Large Area Microstructured Optic Applications

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Abstract: Applications where microstructured optics components are required over large areas are increasing. This paper describes optical microstructures, their applications, and the challenges involved in mastering, replicating, and production of these microstructures over large areas.

1. Introduction

There are many modern applications where the need is to have optical products that incorporate ever increasingly smaller microstructures in ever increasingly large formats. Display applications are one of the most demanding from a cosmetics standpoint as well as increasing size. For instance rear projection televisions and desktop monitors are increasing in size and resolution needs: rear projection screens over 80 inch diagonal in various aspect ratios and LCD desktop monitors over 20 inch diagonal using microstructured optical features in the micron and sub-micron sizes. (Please excuse the mix of metric and inch units as the display industry still defines screen sizes in inches.) Other applications have similar requirements and will be discussed in this paper.

2. Microstructured Optics Examples

For the majority of rear projection screen designs, a fresnel lens is used to take the diverging light from the projection engine and collimate this image towards the viewer. A lenticular or microlens array structure is then placed in the optical path to give proper image distribution in the viewing space: usually in the range of +/- 30-40 degrees in the horizontal plane and in the range of +/- 5 to 30 degrees in the vertical plane. Figure 1 shows the center of a fresnel lens which vary in pitch (groove-to-groove spacing) from less than 0.01 millimeter to 0.05 millimeter. This structure is commercially available in sizes to 200 inch diagonal.

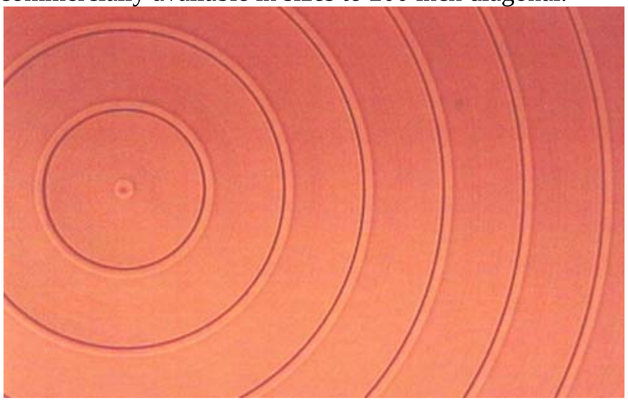

Figure 1 – Center of Fresnel Lens

Another example of a microstructured optic is a retroreflector used for traffic control and sign sheeting where the pitch of the structure ranges from a minimum of 50 micron (smaller pitch sizes have diffraction effects that limit their performance as a retroreflector for visible light applications) to greater than several millimeters. Figure 2 shows and example of a standard retroreflector with a pitch of approximately 200 micron with a 'special' microstructure machined into select prisms in the range of 10 micron size.

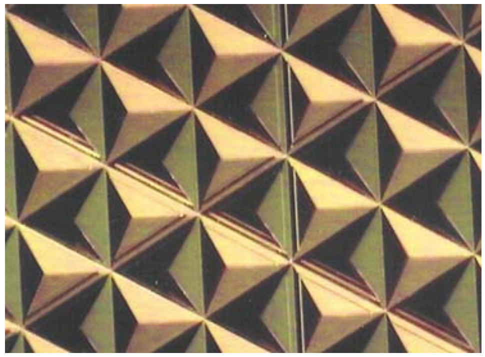

Figure 2 – Retroreflector

Other examples of optical microstructures include multi-element structures (Figure 3) with prism shapes from 50 to 300 microns in the same optical pattern and motheye antireflective structures (Figure 4) with sizes in the 0.2 to 0.25 micron pitch and height.

