Beam monitoring enhances Deep Proton Lithography: towards high-quality micro-optical components

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ABSTRACT

In this paper we will explain the importance of a well controlled and accurately positioned ion beam profile in Deep Lithography with Protons (DLP) to prototype high-quality micro-optical components. We will illustrate how to that aim, we implemented two types of Beam Profile Monitors (BPM) in our in-house beam line. A first BPM device is based on two four-segment apertures that allow to monitor the beam position, while a second one uses a Scintillating Fiber Optic Plate (SFOP) and a CCD camera to visualize the beam profile.

INTRODUCTION

The use of refractive micro-optical and mechanical structures are playing more and more important roles in many optical systems. 2D arrays of spherical micro-lenses together with micro-prisms and cylindrical micro-lenses or mechanical positioning structures like 2D fibre array holders are likely to be combined with opto-electronic emitters, receivers and optical fibres to play a key-role in optical sensor arrays, in high definition display and projection systems, in biomedical and invasive medical technology and in optical interconnection and telecommunication technologies [1].
The concept of this technology is based on the fact that the proton irradiation of a sample, made of linear high molecular weight poly(methylmetacrylate) (PMMA), will result in an important reduction of the molecular weight of the material located in the irradiated zones [2,3]. As a consequence, these irradiated zones feature a higher solubility than the bulk material and they can be selectively etched using a special solvent (Figure 1) [4]. This procedure allows e.g. the fabrication of 2D arrays of micro-holes, rows of smoothly curved cylindrical micro-lenses and optically flat micro-mirrors and micro-prisms. Also alignment features and mechanical support structures can be fabricated with this procedure [5].

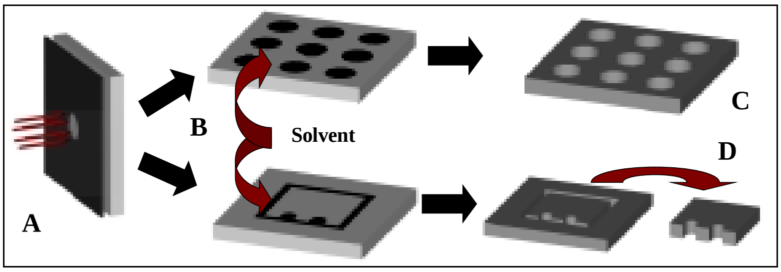

Figure 1: The basic processing steps for the fabrication of micro-hole arrays (C) and more complex 2 1/2 dimensional structures with high optical surface quality (D): Irradiating the PMMA-layer through an accurate pinhole (A) and etching the irradiated zones in a selective solvent (B).

On the other hand, we can swell the irradiated domains using a monomer vapor, which for circular footprints will result in hemispherical surfaces (Figure 2) [6]. This process permits the fabrication of stable spherical micro-lenses with well-defined heights.

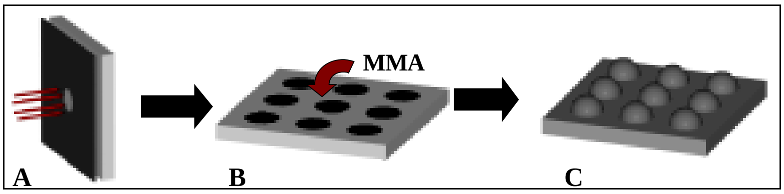

Figure 2: The basic processing steps for the fabrication of 2D arrays of stable and uniform spherical micro-lenses (C): Irradiating the PMMA-layer through an accurate pinhole (A) and applying a MMA-vapour on the surfaces of the irradiated sample (B).

SHORTCOMINGS OF THE PRESENT IRRADIATION SET-UP

The absorbed dose in the irradiated domains of the PMMA sample is a crucial parameter that affects both the etching and the swelling behavior of these zones. Indeed, even small local changes in the particle density of the proton beam and therefore in the absorbed dose distribution in the irradiated zones will result in inhomogeneously etched surfaces, in a tilt of these surfaces (Figure 3.a), or in case of applying the swelling process in a distortion of the symmetrical shape of the spherical micro-lenses (Figure 3.b). If we want to eliminate these shortcomings we have to be able to control the homogeneity of the accelerated ion beams in a fast and efficient way.

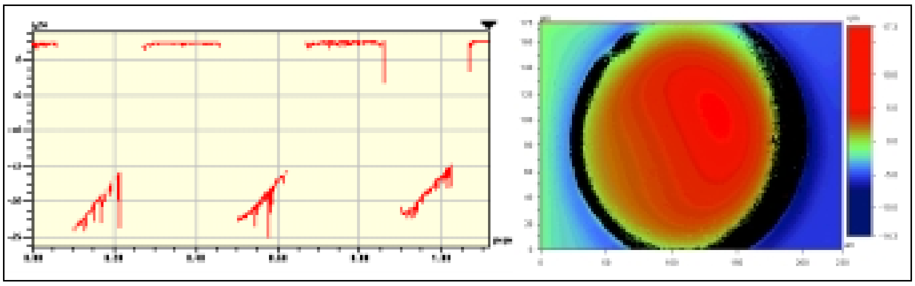

Figure 3: Tilted etching surfaces (a) and shifted lens tops (b) as a direct effect of inhomogenous ion densities.

