Impact of Imprint Pressure on Residual Layer Thickness in UV Nanoimprint Lithography

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Abstract. Ultraviolet nanoimprint lithography (UV-NIL) is an important micro/nano fabrication approach. UV-NIL has the advantage of high solution, high throughput and low cost. However, some inner resist flow mechanism is not completely understood by experimental methods. This contribution used the simulation method based on contact mechanics to analyze the impact of imprint pressure on residual layer thickness (RLT). Seven different pressure, from 0.1 MPa to 0.7 MPa, was applied to imprint the same stamp containing grating patterns with various protrusion density. It was found that RLT is not uniform and the areas with high protrusion density has much higher RLT. The average RLT decreases with imprint time and tends to be stable when the imprint process is completed. Both the maximum and minimum RLT decreases with the increase of imprint pressure. These findings can help engineers to design proper stamp pattern distribution and process parameters.

Introduction

Nanoimprint lithography (NIL) is a powerful tool for the fabrication of micro- and nanoscale devices. In particular, ultraviolet nanoimprint lithography (UV-NIL) offers the advantages of high throughput, high resolution and low cost. It is a straightforward approach for fabrication nanopatterns, used in many areas, such as sensors [1], biology [2], microlens arrays [3], and antireflection structures [4].

Residual layer thickness (RLT) is a vital parameter in the UV-NIL process. The thickness of the residual layer cannot be too thin or too thick. Too thin residual layer will bring the risk of directly contacting of stamp and substrate, which will induce the possibility of stamp broken. Too thick residual layer will increase the process time during the step of removing the residual layer. Therefore, the RLT in UV-NIL must be optimized.

Several groups have studied the residual layer in UV-NIL. To control the RLT in roll-to-roll UV-NIL, Taniguchi et al. have attempted to implement roll-to-roll liquid transfer imprint lithography (LTIL) [5]. This process can remove excess resin by splitting the stamp and substrate in the liquid phase. Voisin et al. examined the stamp flatness issue for UV curing NIL process [6]. They studied the impact of the stamp flatness on the reproduction quality and imprint uniformity. They observed that a low stamp waviness has no impact on the RLT uniformity, while a high stamp waviness is transferred into the resist. By using the optimized dispensing method, Kim et al. minimized the RLT in 3D soft UV-NIL process [7]. Lee demonstrated that a sufficiently high pressure is necessary to achieve near-zero-residual layer [8]. Taniguchi et al. studied the filling behavior of UV-NIL resin observed by using a midair structure stamp [9]. Nakamura et al. demonstrated a high-viscosity UV-curable resin suitable for bubble-defect free UV-NIL process in a condensable gas atmosphere [10]. The approach was effective for leveling RLT in bubble-defect free process. However, few groups have studied the influence of imprint pressure on RLT, especially for the stamp with various protrusion density. This contribution tries to declare the relationship between imprint pressure and RLT employing a program based on contact mechanics.
Methods

Capillary forces are taken into account in this work. A commercial available program Simprint Core (Simprint Nanotechnologies Ltd) was used in the whole simulation work. It is able to simulate RLT and the extent of stamp cavity filling as functions of position and time for both UV-NIL and T-NIL. The program takes as its inputs a stamp design, substrate and resist properties, and imprint process parameters.

A generic UV-NIL resist was employed in the following simulation with viscosity 50 mPas and surface tension 27.5 mN/m. The initial thickness of the resist is 300 nm. For stamp material, quartz was chosen with Young’s modulus 71 GPa and Poisson’s ratio 0.17. Fig. 1 gives the two dimensional (2D) areal stamp protrusion density. The red-to-blue colour scale bar stands for different protrusion density. Fig. 2 shows the cross-sectional plot of areal protrusion density. From Fig. 1 and Fig. 2, we can see that the stamp has five repeat sections, each has four different protrusion density with the maximum density 0.5. Protrusion density is defined as the ratio of the width of the elevated part to the width of the pitch.

