Optical Waveguiding in UV-Curable Nanoimprint

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Nanoimprint lithography (NIL) is a low-cost nanoscale pattern replication technique that has a wide range of applications[1]. NIL has many variations depending on the resist materials used in the process. Ultraviolet-curable nanoimprint lithography (UV-NIL) uses liquid polymer precursor as resist materials and achieves pattern replication thorough solidification of resist by UV-induced polymerization process[2-3].The non-uniform distribution of optical energy in UV-NIL due to waveguiding has been known to UV-NIL. Previous work has studied the optical energy distribution in selective structures[4]. In this work, we thoroughly investigate all factors that affect the optical field distribution in UV-NIL, including the width and height of the protrusions on the template, the index and absorption of the resist formulations, and the reflection from the substrate. While past efforts in nanoimprint development have overlooked the impact of inhomogeneous optical energy distribution, the information obtained in this study can be used to provide new ideas in optimizing UV-NIL to minimize defect generation, for example through template structure tweaks and resist index tuning. Alternatively, this information may also be used in the metrology of nanostructures by pre-identifying the locations where defects are most prone to occur due to inhomogeneous curing in nanoimprinting complex patterns in real-world manufacturing processes.

To investigate energy distribution in micro- and nanostructures in UV-NIL, we perform numerical simulations by solving the Maxwell equations with the finite-difference time-domain (FDTD) method for various structural and material configurations in nanoimprint[5]. Figure 1 shows a schematic diagram of the UV nanoimprint. The UV-curable resist is confined between a fused silica template and an etch transfer layer which is used to facilitate pattern transfer into the substrate. The UV light is irradiated to the UV-curable resist as a single wavelength plane wave optical source above the template. In Fig.1(b) the energy distribution is obviously dependent on material index. The calculated results are shown in Fig. 2(a-c).The relationship between internal energy ratio within the resist region and height ratio or refractive index is simulated. The results in Fig. 2(a) and (b) suggest that there is a specific range where the internal energy ratio can reach a lowest value, which means a situation in which lowest intensity inhomogeneity happens. Figure 2(c) suggests that when the linewidth increases, more inhomogeneity of light intensity occurs due to waveguiding effect. In practical nanoimprint, it is desirable to have the light energy homogeneously distributed in the resist region to achieve uniform curing. We use three UV light sources with incident angles of -45, 45, 90 degrees and the result is shown in Fig. 2(d). It can be seen that the light distribution becomes less inhomogeneous as compared to the case in which only vertical incident light is used.

We will further report the experimental study of the impact of light inhomogeneity on defect generation in UV NIL. The non-uniform curing will be evaluated by measuring the contact force between the mold and the resist and the mechanical properties of the cured resist.

