An initial investigation into the low-cost manufacture of diffracting objects

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Abstract. In this letter we report on an initial investigation into the printing of diffracting objects via the high-speed, low-cost, printing process of offset-lithography, a method more commonly used in the printing of books and newspapers. A series of diffracting objects were printed onto clear substrates and evaluated with a coherent light source. The diffraction patterns generated correlate well with the Fourier transform of the printed image.

Keywords**:** Diffractive, optics, printing, offset-lithography

1. Introduction

This study is an investigation into offset-lithographic printing as a manufacturing method for diffracting objects. Offset-lithography is the technology used to mass-produce books and magazines. Image formation relies on the action of two dissimilar wetting functions on the surface of a smooth and un-embossed photosensitive printing plate that has been photo-imaged with the desired design before fixing. Contact with ink and moistening rollers allows the printing plate to attract both water and ink to the appropriate regions. The image is then `offset' from the plate onto a printing blanket, employed to prevent adverse wear of the printing plate, before transfer onto a substrate. The deposited ink relies on evaporation and/or oxidation to become fixed. This research combines significant developments in manufacturing applications of the offset-lithographic process, (developed at Brunel over the past four years [1,2]), with the industry requirements for cheap, large surface area depixelators and diffusers. An optimized printed diffracting object would satisfy a large number of research objectives, namely:

- Reduced power consumption - optimization of this technology will enhance display performance without requiring additional power for backlighting.
- Lighter weight displays - the diffraction objects are printed on plastic and will add little to the total weight of the screen.
- Better readability - depixelation improves the readability of displays. Diffusers improve the angle of view and contrast without the requirement for greater power.
- Area and cost - current manufacturing methods can only print large areas expensively. The offset-lithographic process can print A3 sheets and larger, far cheaper than current techniques.

The printing of diffracting patterns opens two avenues for exploitation. A regular pattern of an appropriate size could act as a screen depixelator for small-area screens and increase the `apparent' resolution of the image. A random array could act as a diffuser and find applications in larger area screens which would benefit from an increased angle of view and, with the judicious choice of materials, improved contrast.

2. Scientific and technological relevance

The pixel structure of a liquid crystal display can sometimes give rise to a pixelated and unresolved image where displays are small and of high definition. This is due to a combination of the pixel size of a small-screen LCD being an appreciable percentage of the image compared with larger screens, and the viewing distance being shorter for smaller screens. Many LCD manufacturers have found that depixelation is desirable to achieve customer acceptance. Depixelation breaks up the pixel structure to produce a continuous image and can be achieved by the application of a thin optical film containing diffractive structures [3,4]. Generally these consist of polymer films with surface features of the order of 20 µm in diameter, 0.5 µm high, with a pitch of approximately 40 µm. However, the manufacturing costs of these films are significant, making them cost effective only for small LCDs.

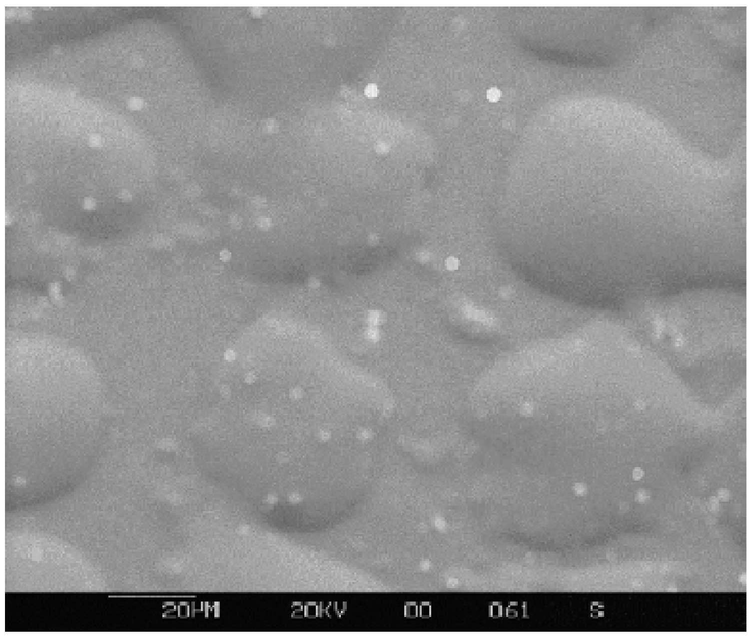

Figure 1. Scanning electron micrograph of the preliminary diffracting objects printed by offset-lithography. The white specks are surface dust charging in the electron beam.

