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Fabrication of Solution-Processed TIPS-Pentacene TFTs with Poly(4-vinylphenol) Bank Layer by using Ink-Jet Printing

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1. Introduction

In recent years, solution processes of organic thin-film transistors (OTFTs) have received considerable attention because they can be fabricated at lower temperature with potentially reduced manufacturing cost compare to silicon-based thin-film transistors (Si-TFTs). Among them, ink-jet printing is considered as a promising candidate to provide simple and flexible OTFT fabrication. Many electronic devices have been fabricated using this method, such as flexible displays, organic light-emitting diodes (OLEDs), organic solar cells (OSCs), and radiofrequency identification devices (RFIDs).

In this paper, we address above-mentioned problem by employing organic bank layer. It was formed by inkjet printing polyvinylphenol (PVP) solution, same material used for gate insulator, on top of source-drain. This method is considered significant, in a sense that no other techniques other than inkjet printing were involved. By this, we could successfully deposit bis(triisopropylsilylenthynyl) pentacene (TIPS-pentacene) on active channel area. Confined TIPS-pentacene by PVP bank showed an improved crystallization behavior and uniform surface geometry. Its transistor performance was found to be fairly improved, compared with the case in the absence of bank, with mobility of 0.18 cm^2/Vs, on/off ratio of 2.09 x 10^5, and threshold voltage of 0.42 V/d.

2. Fabrication

The OTFTs with an inverted coplanar (bottom-gate and bottom-contact) configuration were fabricated on a 100nm thick Al gate electrode on cleaned glass by the process of vacuum-thermal evaporation. Gate electrode was patterned with photoresist. We used PVP solution as gate insulator layer, which was formed by mixing PVP polymer with propylene glycol monomethyl ether acetate (PGMEA) and then we added the cross-linking agent of poly (melamine-co-formaldehyde). The PVP solution was spin coated on the glass substrate with an Al electrode and a curing process was conducted at 200℃ for 20min in a hot oven to enforce the cross-linking of the PVP solution. Source/drain electrodes were patterned by photoresist. Then, Au layer was deposited on a 45nm thick on the gate insulator by vacuum-thermal evaporation and lift-off. We used PVP solution for bank layer on source/drain electrodes, and it was made by inkjet printing. Subsequently, the PVP bank layer was cured at 200℃ for 20 min. We deposited a TIPS-pentacene by inkjet printing as organic semiconductor (OSC) for the active layer. Inkjet printing was carried out with a piezoelectric head of nozzle (50um). On the average, diameter and volume of a jetted TIPS-pentacene (2wt% in tetralin) droplet are 27 um and 10 pl. Fig.1. shows the overall fabrication process flow and schematic structures of OTFT used in the present work.

3. Result and discussion

Solvent for Inkjet printing is required to have a high solubility and compatibility for about TIPS-pentacene. It is found that boiling point of solvents is critical because the drying time upon jetting affects the structure of OSCs. Solvent of higher boiling point is preferred since the generation of coffee stain is avoided, hence, growth of better crystallinity is expected. Therefore, it is obvious that the solvent severely affects the morphology and crystallization of TIPS-pentacene film. In the present work, we used tetralin (1,2,3,4-Tetrahydronaphthalene) as solvent whose boiling point is 207℃ and surface tension is 34.3 dyn/cm. TIPS-pentacene shows good solubility in this solvent.

Typical optical microscope image of TIPS-pentacene ink-printed on channel area is shown in Fig. 2a. The semiconductor widely resides on source-drain, rather than on desired channel area. It is assumed that TIPS-pentacene solution has higher affinity on more hydrophilic Au surface. Increased hydrophilicity on source-drain by UV Ozone treatment is found to be helpful in this regard (Fig. 2b). However, even in this case, the channel is not completely covered with crystals.

In order to improve confinement, hence, crystallization of TIPS-pentacene, we build up bank layer by inkjetting the PVP solution. By this approach, we could cover channel area completely with crystalline TIPS-pentacene. Images of inkjet printed TIPS-pentacene inside PVP bank layer as shown in Fig. 2c. The electrical properties of the facricated OTFTs by ink-jet printing are presented in Fig. 3. The performance parameters are summarized in Table I.

