Development of a semiautomatic Nanoimprint Lithography Prototype

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Introduction
To utilize all advantages of semiconductor nanowire arrays used for light emitting diodes (LEDs) or solar cells, a precise way is needed to determine the diameter and pitch of these nanowires because the geometry affects the light extraction in LEDs and the light absorption in solar cells. To grow nanowires with the right geometry by gold catalysed selective area growth a process is needed to place the gold seeds before the nanowire growth. The Nanoimprint lithography is in contrast to other processes like colloidal gold dispersions able to control the diameter and pitch of the gold seeds and is therefore used for the placement of the gold seeds. Since the manual NIL-process by hand generates a short stamp lifetime, poor large area pattern transfer and poor reproducibility an automated process for molding and demolding is needed. To overcome the shortcomings of manual NIL, a semiautomatic prototype was developed to achieve a precise pattern transfer, good reproducibility and long stamp lifetime.

Principles
The Nanoimprint Lithography is a next generation lithography process which has a high throughput, low investment cost and no physical limit of feature sizes compared to other next generation lithography systems. The NIL uses a stamp to mechanically deform a material and replicates a negative of the stamp pattern. Figure 1 shows the full process to transfer the gold seeds and the highlighted process steps represent the UV-NIL process. At first a Polymethylmethacrylate (PMMA) layer and a liquid resist is spun on the substrate (Figure 1 a). Than a flexible polymer stamp deforms the resist and the stamp cavities are filled with the resist (Figure 1 b). After the molding process the resist is cured by UV-light exposure (Figure 1 c). The stamp is removed from the cured resist (Figure 1 d) and two subsequent etching processes remove the residual layer of resist and anisotropically etch the PMMA to the substrate. A gold film is deposited by thermal evaporation (Figure 1 e) and the Lift-Off process removes the PMMA and leaves the gold seeds on the substrate (Figure 1 f).

Figure 1: Schematic representation of the fabrication process for the gold seeds. The highlighted steps represent the UV-NIL process. a) The PMMA and Resist layer are spun on the substrate. b) The stamp is molded to the resist. c) The resist is cured by UV-Exposure. d) The stamp is separated from the resist. e) Two subsequent etching steps remove the residual layer and the PMMA and a Gold-layer is deposited by thermal evaporation. f) A Lift-Off process removes the PMMA and leaves the gold seeds on the substrate.
Development of the semiautomatic NIL-Prototyp

The developed prototype is based on the waveprinting concept by Philips Research [1] which uses pressurized air to sequentially mold and demold the stamp. The NIL-Prototype consists of a stamp holder, a waferchuck and a valve controller (Figure 2). Figure 3 shows the actual build Prototype. The stamp holder has nine flow chambers which volume flow is controlled by the valve controller. The valve controller can either open or close the vacuum or pressure valve for each individual channel to either pull or push the stamp towards the stamp holder or the resist. The forces on the stamp can be controlled with the pressure regulator. The waferchuck fixes the wafer during the process and allows an easy UV-light exposure through the maskaligner by Süss. The impact of the process parameters e.g. the distance between the stamp and the resist, the imprint pressure, the molding and demolding speed and the waiting period between molding and UV-light exposure were evaluated and optimized to attain a large area, reproducible pattern transfer combined with a long lifetime for the stamp. With the optimized process parameters a molding process without trapped air which would prevent a pattern transfer was achieved. Furthermore the demolding process with these process parameters accomplished no visible fractures of the stamp.

Pattern Transfer

Based on the optimized process parameters three samples were fabricated with the NIL-Prototype to characterize the transferred pattern. In all three samples a large area pattern transfer was achieved. The 800 µm and the 70 µm labels of the patterned areas were transferred in all parts of the two inch wafer. Furthermore, pattern with pattern sizes from 25 nm to 150 nm and pitches from 200 nm to 2000 nm were transferred. The pattern size was broadened compared to the expected pattern, e.g. the 150 nm pattern were about 154 nm to 170 nm wide (Figure 4 a). The change in pattern size can be originated by the resist shrinkage during curing or to the fabrication of the master stamp, which could have resulted in greater pattern sizes due to the involved etching processes. Through
measurements by Atomic Force Microscopy (Figure 4 b) the thickness of the residual layer was obtained on two different samples at two different feature sizes. The residual layer was 58 nm at all measured patterns. A uniform residual layer was achieved despite the different pattern sizes and – densities. The uniform residual layer is beneficial because it reduces the need for overetching and therefore minimizes the parasitic lateral etching [2].

Furthermore the yield of pattern transfer was analyzed to quantify error rate on the first sample. The process yielded an error rate of well below 1%. However the local error rate deviated up to 24% compared to the weighted average. To fully quantify the error rate further research is needed because the error rate needs to be analyzed from more samples and the change of error rate with number of processed samples.

To enable the transfer of the gold seeds the layer thickness of the resist and the PMMA and the etching rates were determined by ellipsometry. The samples were further processed to transfer the gold seeds to the substrate. After each etching step the patterns became more visible and the substrate was visible in the bigger patterns (Figure 5 a). The 800 µm und 70 µm labels of the patterned areas could be transferred to the substrate. However the lift-off did not work as expected and did not remove the PMMA in all areas. Figure 5 b shows the transferred gold film and the PMMA layer is still visible inside the number 0. Therefore the smaller features could not be transferred to the substrate. The lift-off can either be prevented by the variation of etching rates at different pattern sizes so that the residual resist layer was not completely removed or the deposition of gold on the side flanks prevented the contact of PMMA and the solvent. To enable a gold pattern transfer at all pattern sizes the variation of etching rates at different pattern sizes as well as the anisotropic evaporation of the gold need further research.

![Figure 4](image1.png)  
**Figure 4:** a) The transferred 150 nm pattern with a 300 nm pitch. b) Height profile of the 150 nm pattern with a 300 nm pitch measured by atomic force microscopy.

![Figure 5](image2.png)  
**Figure 5 a)** A label after 20 min CF$_4$–Plasma and 10 min O$_2$–Plasma etching. b) A label after the lift-off.
**Conclusion**
A semiautomatic NIL-Prototype was developed and built. The prototype can mold the stamp to the substrate without trapped air between the stamp and the resist. Furthermore the prototype can demold the stamp with minimum stress on the stamp to reduce the stamp defects caused during the demolding process. The NIL-Prototype achieved a large area and reproducible pattern transfer on three samples. The transferred patterns were between 25 nm and 800 µm in size and the pitches were from 200 nm to 2000 nm. The measured structures had a uniform residual layer despite the different pattern sizes and -densities. To place the gold seeds for the Au-catalyzed selective area growth by the UV-NIL process further research is needed to enable a lift-off at all pattern sizes.

**References**