7th World Tribology Congress, WTC 2022
July 10-15, 2022, Lyon, France

Modelling of Layer Uniformity in Roll-to-Plate UV Nano-Imprint Lithography

Jelle Snieder[1) 2)*] and Ron van Ostayen[1)]

[1)]Precision and Microsystems Engineering, Delft University of Technology, The Netherlands
[2)]Morphotonics B.V., The Netherlands.
*Corresponding author: j.snieder@tudelft.nl

Roll-to-plate UV nano-imprint lithography is a unique technology to pattern large area substrates with micro- and nanotextures. A thorough understanding of the involved physics in the imprint process is crucial to further improve the imprint layer thickness and uniformity for future applications. In this study an elasto-hydrodynamic lubrication (EHL) model is developed and used to study the sensitivity of the process variables, and the influence of the resin front on the imprint layer thickness and imprint layer uniformity.

Keywords (from 3 to 5 max): nano-imprint lithography, layer uniformity, Reynolds equation, EHL

1. Introduction

Ultraviolet nano-imprint lithography (UV-NIL) is a patterning technology to replicate micro- and nanostructures in a thin UV-curable resin. Roll-to-plate UV-NIL is a roller-based variant, which is developed to pattern discrete, large area substrates with optically functional layers, for example anti-reflection coatings on solar panels. Figure 1 shows a schematic of the roll-to-plate imprint process, which uses four rubber-coated rollers, for imprinting and to guide a textured flexible stamp. A pattern of UV-curable resin droplets is dispensed on the substrate. The front imprint roller presses the flexible stamp into the liquid UV-curable resin. Typically, in the roll-to-plate imprint process, a resin front is formed before the imprint roller. The resin is cured between the two bottom rollers. A second roller delaminates the flexible stamp from the hardened resin, leaving a negative image of the texture on top of the substrate.

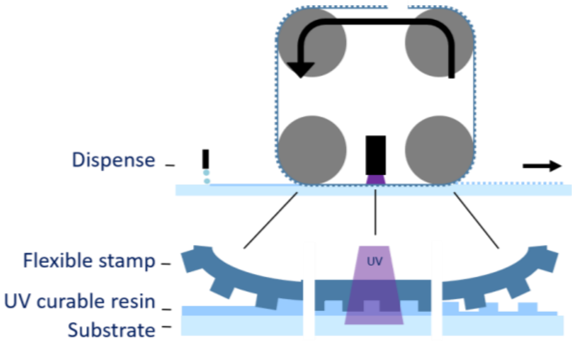

Figure 1: Schematic of the roll-to-plate NIL process.

Ideally, the final imprint layer has a small and uniform thickness over the entire substrate area. Full understanding of the relevant physics of the imprint process is desired to further improve the layer thickness and uniformity for future applications. Typically, the resin flow in NIL is modelled using lubrication theory [1]. In this work, a numerical model is developed and used to study the sensitivity of the process variables (roller diameter and stiffness, imprint force and speed, resin properties) and the location of the resin front. The incoming droplet pattern causes a time-varying supply of resin and thus a varying resin front location, which influences the film height and film pressure, similar to the behavior in starved lubrication [2].

2. Method

A schematic of the model set-up can be seen in Figure 2. A roller of radius R rolls with velocity U over the substrate, which moves at the same speed. The influence of textures is neglected; the flexible stamp is assumed to be flat. Because of the thin resin layer, Reynolds lubrication approximation is valid:

$$\frac{\partial(\rho H)}{\partial t} + \nabla\left(-\frac{\rho H^3}{12\mu}\nabla P + \rho H u\right) = 0$$

with film height H, pressure P, and resin density ρ and viscosity μ. The elastic roller will deform due to the film pressure. The deformation is calculated and coupled to the flow equation, resulting in an elasto-hydrodynamic lubrication (EHL) model. To be more specific, the systems operates in the isoviscous elastic regime, also called soft EHL. Mass-conserving cavitation techniques are used to find the equilibrium film height H_{eq} [3].

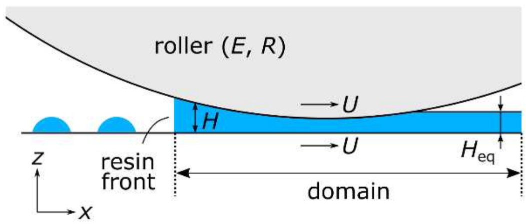

Figure 2: Schematic of the cross-section of the model (not drawn to scale).

References

[1] Cochrane, A., et al., “Elastohydrodynamics of Roll-to-Roll UV-Cure Imprint Lithography,” Industrial and Engineering Chemistry Research, vol. 58, no. 37, 2019, pp. 17424–17432.

[2] Venner, C. H., et al., “Film Thickness Modulations in Starved Elastohydrodynamically Lubricated Contacts Induced by Time-Varying Lubricant Supply,” Journal of Tribology, vol. 130, no. 4, 2008.

[3] Alakhramsing, S., et al., “Thermo-hydrodynamic analysis of a plain journal bearing on the basis of a new mass conserving cavitation algorithm,” Lubricants, vol. 3, no. 2, 2015, pp. 256–280.