Controlled interfacial energy for UV-imprinting using resin adhesion to substrates

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Abstract

We introduce a modified UV-imprint lithography, a resin transfer from the template to the substrate. We analyzed this method by considering the surface and interfacial free energies of the template-resin-substrate system. This technique is purely fast and applicable to large area patterning.

1. Introduction

Nanoimprint lithography (NIL) has been used to fabricate structures such as a memory device,[1] fluidic channels,[2] and protein patterns.[3] Recently it is interested in large area and micro-scale patterning for display fields. Imprint lithography involves applying a high pressure for the imprinting of the template pattern into an underlying polymer layer. This factor could occur to a limitation in a large area patterning.

In this report, we describe a modified imprint lithography using the resin adhesion to the substrate for large area and micro-scale patterning with no pressured applied.

2. Results

Shown in Figure 1 is a schematic illustrating the modified UV-imprint lithography. After a ultraviolet (UV) curable resin is coated onto the patterned template, a substrate is placed on the resin surface.

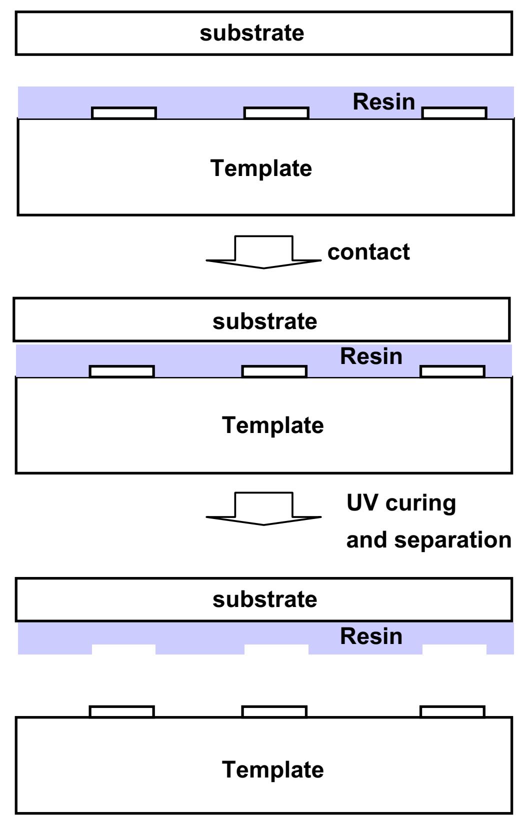

Figure 1. Schematic illustration of modified UV-imprint lithography.

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No external pressure is applied while UV cured the resin. After the UV curing, the substrate is lifted up. The UV cured resin adheres to the substrate and detached from the template.

Using this approach, we have successfully imprinted micro-patterns down to 5 ㎛ as illustrated by our imprint results shown in Figure 2.

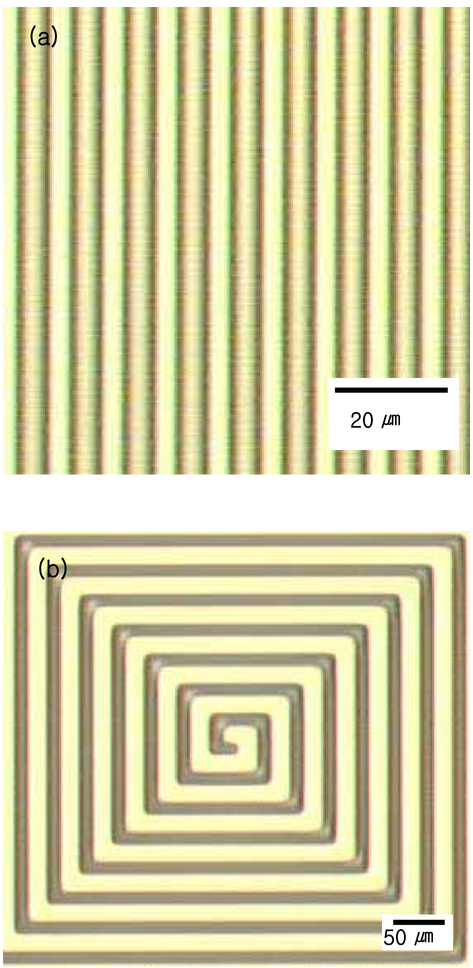

Figure 2. Optical microscopy images of a UV cured acrylate pattern on bare glass substrate (a) 5 ㎛ line-and-space pattern, (b) Spiral pattern.