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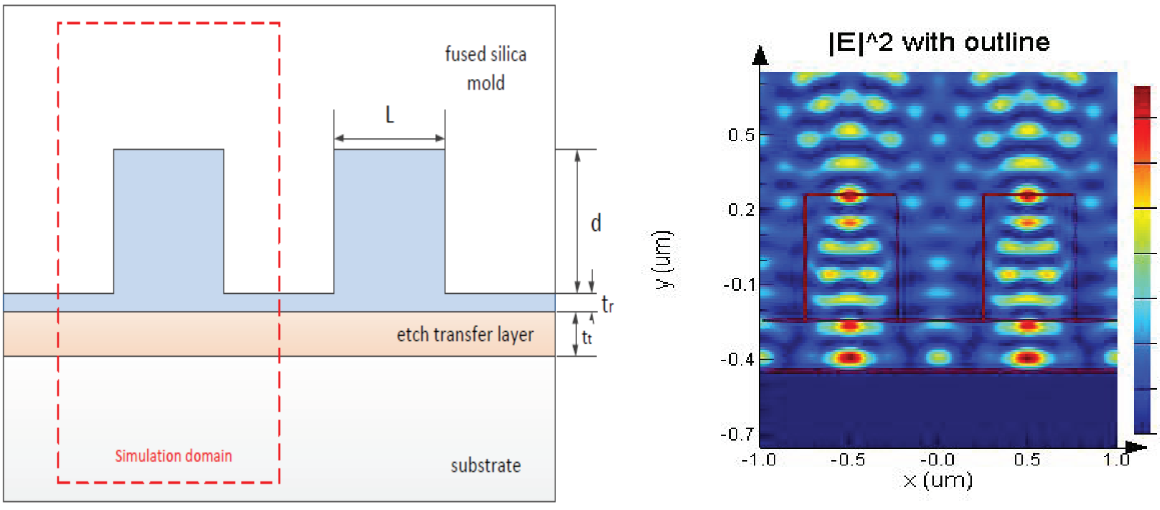
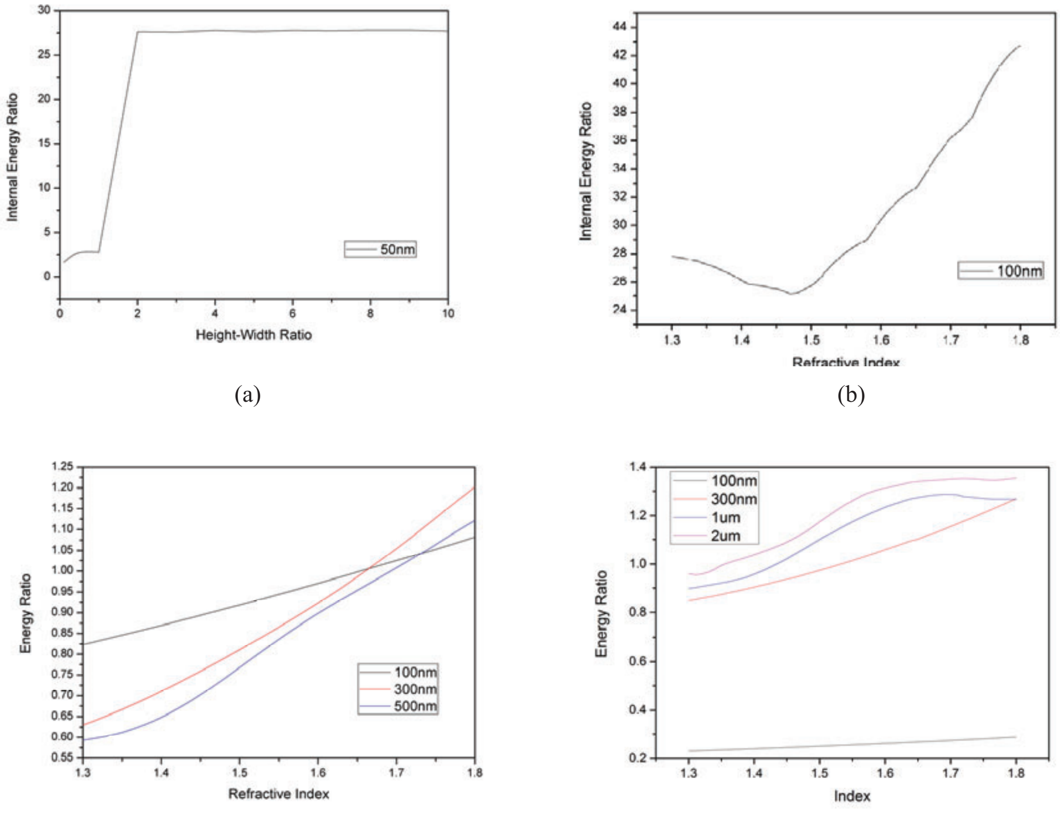


(a) (b)

Fig. 1. (a) A schematic of the simulated structure in UV nanoimprint. The red dashed box indicates simulation domain; (b) An exemplar field distribution plot is obtained from simulation. The energy distribution is illustrated and the intensity is visualized with different colors.



(a) (b)

(c) (d)

Fig. 2 Calculated UV light inhomogeneity in UV NIL. (a) Internal energy ratio (maximum light intensity divided by minimum light intensity within the resist region) as a function of pattern height-width ratio for 50 nm structures; (b) Internal energy ratio as a function of resist refractive index for 100 nm structures; (c) Total energy ratio of UV energy in resist region (integrated UV energy in resist region divided by integrated UV energy in mold protrusion region) as a function of refractive index of the resists for different pattern widths. All above simulations use one UV light source with incident angle perpendicular to the resist surface. (d) Total energy ratio as a function of refractive index of the resists for different pattern widths when illuminated by three UV sources with incident angles of -45, 45 and 90 degrees.