Solvent-etching and Dewetting Techniques for Residual Layer Removal in Thermal Nanoimprint

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After decade-long development, nanoimprint lithography has emerged as an ideal technique for replicating dense nanostructures with high throughput and low cost [1]. In conventional nanoimprint lithography, there is always a residual layer that needs to be removed for further processing. The standard practice used today is to remove the residual layer by a reactive-ion etching (RIE) step, which limits the overall throughput of the nanoimprint process. More importantly, using RIE to remove residual layers eliminates the possibility of patterning isolated structures in functional polymers, such as polymer semiconductors, by thermal nanoimprint because RIE degrades or even destroy the functional polymers. It is thus of great interests to develop a new technique to remove the residual layers in thermal nanoimprint to eliminate the RIE step. In this work, we present two methods to achieve this goal. The techniques presented here are all based on solution processing to maintain a high throughput for the overall patterning process. These techniques are also benign to soft functional materials, thus open up many opportunities to build novel devices based on those materials by nanoimprint.

The techniques developed here are illustrated in Figure 1. The first step is to expose the residual layer by transferring the imprinted polymer layer to the mold surface. Once the residual layer is exposed on the top of the mold, it can be easily removed by solvent-etching or dewetting without affecting the shape of the nanostructures and the properties of the polymer material. In solvent-etching, the residual layer is removed by dissolving the surface layer of the polymer in a solvent (Fig. 1(b)). In dewetting, the polymer layer is heated to above its glass transition temperature. Dewetting occurs on mold protrusions where a thin layer of polymer melt is supported by a low energy surface (Fig. 1(c)). Careful control of residual layer thickness, annealing temperature and mold surface energy can result in discontinued polymer patterns. After removing the residual layer, the polymer nanostructures can be transferred to a substrate by a transfer-bonding technique. In this work, the details of the solvent-etching and dewetting techniques will be presented and the effects of the processing parameters on the removal results will be discussed. Exemplar applications of the techniques developed here are also presented. Isolated micro- and nanostructures of many thermoplastic polymers, such as PMMA, P3HT and MEH-PPV, are obtained by those techniques. Figure 2(a) shows a fluorescent image of MEH-PPV microstructures without residual layer. Under optimized processing conditions, the reversal nanoimprint and transfer-bonding can be used to create advanced three-dimensional polymer micropatterns [2]. By incorporating a residual layer removal step, interconnected polymer three-dimensional scaffolds (Fig. 2(b)) can be achieved, which may found many applications in photonics, bioengineering and sensors.

1. S.Y. Chou, P.R. Krauss, W. Zhang, L. Guo, and L. Zhuang, *J. Vac. Sci. Technol. B*, 1997. **15**: p. 2897.
2. H. Park, H. Li, and X. Cheng, *J. Vac. Sci. Technol. B*, 2007. **25**(6): p. 2325.

