Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 222-223

B-5-6L

Organic Thin-Film Transistors with Alignment-Free Printable Electrodes

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1. Introduction

Organic thin-film transistors (TFT) are promising candidates for the building blocks of electronic systems based on flexible, large-area substrates, since they can be manufactured by cheap solution processing and direct printing rather than vacuum deposition and photolithographic patterning[1)]. Semiconducting organic molecules and polymers are self-assembled from solution into ordered structures with field-effect mobilities comparable to those of inorganic films such as amorphous silicon. However, this requires the development of novel printing techniques and device structures that provide accurate definition of the device components without increasing process complexity.

In this paper, we present a novel process fabricating alignment-free printable electrodes for organic TFTs, where solution-processed source/drain electrodes are self-aligned to a gate electrode by using a hydrophobic (or liquid-repelling) self-assembled monolayer (SAM) optically patterned by back substrate exposure technique. TFT performance and a potential high-resolution patterning using this simple technique will be demonstrated.

2. Experiments

The TFT fabrication processing steps are shown in **Fig.1**. After stripe patterns of gate electrodes of sputtered Cr formed on quartz substrates, a silicon dioxide (SiO_2) film with 400 nm thick was deposited in a plasma-enhanced chemical vapor deposition system using TEOS (tetra-ethoxy-silane) and O_2 gases. A hydrophobic SAM was dip-coated and the substrate was exposed from the back with UV light until contact angle of water on the SAM-treated surface reduced from about 110 to less than 30 degree with the back exposure. Source and drain electrodes were fabricated by painting water-based ink of Ag nanoparticle on the hydrophilic stripes interposed between the residual hydrophobic stripes just above the gate electrodes using a micro pipette and baking in vacuum at 120 ℃ for 20 min. The substrate surface was partially covered by black sheet of paper and exposed from the top with the UV light until contact angle of the whole surface of the exposed SiO_2 film reduced to less than 30 degree. Finally, pentacene organic semiconducting layer of 50 nm thick was deposited by thermal evaporation in vacuum without heating at deposition rate near 0.1-0.2 nm/s. TFT characteristics were measured in a vacuum chamber.

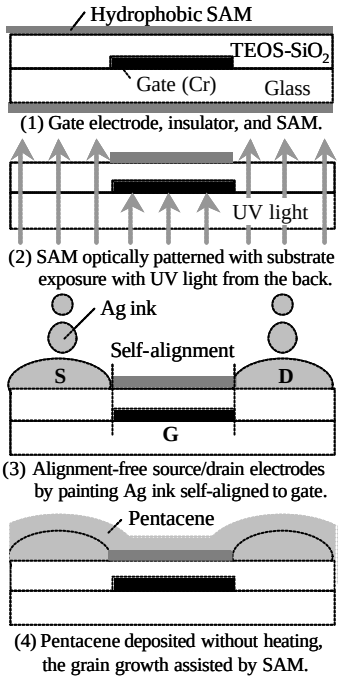

Fig.1 TFT Fabrication processing steps.

Atomic force microscopy (AFM) images of pentacene deposited on the hydrophobic and hydrophilic stripes were measured and the TFT performances were compared.

3. Results and Discussion

Plane optical image of the self-aligned TFT arrays is shown in **Fig.2**. Channel length and width are 800 μm and 10 mm, respectively, and the size is almost the same as that for gate electrode patterned by photolithographic step. Width of source/drain electrodes is completely restricted by the hydrophobic stripes just above the gate (or channel) regions and is 400 μm and the small self-aligned overlaps between the bottom gate and the top source/drain electrodes are less than 1 μm.

Typical drain current (I_d) vs. source-drain voltage (V_{ds}) plots are shown in **Fig.3** with gate-source voltage (V_{gs}) as a parameter. Linear output and current saturation are clearly observable. Semi-logarithmic plots of I_d vs. V_{gs} were shown in **Fig.4** with V_{ds} as a parameter. The field effect mobility and the threshold voltage deduced from the data are 0.14 cm^2/Vs and -13 V, respectively. The on/off ratio of 10^4 is reasonably high for devices without passivation.

