ABSTRACT

The ability to imitate architecture of naturally existing systems in an economical way is important because this will provide platform for various fundamental and applied research activities. One of the interesting architectures is the perforated membrane structure containing micro- and nanoscale openings accessible from both sides. The perforated membrane structures can be found in many biological systems and thus have potential for research on transport behavior [1] in cell biology and separation of biological vesicles. Such structures can also be used as components in polymer optics and modular micro/nanofluidic devices.

We will present fabrication of the perforated membrane structure at the micrometer scale down to 3 µm in diameter in polymer substrates. Use of polymer substrates is viable due to their biocompatibility and low cost manufacturing possibility. In order to realize low cost production of the membrane structures, a single step thermal embossing process [2] was employed, which was combined with semiconductor micromachining processes. We will discuss the several technical challenges including stamp fabrication, optimization of embossing of high aspect ratio patterns, and post-processing.

Stamps with micrometer scale features were fabricated using photolithography in a resist coated on Si wafer. The Si wafers were spin-coated with S1813 (Shipley) photoresist at 2000 rpm for 60 s followed by a post baking process at 95 °C for 90 s. The thickness of the photoresist layer was measured to be 2 µm using a profilometer. Prior to the coating of the photoresist an adhesion promoter, hexadimethylsilazane (HDMS) was spin-coated on the Si wafer at 3000 rpm for 60 s. [3]. UV exposure was performed on the resist-coated Si wafer using a Quintel UV station at CAMD. Figure 1(a) and (b) shows the results of photolithography with and without HDMS, respectively, indicating an enhanced adhesion of the photoresist to the Si wafer by using HDMS. The patterns in the photoresist were transferred into Si using an inductively coupled plasma deep reactive ion etching (DRIE) [4], which was performed at the Microelectronics Research Centre, Georgia Tech. The gas composition and power used for DRIE were SF₆:O₂:C₄F₈ =130:13:100 sccm and 600W, respectively. Figure 2 shows SEM images of Si stamps after DRIE. The images show a vertical sidewall profile and low surface roughness in comparison to metal mold inserts fabricated by LIGA and Micromilling.

Increase in the effective surface area by the presence of micro and nanostructures necessitates the use of an anti-sticking agent for the NIL stamp surfaces. For the anti-sticking coating, the stamp surface was coated with a fluorinated silane in the vapor phase [5] using a homemade chemical vapor deposition chamber. Contact angle measurements showed an increase in the hydrophobicity of the surface after the silane coating which was found to improve the demolding process (Fig.3).

Optimal conditions for embossing in a polymethylmethacrylate (PMMA) sheet with 1.31 mm thickness were found at 175°C and 5000 kPa. Figure 4 shows optical micrographs for Si stamps with 5µm height posts and gratings. The imprint results depict complete filling of polymer with good replication fidelity. While lowering embossing temperatures resulted in partial filling of cavities [6] or impractically longer embossing time, embossing at higher temperatures increased warping, which was severe for thin polymer substrates. Demolding performed at 100°C showed minimal or no damage to both stamps and embossed structures. The embossed structures were subsequently micro-milled from the backside to reach the vicinity of the embossed structures (Figure-5). The membrane structure was completed by removing the residual polymer layer by O₂ plasma treatment.

The process developed to fabricate the membrane architecture can easily be extended down to the nanometer scales, if combined with a stamp fabrication technology for
nanometer scale features and imprinting of structures with increased aspect ratio. This will help to open new vistas in several research fields especially in bioanalytic-micro/nano-fluidic devices.

Figure 1. Optical micrographs of resist patterns fabricated via photolithography and subsequent development (a) with or (b) without using an adhesion promoter, HDMS.

Figure 2. SEM images for Si stamps with pillars of 9 µm diameters and 5 µm depths fabricated via photolithography and DRIE.

Figure 3. Water contact angle measurements on Si surfaces before and after coating of a fluorinated silane in the vapor phase.

Figure 4. (a) Optical micrographs for Si stamps with pillars of 3 µm diameter and 5 µm depth and (b) the imprinted PMMA at 175°C, 5000 kPa using the stamp shown in Fig 4(a).

Figure 5. Results of micro-milling of 7µm dia PMMA holes, (a) top-view, (b) backside view.

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