Fabrication of Flexible Inorganic/Organic Hybrid Thin-Film Transistors by All Ink-Jet Printed Components on Plastic Substrate

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Abstract

We report all-ink-jet printed inorganic/organic hybrid TFTs on plastic substrates. We have investigated the optimal printing conditions to make uniform patterned layers of gate electrode, dielectrics, source/drain electrodes, and semiconductor as a coplanar type TFT in a successive manner. All ink-jet printed devices have good mechanical flexibility and current modulation characteristic even when bent.

1. Introduction

Organic thin film transistors (OTFTs) are of great interest for applications in low-cost disposable electronic devices such as smart cards and radio-frequency identification tags, as well as in flexible-display driver circuits, nonvolatile memory, and sensor[1,2]. In particular, since organic semiconductors based on polymers and oligomers are attractive for their easy solution processability for film formation, recent research on OTFTs has been more focused on flexible electronic devices/display applications. Therefore, the most desired ultimate goal of organic semiconductor devices is to realize flexible electronics and displays that can be processed through all-solution processes including deposition of the active layers, the gate insulators, and the electrodes.

A typical active matrix thin-film transistor backplane contains one transistor per pixel, in a structure having four to six separate layers composed of conductors, dielectrics, and semiconductors. Although other research groups have used ink-jet printing or other solution-based deposition methods for electronic devices, in each case photolithography or other techniques were utilized for at least one layer of the device structure. While it is obviously possible to use different techniques for different layers in the device, the use of a single printing technique for whole arrays would bring about the minimization of the fabrication cost and the reduction of the processing complexity. In this contribution, we report all-ink-jet printed inorganic/organic hybrid TFTs on plastic substrates. . We have investigated the optimal printing conditions to make uniform patterned layers of gate electrode, dielectrics, source/drain electrodes, and semiconductor as a coplanar type TFT in a successive manner.

2. Experimental

Silver nanoparticles of about 20 nm size were synthesized in our laboratory by the polyol method and used as conductive materials for ink. The details of the synthesis procedure and the ink preparation method were presented in our previous study[14, 15]. The organic-inorganic hybrid gate dielectric precursor solution for dielectric layer was synthesized by a sol-gel process using 3-methacryloxypropyltrimethoxysil--ane, zirconium propoxide, and methacrylic acid,. This organic-inorganic hybrid dielectric, developed in our group, is not only photo-patternable, but also ink-jettable. The detail of synthesis procedure is found in both the experimental section and the previous study. Pentacene derivatives, bis(triisopropylsilylethynyl) pentacenes (TIPS-pentacene) was used as a semiconductor for OTFTs. 1 wt% of TIPS-pentacene was dissolved in the solvent mixture of tetralin and cyclohexanol.

The printer setup consisted of a drop-on-demand (DOD) piezoelectric ink-jet nozzle (with an orifice size of 30 μm for conductive ink and 50 μm for hybrid dielectric and TIPS-pentacene inks) manufactured by Microfab Technologies, Inc. (Plano, TX). Uniform droplet ejection was achieved by applying a 20-μs long 3-V pulse at a frequency of 1000 Hz. PES (polyethersulfone) plastic substrate was used after cleaned with isopropyl alcohol and de-ionized water. After the silver ink (gate) was ink-jet printed on PES, the substrate was heat-treated at 170 °C for 30 min. The organic-inorganic hybrid dielectric was deposited by ink-jet printing, followed by prebake at 110 °C on a hot plate for 30 min and UV-exposure for 5 min with an intensity of 15 mW using UV-lamp to induce a cross linking reaction. Further thermal treatment was carried out at 170 °C for 3 hrs. The source/drain electrodes are ink-jet printed on top of the hybrid dielectrics, followed by annealing at 170 °C for 30 min. Finally TIPS-pentacene was selectively deposited between source and drain electrodes by ink-jet printing. All-printed TFTs are annealed at 100 °C for 30 min in vacuum oven prior to the measurement.

3. Results and discussion

Fig. 1 shows a schematic of the structure and optical images of the pixel array of TFTs fabricated using all-ink-jet printed components including gate, dielectric, source/drain and active layer on the PES substrate. The TFT array has 40 x 40 pixels in 20 x 20 mm^2 (each pixel size is 500 μm). PES has been used for substrate of electronics due to transparency and relatively good durability at high temperature up to 200 °C.

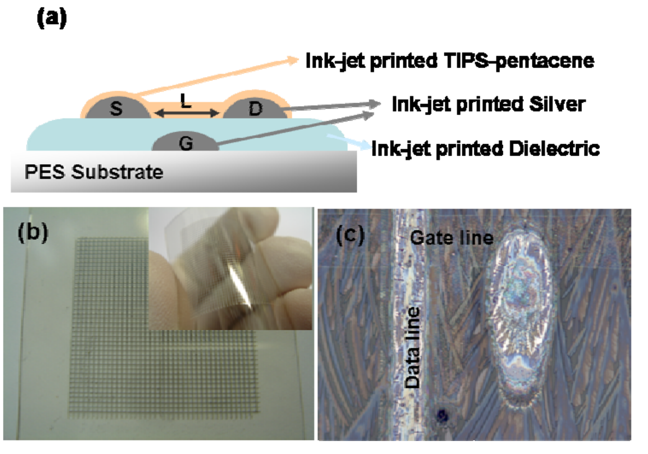

Fig. 1. (a) Schematic of cross-sectional structure, (b) optical images of the pixel array and (c) single cell of TFTs fabricated using all ink-jet printed components including gate, dielectric, source/drain and active layer on the PES substrate.

