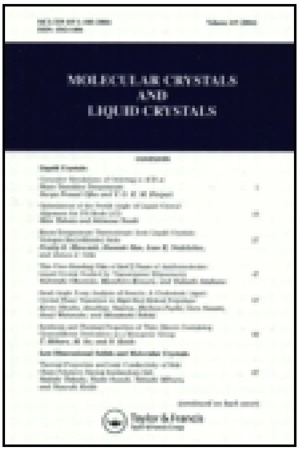

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In this work, the fabrication of arrays of parabolic convergent and divergent microlenses is presented. The used material is the Novolak-based polymer All-Resist AR P322, which can be used both for optical UV lithography and for electron beam direct write lithography. Gratings of parabolic divergent microlenses with f-number of 0.5 were fabricated using traditional optical lithography, employing the diffraction characteristics of de-focussed light during the photolithography exposure. Direct write electron beam lithography was used to obtain convergent parabolic microlenses, with different diameters and different heights, allowing the control of the focal length of these lenses. The same technique was employed to manufacture gratings of parabolic convergent microlenses with different diameter and focal length, what enables one to control the intensity of the different orders of the diffracted light. These structures have several applications in the fields of pattern recognition, robotic vision and optical sensors.

Keywords: Novolak; Microlens; Grating; Microoptics

1. INTRODUCTION

The employment of polymers in micro-optics is becoming increasingly important [1]. There are a large number of works in the literature about Epoxy- and PMMA-based polymers [2,3]. Novolak based photo resists are common resists for microelectronic applications, but the literature mentions few applications of this polymer for micro-optics applications. A drawback of this material is its opaqueness which limits its applications for UV-range wavelengths, but for visible and IR applications it is very suitable. The AR P322 Novolak-based resist has the advantages over more traditional photo resists that it can be deposited over a wide range of thicknesses (typically from 5 to 20 μm) and that it can be used both as an electron and as a photo resist. This enables the fabrication of microlenses with low f-numbers (<1).

2. FABRICATION AND RESULTS

We implemented two types of devices using the AR P322 polymer :1) phase gratings of parabolic divergent microlenses with f-number of 0.5 for splitting a laser beam in several diffracted orders over a wide fan-out angle [4-7, 9]; 2) parabolic convergent microlenses which can be used e.g. for improvements of the efficiency of photo detectors in high speed HEMT optoelectronics devices. The first one uses the AR P322 as a photo resist and the second as a electron resist: Phase gratings of parabolic convergent microlenses with different diameter and focal length, what enables one to control the intensity of the different orders of the diffracted light, were also implemented using the AR P322 as an electron resist [8].

In the first of the two devices, 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. The diameter of the lens was chosen to be 10 μm, resulting in a focal distance of 5 μm. A parabolic divergent lens was found to be a good solution for this application [4, 9]. The curve of the parabola and a surface relief depth of 6.5 μm was calculated considering the phase distributions of such lens, the wavelength used and the index of refraction of the photo resist.

When exposing the sample using a contact printer in proximity mode, light penetrates under the metal line on the mask and its intensity is not constant over the space beneath the mask, because of the effect of diffraction [10,11]. 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 spaces. For all these reasons, the optical device design consists of one thousand 10 mm long - 4 μm wide lines, with spaces of 6 μm between them.

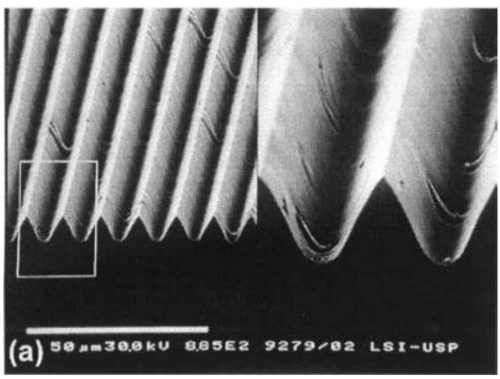

FIGURE 1: Scanning electron micrograph of the parabolic, divergent microlens array, fabricated by UV lithography using the AR-P 322 as a photoresist. The right side is a magnification of the rectangular insert on the left side.

A 10 μm thick AR P322 resist was spun on a 3-inch diameter, optically flat, high transparency substrate. 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, what 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 doses were varied from 850 to 1000 mJ/cm^2 and the resulting resist profiles were analysed.