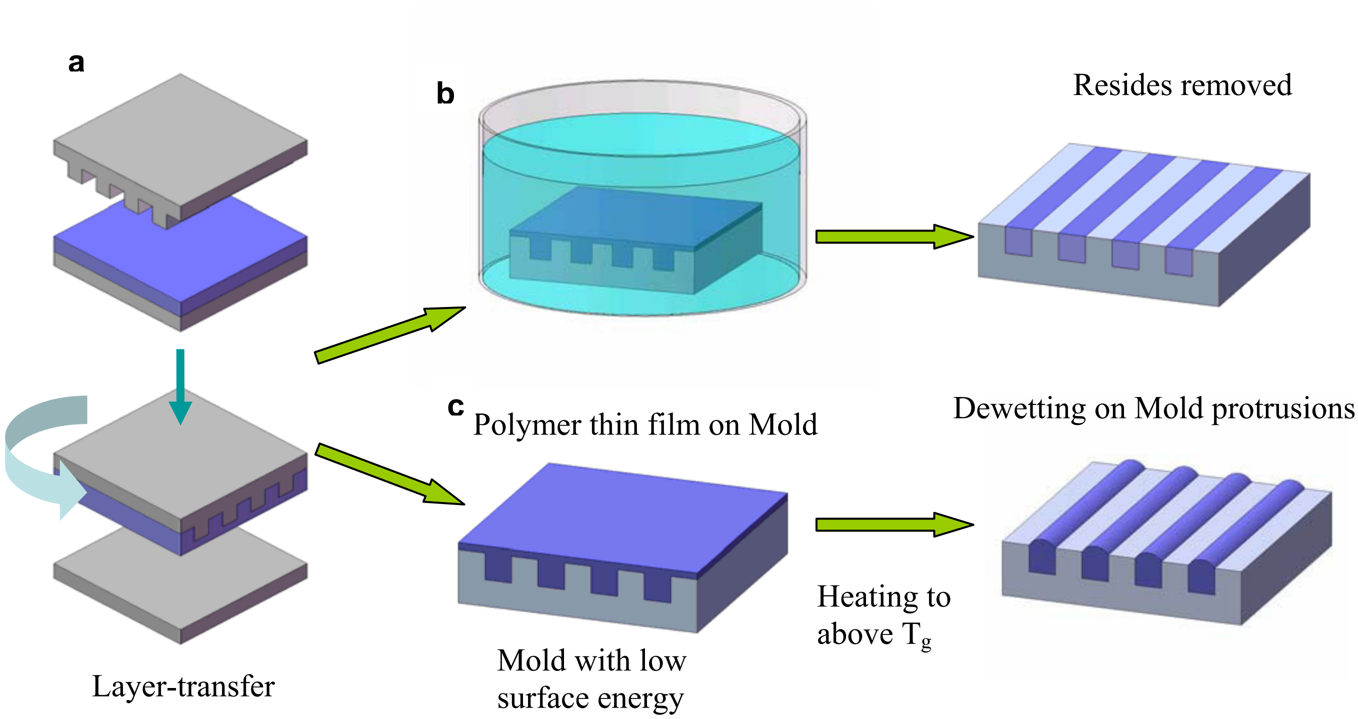

Figure 1. Schematics of residual layer removal in thermal nanoimprint. a) layer-transfer to place polymer film on mold surface and expose the residual layer; b) solvent-etching technique to remove the residual layer; c) dewetting technique to remove the residual layer.

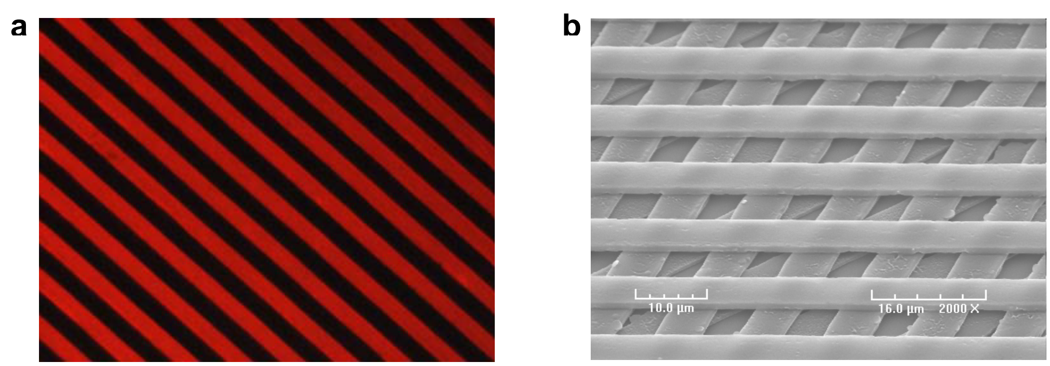

Figure 2. (a) 10 µm MEH-PPV grating without residual layer; (b) three-dimensional multilayer PMMA scaffold. Residual layers are removed by solvent-etching in (a) and dewetting in (b).