A parallel, grey-scale direct-writer for micro-optics and microstructures

Carsten Glasenapp, Hans Zappe

Institute of Microsystem Technology, University of Freiburg
Laboratory for Micro-optics

mailto:glasenap@imtek.de

Grey-scale lithography is normally a complicated and expensive process. As an alternative, a liquid crystal-based, parallel grey-scale direct-writer was realized. We demonstrate micro-optical structures made with this new device.

1 Introduction

By using a parallel direct-write technique based on a liquid crystal display, arbitrary structures with micrometer dimensions may be patterned in photoresist. Both binary and grey-scale structures can be made by direct two-dimensional modulation of the intensity distribution of the exposure using the LC display.

2 Experimental setup

The exposure setup is configured as follows (see Fig. 1) : a broadband mercury lamp illuminates the reflective liquid crystal display (LCD) via a polarizing beam splitter (PBS) with diffuse and linearly polarized light. For each pixel, the LCD may rotate the polarization of the incident light individually. The light is reflected at the LCD and passes the PBS a second time where only the polarization-rotated light may pass the PBS. The transmitted light is imaged by a 50 mm macro objective onto a photoresist-coated wafer. The spatial intensity distribution on the photoresist can be set by the rotation angle of the LCD. To program the LCD, a grey-scale picture can be loaded from a computer in less then 10 ms.

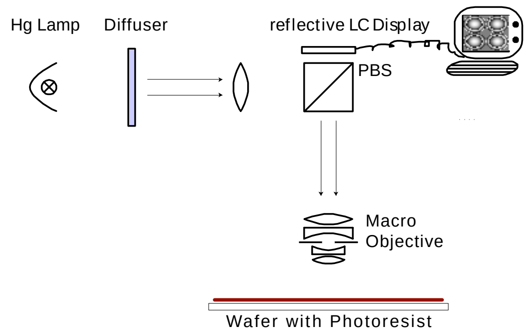

***Fig. 1** Setup of LC grey-scale writer*

The photoresist exposure is simply controlled by the illumination time. The resolution of the resultant image is set by the pixel size of the LCD (13 µm) and the magnification of the optics. In the present setup, the resolution is 2 µm.

3 Photoresist characteristic

To generate linear topographies in photoresist, the exposure characteristics of the resist employed have to be well known. The loss in photoresist height after development as a function of exposure dose is shown in Fig 2. It is seen that a certain minimum dose is required before any photoresist is removed. For a limited range of doses above this level, dissolution varies roughly exponentially with the dose. The characteristic saturates if all resist is removed.

To utilize the full dynamic range of a 256 level grey-scale picture, a pre-exposure with white light is thus useful. Multiplication of the grey-scale picture with the inverse characteristic exposure function compensates for the exponential exposure dependence. In the most cases, it is sufficient and easier to avoid the saturation area. The maximum structure depth will be set by the exposure time.

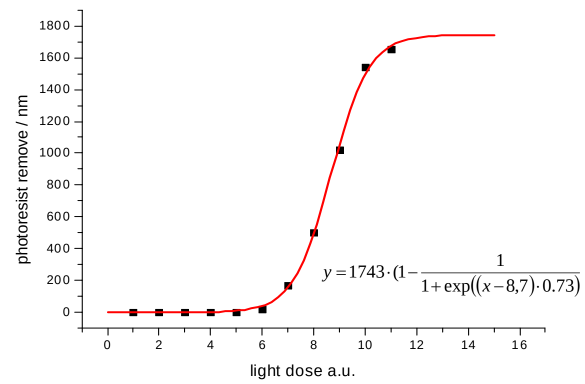

***Fig. 2** Characteristic curve of AZ1518 photoresist with exponential fit*

4 Experimental results

To characterize the system, a sawtooth test structure was fabricated. As seen in Fig. 3, the slope of the sawtooth is nearly linear. To determine the maximum steepness of a structure, we measured the width of the sawtooth's backward slope (Fig. 3 left slope). The slope width is 7.5 µm. The height of the slope is 2 µm.

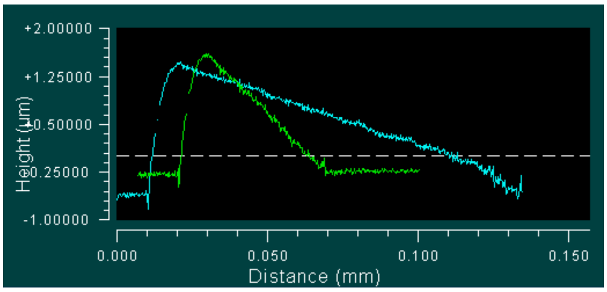

Fig. 3 *Cross-section over sawtooth structure*

To demonstrate the utility of the process for optical structures, a micro-lens with a diameter of 300 µm, a radius of curvature of 1.8 mm and a height of 1.26 µm was exposed directly in photoresist. The focal length of this lens is 2.8 mm and the N.A. 0.05. The lens showed a maximum roughness of 16 nm, as measured with a Zygo white light interferometer (see Fig. 4). After mathematically subtracting an ideal sphere from the measured profile, the maximal peak to valley error was determined to be 100 nm.

