Laser Direct Write Grayscale Photolithography

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Abstract:

Laser direct write photolithography is typically used to make two dimensional patterns on photoresist coated substrates. The intensity of the beam is chosen such that the resist is completely exposed during pattern writing while the beam is in the "on" state. Three dimensional (3D) pattern writing can be achieved by modulating the intensity of the beam to partially expose the resist [1]. This type of exposure is commonly referred to as "grayscale" photolithography and is capable of creating microscale features with multilevel topography.

This project investigated two applications of this fabrication technology: microlenses for micro-optics and filtering structures for microfluidics.

Introduction:

Grayscale photolithography is frequently performed using projection photolithography. This process requires the use of a specially designed photomask. These masks employ variable optical transmission materials and/or complex patterning techniques to modulate the intensity of the exposed pattern. In contrast to binary or 2D patterning where photoresist is either completely exposed or unexposed, this process produces a 3D surface profile. Unfortunately, production of these photomasks is both costly and time consuming.

Laser direct write grayscale photolithography (LDWGP) differs from reduction techniques in that the mask is eliminated. The intensity of the laser is directly modulated as it is scanned across the substrate, producing the same affect [1]. By using this maskless approach, grayscale patterns can be designed and exposed rapidly allowing for increased flexibility. This project focused on the development of LDWGP processes and their use in two application areas: micro-optics and microfluidics. LDWGP combined with reactive ion etching (RIE) was successfully used to create arrays of microlenses in quartz and microfluidic filtering devices in Si.

Procedure:

Microlens Structures: In this work, a Heidelberg Instruments DWL 66 laser pattern generator was used to perform LDWGP exposures. This system uses an acousto-optic crystal to modulate the intensity of the beam to 31 different intensity or "gray" levels where level 31 has the most intensity and level 1 is barely exposed. The resulting 3D structures in the resist can be transferred into the target substrates using RIE.

90 μm diameter microlens structures were designed using a selection of 24 of the available 31 gray levels to obtain optimal curvature. A 100 mm diameter quartz wafer was used as the substrate. Vapor priming in hexamethyldisilizane (HMDS) was performed to improve the adhesion of photoresist to the wafer. Following this process, the wafer was coated with approximately 3.8 μm of Shipley 1045 resist and baked in a 90°C oven for 30 minutes.

The wafer was then exposed using the DWL 66. Exposed wafers were developed in a Hamatech HMP 900 using 300 MIF for 2 minutes using a double puddle process. Developed wafers were placed on a 185°C hotplate for 3.5 minutes to reflow the photoresist and smooth out the transition between the gray levels. Pattern transfer was performed with the Oxford 100 deep reactive ion etcher using an ICP CHF_3/O_2 plasma. Selectivity of quartz to resist was ~1:1.4 resulting in a final lens height of 2.7 μm at the apex (Figure 1).

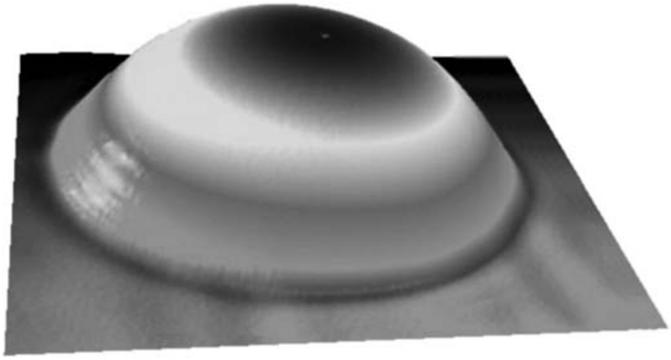

Figure 1: Optical profilometer image of a completed lens. The height is 2.7 µm tall at the apex and the base is 90 µm in diameter.

Microfluidic Filtering Devices: The microfluidic filtering devices were designed to filter particles smaller than 1 μm from larger particles. This was accomplished by creating a ramp separating a 2.5 μm deep region from a 0.7 μm deep region of a fluidic channel [2].

Fabrication of these devices was performed on Si substrates using the same exposure and development process as the microlens structures but without the vapor priming step. Pattern transfer was performed with the Oxford 100 deep reactive ion etcher using an ICP CF_4 plasma. Images of a completed structure are shown in Figure 2. A film of polydimethylsiloxane (PDMS) was used to cover the channel. Holes were cut into the PDMS to allow transport of fluid into and out of the channel.