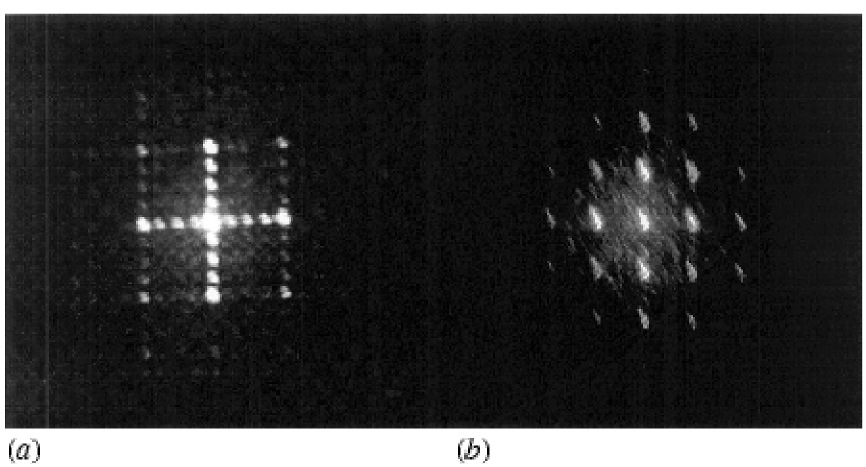

Figure 2. Diffraction patterns of some lithographically printed diffracting objects: (*a*) inverse grid (squares), (*b*) 20 µm dots, 60 µm pitch, as per SEM.

Present manufacturing methods rely either on the fabrication of a metal shim with the diffraction pattern being embossed into a polymeric surface and fixed by UV irradiation [5], or photolithography, a subtractive technique capable of very high resolution (submicrometre) but, by comparison with offset-lithography, a low-volume technique [6,7,8]. Interest is growing in the use of printing technology as a high-volume manufacturing technique, for example in ceramics research [9], but at present it is limited commercially to screen-printing thick films and sensors, and modified ink-jet printing. The major constraint with ink-jet printing diffracting objects is the current reliance on water-based inks. For substrates to absorb the solvent, a specialist coating is applied which gives transparent substrates an undesirable degree of opacity. Also, the inks themselves contain a large percentage of solvent that needs to be dispersed before an image is formed. The current state of the art in ink-jet printing is limited to 1400 dpi, which will resolve a dot to a resolution of approximately 20 µm. Whilst this is adequate for printing diffracting objects, the slow speed of printing at that resolution makes ink-jet printing as a production method impracticable. Most commercial high-resolution printers are limited to printing semi-transparent or opaque inks. Whilst diffraction patterns can be readily achieved with these inks the resultant image is diminished because of absorption of the incident light source. Such a process will limit the advantages because the light losses would require more powerful backlighting.

If the market for depixelation is to expand to larger displays and allied products, (for example laptop computers), the cost of manufacture must be reduced by an order of 100. This level of cost reduction is possible with the offset-lithographic process, if the level of feature size and precision required can be obtained. The offset-lithographic process has the potential to manufacture diffractive optics on a wide range of flexible substrates, using specialist inks having a range of optical properties.

A second possible application area for printed optical devices is in rear-projection systems, which are under development for high-definition television and workstations. Here the light driver is typically an LCD. The principle requirement is for an enhanced angle of view. Structures currently under consideration to provide this are diffusers, either based on photopolymers, (efficient but expensive), or polymer-based dispersed particle diffusers, (cheaper but less efficient since they are based on light scattering). A screen incorporating surface relief microlenses, printed by the offset-lithographic process, could be an `ideal' solution, providing the microlenses are randomly arranged and include a variety of sizes (ranging from 3 to 8 µm) [2].

3. Description of preliminary work and results

Standard printing plates were imaged with regular arrays of dots. A range of dot sizes and spacings were imaged, ranging from 20 µm dots with a 60 µm pitch, to 40 µm dots with a 120 µm pitch. The pitch is defined as distance between the centre of two adjacent dots. Transparent inks were printed onto clear polyester substrates differing in thickness and coating. Printed films were evaluated using a coherent light source and the dot spacing was estimated from the projected image using the equation $d \sin\theta_m = m_\lambda$; this appeared to correlate well with expected results.

4. Conclusions

Following the success of the preliminary work in printing diffracting objects, there is the need for further development. The aim of the next stage of work is to generate an understanding of the relationships between the optical properties of printed diffracting objects for displays and the materials used in their fabrication. This will allow the fabrication of depixelators and diffusers that match or improve on the optical characteristics of current technology and provide larger areas at a fraction of the cost.

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