The first layer of gate electrode on the PES substrate is patterned by ink-jet printing of conductive ink with 20-nm sized silver nanoparticles which were synthesized in our laboratory. The ink-jet printer is consisted of a drop-on-demand (DOD) piezoelectric ink-jet nozzle with an orifice size of 30 μm manufactured by Microfab Technologies, Inc. (Plano, TX). The ink-jet printed silver conductive tracks are annealed to highly conductive metal electrodes at 170 °C for 30 min. At this heat-treatment temperature, the silver electrodes have a relatively low resistivity of about 20 μΩcm and the substrate receives no damage by heat-treatment.

Second layer of dielectric was also patterned by ink-jet printing of organc-inorganic hybrid dielectric ink which was synthesized by sol-gel process. Completion of the TFT fabrication includes successive ink-jet printing of both source/drain electrodes on top of the printed dielectric and semiconductor channel layer between the annealed source/drain electrodes. The source/drain electrodes were formed by the same manner as the gate electrode. 1 wt% bis(triisopropylsilylethynyl) pentacene (TIPS-pentacene) for the channel layer was ink-jet printed.

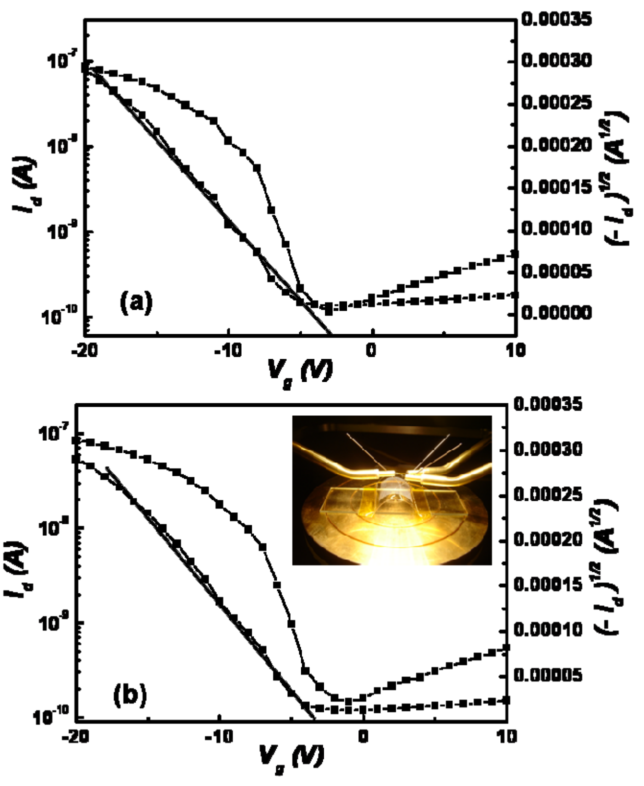

Figure 2. (a) Transfer characteristics of OTFTs fabricated by all-ink-jet printed component. (b) The bending test of all-ink-jet printed device.

Fig. 2 shows the transfer characteristics of devices fabricated by ink-jet printing. The OTFT devices exhibited excellent field-effect transistor characteristics. The OTFT device shows mobility of 3.5 X 10^{-3} cm^2 V^{-1} s^{-1} in the saturation regime, on/off current ratio of about 10^3 and a threshold voltage of about -3.85 V. Although we used the ink-jet printed silver gate electrodes, dielectrics, source/drain electrodes and active layer, the device performance shows good electrical properties. Furthermore, the bending effect of the fabricated all-printed flexible devices was observed (Fig. 2(b)). The radius of curvature was 20 mm and the observed device performance of mobility of 3.5 X 10^{-3} cm^2 V^{-1} s^{-1}, on/off ratio of 10^3 and a threshold voltage of 0.13 V. This demonstrates that our flexible device was significantly unaffected by bending.

4. Summary

The ink-jet printing technique is an effective means of patterning functional materials, because a fully data-driven deposition of materials is accomplished simply in ink-jet printing by a one-step additive process of droplet-based liquids. We demonstrated all ink-jet printed organic-inorganic hybrid TFTs and fabrication method using a single process of ink-jet printing technique. The resulting TFT arrays have good mechanical flexibility and current modulation characteristics. Furthermore, it should be noted that the entire fabrication process is carried out at low temperatures which is compatible with plastic substrate such as PES and PI, thus providing an attractive method applicable to large-area flexible electronics.

5. References

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