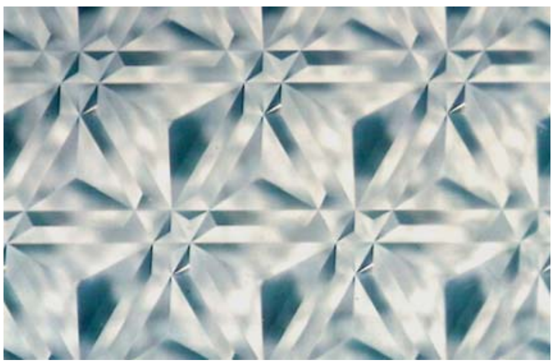

Figure 3 - Multi-element microstructure

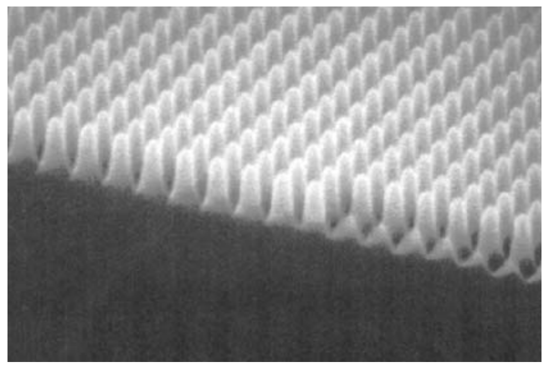

Figure 4 – Motheye Antireflective structure

3. Manufacturing Methods

A few of the most common 'mastering' techniques (getting the structure formed) include single point diamond machining (SPDM), photolithography, and laser writing. SPDM processes include lathe turning, flycutting, and ruling. These processes create three-dimensional microstructures whose overall size is mainly dependent upon the machine tool geometry limitations.

Photolithography includes gray scale lithography, deep X-ray (used in the LIGA process), ion beam milling, and holography. These processes are able to produce microstructures with sizes below the wavelength of visible light, with high aspect ratios, and extremely complex.

4. Getting To Large – Replication Techniques

Single point diamond machined parts are limited by the substrate preparation and the machine tool size with this being the primary limiting factor in the size. There are lathes that are able to machine fresnels surfaces to 5.0 metes diameter but flycutters and ruling machines have limitations in the 1 meter range size. Photolithography is mainly driven by the semiconductor industry and has maximum sizes in the 300 millimeter range. Laser writing is machine tool dependent and current size limitations are in the 1 meter by 1 meter range. Specialty holographic microstructure equipment is able to produce microstructures in the 600 x 800 millimeter size.

To go from the master to larger areas, several techniques are employed that include step-and-repeat replication techniques and parqueting of smaller sized parts in close proximity to achieve large area microstructures. The application of the final optic dictates the process acceptability of the replication process to get to the large area: if the optic is a direct view type such as a display screen, the cosmetic requirements are critical which circumvents the use of parqueting. In many cases, any variations caused by the parqueting process will be noticeable in the finished product and make the product unacceptable for commercial use. If on the other hand, the application has less stringent cosmetic requirements or is for a non-imaging application, parquet joints or seam lines are more acceptable.

Once the master has been ‘parqueted’ into a large area, there is a need to make this into a commercial product. In many instances, electroforming is used to take the master, make an exact (but opposite generation) replication. If the master is conductive as with most metals, the part can be readily electroformed. For plastic or photoresist masters, a conductive coating must be applied prior to electroforming. This is usually done with a silver spray process or through evaporative or sputtering a conductive thin film metal on the surface. Once the reverse generation is produced through electroforming, opposite generations can be electroformed and used a ‘stampers’ for production of polymer or glass optic through processes such as casting, injection molding, compression molding or extrusion.

5. Challenges

For the SPDM mastering process, challenges include microstructures that have increased aspect ratios (height to pitch ratio) over larger areas. These structures many times also have complex shapes that make the diamond tool manufacturing difficult. Diamond tool wear over large areas is a concern and is limited by the substrate purity and hardness. Also, tolerances on the microstructures are tightening which is pushing the limits of accuracy and repeatability of the diamond machining equipment.

Lithography and laser writing have photoresist limitations: overall size of the substrate, uniformity of the photoresist, thickness variations, and bulk absorption as well as limitations such as laser power, chamber size for vacuum-based processes, and mask resolution and size limits. The machinery used to traverse the part or the laser also limits laser writing sizes. Thermal and environmental issues are important in these processes due to the time involved for producing the master.

For the electroforming process challenges include stress control for dimensional stability. The microstructure geometry is also critical for success as high aspect ratio parts without proper draft angles can ‘lock on’ during the electroforming process. Current density issues in electroforming tend to scale with size and can cause difficulties to make large area microstructured optic.

6. Applications

Application for microstructured optics over large areas include Figure 5, a luminaire with a MesoOptic holographic diffuser and Figure 6 a solar collector array of 2880 fresnel lenses which are 178 mm square each, parqueted and compression molded.

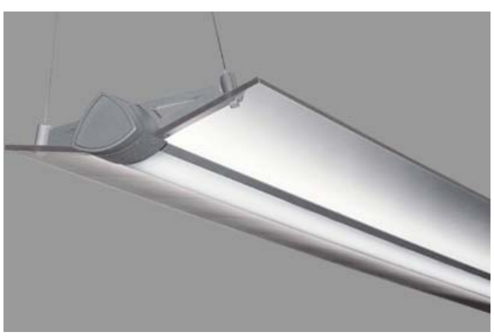

Figure 5 – Luminaire

Figure 6 – Solar Collector