Fabrication of Arrays of Electrically-Isolated Nanoscale Organic Thin-Film Transistors

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Organic thin-film transistors (OTFTs) and other relevant organic devices have become important building blocks for emerging electronic/photonic applications, such as large-scale low-cost, flexible, wearable displays, sensors, and memories, *etc*.[1-4] Because of relatively low carrier mobility and conductivity values of organic semiconductors, a typical OTFT needs an active channel with very large aspect ratio (*i.e.*, the ratio between channel width (W) and length (L) is in the range of 100s to 1000s) to enable a sizable drive current (nA to μA levels at $V_{DS} < 5$ V). Given such a requirement of the large channel aspect ratio, to make OTFTs with even microscale foot-print sizes, the transistor channel length needs to be scaled down to 10s to 100s nm regimes. Furthermore, nano- or microscale etching processes are needed for electrically isolating densely-arranged microscale OTFTs, aiming to eliminate the device-to-device interference. Therefore, to produce densely-arranged, electrically-isolated nanoscale (even microscale) OTFT arrays with the minimal device-to-device crosstalk, low-cost high-throughput nanolithography techniques are needed. However, most state-of-the-art parallel lithography techniques are not compatible with most chemically sensitive organic semiconductor materials. Therefore, additional cost-effective, high-throughput nanolithography methods compatible with organic semiconductors are demanded for producing commercially viable nanoscale OTFT arrays.

Here, we present a nanofabrication route capable of producing arrays of electrically-isolated P3HT OTFTs with nanoscale channel lengths. The presented fabrication route is based on angled deposition and transfer-printing processes, which are compatible with organic semiconductors. Using this route, we have demonstrated the fabrication of large-arrays of OTFTs with channel lengths down to 60 nm and drive currents up to 0.1 μA (at $V_{DS} = 5$ V).

Fig. 1 schematically illustrates the processing steps for fabricating arrays of electrically-isolated P3HT OTFTs with nanoscale channels, which include (a) pre-fabrication of the OTFT contacts (i.e., drain/source (D/S) and back-gate (BG) contacts) on the substrate, (b) patterning and angled-deposition of a shadow mask structure for defining the nanoscale channel length, (c) spin-coating of P3HT, (d) transfer-printing of polymeric mask structures on top of P3HT OTFT channel areas, and (e) plasma etching for isolating OTFTs. **Figs. 2 (a)** and **(b)** display the optical micrographs (OMs) of pre-fabricated OTFT contacts, and **Fig. 2 (c)** shows the SEM image of a representative 66 nm D/S gap formed by angled deposition. **Fig. 2 (d)** displays the OM of a PDMS transfer-printing stamp bearing prepatterned photoresist-based isolating masks, which can be transfer-printed on top of OTFT channels blank-coated with P3HT and serve as etching masks for isolating OTFTs (**Figs. 2 (e) and (f)**). **Figs. 3 (a) and (b)** show the output and transfer characteristics of a presentative P3HT OTFT, respectively, which exhibit On/Off ratios > 100 and drive currents up to 0.1 μA at $V_{DS} = 5$ V.

This work advanced the critical nanofabrication technology suitable for producing dense arrays of nano/microscale OTFTs and other relevant organic devices.

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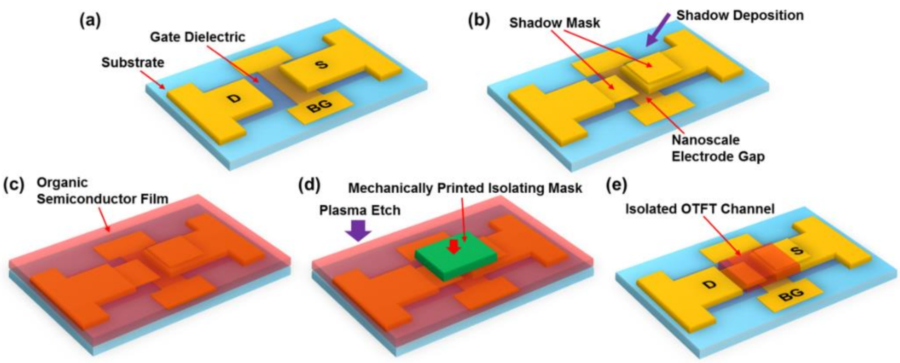

Fig. 1 Schematic steps for making nanoscale OTFT arrays.

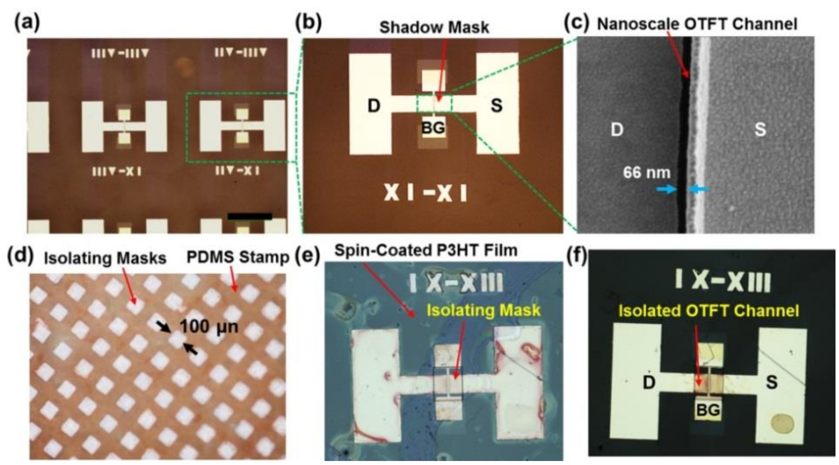

Fig. 2 (a) Optical micrograph (OM) of pre-fabricated TFT contacts, (b) zoomed OM of a TFT structure, (c) SEM of a nanoscale OTFT channel gap formed by angled deposition, (d) OM of a PDMS transfer-printing stamp bearing photoresist-based isolating masks, (e) OM of a OTFT blank-coated with a P3HT film, and (f) OM of a OTFT with an isolated P3HT channel.

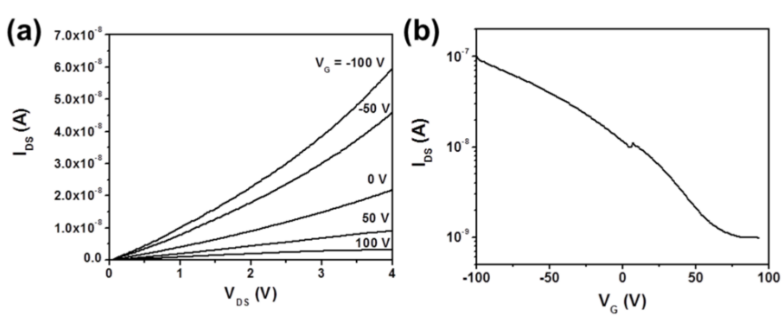

Fig. 3 Output (a) and transfer (b) characteristics of a P3HT OTFT.

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