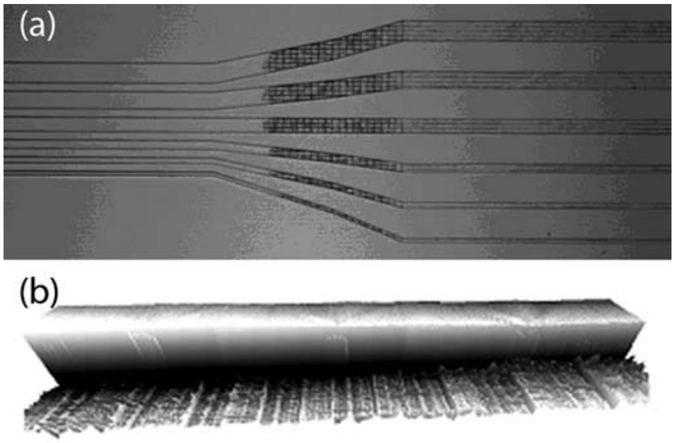

Figure 2: Microfluidic filtering device showing the gradual transition from the deep end (left) to the shallow end (right). (a) Optical microscope image of the channels. (b) Optical profilometer image of the channel transition region. The deepest part of the channel is 2.5 µm, the shallowest 0.7 µm.

Results:

To test the microlenses, a pinhole aperture was inserted into the illumination path of an Olympus BX60 optical microscope. An image of the aperture was obtained by placing the focal plane of the microlens into the focal plane of the objective lens of the microscope. This was accomplished by moving the stage towards the objective lens. A series of images showing this process is presented in Figure 3, demonstrating the operation of a single lens.

Verification of the microfluidic filtering device was not completed during this project. However, a simple experiment involving 1 μm and 0.5 μm diameter latex beads could be used to demonstrate its functionality. The larger beads should remain trapped in the deeper region of the channel while the 0.5 μm diameter beads should flow through the channel unrestricted.

Conclusion:

LDWGP is a useful tool for the fabrication of microstructures with multilevel topography. This work demonstrated the application of LDWGP to micro-optics and microfluidic systems. By using this maskless approach to grayscale photolithography, it is possible to reduce the cost and complexity traditionally associated with mask-based grayscale techniques.

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References:

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[2] Microfluidic Tutorial, 7 Sep. 2001. "Basic Microfluidic Concepts," 1 Aug. 2005, http://faculty.washington.edu/yagerp/microfluidicstutorial/basicconcepts/basicconcepts.htm.

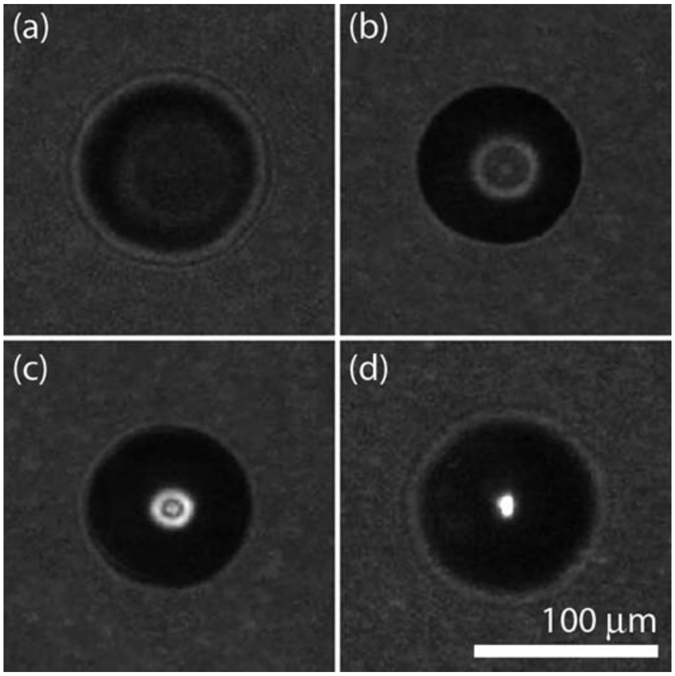

Figure 3: Optical microscope images of a single microlens illuminated with a pinhole aperture. The stage height is changed in (a) - (d) to find the focal plane of the lens.