Fabrication of Screen Printed Organic Thin-Film Transistors

Jong-Su Yu[1,2], Jeongdai Jo[1] and Do-Jin Kim[2]
[1]Nano-Mechanical Systems Research Division, Korea Institute of Machinery & Materials (KIMM), Daejeon, 305-343, Korea.
[2]Dept. of Materials Science and Engineering, CNU, Daejeon, 305-764, Korea.
TEL:82-42-868-7162, e-mail: micro@kimm.re.kr.

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Abstract

Printed organic thin-film transistors (OTFTs) were used in the fabrication of a screen- printed gate, source and drain electrodes on flexible plastic substrates using silver pastes, a coated polyvinylphenol dielectrics, and jetted bis(triisopropyl-silylethynyl) pentacene (TIPS-pentacene)organic semiconductor. The OTFTs printed using screen printing and soluble processes made it was possible to fabricate a printed OTFT with a channel length as small as 13 μm on plastic substrates; this was not possible using previous traditional printing techniques.

1. Introduction

Printing processes were originally developed for the exchange and storage of information adapted to human vision. