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Fabrication of an Array of Divergent Microlenses for Multiple Beam Splitting

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Abstract

In this work, the design, fabrication and analysis of an array of parabolic divergent microlenses for multiple beam splitting is presented. Because of the equipment constraints, the width of the microlenses was determined to be 10 µm. It was calculated that a divergent parabolic lens with f-number of 0.5 would deliver the desired optical pattern of multiple beams distributed over 90 degrees. A surface relief depth of 6.5 µm was calculated considering the phase distributions of such lens. The lenses were fabricated in a 10 µm thick photo resist, using a contact printer exposure through a mask with a repetitive 4 µm line - 6 µm space pattern. The developer concentration and development time were fixed for these tests and the exposure time was varied in order to obtain the desired profile. The resulting diffraction patterns were characterised and a satisfying result was obtained. This pattern can be used in robot and other applications.

1.Introduction

The wavefront modulation capability of the so-called diffractive optical element (DOE) makes a wide range of applications possible such as optical interconnections with fan-in and fan-out DOE's, beam splitting patterns for robot vision etc. [1]. Many authors have reported on the diffraction properties of a continuous conical phase relief grating for multiple beam splitting [2-4]. In these gratings, each conical phase relief acts as a convergent lens, concentrating all the incident light just behind the grating [5], producing an array of beams. This array of beams can be approximated by the light distribution $I(u) \times comb(u/U)$. The desired optical pattern is obtained by calculating the Fraunhofer diffraction pattern of $I(u)$, what is obtained by the Fourier transform of $I(u)$, giving $i(x) \times U comb(ux)$ [6]. The approximation of $I(u)$ to $comb(u/U)$ is increased by making the microlens f-number as low as possible and also by making the continuous conical relief shape to be well reproduced during the fabrication. A poor lens design results in a strong intensity variation (about 10 times considering the maximum and the minimum intensities) in the light distribution $i(x)$.

It is possible to obtain an array of microlenses using microelectronic manufacturing techniques. One possibility is to perform different exposures with different focal distances and in this way determine the geometry of the resulting resist pattern [7]. In this work, divergent microlenses were created in a thick photo resist using a simple contact printer. They were formed into the photo resist by exploring the diffraction characteristics of the light projected through a mask with a 4 µm line- 6 µm space pattern. This array of divergent microlenses produces the same optical effect as an array of convergent microlenses.

2. Design and Fabrication of the Array of Microlenses

In this project, the goal is to generate a linear array of 19 beams distributed over 90 degrees using an array of divergent microlenses. To obtain a diffraction angle of 90 degrees, the virtual lens focal plane has to be located at a distance of half width of the lens diameter, what results in a f-number of 0.5. Because of the used equipment, the resist thickness has to be in the 5 µm to 10 µm range. The width of the lens was chosen to be 10 µm, resulting in focal distance of 5 µm. It is possible to calculate the form of the ideal lens and for this application, a divergent parabolic lens was found to be a good solution. The dimensions of the parabola were designed considering that each surface acts as a divergent cylindrical lens with a f-number equal to 0.5. A surface relief depth of 6.5 µm was calculated considering the phase distributions of such lens [2], the wavelength used (0.810 µm) and the index of refraction of the photo resist. A schematic view of the desired surface relief is shown in figure 1.

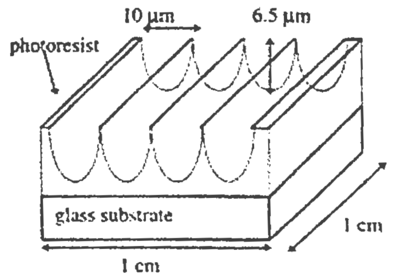

Fig. 1 : Designed profile of the device surface

The typical resist thickness for microelectronic applications is 1 µm. In order to deposit a layer of at least 6.5 µm, a special resist was used: the All-Resist AR-P320. This resist was spun on a 3-inch diameter optically flat B270 SUPERWITE high transparency glass, during 10 seconds at 2000 rpm, after which the spin speed was accelerated up to 4000 rpm where it remained for an extra 25 seconds. This results in a layer of approximately 10 µm thick.

