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LASER FIGURING FOR THE GENERATION OF ANALOG MICRO-OPTICS AND KINEFORM SURFACES

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ABSTRACT

To date, there have been many techniques used to generate micro-optic structures in glass or other materials. Using methods common to the lithographic industry, the manufacturing technique known as "binary optics," has demonstrated the use of diffractive optics in a variety micro-optic applications. It is well established that diffractive structures have limited capability when applied in a design more suited for a refractive element. For applications that demand fast, highly efficient, broadband designs, we have developed a technique which uses laser figuring to generate the refractive micro-optical surface. This paper describes the technique used to fabricate refractive micro-optics. Recent results of micro-optics in CdZnTe focal planes are shown.

1.0 INTRODUCTION

Interest in the production of microlenses and microlens arrays has steadily increased with demand for improvements in detector arrays, optical processors, and laser diode systems. There are several techniques that are capable of generating microlenses in opto-electronic materials such as Si and CdZnTe. These include lithographically generated[1], melting[2] and gray-scale or half tone[3]. Each of these techniques has been found to have one or more limitations, such as; inadequate resolution, high scatter, inability to achieve high numerical aperture, inaccessibility to controlled aspherics or high efficiency.

The technique developed at HDOS involves the laser figuring of photoresist followed by a subsequent pattern transfer by ion milling[4]. This approach permits the

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[1] G. J. Swanson, W. B. Veldkamp, "Binary Lenses for use at 10.6 Micrometers," *Opt. Eng.* **24**, 1985.
[2] Z. D. Popovic, et al, "Technique for Monolithic Fabrication of Microlens Arrays," *Appl. Opt.* **27**, 7, 1988.
[3] W. W. Anderson, et al, "Fabrication of Micro-Optical Devices" Conf. on Binary Optics, Huntsville, 1993.
[4] E. J. Gratrix, C. B. Zarowin, "Fabrication of Microlenses by Laser Assisted Chemical Etching (LACE)," *SPIE* **1544**, 238, 1991.

generation of accurate, highly efficient refractive micro-optics in materials suitable for implementation on detector arrays, optical processors, or laser diodes.

We will report on the recent progress of this technique in the fabrication of optical elements in photoresist, Si and CdZnTe. Specifically, results from the fabrication of 128 by 128 element arrays of microlenses in CdZnTe, will be shown. Extensions of this technique toward the computer figuring of the kineform diffractive surface will be evident.

2.0 MICRO-OPTICAL FIGURING

The technique we have developed is a microscopic, computer controlled exposure technique similar to the more macroscopic versions of plasma chemical figuring[5] and computer controlled polishing[6]. In each of these cases, the desired surface is generated by moving a tool, with a known footprint, over the surface while appropriately adjusting the amount of material removed. The tool in our approach is a laser spot, focused onto positive photoresist, with a footprint capable of addressing the spatial frequencies necessary to accurately figure a microlens. The laser spot is recorded by the photoresist for subsequent photodevelopment to yield the lens feature.

With knowledge of the shape of the laser spot, the photoresists response to the laser and an accurate description of the surface to be generated, we can calculate an intensity map[7]. The information from the intensity map, the lenslet location, and the footprint trajectory are coded into a computer. The entire array is exposed in a raster form with the appropriate intensity adjusted on-the-fly depending on the laser spots exact location. For arrays which have identical, symmetric lenslets, the range of calculations extends only over a single lenslet radius and is repeated as the spot enters the next region. Unique features can also be generated by solving for the various surface relief functions.

3.0 PHOTORESIST AS A MICROLENS

Photoresist lenses made by this microfiguring approach are shown in figure 1. This array was designed with 180 micron diameter, 200 micron square on center, lenses. The f-number of each lens was designed to range from infinity (flat), to f/1. For this, positive photoresist is coated onto a glass substrate and pre-baked. The array was then exposed by moving the substrate under a stationary laser position which varied in intensity. Finally, the array is completed by immersing the substrate in developer solution. The optical performance of this type of lens array was reported to be superior

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[5] L. D. Bollinger, C. B. Zarowin, "Rapid, Non-Mechanical, Damage-free Figuring of Optical Surfaces Using Plasma Assisted Chemical Etching," *SPIE* **966**, 1988.

[6] R. A. Jones, "Modeling the Computer Controlled Polishing Process," Appl. Opt. **22** (15), 1983.

[7] C. B. Zarowin, "A Robust, Non-Iterative Computationally Efficient Modification of van Cittert Deconvolution," *JOSA*, in press.

to many other lens manufacturing techniques[8]. The interferogram in figure 2 demonstrates the optical surface generated in photoresist lenslets designed to be 200 micron on center, f/1.4, with a full fill-factor. Due to the high spatial frequency content of the laser spot, this technique can accurately figure over most of the available lenslet surface, which typically exceeds 95%. The fill factor is clearly demonstrated when the reference leg of the interferometer is positioned at the intersection of four adjacent lenslets, as shown in figure 3.