A 3-D overall view of the resulting structures is shown in figure 1: exposure dose was 900 mJ/cm^2. This profile approximates well the desired parabola. The depth of the structures is approximately 6 μm.

The optical characterization shows that a He Ne laser beam can be deflected over an angle of more than 45 degrees relative to the zeroth order and that the maximum to minimum intensity ratio of the different diffracted orders can be limited to approximately 4, which is an acceptable result for most applications [9].

A drawback of this standard lithography technique is that one can not obtain lenses with different dimensions on the same wafer, because the diffraction pattern has to be the same for all the exposed structures. Direct write electron beam lithography does not have this limitation.

The adequate exposure dose for modulating the resist thickness can be determined, using the contrast curve of the used resist. In order to obtain the contrast curve of the AR P322 resist, the samples were exposed to a variable dose in the range of 1 μC/cm^2 to 240 μC/cm^2. Afterwards, the resist was developed during 120 seconds, in AR-300-26 developer, at 21^{0}C. The resulting contrast curve showed a gamma factor of 3.02. The gradient of this contrast curve is not very high, what is bad for microelectronic applications, but is good for optical applications, because now it will be possible to control relatively well the remaining thickness of the resist, by controlling the exposure dose.

In order to obtain microlenses in a positive resist, such as these in figure 2, the maximum dose has to be applied where the resist has to be removed completely (between the lenses) and for the domes, the dose has to be decreased where the remaining resist is thicker. With this technique several dome-like microlenses were implemented. For our application the focal length and the lens diameter are the project entries.

For the microlenses showed in figure 2, a 50 μm diameter and a 40 μm focal length were necessary. This results in a f-number of 0.8, considering the index of refraction of the resist equal to 1.62. These lenses were obtained by varying the dose from 70 μC/cm^2 to 140 μC/cm^2. Theoretically, it is possible to obtain such structures with standard photolitography, using a negative resist and a large distance between mask and resist. However, when trying to obtain these structures in practice, the distance mask-resist is always limited in the exposure equipment, and negative resist is much more difficult to deal

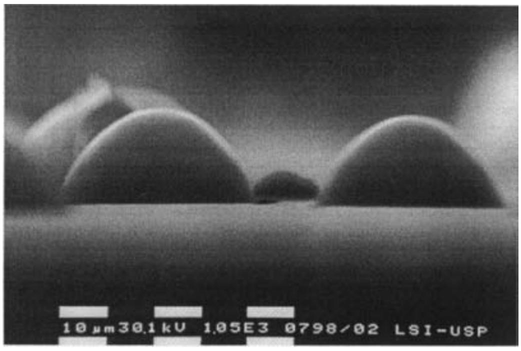

FIGURE 2: Scanning electron micrography (cross section) of the spherical and convergent microlens array, fabricated by electron beam lithography using the AR-P 322 as an electron-resist.

with than positive resist, making it almost impossible to obtain convex structures with dimensions larger than 10 μm. With electron beam direct write, it is also possible to obtain parabolic microlenses with different dimensions on the same wafer, something which is completely impossible with traditional photolithography.

The advantage of all these relatively large structures (of approximately 50 μm), comparing with smaller structures, is that the robustness of these fabrication processes is much higher. Using the same equipment, the absolute dimensional error for these large structures will be the same (or even less) than for smaller structures, what results is a smaller relative error, therefore the light diffraction will be controlled better. The larger the structures, the more precise the electron beam processes will determine the curvature of the resist domes, again resulting in a better controlled light pattern. Using a similar process, phase gratings of parabolic convergent microlenses were manufactured.

CONCLUSIONS

Different kinds of parabolic microlenses were designed and manufactured, using a thick, positive resist ARP 322. Both convergent and divergent lenses were fabricated. A wide range of focal lengths can be easily implemented using this material, without the need of going to very small horizontal dimensions. Traditional photolithography was employed to manufacture gratings of divergent parabolic lenses with constant periods and f-numbers. With direct write electron lithography, convergent spherical lenses with different dimensions and f-numbers and gratings with different periods and f-numbers were implemented. This approach allows the manufacturing of any kind of microlens in a relatively simple, controlled, reproducible and robust way.

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