In order to understand the obtained results, it is necessary to explain briefly the mechanism of diffraction through a mask with relatively small line-space features [8]. The effect of light diffraction is shown in figure 2: the modulation of the light behind the mask is less than 1: light penetrates under the metal line on the mask and its intensity is not constant under the open space.

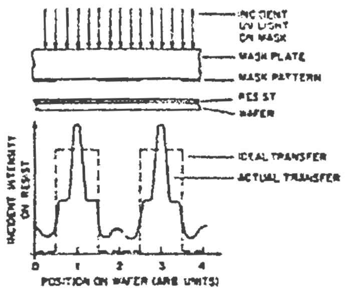

Fig.2 : Ideal and real intensity distribution of light passing through a mask with narrow spaces [8]

The smaller the open space, the larger the diffraction effect. For a contact printer, the diffraction effect is larger when the distance between wafer and mask is bigger. This also means that for a thick resist, there is more diffraction than for a thin resist. In this application, diffraction is used to our advantage: in order to obtain the desired parabolic profile, we want the light to penetrate under the mask and to have a non-uniform light intensity in the open space. For all these reasons, the optical device design consists of one thousand 1 cm long 4 µm wide lines, with spaces of 6 µm between them. Each mask consists of 24 of these devices. A conceptual design is shown in figure 3.

In standard microelectronic applications, the walls of the resulting resist patterns have to be as vertical as possible. In this application, the desired profile is completely different. The three most important parameters to be optimised in the lithography process are: exposure time, developer concentration and development time. A higher developer concentration results in steeper resist walls, which is preferable for microelectronic applications but not for this application. Whereas for microelectronic applications a 4:3 DI-water:developer mixture was used, a mixture of 5:2 was used for this application. Several tests were performed and a development time of 1 minute was found to yield good results. The exposure times were varied from 34 to 40 seconds and the resulting resist profiles were analysed.

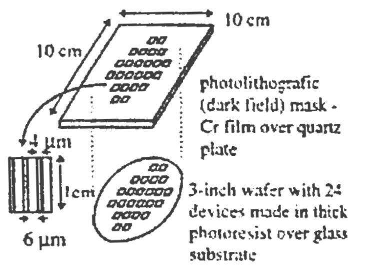

Fig.3 : Conceptual design of the lithographic mask and pattern transfer to the wafer

Figure 4 shows a 3-inch quartz wafer with 24 optical devices, fabricated using a 36 seconds exposure time.

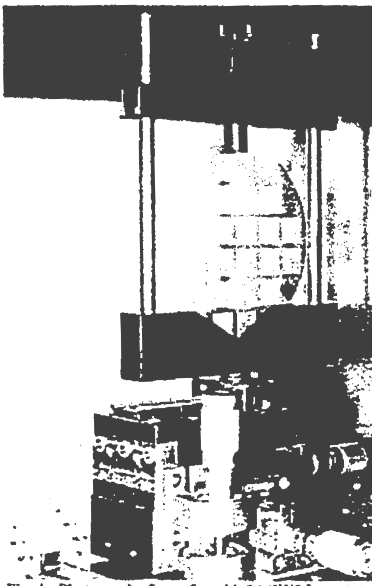

Fig. 4 : Photograph of a wafer with 24 CHIPS consisting of a 1 cm by 1cm array of microlenses made in photoresist

3. Optical Characterization of the Fabricated Devices

The optical characterization of the fabricated devices consists of the measurement of the intensities of the Fraunhofer diffraction pattern generated by the grating when it is illuminated with a He-Ne laser, 633 nm. These intensities are measured with a photodetector.

