Dual-Layer Thermal Nanoimprint Lithography without Dry Etching

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Nanoimprint lithography (NIL) has been widely researched as one of the next generation lithography techniques because of its sub-10 nm resolution patterning capability at a low cost[1]. In spite of the high-resolution patterning capability, NIL usually uses oxygen dry etching to remove a residue layer[2]. The dry etching increases the process complexity and lowers the fabrication throughput. Moreover, oxygen dry etching renders NIL incompatible with functional polymer patterning. One way to eliminate this adverse dry etching step after NIL is to achieve polymer structures free of residue layer during the imprinting cycle. The goal can be achieved through a delicate thickness control of imprint resist on a non-compatible polymer layer. In this work, we demonstrate an efficient thermal nanoimprint on dual non-compatible polymer layers - poly (methyl methacrylate) (PMMA) on poly (3-hexylthiophene) (P3HT) - without the need for the oxygen dry etching step. Depending on thermal nanoimprint parameters such as polymer layer thickness, mold depth, and nanoimprint temperature, two distinct and useful patterns can be formed as schematically shown in Fig. 1 and Fig. 2. In Fig. 1, pattern is only formed in the PMMA layer and this case is referred to as single-layer patterning. In Fig. 2, pattern is formed in both PMMA and P3HT layers and this scenario is referred to as double-layer patterning.

For dual polymer resist layers to imprint single-layer patterns, 3 wt. % PMMA in toluene was spin-coated at various spin-coating speeds after depositing a thin P3HT layer (85 nm) on an oxidized silicon substrate that was adhesion-promoted by coating an amino-functionalized alkylsilane monolayer[3]. A mold with 10 μm period grating and 200 nm depth was prepared for this case. NIL was performned at 180 ˚C and 2500 psi for 20 min. After mold releasing, desired single PMMA layer patterns were found from samples whose PMMA layer was spin-coated between 3300 and 4000 rpm. As shown in Fig. 3 (c), there is no residue layer after nanoimprint as clearly verified by a subsequent gold deposition and lift-off process. Unlike the single-layer patterning, a thick P3HT layer (700 nm) was spin-coated on an adhesion-promoted silicon oxide substrate for dual-layer patterning. A multiple spin-coating approach smoothed a rough P3HT surface that resulted from the semi-crystalline nature of P3HT[4]. After depositing the thick and smooth P3HT layer, a thin PMMA layer (60 nm) was spin-coated. And then, nanoimprints were carried out at 180 ˚C and 2500 psi for 20 min. As shown in Fig. 4, an overall uniform PMMA pattern on top of a P3HT pattern was formed when a mold with 750 nm period grating was used. The result corresponded well to polymer flow simulation[5] that showed the effect of the ratio of mold cavity width to polymer thickness on polymer flow profile. Because both single- and double-layer patterns are done without the oxygen dry etching step, this technique is highly compatible with organic functional materials, thus it is very useful in the fabrication of organic electronics with improved performance.

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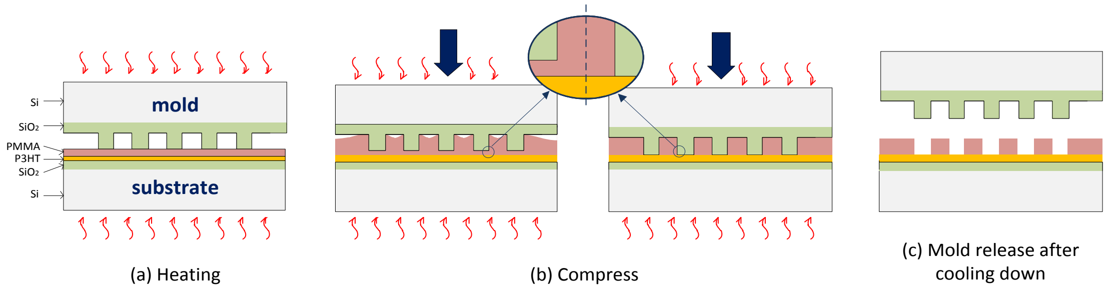

FIG. 1 Dual-layer thermal nanoimprint lithography process for single-layer patterning.

