A Competition Between Vertical and Lateral Instabilities in Parallel Line-Space Gratings Fabricated by Nanoimprint Lithography

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Nanoimprint lithography (NIL) is a versatile way to fabricate nanoscale structures into a broad range of different materials. NIL is a mechanical stamping technique whereby the patterned media is squeezed into the nanoscale cavities of the imprint template, with the potential for high volume manufacturing. There are examples of roll-to-roll imprint processes being developed for the continuous patterning of large area media. High volume manufacturing means fast processes where the material is quickly squeezed into the mold cavity, with the potential to generate aggressive shear flow fields. Previous measurements show that this has the potential to generate large levels of residual stress in the imprinted patterns. This will be exacerbated by roll-to-roll processes where the material is also quickly ejected from the imprinting rollers at elevated temperatures, where these internal stresses are prone to relax and distort the pattern. A central theme of our research has been to quantify how the NIL patterning processes generate these internal stresses and thereby compromise the stability of the imprinted structures. In this work we have identified an interesting competition between two competing instabilities for line-space pattern fabricated by NIL thermal embossing. Imprinting introduces a thermodynamic surface energy penalty and a smooth surface that minimizes surface area is energetically favorable. Depending on the viscosity and/or modulus of the patterned material, the Laplace pressure generated by creating the nanoscale pattern, and the level of residual stress in the pattern, there is a strong driving force to decrease the surface area. We have already shown that imprinting can induce residual stresses that lead to an elastic recovery that causes the patterns to rapidly shrink in height to relieve the stress and decrease surface area. Here we identify a new lateral instability that competes with this vertical decay, creating buckling patterns in the line-space gratings that also reduce the surface free energy. This lateral instability occurs in high viscosity patterns imprinted under conditions that minimize the residual stress. In these systems the vertical decay from viscous flow is extremely slow, so the system develops lateral undulations that also minimize the surface free energy. The origins of these lateral instabilities are discussed in terms both an elastic and a Rayleigh-like instability.

Figure 1. Based on the principles of time-temperature superposition, the series of AFM micrographs in part (a) show the development (moving left to right, and then top to bottom) of the lateral instability for a series of 400 nm pitch patterns polystyrene patterns with a molecular mass of 1570 kg/mol as a function of annealing time. As shown in part (b), the power spectrum of the AFM images in the vertical direction reveals a characteristic wavelength of the instability.   Part (c) shows that there is a characteristic wavelength of the lateral instability that increases with the annealing temperature, indicated on the horizontal axis in °C. These intriguing results are discussed in greater detail in this presentation.