in a precise replication or micro-moulding of the fine structure of the OVD on the coin.

This process was carried out using a 3-axis Cartesian robot that positioned a precision fluid dispenser above each coin in the nested array and applied a measured volume of resin. The robot then exchanged the dispenser for an elastomer stamp and placed the stamp with controlled pressure spreading the resin over the surface of the coin. The array of coins was removed from the robot and passed through a further machine for final curing. The elastomer stamps were then removed for re-use on the next set of coins.

A schematic illustration of the steps in the manufacturing process has been summarized in Figure 5. The quality of the image must be maintained during each transfer step in order to ensuring a perfect relief OVD on the coin. A photograph of the OVD on the final coin has been shown in Figure 6. The $1 denomination coin was 25 mm in diameter with a centrally located OVD.

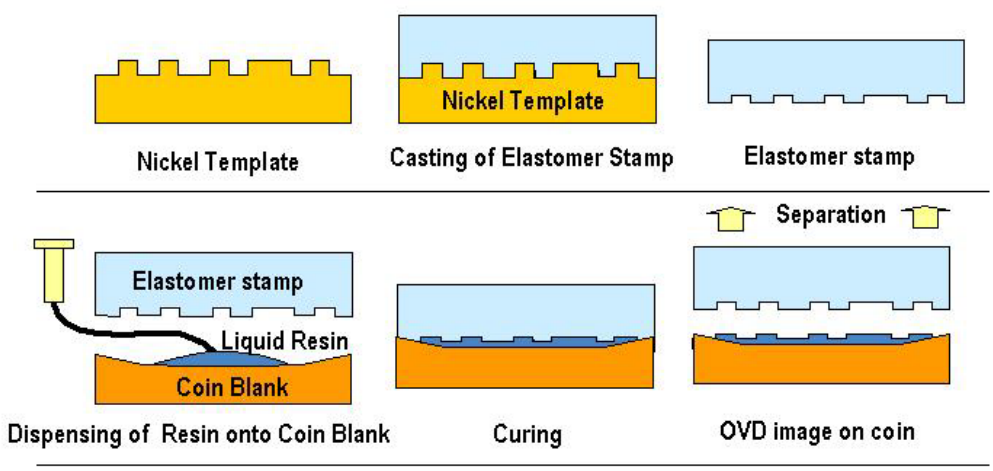

Figure 5. Schematic illustration of the stages in the micro-moulding of the OVD coin.

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Figure 6. “Kangaroo” coin showing the centrally located OVD.

Summary

The “Kangaroo” OVD coin has been manufactured by a unique new method developed by the Royal Australian Mint and the CSIRO. The process has enabled the forming of iridescent OVD images on the surface of aluminium bronze or base alloy coins. The “Kangaroo” coin has extended the series of commemorative OVD coins already issued by the Royal Australian Mint. The previous set of three OVD coins has recently received the Engineering Excellence Award (2003) from Engineers Australia.

References

1. B. Valentine, P. Leech, B. Sexton, R. Marnock and F. Smith, “Finale coin in the Australian Centenary of Federation Program Featuring an Optically Variable Device”, Mint Director’s Conference, Osaka, (April 2002).
2. P.W. Leech, B.A. Sexton and R.J. Marnock, “Scanning probe microscope analysis of microstructures in optically variable devices” *Microelectronics Engineering*, 60, 339-346, (2002).

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