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“Complex Pattern Formation by Adhesion-Controlled Anisotropic Wrinkling”

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1. Annealing the film at 60 °C for 12 hours may remove a small portion of residual solvent, but it may not be able to relieve residual stress generated via spin-coating. Conventional wisdom is that the film needs to be annealed well about the T_g of the polymer film to relax orientation and residual stress. The high temperature annealing, however, was avoided in our experiments because of a possible thermal memory effect of the polymeric film. When the polymeric film has a thermal memory, a much higher temperature well above T_g is needed to induce the bilayer wrinkling, which will make it difficult to estimate the mechanical property of the metal-capped polymeric layer.

It is expected that the polymer film of very high MW in our system is strongly confined by the lower Si substrate and the upper capping Al layer. Under the condition, the axial stress from stacked layers overwhelms the lateral stress generated from spin-coating. To confirm our hypothesis, we prepared a bilayer sample over a full 4 inch wafer and made confinement-induced wrinkle patterns. As shown in the

figure 1, ordered wrinkle patterns (4 groups of boxed patterns) were successfully obtained with their pattern symmetry intact, which was checked with AFM. More importantly, we also looked into the non-patterned wrinkle areas that are numbered from 1 to 5 in the figure and confirmed with Fast Fourier Transform (FFT) analysis that wrinkles are perfectly isotropic without any directional skew. Based on these observations, we believe that the residual lateral stress due to the spin-coating is negligible in the system.

2. Patterned wrinkles shown in Figure 4 appear more like nodules than wrinkles, albeit with a defined periodicity. The formation of nodule-like pattern implies that upward wrinkling of the bilayer is favored than downward one. To confirm this difference in the confined wrinkling, we converted the images in Figure 4 to inverted phases.

As shown in the figure, nodules are more pronounced in the inverted images (expressed as darkened dots). It can be attributed to the substrate effect of rigid silicon. In bilayer wrinkling, wrinkles should propagate through the layers that are confined by the underlying solid substrate and the upper elastomeric PDMS mold. Under such a confinement, upward deformation is more favored than downward deformation, leading to the formation of nodules rather than normal wrinkles.