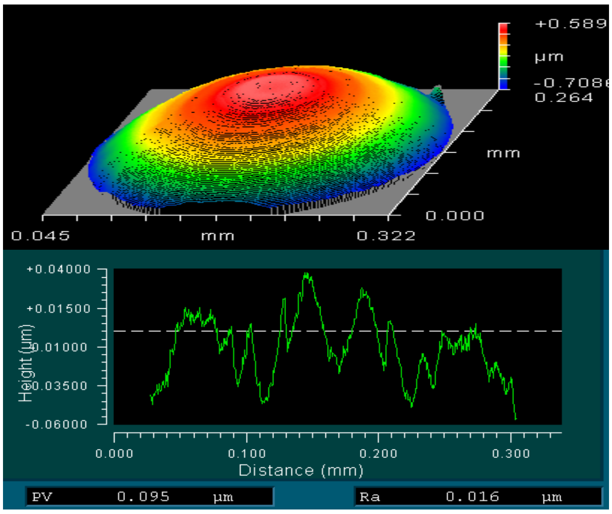

Fig. 4 *top: Microlens; d = 300 µm; bottom: cross-section after subtracting an ideal sphere*

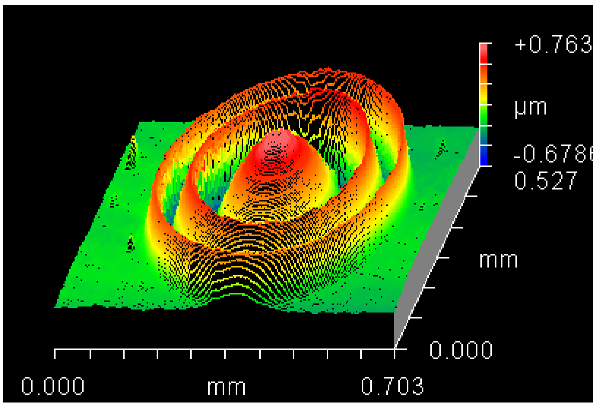

Fig. 5 *Two ring Fresnel lens; d = 500 µm; h = 1.4 µm*

In addition, a micro-Fresnel lens with a diameter of 500 µm, a radius of curvature of the central zone of 1.2 mm and a height of 1.4 µm was also fabricated (see Fig. 5). The focal length of this lens is 1.8 mm and the N.A. 0.14. It is possible to generate thin micro-lenses with a shorter focal length and a higher NA as compared to purely refractive ones.

5 Discussion

The use of rectangular bitmap graphics to generate circular objects is not optimal. Under SEM examination of the above lens structures, a recognizable pixel error is observed. By reducing the size of the exposed area with the same LCD pixel count through the use of different exposure optics, we expect to be able to reduce this pixilation effect to below 1 µm. This could be possible with a special high aperture photo-objective. As the magnification of the optics increases, diffraction effects play an increasing role in limiting the resolution of the exposed object.

Larger structures may be made by stitching these smaller areas together.

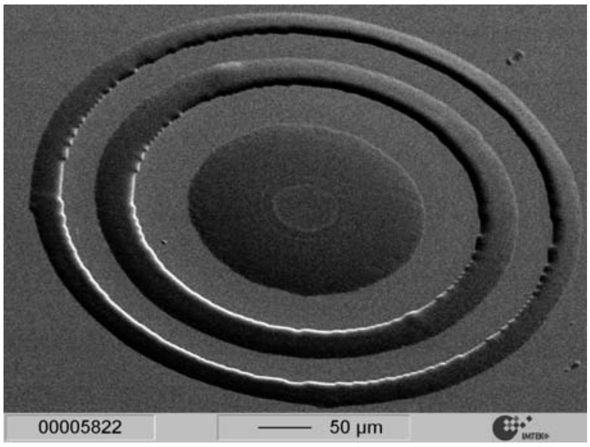

Fig. 6 *SEM picture shows pixel error of circular object*

Finally, we have also shown that it is possible to generate linear topographies in photoresist with this approach. Optical surfaces with a maximum roughness of 16 nm were realized. Direct exposure is thus an alternative way to produce microoptical elements such as microlens-arrays, gratings and holograms. It is also possible to manufacture 3D microstructures for micromechanical devices.

With this method, creation of custom-made structures is inexpensive, fast and easy. Compared to existing manufacturing techniques, this direct-writing method simplifies component development by reducing the design-to-fabrication time and by not requiring cleanroom facilities.