4.0 PATTERN TRANSFER

The use of photoresist as an optical medium is limited by the material transmission, index of refraction, and/or the robustness. There are a few techniques to eliminate photoresist as the final optical medium. One technique is to transfer the shape generated in the photoresist into the underlying substrate. This can be accomplished by either ion sputtering or chemical plasma etching. The basic principle behind this pattern transfer is to controllably erode the photoresist as well as the underlying substrate. While the erosion process may provide an additional mechanism to control the figure of the lenslets, it is not without limitations. In many cases the distortion of the microlens surface due to non-linearity in the pattern transfer process are not negligible[9].

For sputter erosion, or ion milling, the relative etch rate between photoresist and the substrate varies depending upon which materials are chosen, and at which angle the ions impinge. Ion milling, as a pattern transfer mechanism, has some limitations; the rates are slow (typically at hundreds of angstroms per minute) and the relative etch rates are low (typically between 1 : 1 to 5 : 1). For lens designed with a large sag it may take several hours of ion milling to complete the pattern transfer. However, since ion milling is accomplished at very high ion energies, it is a relatively robust technique when encountering defects, chemical impurities and processing changes. The inclusion of preferentially reactive species as the impinging source is termed reactive etching. This can extend the relative etch rate by several times however it still suffers the angular rate dependence described earlier.

Chemical plasma etching is strongly dependent upon the chemical composition of the materials and, to a lesser extent, the geometry of the surface to be generated[10]. One of the limitations to implementing a chemical plasma etch is that it is extremely difficult to find suitable etching conditions for materials which are not amorphous.

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[8] P. de Groot, F. X. D'Amato, E. J. Gratrix, "Interferometric Evaluation of Lenslet Arrays for 2-D Phase-locked Laser Diode Sources," *SPIE* **1333,** 1990.

[9] C. B. Zarowin, "Comparison of the Smoothing and Shaping of Optics by PACE and Ion Milling," Appl. Opt., in press.

[10] C. B. Zarowin, "Relation Between the RF Discharge Parameters and Plasma Etch Rates, Selectivity, and Anisotropy," *J. Vac. Sci. Tech. A,* **2** (4), 1984.

G. M. Gallatin, C. B. Zarowin, "Unified Approach to the Temporal Evolution of a Surface Profile in Solid Etch and Deposition Processes," *J. Appl. Phys.* **65** (12), 1989.

Additionally, the chemical purity of the materials may locally interfere with the etch process causing micro-masking. Also, slight variations in the process parameters can cause large variations in the etch rates. However, there are conditions where with the correct materials and chemical plasma etching conditions, this approach can provide superior control over the relative etch rates and preservation of the initial photoresist figure.

4.1 ADJUSTMENTS TO THE FIGURE

The laser figuring approach presented here is amenable to correcting any distortions or errors associated with the pattern transfer mechanism. The optical designs which have been addressed have not needed significant amounts of lenslet sag, therefor, ion milling is an acceptable transfer method. It is possible to describe the evolution of the surface with knowledge of the transfer function due to ion milling, or any other transfer technique. This will allow us to predetermine the initial shape in photoresist which will generate the desired final lenslet figure after ion milling. We have measured the ion mill rate as a function of angle for different photoresists as well as optical materials such as Si, CdZnTe and SiO_2. With this data, We have been able to fabricate microlenses for numerous opto-electronic applications.

5.0 RESULTS

Figure 4 shows a scanning electron micrograph of a 10 by 10 array of lenslets etched into a silicon wafer. The design of these lenslets yielded f/1, parabolic lenses with 100 micron square lens aperture. Lenslet arrays of this type have been designed for optical improvements in Si detector arrays. Figures 5 and 6 show a region of a 132 by 132 element lens array in CdZnTe. These lenslets have a 60 micron square aperture, parabolic shape with a 100% fill-factor. Each lens was designed to work f/2, immersed, thus focusing light into a detector area located 120 microns below the lens. The array is designed to be aligned and etched into the backside of a thinned HgCdTe detector array to concentrate light into a reduced area detector.

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Figure 1.
This is an array designed with 180 micron diameter, 200 micron, square on center, lenses. The sag of each lens was designed to linearly range from a flat the to that of an f/1 lens.

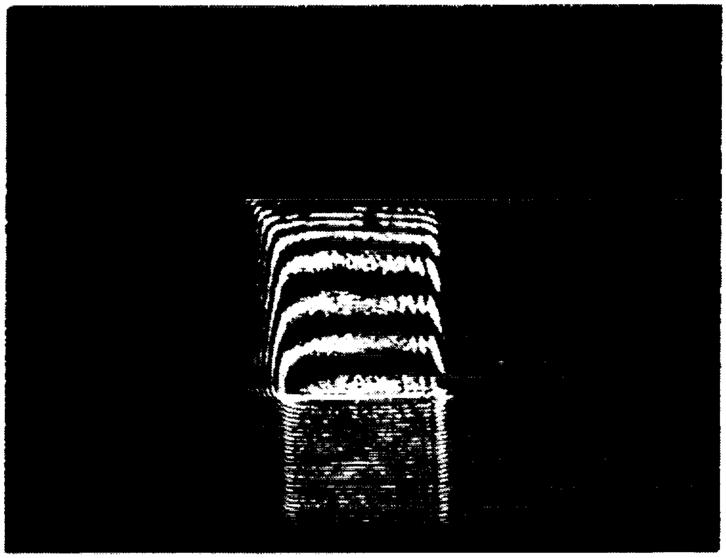

Figure 2.
Interferogram of a region of the array in figure 1 showing fringes from two adjacent lenslets.

