Fabrication of organic MESFET device by dual-layer thermal nanoimprint

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In order to avoid ultraviolet light and oxygen which seriously degrade the performance of organic semiconductors[1], organic semiconductor devices have usually been patterned through low-resolution lithography techniques such as shadow masking, ink-jet printing, and screen printing. Therefore, the fabrication of sub-micron and nanoscale organic electronic devices for integrated circuits (IC) have been regarded as a challenging task. As an effort to realize organic integrated circuits at the nanoscale, thermal nanoimprint on dual non-compatible polymers was investigated in our previous research[2]. The removal of a destructive dry etching step in the dual-layer thermal nanoimprint enabled high-resolution metal patterning on organic semiconductors without performance degradation. In spite of the success in nanoscale metallization, the technique still needs to overcome alignment difficulty for a multi-level metal patterning that is essential to implementing organic ICs. Thermal nanoimprint has inevitable and significant alignment errors that are resulted from thermal expansion, mold shift, wafer bending, and resist surface variation[3]. One effective way to eliminate the inherent alignment errors is a self-aligned metal patterning approach. Such a self-alignment can be achieved through 3-dimensional resist structures shown in Fig. 1. The 3-D resist patterns are utilized to deposit two different metal patterns with a regular space. Because the first metal patterns have ohmic contact to poly (3-hexylthiophene) (P3HT) while Schottky barrier exists between the second metal patterns and P3HT, the process can be utilized to implement metal semiconductor field effect transistors (MESFET) that can be efficient parts of organic ICs.

The first step of the process is a 3-D mold fabrication. As shown in Fig. 2, the mold was generated through a combination of wet and dry etching. A silicon oxidized wafer with chromium grating patterns was dipped in buffered oxide etch (BOE) for 2.5 min to make 155 nm depth trenches with curved undercuts whose width determines the gap between self-aligned metal patterns. After the isotropic oxide wet etching, reactive ion etching was carried out to anisotropically etch the trenches by additional 200 nm and then the chromium mask was removed. The 3-D mold was used for a dual-layer thermal nanoimprint with a single PMMA layer patterning. Through the nanoimprint, 3-D poly (methyl methacrylate) (PMMA) patterns without residue layer shown in Fig. 4 (a) were formed on a thin P3HT layer. For the first metal patterns, chromium was deposited after gold evaporation on the PMMA-patterned sample in order to increase the durability of the side wings. As shown in Fig. 5, most gold side wings without chromium were destroyed by ultrasonic agitation during a lift-off while gold side wings reinforced with chromium layer remain. Although chromium strengthened the side wings, excessively thick chromium led to a unwanted metal-film peeling that eventually widened the gap between the metal patterns as shown in Fig. 5 (b). The metal-film peeling was managed by adjusting the stress existing in the gold-chromium film through changing chromium/gold thickness ratio as shown in Fig. 4 (b) and Fig. 5 (c). After forming the first metal patterns without metal-film peeling, the second metal patterns was formed by aluminum evaporation so that self-aligned metal patterns was successively completed as shown in Fig. 4 (c). The fabrication and characterization of organic MESFET by aforementioned technique will be reported.

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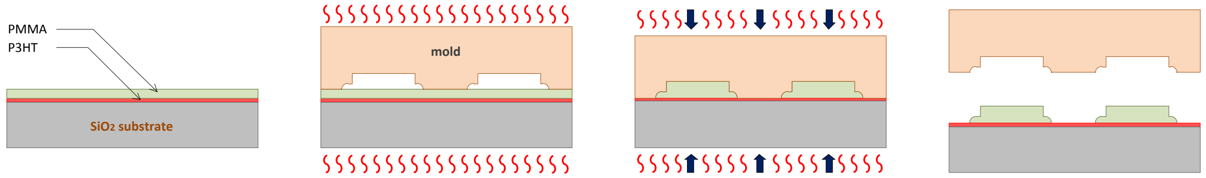
[1] Jørgensen, M., et al., Solar Energy Materials and Solar Cells, 2008. **92**(7): p. 686-714.

[2] Jung, Y., Cheng, X., Journal of Micromechanics and Microengineering, 2012. **22**(8): p. 085011

[3] Zhang, W., Chou, S.Y., Applied Physics Letters, 2001. **79**(6): p. 845-847.