The imprint was conducted at room temperature for 0.12s imprint time with different imprint pressure: 0.1 MPa, 0.2 MPa, 0.3 MPa, 0.4 MPa, 0.5 MPa, 0.6 MPa and 0.7 MPa.

Results and Discussion

When imprint pressure was 0.1 MPa, the residual layer thickness distribution was shown in Fig. 3. From Fig. 3, we can find that the range of RLT is 60 nm~260 nm. The RLT is not uniform and it is obvious that the areas with high protrusion density has much higher RLT, which can be further demonstrated by the cross-sectional plot of residual layer thickness after imprinting with 0.1 MPa, as is shown in Fig. 4. The reason is due to that the cavity with high protrusion density can be filled with less resist flow, therefore the remain resist leads to high RLT.

![Figure 1. 2D areal stamp protrusion density.](image1)

![Figure 2. Cross-sectional plot of areal protrusion density.](image2)

![Figure 3. Residual layer thickness distribution after imprinting with 0.1 MPa.](image3)
For imprint pressure 0.2 MPa, the imprint result was similar with the case of imprint pressure 0.1 MPa. Fig. 5 shows the evolution of mean RLT (nm) against time with imprint pressure 0.2 MPa. It is obvious that the average RLT decreases with imprint time and tends to be stable when the imprint process is completed.

Fig. 6 gives the cross-sectional plot of cavity filling extent with imprint pressure 0.2 MPa. It demonstrates that the cavities in high protrusion density (0.5 and 0.3) areas can be 100% filled. For protrusion density below 0.3, the cavity volume proportions filled decreases with protrusion density. This phenomena can be explained by the fact that the cavity with higher protrusion density needs less resist to fill its cavity. Therefore, it is easier for resist to fully filled those cavities with higher protrusion density. For those cavities with lower protrusion density, they are difficult to be completely occupied by resist, especially at lower imprint pressure such as 0.2 MPa.

When the imprint pressure was increased to 0.7 MPa, all cavities with different protrusion densities can be 100% filled. We summarized the maximum and minimum RLT for different imprint
pressure. Fig. 7 shows the evolution of maximum and minimum RLT over imprint pressure. It declares that both the maximum and minimum RLT decreases with the increase of imprint pressure. The reason is that high pressure promotes the resist flow and increases the imprint uniformity. Therefore, the RLT reduces with imprint pressure until the imprint process is fully completed.

These findings can help people to design proper stamp pattern distribution and process parameters. With the condition allowed, a stamp with uniform pattern density is suggested to avoid partial high RLT. There is a threshold pressure, with which the resist can completely filled all the cavities of the stamp. Therefore, we should use this threshold pressure to realize the goal of faithfully replicating the stamp pattern and maximally protecting the stamp at the same time.

Summary

UV-NIL is a powerful and versatile approach for the fabrication of micro- and nanodevices. It has been widely used in various fields, such as sensors, biology, microlens arrays, MOSFETs, SERS and antireflection structures. Residual layer thickness (RLT) is a vital parameter in the UV-NIL process. Although several groups have studied the residual layer in UV-NIL, few of them have studied the impact of imprint pressure on RLT. This paper studied the relationship between imprint pressure and RLT employing a contact mechanics based program. Keeping other parameters the same, seven different pressure, 0.1 MPa, 0.2 MPa, 0.3 MPa, 0.4 MPa, 0.5 MPa, 0.6 MPa and 0.7 MPa, was applied to the stamp with diverse protrusion densities. It was found that the areas with higher protrusion density have higher RLT and they can be filled slower compared to the ones with lower protrusion density. Both the maximum and minimum RLT decreases with the increase of imprint pressure and imprint time, and tends to be stable when the imprint process is completely done. These findings can provide guidelines for designing reasonable stamp pattern distribution and process parameters.

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References


