Deep Lithography with Protons as a rapid prototyping technology for cylindrical microlenses

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Cylindrical microlenses are widely used in different areas of applications. Therefore, we started to fabricate the latter optical component with Deep Lithography with Protons (DLP). In this paper we will explain the general fabrication process of DLP consisting of two different steps: an irradiation and a swelling process. We will comment on the necessary adjustments made for the fabrication of cylindrical microlenses. In this case, an irradiated line with a homogenous deposited dose is required, instead of circular footprints which are needed for spherical microlenses. We will show the results from our first experiments and we will discuss the advantages and disadvantages of our fabrication technique for the fabrication of cylindrical microlenses.

Introduction

Today cylindrical microlenses are used in several application areas such as laser projection, bar code scanning, and optical information processing and computing. Due to their different lens profile in two orthogonal directions, they focus light into a line, thus they can be used for stretching images, focusing light into slits, or causing light to converge on a line-scanning detector. Cylindrical lenses are also use to create holographic displays where the lenses direct the appropriate view to each eye.

Due to the increasing importance of cylindrical microlenses and microlens arrays we decided to start with the fabrication of cylindrical microlenses. It was a challenge for our technology, Deep Lithography with Protons (DLP), and also a proof of the versatility of our technique when we succeed in the fabrication of cylindrical microlens array. Some adjustments had to be made to the initial setup to fulfil the requirements for the fabrication of cylindrical microlenses.

In a first part of this paper, we will explain the changes we had to make to our standard fabrication process for swelling spherical microlenses, to obtain cylindrical microlenses. In the second part, we will show the results from our first experiments and we will discuss the advantages and disadvantages of our technology (DLP) to fabricate cylindrical microlenses.

Design and fabrication of cylindrical microlenses

When designing a cylindrical microlens several parameters have to be specified: the length, the width, the radius of curvature, and the pitch in the case of an array of microlenses (Fig 1). As a matter of fact, the line we irradiate is an overlapping of points. Assuming that the proton current is constant during the irradiation, we move the proton beam at a constant speed along a line path, obtaining the desired footprint for the cylindrical microlenses. Changing the speed we can control the uniformity along one lens, avoiding undesirable points with higher dose. With the proton current, we control the deposited dose: the higher the dose, the higher the lens. Therefore, by controlling the proton current we are able to obtain different heights and hence different radii of curvature. The width of the cylindrical microlens is determined by the beam diameter.

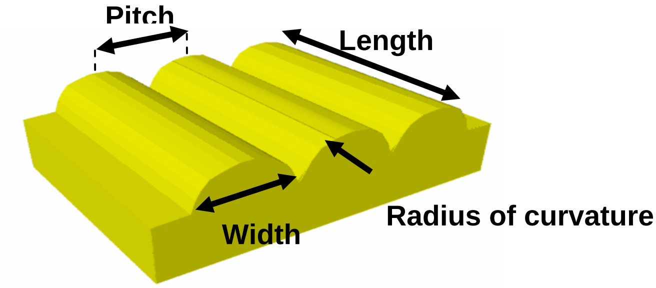


Fig 1: Design parameters for a cylindrical microlens array.

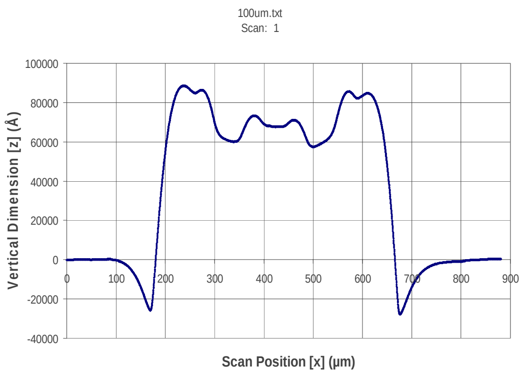
Next we have investigated if our in-house technology, Deep Lithography with Protons could be used to fabricate these cylindrical microlenses and arrays. The DLP process allows for example the fabrication of 2D arrays of micro holes, microlenses, optically flat micro mirrors, and micro-prisms [1]. The idea behind this process is to take advantage of the molecular change that is produced in the irradiated areas. Therefore, in a first step we make a proton irradiation of a PMMA sample with the desired design. Afterwards either a selective solvent can be applied to develop the irradiated regions or an organic monomer vapour is used to expand the volume of the bombarded zones through a diffusion process. If needed, both processes can be applied to different regions on the same sample.

In the irradiation step for the case of cylindrical microlenses, instead of making point irradiations through an irradiation mask as for spherical microlenses, a line irradiation is needed. Moreover, the deposited dose should be constant along the length of the irradiated line to obtain a uniform radius of curvature over its entire length. This is achieved by performing a fast line scanning at a constant speed while assuming a constant proton current. Varying the deposited dose from one lens to the other by means of changing the speed at which the proton beam is moving and/or the current of the beam, we can obtain cylindrical microlenses with different heights or radii of curvature. The width of the lenses can be also chosen by changing the irradiation mask diameter.