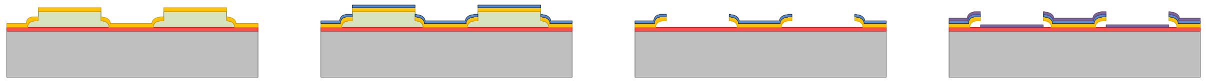


(a) dual-polymer layer for single-layer patterning

(b) heating after mold contact

(c) compress

(d) mold release after cooling



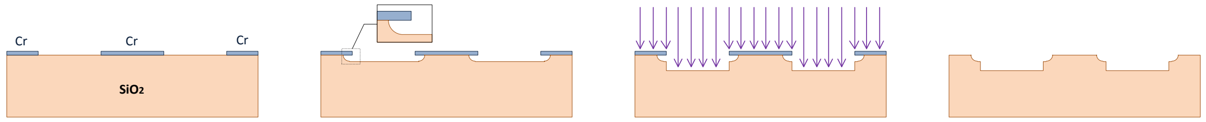
(e) Au deposition

(f) Cr depostion

(g) lift-off

(h) Al depostion

Figure 1. A schematic for self-aligned two-layer metal patterning on P3HT through 3-D dual-layer nanoimprint



(a) Cr patterns on SiO2

(b) wet etching

(c) reactive ion etching

(d) Cr removal

Figure 2. 3-D mold fabrication process

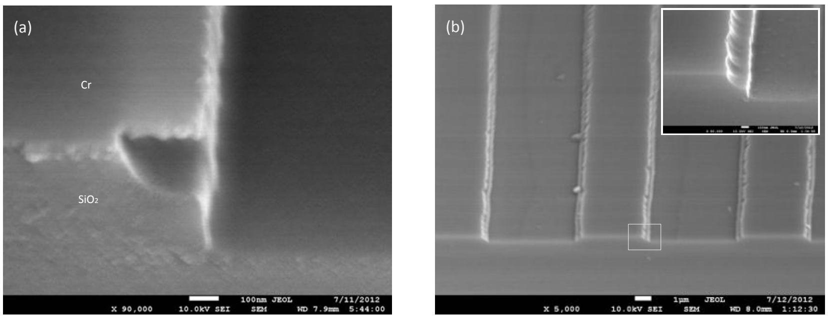


Figure 3. Prospective SEM images of the 3-D mold with undercut structures before (a) and after (b) Cr removal

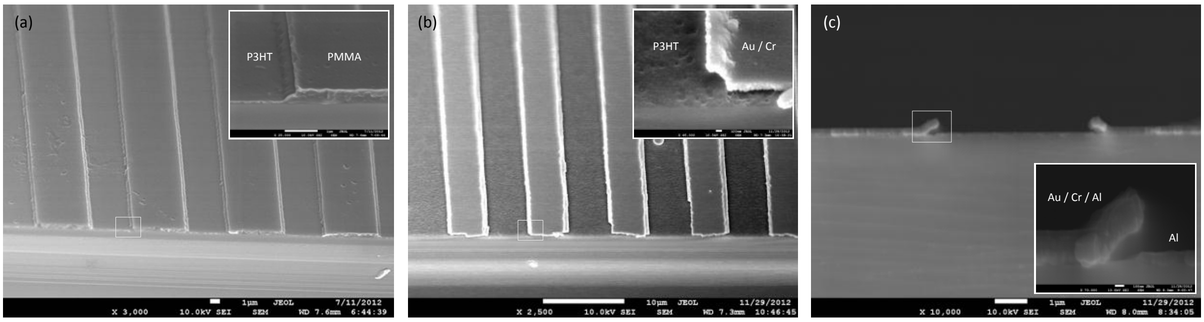


Figure 4. SEM images of 3-D patterns; a prospective image of 3-D PMMA patterns (a), a prospective image of the first Au/Cr patterns with curved side wings (b), and a cross-sectional image of self-aligned metal patterns (c)

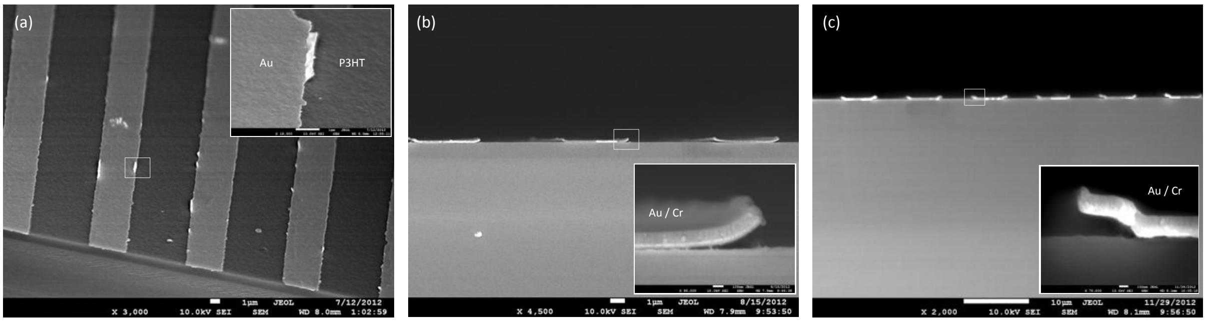


Figure 5. SEM images of the first metal patterns whose side wings are affected by the Au-Cr ratio: a prospective image ((a): 50 nm Au) and cross-sectional images ((b): 50 nm Au / 100 nm Cr and (c): 110 nm Au / 60 nm Cr)