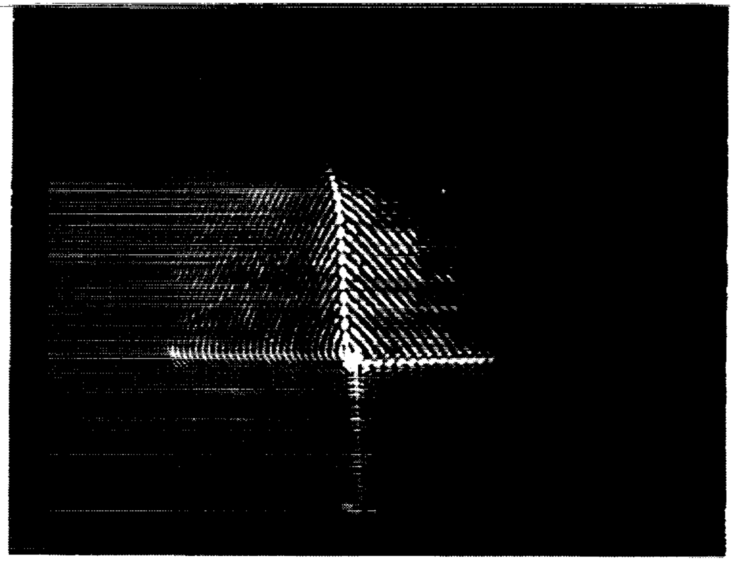

Figure 3.
Interferogram of a region of the lens array in figure 1. The reference leg is centered at the intersection of four adjacent lenses showing the fill factor achieved.

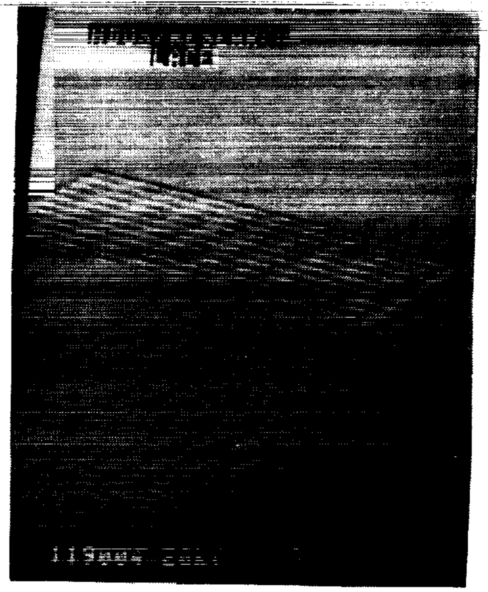

Figure 4.
This is a photomicrograph of a 10 by 10 array of f/1 microlenses, 100 micron on center, etched into a wafer of silicon.

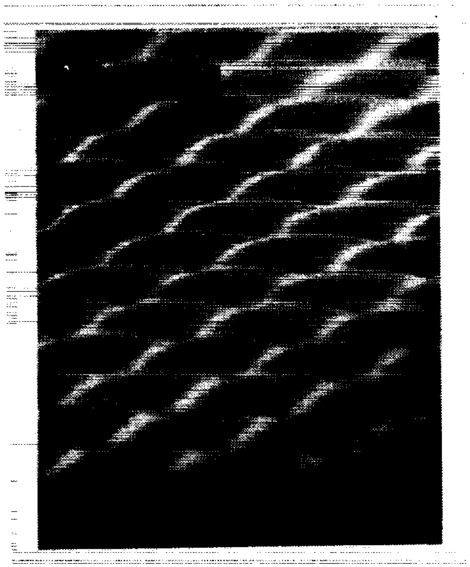

Figure 5.
This is a photomicrograph of a 132 by 132 array of 60 micron, f/2, microlenses etched into CdZnTe. The array is designed to concentrate light unto a reduced area detector located 120 microns behind the lenses.

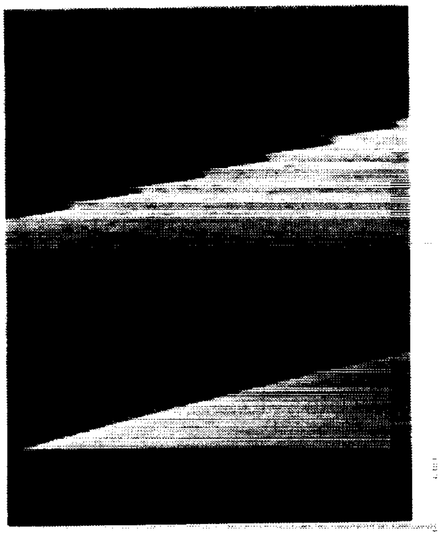

Figure 6.
This is a view of the edge elements of the array shown in figure 5.