BEAM MONITORING

It is evident that controlling the size, the shape and the profile of the proton beam is quite important. A better control of this micro-beam, by means of a set of enhanced diagnostic tools, can remarkably improve the quality of the components made with Deep Lithography with Protons.
In a first approach we adapted the first of three collimators in the ion beam line at the Vrije Universiteit Brussel [7]. This water-cooled aperture stops the outer part of the beam, allowing only the central part to pass. Measuring and analyzing this part of the beam by means of metallic segments we are able to roughly position and shape the beam. The second aperture acts as a pre-mask and reduces the beam diameter further down to 1mm. The final mask is a 300µm Nickel plate sufficiently thick to fully absorb the incoming 8,3 MeV protons. To fine-tune the tip-tilt of this mask we placed a Scintillating Fiber Optic Plate (SFOP) just behind the mask. By visualizing the

illuminated spot via a CCD and a frame grabber it is possible to position the mask perpendicular to the proton beam and this in real-time. This experiment was performed at the INFN LNS Tandem facility.

Eight segment beam monitor

This beam monitor consists of eight electrically isolated Aluminium segments fixed on a water-cooled disc by means of a thermally conductive sheet. The four segments facing the proton beam have an inner diameter of 2cm while the other four collimate the beam to a diameter of 1cm (Figure 4.a). Each segment covers a given area (Top, Left, Bottom and Right) and two planes, vertical (Top and Bottom segment) and horizontal (Left and Right segment) are defined. When the proton beam hits a segment, a current is induced in a sensitive picoammeter, built around four dual current input 20bit AD converters (DDC112 from Burr-Brown).

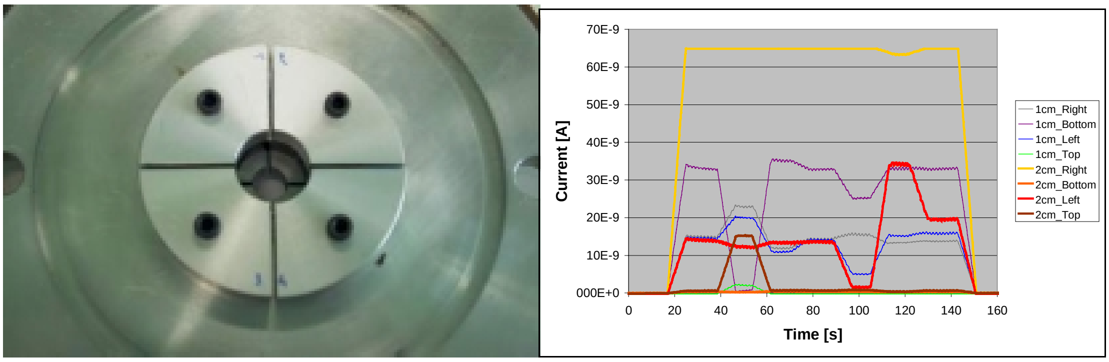

Figure 4: Construction of an 8 segment beam monitor (a) and resp. current measurements with individual picoammeters (b).

The measurements with the 8 segments beam monitor are represented graphically in figure 4.b. The proton beam can be manipulated by a set of magnetic quadrupole lenses. When for example the beam is moved upwards, the current on the Top and Bottom segments change in an opposite way. Because the incident beam is not necessarily circular, the current on other segments will also vary.

µ-SFOB beam monitor

This device is mainly meant to get live images of the beam intensity distribution in the transverse plane. For this purpose we used a Scintillating Fiber Optic Plate (SFOP), made from a bundle of Terbiumglass scintillating fibres, observed by a compact CCD camera. Each fibre in the bundle has a 10 µm diameter, while the overall plate size is 25x25x1.6 mm^3. From a practical point of view, we decided to perform these first experiments in air, using a 10 MeV proton beam accelerated at the LNS Tandem facility. In figure 5 we image two pictures of proton beams with diameters of respectively 800µm (I_{tot} = 40pA) and 50µm (I_{tot} = 2.5pA). These images can be rapidly processed to determine the detailed profile of the ion beam and consecutively allow the fine-tuning of the acceleration parameters [8, 9].

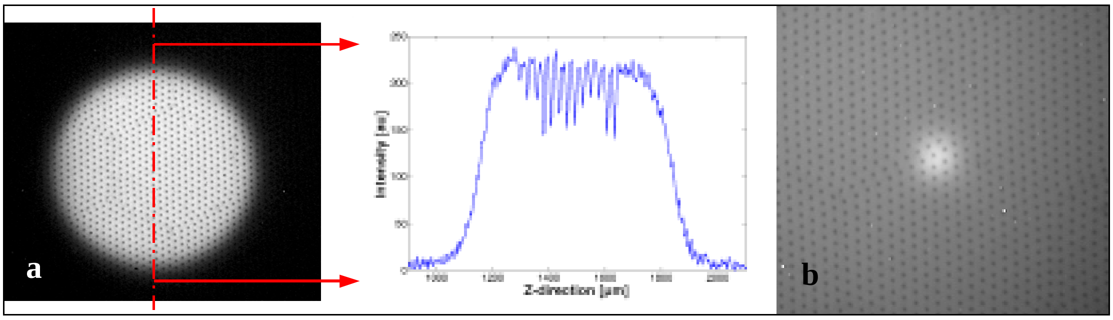

Figure 5: Images of an 800µm (a) and 50µm (b) 10 MeV proton beam, delivered by the LNS Tandem, with a SFOP that allows for real-time beam analysis.

CONCLUSION

In this paper we have described the benefit and added value of beam monitoring to improve the quality of micro-optical components made with Deep Lithography with Protons. The first Beam Profile Monitor (BPM), based on two sets of four-segment apertures allows the monitoring of the beam position while a second one uses a Scintillating Fiber Optic Plate (SFOP) and a CCD camera to visualize the beam profile. The results of the SFOP are promising in that this device will definitely allow a better beam position and beam quality control. In its turn this will greatly improve the accuracy and quality with which micro-optical components can be fabricated using DLP.

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