# Optimizing Nanoimprint and Transfer-Bonding Techniques for Three-Dimensional Polymer Structures

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Three-dimensional (3D) polymer structures are attractive in many micro- and nanofabricated devices and systems. The extra structural dimension can provide denser integration and superior performance to accomplish complex tasks. Reversal nanoimprint has become a simple technique to create 3D polymer structures by additive transfer-bonding of polymer thin layers. Being a soft material, polymer underlayer can deform during the bonding of the top layer. Past attempts in creating 3D polymer structures have been limited to using progressively lower $T_g$ polymers [1] or using cross-linkable materials [2], which constrain the usefulness of 3D polymer structures. Ooe et al. performed reversal nanoimprint at a temperature below $T_g$ of the polymers to avoid polymer deformation [3]. In this paper, we optimize the nanoimprint and transfer-bonding processes to develop a generic approach to create 3D structures in most polymers.

The basic processing steps involve cyclic combinations of nanoimprint and transfer-bonding as outlined in figure 1. The molds for nanoimprint were fabricated from silicon thermal oxide by electron-beam lithography or photolithography and reactive ion etching. The molds were coated with 1H,1H,2H,2H-perfluorodecyltrichlorosilane (FDTS) for easy releasing. First, patterns in 15 k Mw. PMMA were created by normal nanoimprint as shown in figure 1(a). The PMMA layer to be transferred was then patterned by another nanoimprint step. Compared to conventional spin-coating on mold, this method avoids very low yield of spin-coating on FDTS coated mold and surface topology for thin film on mold. In order to keep the polymer layer on the mold after separation (figure 1(b)), the substrate was coated with octadodecyltrichlorosilane (OTS) to reduce polymer-substrate adhesion. The PMMA layer on the mold was then transfer-bonded with the first PMMA layer in figure 1(a) as shown in figure 1(c). More layers can be added by repeating previous steps to construct multiple-layered polymer structures (figure 1(d)). Figure 2 shows some 3D PMMA structures obtained by this technique.

A critical issue in such scheme is that the adhesion between the underlayer and transferred layer is weak and it often leads to very low transfer yield. To solve this problem, various approaches, such as solvent damping and using very thin “glue” layer to enhance interfacial adhesion are explored. The process yield is also related to the mold pattern itself. Scarce patterns have much larger yield than dense patterns due to smaller total interfacial area and hence weaker mold-polymer adhesion. In this work, we study the factors that affect the process yield such as surfactants, processing temperatures and mold pattern density. Special techniques will be developed to increase the yield to a point valuable for practical usage. Such optimized process will enable easy creation of 3D structures on almost any polymer material for novel applications, including numerous functional polymers for broad applications in electronics, photonics and bioengineering.

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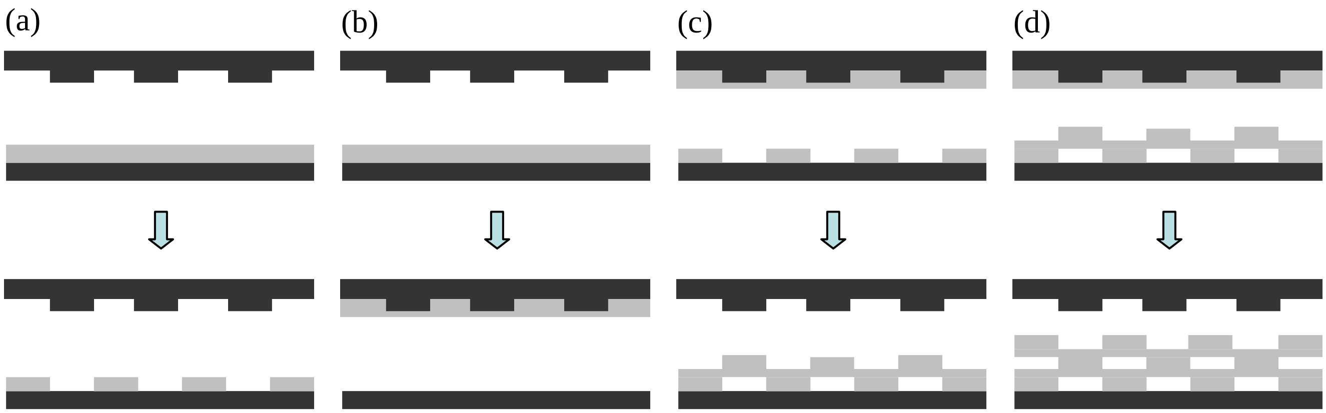


Figure 1. Schematic of 3D polymer patterning process. a) nanoimprint to create first polymer layer; b) nanoimprint on OTS coated substrate to transfer polymer layer to mold; c) transfer-bonding at a temperature below polymer $T_g$ ; d) adding more polymer layers by repeating step (b) and (c). This technique is suitable for all soft materials, including thermoplastic polymers.

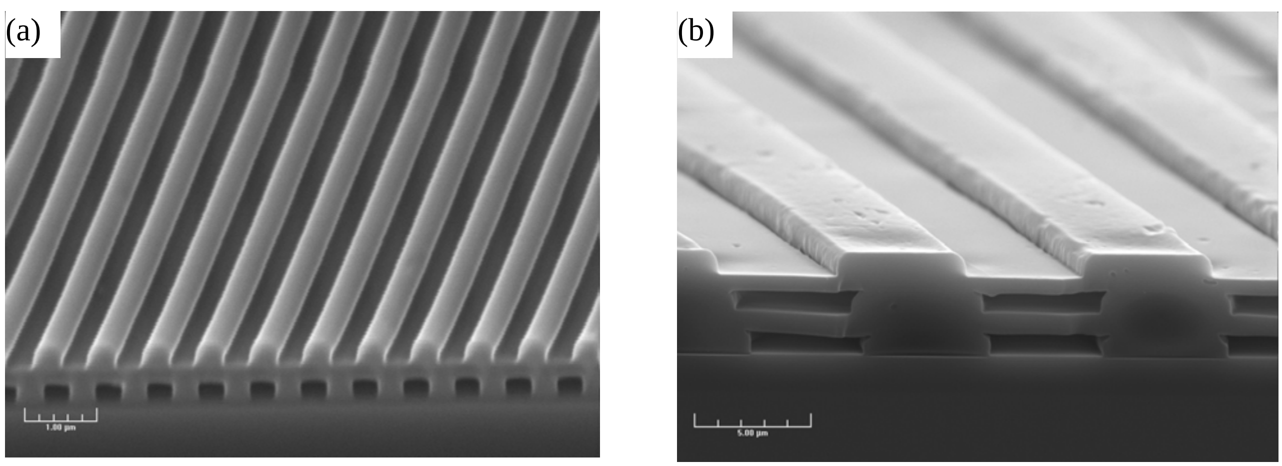


Figure 2. SEM micrographs of 3D PMMA structures. (a) two-layered 700 nm pitch grating, scale bar 1 μm; (b) three-layered 10 μm pitch grating, scale bar 5 μm.