Effects of a compliant layer in solid parallel-plate UV-based nanoimprint lithography

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Abstract. We deal with solid parallel-plate UV-based nanoimprint lithography (UV-NIL) using rigid quartz stamps and spin coated substrates. Achieving homogeneous imprints with a thin residual layer are important for a succeeding reactive ion etching (RIE) step. Since the solid stamp and the substrate are not perfectly flat and mounted on solid parallel plates giving them little chance to adapt and compensate for the unevenness and causing additional distortions, this is difficult to achieve. We investigated the bending of a rigid quartz stamp during imprinting and the effect of a thin compliant layer located below the substrate with finite element simulations and compared them with experimental results. We show that a close contact of stamp and substrate can be achieved with a correctly designed compliant layer and using a commercially available EVG® 620 mask aligner.

1. Introduction
In UV-based nanoimprint lithography (UV-NIL) the residual layer (the layer between the protruding features of the stamp and the substrate surface remaining after the imprinting process) is an important indicator of the imprint quality. After the UV-transparent nanostructured stamp has been brought into contact with the substrate, subsequent UV-curing of the resist and separation of stamp and substrate this layer has to be as thin and homogeneous as possible for a succeeding reactive ion etching (RIE) step. For this goal, a conformal contact of stamp and substrate is of paramount importance. This is however difficult if not impossible to achieve, since the solid stamp and the substrate usually are not perfectly flat and mounted on solid parallel plates giving them little chance to adapt and compensate for the unevenness and causing additional distortions.
To get a homogeneous imprint and a homogeneous residual layer over the whole stamp area, a close contact of stamp and substrate has to be guaranteed. Also other research groups deal with contact issues and suggest different solutions e.g. an air cushion press or a sample-on-flexible-thruster stage setup [1, 2].
We investigated the effects of supporting our substrate with a thin compliant layer to compensate unevenness of stamp and substrate. The importance of a compliant layer for a proper working imprint process is confirmed by finite elements simulations.
2. Finite elements simulations

Finite elements simulations can be used to determine the deformation of an object - or an ensemble of objects - with given dimensions, material parameters like Young's modulus and Poisson's ratio, boundary conditions and applied forces. In this work finite element simulations were used to explain the imprint results with EVG®620 because initially in experiments an unintentional deformation of the stamp was found.

2.1. Initial situation

Figure 1 shows the average setup of the imprint process with EVG®620 drawn in ABAQUS CAE. The upper part (figure 1 (1)) is the stamp connected with the lower glass plate of the stamp holder, the middle part illustrates the Si-wafer (figure 1 (2)) and the lower part the substrate holder (figure 1 (3)). Also the boundary conditions and the applied vacuum pressure $p_v$ are depicted as arrows. The stamp holder, the substrate and the substrate holder are fixed at the edges.

![Figure 1](image)

**Figure 1.** Schematic model of imprint setup: stamp (x: 25 mm, y: 2.4 mm) fixed at lower glass plate of stamp holder (1) (x: 100 mm, y: 2 mm), Si-wafer (2) (x: 100 mm, y: 0.5 mm), substrate holder (3) (x: 100 mm, y: 5 mm).

The deformation of the stamp and stamp holder during the imprint process with an imprint pressure $p_v$ of 800 mbar is shown in figure 2 (b). This deformation behaviour occurs because the glass plate on the left and on the right side of the stamp bends down due to the applied imprinting pressure. Therefore the glass plate is bent downwards at the stamp edges which induces the upward bending of the stamp middle. Therefore the stamp is just at the edges in contact with the substrate (figure 2 (d)). The maximum vertical distance of stamp and substrate is about 3.4 µm (figure 2 (c)) in our simulations which is a strong bending in comparison to the features depth on the stamp of 200 nm or 400 nm. This simulation shows that it is not possible to achieve a close contact between stamp and substrate with this setup – rigid stamp and substrate mounted on solid parallel plates.

2.2. Compliant layer

The following figures 2 and 3 compare the simulations without (left column) and with (right column) a compliant layer. The compliant layer (25 x 25 mm², thickness of 900 µm) was located underneath the substrate and made of PDMS (Poly-dimethyl siloxane, Young’s modulus 2 MPa, Poisson’s ratio 0.48). For figures 2 (b) and 3 (b) the distances perpendicular to the substrate surface are stretched to make the bending effects more visible. In figures 2 (c) and 3 (c) the calculated positions for stamp and substrate surface are compared. As can be seen, with the compliant layer, these values are equal which means that a close contact is achieved. Also experimental results show that the compliant layer works as intended and confirm the simulated imprint behaviour. Figures 2 (d) and 3 (d) show photographs of two imprints, 2 (d) without and 3 (d) with compliant layer. Without the compliant layer the stamp was in contact only at the edges, which corresponds with the simulated behavior shown in figures 2 (c) and 3 (c).
Figure 2. (a) Setup for an imprint process without use of a compliant layer. (b) Deformation calculated with ABAQUS CAE. (c) stamp (upper curve) and substrate surface. (d) photograph of an imprint (25 x 25 mm²). Only the edges of the stamp were in contact with the substrate.

Figure 3. (a) Setup for an imprint process with use of a compliant layer. (b) Deformation calculated with ABAQUS CAE. (c) stamp and substrate surface. (d) photograph of an imprint (25 x 25 mm²). The structures on the whole stamp area were transferred to the spin coated substrate.
3. Experimental Results
We perform our imprint experiments with an EVG® 620 nanoimprinter using rigid quartz stamps and Si substrates. The stamps with a size of 25 x 25 mm² contain mainly line and space structures with a width ranging from 200 nm to 600 nm and a depth of 400 nm or 200 nm. The substrates are spin coated with the UV-NIL resist mr-UVCur06 from micro resist technology GmbH, www.microresist.de, Germany [3]. Using a suitable compliant layer imprints of a high quality, which means homogeneous imprints with a thin residual layer can be achieved. Figure 4 shows SEM pictures taken on the right and left edge of the imprint area of 25 x 25 mm². These pictures show that the residual layer - here 60 nm - is homogeneous over the whole sample.

Figure 4. SEM pictures of an imprint with a period of 2400 nm on the left edge (left) and on the right edge (right) of the imprinted area (25 x 25 mm²) with a homogeneous residual layer of less than 60 nm.

Also thinner residual layers down to 10 nm can be achieved [4]. It has been reported that an imprint pressure of about 30 bar is used to get a small residual layer with a resist whose viscosity is about 10 mPa·s [5]. In contrast to these experiments we achieve ultra-thin residual layers with a pressure of only about 1 bar and with a resist viscosity of about 14.2 mPa·s.

4. Conclusion
In an imprint process a close contact between stamp and substrate has to be achieved to be able to transfer the structures of the stamp to the resist. Finite element simulations show that a suitable compliant layer provides a close contact. Experimental results - homogeneous imprints with a residual layer down to 10 nm - confirm the simulated results. The structures were also successfully etched down into silica using RIE.

Acknowledgement
The authors acknowledge funding from the European Community's 6th Framework program (COOP-CT-2004-512667 3DNanoPrint, www.3Dnanoprint.org) and the support from M. Vogler (micro resist technology), H. Schmidt and E.B. Kley (Institute of Applied Physics, Friedrich Schiller University).

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