The successful patterning relies on a difference in adhesion force between two interfaces. The adhesion force ($W_{S\text{-}R}$) at the substrate-resin interface should be larger than that at the resin-template interface.[4]

For a single-layer process, as the feature pitch decreases, the interface area between the resin and the template ($A_{R\text{-}T}$) increases while that between the resin and the substrate ($A_{S\text{-}R}$) remains constant. This causes $A_{R\text{-}T}W_{R\text{-}T}$ term inequlality to increase. At a certain pitch, the term will overtake the $A_{S\text{-}R}W_{S\text{-}R}$ term, resulting in the resin detaching from the substrate and adhering to the template.

As the interface area between the resin and the template was increased, the resin was more likely to adhere to the gap between features on the template and detach from substrate surface during the template separation. In this case, surface modification techniques have been used to provide much easier the template release. However, we have not a release layer on the template or template surface treatment. Seo et al.[5] introduce adhesive force lithography (AFL), a detachment-based method for patterning metal surface. In this method, they used only the relationship of interfacial energy between the resin-template-substrate and a template with protruding features is brought into intimate contact with a resin layer coated over a metal surface that is heated to a temperature above the glass transition temperature (T_g). There are other detachment-based methods reported earlier: lift-up soft lithography[6], and hot lift-off[7]. Other detachment-based methods including AFL have to use a specific surface energy system, cannot control the interfacial energy between the template and the resin or the resin and the substrate.

In our results, we can control the interfacial energy as optimization of UV cure condition.

First of all, the selection of the UV curable resin is important to achieve the modified UV-imprint lithography. Ultraviolet curing of acrylate or methacrylate eliminates the need for solvent and allows ambient temperature solidification in contrast to AFL approach.

A representative resin for simple release is PDMS (polydimethylsiloxane) because of its low surface energy (below 20 mJ/m^2). Our approach focused on achieving a surface property like the PDMS surface property.

We can present the hydrophobic property of the surface through Young equation and theory of Good-Girifalco. The definition can be expressed by

$$\alpha = \left[\left(0.3 \times \frac{\gamma_R^d}{\gamma_{water}} \right)^{1/2} + \left(0.7 \times \frac{\gamma_R^p}{\gamma_{water}} \right)^{1/2} \right] \leq 0.5 \qquad (1)$$

where, γ_R^d and γ_R^p are the dispersion and polar term of the resin surface energy, respectively.

The meaning that the coefficient α is below 0.5 can be that the water contact angle on the surface is above 90°.

For the PDMS (Sylgard 184, Dow Corning Corporation) resin, the coefficient α is 0.4, which the polar term is 1.2 mJ/m^2 and the dispersion term is 18.8 mJ/m^2.

In our experimental, we used the monofunctional acrylates and dimethacrylates that can be controlled the surface energy at the cured state as UV intensity and irradiation time.

As shown in figure 3, the coefficient α is decreased as increasing the UV irradiation time. At low UV intensity, we cannot obtain the α below 0.5. We can find dramatically reduce of the coefficient α both 3 and 11 mW/cm^2 at lower dose.

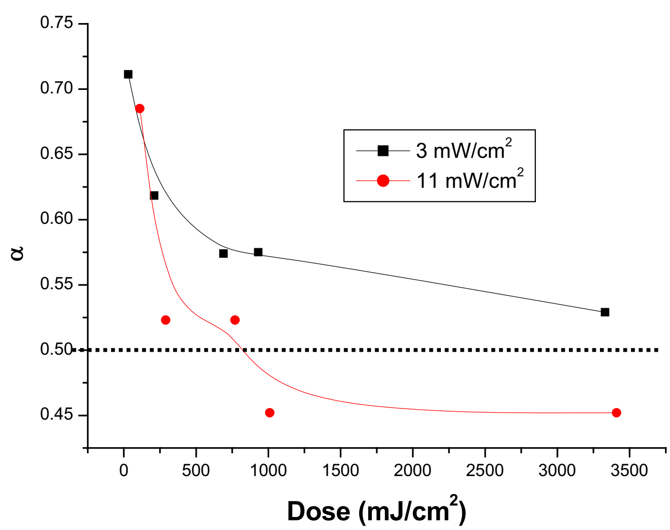

Figure 3. The coefficient α as a function of dose at two different UV intensities.

3. Conclusions

We demonstrated a new approach for micro-scale patterning using the modified UV-imprint lithography. The method can overcome several problems in the conventional nanoimprint lithography.[8-10] Firstly, the method can achieve micro-patterns at ambient pressure and temperature. Secondly, we have not a release layer on the template in contrast to other approach[11] that employ hydrophobic release layer on the template. Finally, the release between the patterned substrate and the template can be achieved using the UV intensity and irradiation time.

4. References

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