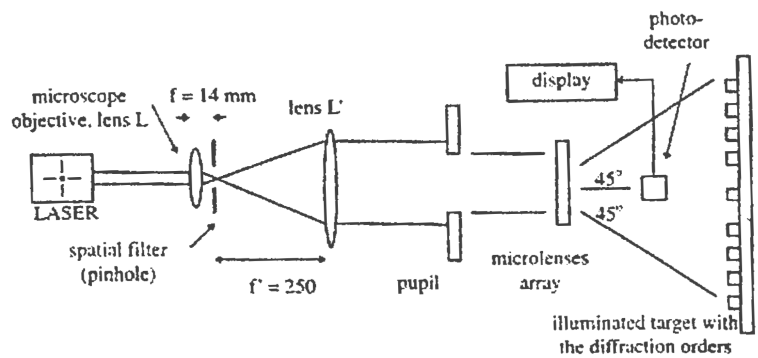

Fig. 5 : Schematic view of the experimental set-up used for the optical characterisation of the devices

A schematic view of the experimental set-up is shown in figure 5. A spatial filter (pinhole) and a lens L' (focal length equal to 250 mm) serve to expand the laser wave front. The pupil aperture assures that only the area over the optical element is illuminated [9].

A summary of the results is shown in table 1. We have measured the total number of diffraction orders, the angular aperture of each side (relative to the zero order), and the maximum and minimum intensities within the signal window corresponding to nine diffraction orders. The samples were analysed in a Philips 515 SEM. Two profiles are shown in figures 6 a and b: exposure times were respectively 36 s and 40 s. The profile of figure 6a approximates well the desired parabola. The total depth of the structures is approximately 6 µm. The ratio of maximum to minimum intensity varies between 7.1 to 3.7 for the 36 s exposure time samples: this 3.7 ratio is the lowest obtained in these tests. The resist which was exposed for 40 seconds was completely developed in the open lines, exposing the flat glass substrate, and the resulting profile is not what we aimed for. This results in the extremely high intensity of the zero order: most of the light passes straight through the optical element. In this case, the maximum to minimum intensity ratio is 21.7: very high. It is clear that this is not the desired device. For an exposure of 34 s, the resulting profile was less than 6 µm deep, and therefore also results is a higher maximum to minimum intensity ratio.

The optical characterization shows that a laser beam can be deflected over an angle of more than 45 degrees and that the maximum to minimum intensity ratio can be limited to approximately 4, which is an acceptable result for most applications.

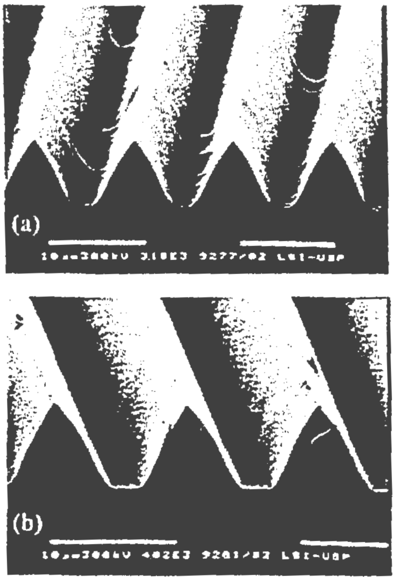

Figure 6 : SEM micrographs showing the obtained resist profile for a 36 s exposure time (a) and 40 s exposure time(b)

5 Conclusions

An array of microlenses has been designed, manufactured and characterized. In a 10 µm thick photo resist, 10 µm wide and 6.5 µm deep parabolic lenses were obtained by varying the exposure time of a contact printing process. The resulting structures have approximately a parabolic profile and the desired depth. The optical characterization shows that a laser beam can be deflected over an angle of more than 45 degrees and that the maximum to minimum intensity ratio can be limited to approximately 4, which is an acceptable result for most applications.

Table 1 : Summary of the optical results obtained for various exposure times

exposure time [sec]	number of diffraction orders	aperture angle [±1degree]	zero-th order [mW]	maximum intensity [mW]	minimum intensity [mW]
34	15	69	5.0	14.5	1.9
36	15	65	5.6	22.3	3.1
36	15	66	9.0	14.4	3.2
36	15	76	4.3	15.0	4.0
38	14	63	8.4	19.0	3.1
40	14	63	21.7	19.8	1.0

6. Acknowledgements

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