Deep lithography with protons for the fabrication of refractive micro-optical modules.

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Abstract

In this paper we present the state-of-the-art of Deep Lithography with Protons as a candidate technology dedicated to the fabrication of 2 1/2D and 3D. Its concept is very similar to that of LIGA, but uses ions rather than electromagnetic radiation to structure and shape poly(methyl methacrylate) substrates. We will highlight the different fabrication steps of this high-quality day-to-day reproducible micro-opto-mechanical system technology and we will give a detailed overview of various precision microstructures that we fabricated such as fiber array holders, micro-mirror surfaces, micro-lens arrays and their combination in more complex optical interconnect modules.

Introduction

Refractive micro-optical components and micro-opto-mechanical structures (MOMS) will be key-role players in future high-bandwidth optical Local Area Network systems, in fire-hose capacity switching fabrics, in ultra-fast parallel interconnection modules, in multi-functional optical sensor arrays, in high-definition imaging, display and projection systems, in invasive medical technology and in many more applications. This vast domain of uses is the major driving force behind the recently increased interest in these components and their fabrication technologies. Indeed, today the quality of micro-optical components is such that they can help to overcome practical problems of performance, weight and size, while featuring all the economical advantages of low-cost fabrication through mass-production techniques. They also bring plenty of prospects for innovation and diversification and therefore could open different unexplored market opportunities[1].

Concept and technology

In this paper we will present the state-of -the-art of Deep Lithography with Protons (DLP) as a candidate technology dedicated to the fabrication of 2 1/2D and 3D micro-opto-mechanical systems. Its concept is very similar to that of LIGA, but uses ions rather than electromagnetic radiation to structure and shape poly(methyl methacrylate) (PMMA) plates. The idea originated at the Erlangen-Nurnberg University, where its proof-of-principle was demonstrated for the first time[2]. We adopted this concept, thoroughly upgraded its practical implementation, turned it into a high-quality day-to-day reproducible MOMS technology and are continuously improving its performances and extending its range of practical applications.

The first process step consists in proton irradiating those regions of the PMMA plate that we want to shape into a micro-optical module. To define these zones a commercially available PMMA sample is covered with a patterned 300µm thick nickel mask that is only transparent to the proton beam at a lithographically defined high aspect-ratio micro-hole. During the irradiation, the accelerated protons will completely pass through the 500µm thick high-molecular-weight PMMA plates. The interactions between these penetrating particles and the molecules will induce molecular chain scissions and create free radicals. Due to this energy transfer, the ions will gradually slow down and their interaction density with the PMMA molecules will increase significantly. As a result the irradiated zones will feature a lower molecular weight than the bulk material[3].

To accurately define the irradiated zones we first position the PMMA sample behind the micro-aperture in the ion mask and then move the sample according to the design pattern. For this purpose we use a closed-loop positioning system that consists of two inchworm-driven translation stages with a 50nm travel precision. The set-up is computer controlled and runs on in-house developed CAM software. Besides a precise position and well-defined accurate movement of the sample, the second most critical parameter of the irradiation process is the total number of ions that we have to deposit onto the PMMA. We therefore developed a technique that allows a real-time dose measurement at the sample holder since for a sufficiently high energy, the protons pass through the PMMA sample and induce a charge in the metal plate positioned behind the sample. The measurement tool is based on a precision-switched integrator trans-impedance amplifier and its concept is averse to any fluctuations in the proton current caused by instabilities of the cyclotron[4].

When a point irradiation is performed, a small cylindrical zone with low molecular weights is formed inside the PMMA plate. As a first option we can expand the irradiated volumes by selectively diffusing MMA monomers in these irradiated zones, hence swelling three-dimensional uniform and stable shapes with lens properties (Figure 1). By varying the total collected charge, we are able to fabricate spherical micro-lenses with diameters of 200µm and heights ranging from 8,5µm to 70µm[5].