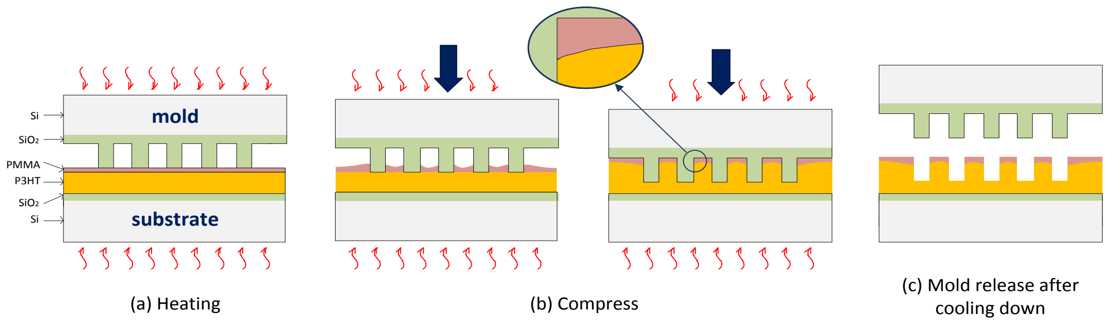

FIG. 2 Dual-layer thermal nanoimprint lithography process for double-layer patterning.

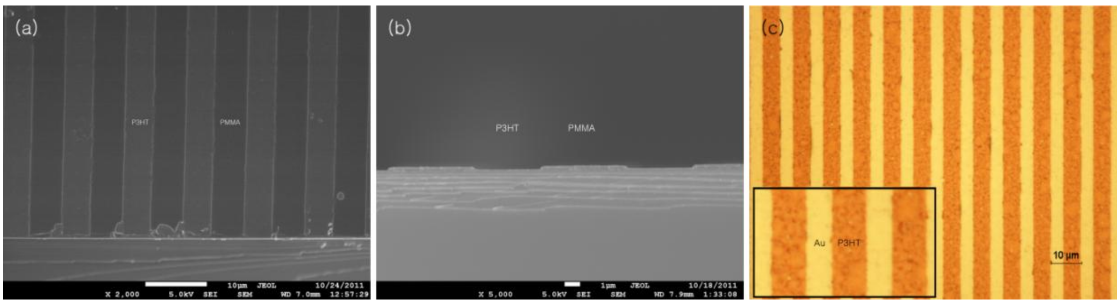

FIG. 3 Single-layer patterning: perspective view (a), profile (b), and gold pattern after lift-off (c).

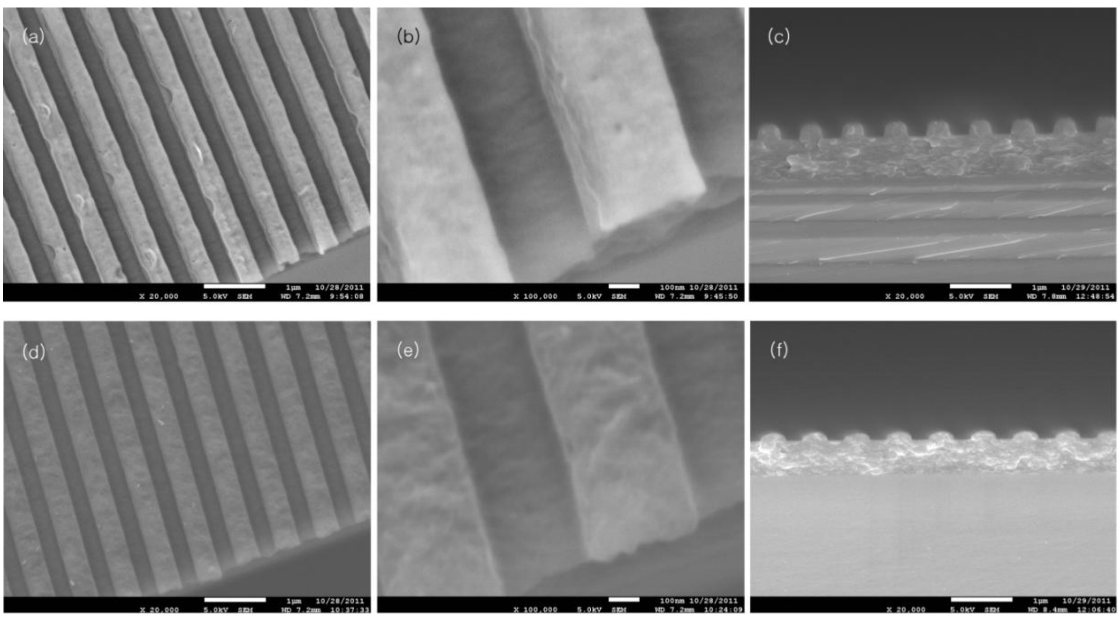

FIG. 4 Double-layer patterning: PMMA and P3HT pattern (a, b: perspective view and c: profile) and P3HT pattern after removing PMMA by dipping into PGMEA solvent (d, e: perspective view and f: profile)