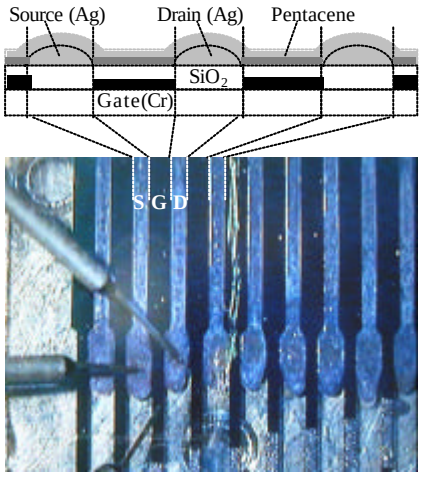

Fig.2 TFT arrays with alignment-free printable electrodes.

The field effect mobility of pentacene deposited on channel region with SAM is about 2 times as high as that without the SAM. Atomic force microscopy image revealed the increase in grain size of pentacene film on SAM. These results indicate that the SAM functions not only for patterning electrodes in solution process but for ordering self-assembled structure of the semiconducting molecules[2].

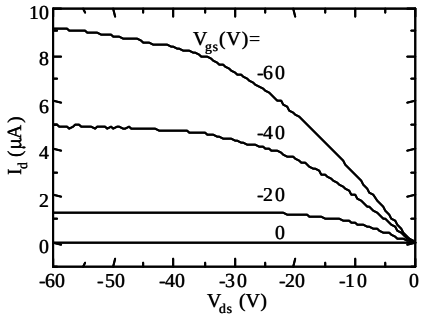

Fig.3 I_d-V_{ds} transfer characteristics.

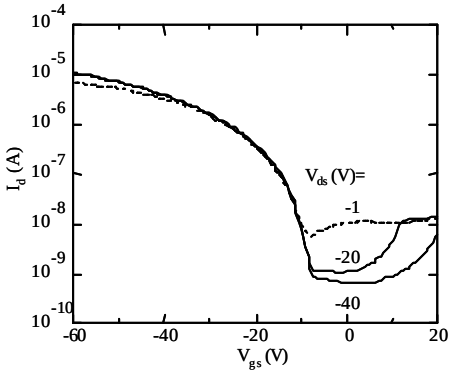

Fig.4 I_d-V_{gs} transfer characteristics.

Plane optical image of electrodes painted on optically-patterned SAM is shown in **Fig.5**, where widths of hydrophobic lines (just above gate lines shown as bright images) and hydrophilic spaces (shown as dark images) are 3 μm and 7 μm, respectively. Although only two lines in the center and in the right side could be filled with ink to complete electrodes, this image indicate that organic self-aligned TFTs with channel length of 3 μm can be made using this patterning technique.

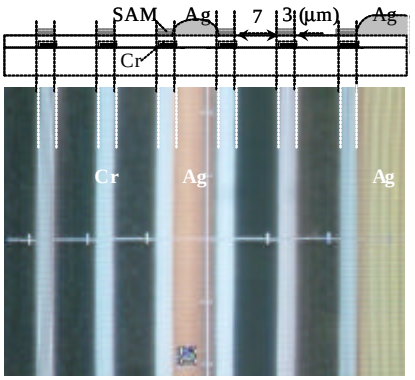

Fig.5 Potentially high-resolution electrode and channel length.

Such high-resolution printable electrodes is possible since the hydrophobic SAM is quite thin of ~1 nm thick, approximately three orders of magnitudes thinner than that of photoresist usually used for this kind of self-align process[3),4)], and it can be precisely patterned by UV light without suffering diffraction effects. The optical patterning is a complete dry process, which is another merit of the hydrophobic SAM for process simplicity compared with photoresist using wet chemical process for patterning.

Although gate electrode, semiconductor, and insulator were made using vacuum and photolithographic process in the present study, this alignment-free process for source/drain electrodes will give a clue to a novel fabrication process for high-definition printable organic TFTs with high performance, combined with recent high-definition inkjet for electrodes[5)] and solution-processed semiconducting and insulating films for organic TFTs[6),7)].

4. Conclusions

A novel process fabricating alignment-free printable electrodes for organic TFTs was presented for the first time, where solution-processed source/drain electrodes are self-aligned to a gate electrode by using an optically patterned hydrophobic SAM and back substrate exposure technique. The field effect mobility of 0.13 cm^2/Vs and potentially minimum channel length of 3 μm were experimentally confirmed for the future high-definition printable organic TFTs with high performance.

Acknowledgement

A part of this work belongs to "Advanced Organic Device Project" under contraction between OITDA and New Energy and Industrial Technology Development Organization (NEDO). We thank Drs. M. Hongo and M. Okunaka in Hitachi,Ltd. for fruitful discussion.

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