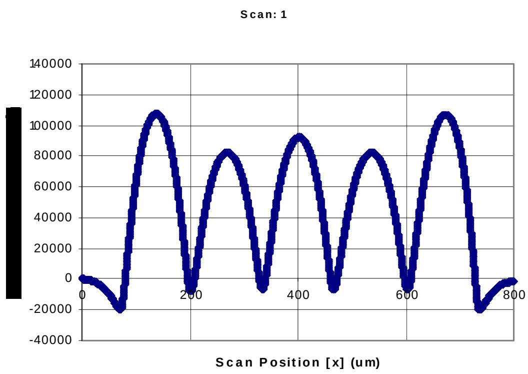
Afterwards the cylindrical lenses are fabricated by applying an etching process after the irradiation step or by performing a selective swelling in an organic monomer vapour of the irradiated regions. We will focus on the last one, where after the irradiation process the sample is placed inside a reactor in order to in-diffuse the monomer in the irradiated areas. After the irradiation and the swelling process are finished, we stabilize the lens arrays. The monomers will bond to the irradiation-induced free radicals and as a consequence will be fixed in the sample. This stabilization process is performed by means of UV exposure.

As explained before, there are several parameters to take into account during the fabrication of cylindrical microlenses. In the first experiments we investigated the influence of the pitch on the microlenses. A too small pitch causes an important overlapping between the lenses. In Figure 2a we show an example of an array of cylindrical lenses with a width of 140µm and a pitch of 100µm. Two neighbouring lines are mixed up without any cylindrical microlens as a result. On the contrary larger pitches result in higher lenticulars since the influence from one lens to another is cancelled and the microlenses have enough material around them to develop (see Fig 2b).

Pitch = 100µm



Pitch = 140µm



a) **b)**

Fig 2: Cross-section of two arrays of five cylindrical microlenses each with a) pitch 100µm and b) pitch 140µm.

Next we investigated the influence of another parameter, which is the translation direction of the sample during the irradiation process. In our irradiation setup the sample is hold perpendicularly to the proton beam, this means that the translation speed is slightly affected depending if the movement is going downwards or upwards. This effect can be clearly seen in an array of twenty cylindrical microlenses with a pitch of 140µm, where the pitch is chosen large enough and where there is no influence from one lens to another (see Fig 3).

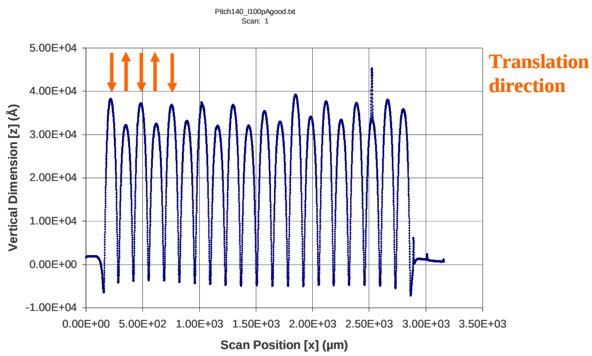
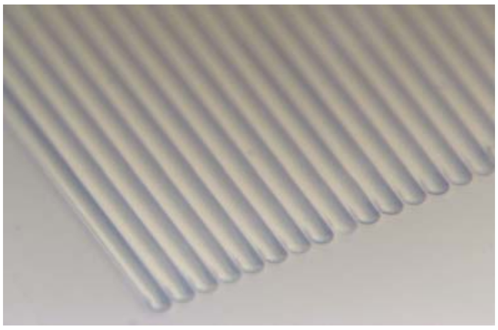
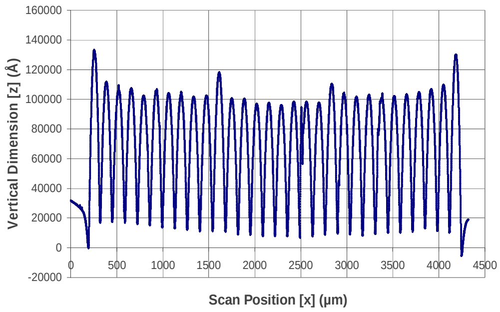


Fig 3: Cross-section of an array of twenty cylindrical microlenses with a pitch of 140µm. The influence of the irradiation direction can be observed.

Once all these parameters were studied and controlled, we were ready to fabricate the first cylindrical microlenses array with the desired parameters. We designed an array with a pitch of 140µm, where there is no influence from one lens to the next one, a scanning speed of 150µm/sec, one direction for the irradiation and we irradiated an array of twenty lines. A scan obtained with a stylus profilometer can be seen in Fig 4.

In a next step we characterized the fabricated cylindrical microlenses to determine all the geometrical properties. To complete this quantitative characterization we used an optical non-contact profilometer (WYKO NT 2000), and a stylus contact profilometer (Dektak 8). Out of these measurement data we determined the radius of curvature 250µm, the width 130µm aprox, and pitch 140µm of our developed sample.





a) **b)**

Fig 4: a) Picture of the cylindrical microlens array. b) Cross-section of this cylindrical microlens array.

Conclusion

As we have shown, DLP technology is promising for the rapid prototyping of cylindrical microlenses with the desired parameters. Moreover we can monolithically combine the latter lenses with other micro-optical components.

In the future we will use a Mach-Zehnder interferometer to measure the optical quality of the lenses and we will explore different irradiation set-ups to reduce the irradiation time and improve the optical lens quality.

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