Nano Imprint Lithography for Photonic Structure Patterning

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Nano Imprint Lithography offers a route to high resolution patterning beyond the resolution limits imposed by optical lithography and at low cost. In this paper we present results of Nano Imprint Lithography of photonic structures using conventional Mask Aligner equipment. We present high resolution imprint results over large areas on glass substrates using a silicon mold fabricated by DUV lithography. We describe how to use this technique for the fabrication of transparent imprint molds. By combining lift-off and nano imprint, gold micron- and submicron structures are successfully fabricated on top of a silicon substrate.

Introduction

Nano imprint lithography was first introduced in 1995 [1]. Since then, a vast number of laboratories started to experiment with this technique employing its interesting potential as a low cost, parallel and flexible patterning technology. Conventional nano imprint lithography requires thermal cycles and high pressures during the hot embossing procedure. UV-based nano imprint lithography however is performed under low pressures (< 1 bar) and does not need thermal cycles. Hence, UV-NIL allows for more flexibility in the choice of materials and less sophisticated mechanics. Moreover, the use of a transparent mold serving as the window for UV curing offers possibilities for precision alignment.

We have been developing a UV-NIL technique using conventional Mask Aligner equipment. The plan of this paper is as follows. First, we introduce the principle of UV-NIL, followed by a more detailed description of our process. Then, we focus on our procedure for transparent mold fabrication. And finally, we prove our technique suitable for gold patterning on top of silicon substrates by presenting results of lift-off after nano imprint.

Principle of UV-NIL

The concept of patterning by UV-NIL is illustrated in Fig.1. The mold containing the desired patterns is pressed into a low-viscous photoresist which becomes rigid by UV-curing. The mold is released and leaves a replica of the mold pattern in the resist on top of the substrate.

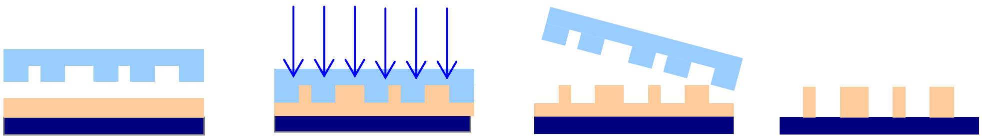
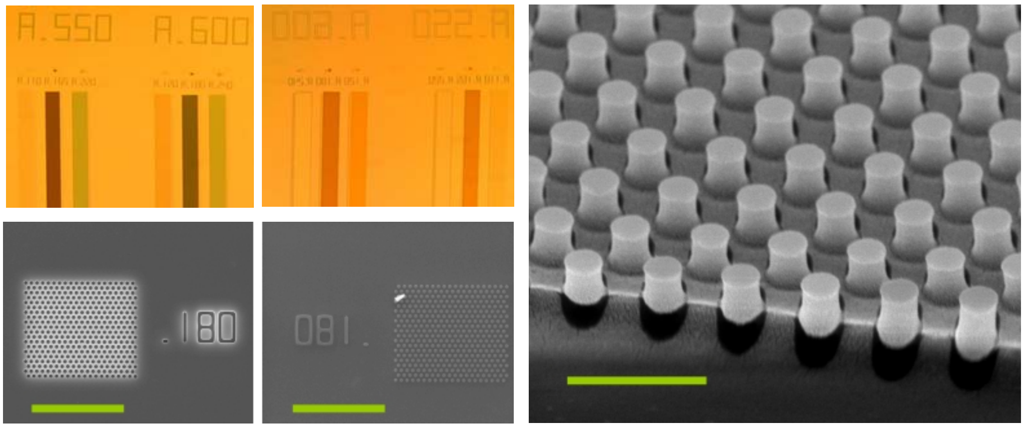


Figure 1. Basic steps in UV-NIL: mold and substrate alignment, resist curing, mold release and break-through etch.

For further processing, imprint is followed by a “break-through etch” during which the residual layer in the trenches of the resist pattern is etched down in order to expose the substrate. In the figure, nano imprint is illustrated on non-transparant substrates using a transparent mold. However, imprint on transparent substrates using a non-transparant mold is equally possible.

Process details

We use a Mask Aligner of type MA-6 from *Süss MicroTec* as imprint machine. Before imprinting, we use its built-in Wedge Error Compensation procedure to place mold and substrate parallel to each other. Next, mold and substrate are allowed to approach while a drop of resist is pressed between them. As the resist is spreading, it fills all structure cavities in the mold and the resist is gradually brought into shape. The pressure between mold and substrate is maintained for a certain time interval without curing by blocking the light from the Mask Aligner’s UV-lamp. In this way, we obtain complete filling of the mold cavities over very large areas. Next, the resist is cured. After curing and unloading, the mold is manually removed from the substrate using a scalpel. Sticking of resist to the mold is prevented by an anti-adhesion treatment of the mold prior to imprinting. Fig.2 shows a microscope image of 1 mm^2 of a silicon mold and its imprint, together with a detailed SEM image of mold and imprint on top of a glass substrate.



A **B** **C**

Figure 2. Nano imprint with a conventional Mask Aligner. The mold consists of long arrays of holes ordered in triangular lattices with different periods and pitches. A. 1 mm^2 of mold area and detail (bar length: 10 micron). B. 1 mm^2 imprint area and detail (bar length: 10 micron). C. Detail of imprint cross section (bar length: 1 micron).

