ORIGINS OF STAMP BENDING IN NANO-IMPRINT LITHOGRAPHY

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This paper presents experimental observation and model interpretation of two distinct regimes of stamp bending in nano-imprint lithography (NIL)[1]. When the flow of the polymer is limited by the high viscosity of the resist, the stamp responds to pressure build-up by a compression along its mid-plane, resulting in pure bending. Conversely, when a pure squeeze flow of the resist is enabled by low viscosity, a tensile stress develops along the mid-plane of the stamp, corresponding to a membrane behavior. These two phenomena illustrate the interplay between fluid flow under the protrusions and the plate vs. membrane behavior of the stamp. Importantly, they involve two very different lateral length scale of the resulting stamp bending. This goes beyond conventional analysis based on Stefan's equation[2] which links the applied imprint pressure to the embossing time, providing an accurate order of magnitude of the embossing time, but failing to address stamp bending.

In experiments, imprinting a regular grating (Fig. 1) at various temperatures gives a clear picture of the interplay of resist flow and stamp bending[3]. In these experiments, the 500µm thick, 4-inch diameter, silicon stamp contained a 1×1mm area patterned with a 25µm half-pitch line grating, 300nm high. A MRI7000E resist in an EVG520 HE imprint tool were used at an imprint pressure of 6.4 bar for 5 min. The stamp was removed at 50°C (Tg-15°C) to minimize viscoelastic recovery before observation. The only parameter varied was the embossing temperature, and as a result the viscosity of the resist. Two distinct results are obtained for a low and high viscosity: Fig. 2, as evidenced by the lateral length of the bending. With a resist of low viscosity, stamp bending is distributed homogeneously over the structure, resulting in a smooth bell shape. Conversely, a flat residual layer is obtained at higher viscosity resist, apart from the sides of the structure. These results can be interpreted by considering the distance that the resist can travel when squeezed by a protrusion. In the case of high viscosity, the resist does not have the possibility to redistribute over long distances. As a result, the pressure builds up under the protrusion: in terms of spring back stress on the stamp, this situation corresponds to applying a evenly distributed pressure in the patterned region. The resulting deflection is similar to that which would be obtained by pressing a flat punch on the stamp over the patterned area, and the stamp behaves essentially like a plate, in pure bending. For a low viscosity, this pressure is redistributed over the whole stamp area, which conforms to the resist surface. The stress distribution in the stamp differs dramatically from the previous case, as tensile forces originating from area wide interfacial shear forces enter the force balance. As such, the stamp behaves like a membrane, and a smoother deflection is obtained. These two complementary behaviors are well captured by a coarse grain model[4], as shown in Fig. 2. This phenomenon explains the often unexpected results of NIL experiments, where a higher resist viscosity often leads to a lower residual layer thickness than obtained with a lower viscosity.

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2: J. Stefan, Annalen der Physik, 230:316-318, 1875
3: R.H. Pedersen, et al., in Proceedings of MNE'08, Athens, Greece, Sept 15-18, 2008
4: V. Sirotkin, et al., Microelectronic Engineering 84:868–871, 2007

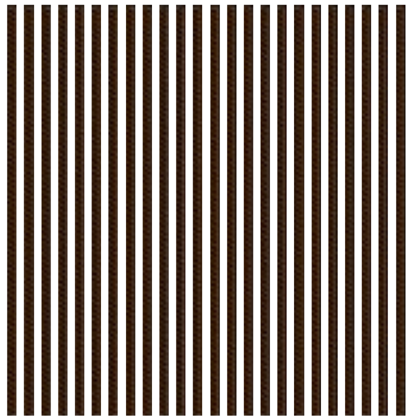

Fig. 1: Stamp geometry: 1×1mm grating of 24 lines 25μm wide

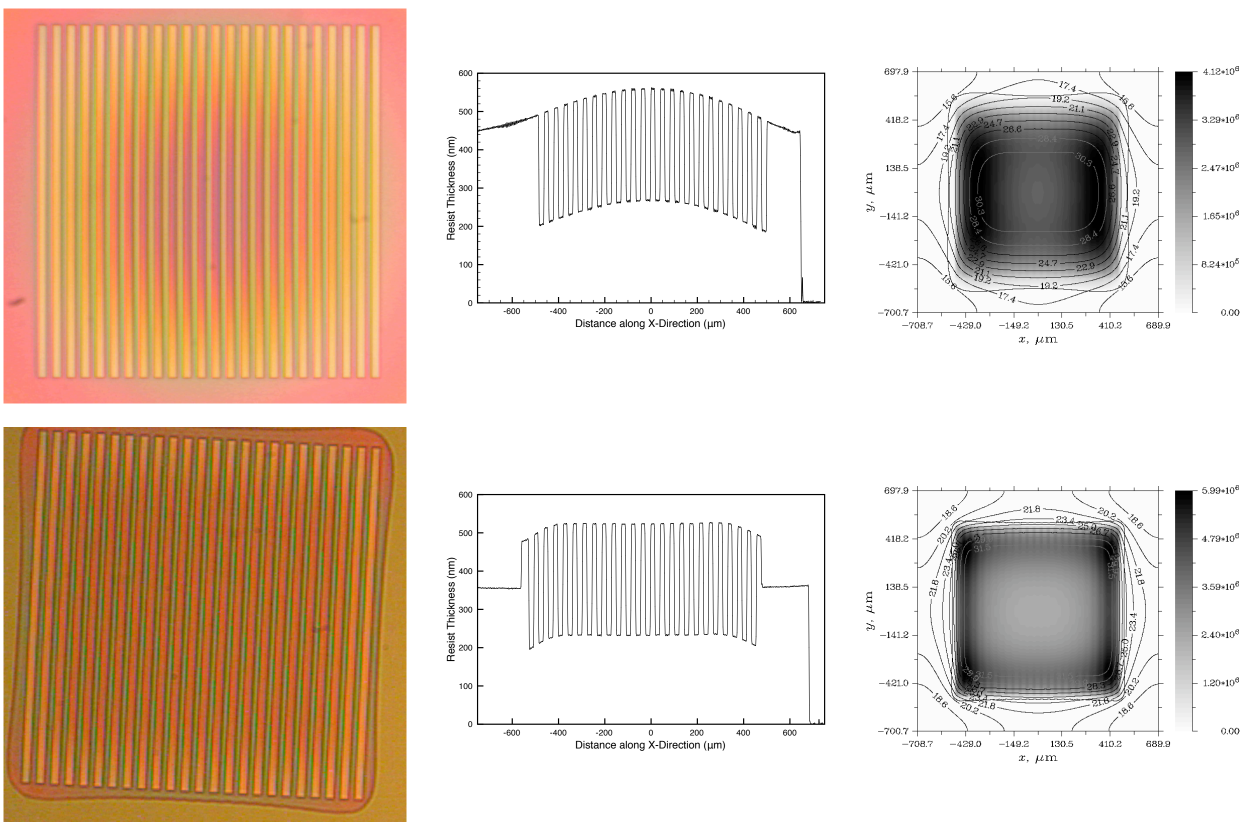

Fig. 2: Experimental (left and center) vs. model (right) results. Top: low viscosity (T= 140°C, η≅3’500Pa·s) resist; Bottom: high viscosity (T=120°C, η≅30‘000Pa·s) resist. The gradient of residual layer thickness is clearly visible on the microphotographs - notice the bell shape of the low viscosity result. The simulation results feature both the pressure profile at the end of embossing (t=5min) and the contour of the residual layer. The values indicated by contours are the excess RLT with respect to the average layer thickness at the end of embossing