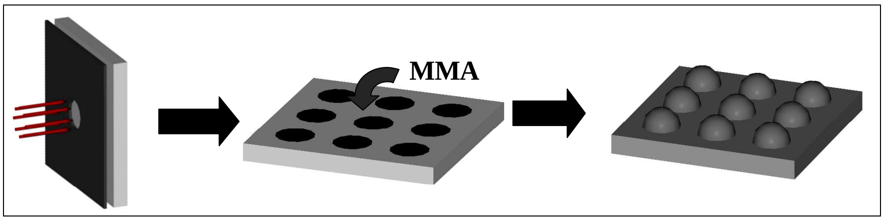

Figure 1 : Basic process steps for the fabrication of stable and uniform spherical micro-lenses.

As a second and completely different processing procedure, the irradiated volumes can be removed with a specific solvent mixture (Figure 2). This is a selective etching fluid that will solve the PMMA zones with a low molecular weight much faster than the ones with a high molecular weight, yielding cylindrical precision micro-holes that can find use as passive optical fiber positioning systems. Due to the large scattering or straggling effect that the protons will experience at the end of their travel range, conical holes with exactly defined diameters at the front (corresponding to the aperture in the mask) and larger diameters at the backside of the PMMA-sample will be obtained. Such profiles allow a user-friendly and smooth optical fiber insertion.

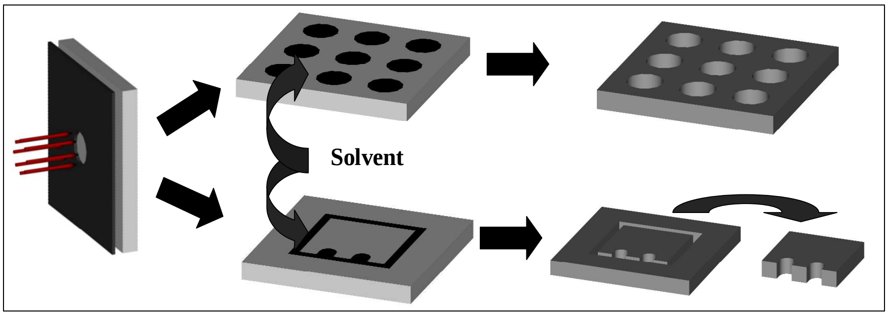

Figure 2 : The basic proces steps for the fabrication of micro hole arrays and more complex 2 1/2D structures.

In case we translate the sample during irradiation we can produce small complex block-shaped volumes with a reduced molecular weight (Figure 2). Applying the selective etching procedure to these irradiated volumes, we now produce surfaces with a roughness of $\lambda/20$ at 632nm over 300µm instead of cylindrical micro-holes. These surfaces can be flat or curved depending on whether the movement of the sample corresponds to a straight or a curved line. The flatness of the resulting surfaces is determined by the magnitude of the proton straggling effect, the precision of the movement of the translation stages and the homogeneity of the deposited dose. The resulting individual microstructures like micro-mirrors, cylindrical micro-lenses and precision 1D fiber alignment features (figure 3) can form the basis for building more complex optical modules and systems[6].

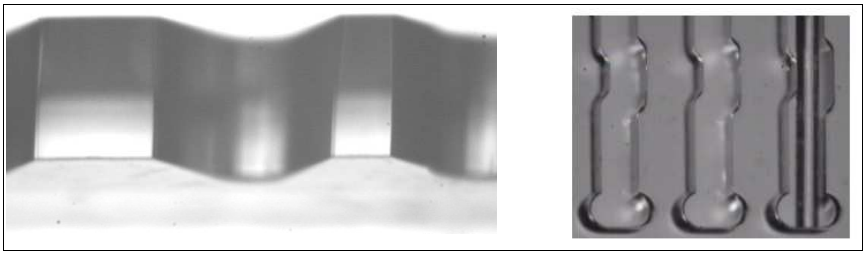

Figure 3 : Photographs of uniform cylindrical micro lenses and optical fiber alignment grooves.

In some cases where optical surfaces, alignment features and micro-lenses need to be combined monolithically, it is also possible to consecutively apply both etching and diffusion processes to the same sample.

In our presentation we will highlight the different fabrication steps of DLP and we will give a detailed overview of the state-of -the-art of the various above-cited precision microstructures and their combination in more complex optical modules.

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