UV-NIL requires special resists. We have been working with a number of commercially available UV-NIL resists such as PAK-01 from *Toyo Gosei Co*. PAK has a rather high viscosity, leaving thick residual layers after imprint of hundreds of nanometers. This makes it very challenging to break through the residual layer without loss of critical dimension. Therefore, we have also been experimenting with a self-mixed product based on benzylmethacrylate, 3-acryloxypropyl-tri-methylsiloxisilane and polydimethylsiloxane. This mixture, described by Jung and coworkers in reference [2] will be further referred to as J-resist. The viscosity of J-resist is only slightly higher than the viscosity of water at room temperature and leaves ultrathin residual layers in the order of a few tens of nanometers. We note however that imprinting with MA-6 with mold and substrate both of a hard material such as silicon or quartz does not lead to uniform residual layers. From our experiments, we infer that higher uniformity is obtained by using a combinatorial quartz-PAK mold. The fabrication process for this mold will be outlined in the next section.

Mold fabrication

For nano imprint on semiconductor substrates such as silicon, a UV-transparant mold is needed. Such a mold is typically fabricated by e-beam lithography. However, we developed an alternative mold fabrication process based on nano imprint. This process is illustrated in Fig. 3 and starts from a non-transparant mold made of silicon and fabricated with Deep UV lithography. First, PAK on top of a quartz substrate is imprinted by the mold. Next, a layer of silicon oxide is deposited onto the PAK. This is followed by an anti-adhesion treatment of the silicon oxide with trideca-fluoro-(1,1,2,2)-tetrahydrooctylsilane (*ABCR GmbH*). Once treated, the mold is ready for imprint and can be reused several times. For example, the pictures of lift-off after nano imprint that are shown in the next section have been taken after several imprints with the same mold.

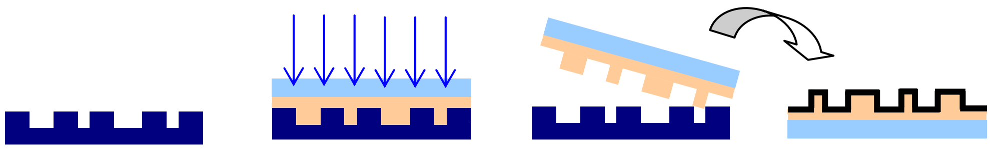


Figure 3. Fabrication of transparent molds by nano imprint: imprint in PAK on top of a quartz substrate, deposition of silicon oxide and anti-adhesion treatment.

Results of lift-off after nano imprint

A mold was fabricated according to the method described in the previous section. A silicon substrate was cleaned and put into a piranha solution prior to imprinting. J-resist was used as the nano imprint resist. After imprint, a break through etched was performed by RIE. We used a gas mixture of O_2 and CF_4, 50 and 5 sccm respectively at a power of 50 W. Etching time was set to 10 seconds. Next, 3 nm of titanium, followed by 30 nm of gold was evaporated onto the sample. Lift-off was performed in acetone in an ultrasonic bath. The results are shown in Fig. 4, representing three areas on the same sample, illustrating that large micron sized as well as submicron sized structures can be imprinted in the same step.

Conclusion

We proved a conventional Mask Aligner to be a suitable machine for UV-based nano imprint. We developed a method for transparent mold fabrication based on UV-NIL and demonstrated its use for fabricating gold micron- and submicron sized structures on top of a silicon substrate.

Acknowledgements

This work was supported by the EU through the IST-ePIXnet network of excellence. I would like to acknowledge the Flemish Institute for the Industrial Advancement of Scientific and Technological Research (IWT) for a specialization grant.

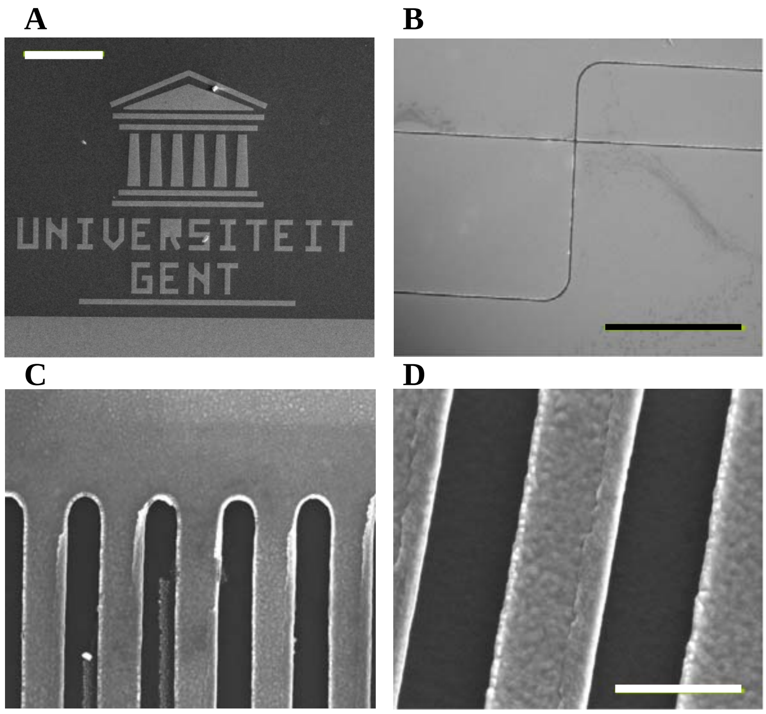


Figure 4. Gold patterning on silicon by lift-off after nano imprint. Dark area is silicon. A. Ghent University logo (bar length: 100 micron). B. Crossing of two 340 nm lines (bar length: 20 micron). C. Grating. D. Detail of this grating (50º tilt, bar length: 200 nm)

References

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