For BCS without treatment, the field effect mobility was 0.012 cm^2/Vs, on/off ratio 1.51 x 10^3, threshold voltage -0.94 V, and sub-threshold slope 0.84 V/dec and off state current is 0.78 pA/μm. For BCS with UV treatment, the field effect mobility was 0.07 cm^2/Vs, on/off ratio 1.66 x 10^5, threshold voltage is 0.97 V, sub-threshold slope is 0.64 V/dec and off state current is 1.7 x 10^{-2} pA/μm. The OTFT with bank layer exhibited an on/off current ratio of 2.07 x 10^5, a threshold voltage of -0.14 V, a sub-threshold slope of 0.42 V/decade and a field-effect mobility of 0.18

cm^2/Vs in the saturation region.

4. Conclusions

We fabricated OTFTs with TIPS-pentacene printed inside PVP bank layer. TIPS-pentacene becomes well-confined on active channel region, leading to improved crystallization and good surface uniformity. As a consequence, the transistor performance was much improved, compared with the case in the absence of bank.

We find current approach very meaningful since it is entirely made up of inkjet printing processes. Further research is in progress as an effort to optimize interfacial balance between bank and semiconductor, and to correlate resulting crystallization with OTFT performance.

Acknowledgements

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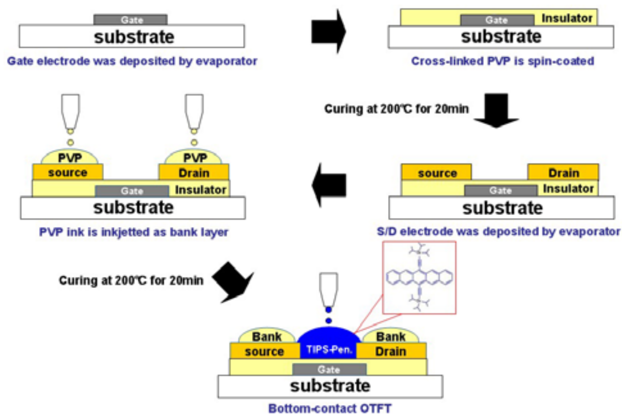

Fig.1. Fabrication process flow and the schematic structures of OTFT

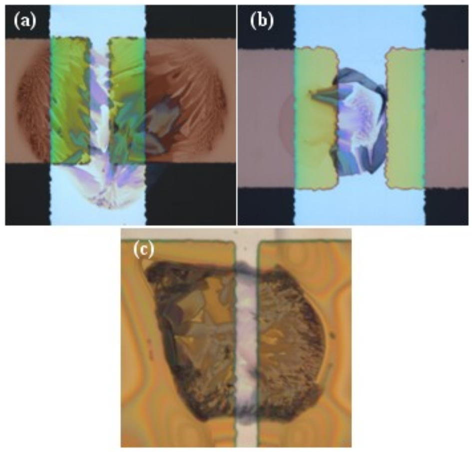

Fig. 2. Crystallized TIPS-pentacene on channel a) without treatment, b) with UV ozone treatment, c) inkjet printed TIPS-pentacene inside PVP bank layer

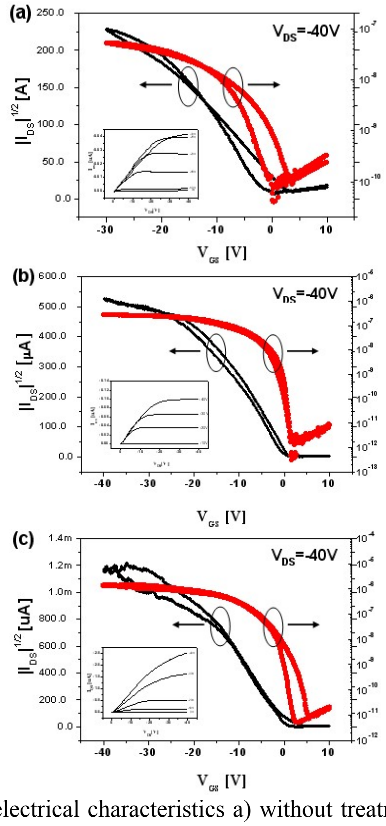

Fig. 3. The electrical characteristics a) without treatment, b) with UV ozone treatment, c) with PVP bank layers for OTFTs fabricated by ink-jet printing method.

Table I Electric Parameters

Type	Channel (W/L)	Mobility ($cm^2/V\cdot s$)	On/Off	V_{th} (V)	SS (V/dec)	Off state current (pA/mm)
BCS (no treatment)	100/20	0.012	1.51×10^3	-0.94	0.84	0.78
BCS (UV treatment)	53/40	0.07	1.66×10^5	0.97	0.64	1.7×10^{-2}
BCS (PVP bank layer)	68/10	0.18	2.09×10^5	-0.14	0.42	4.9×10^{-2}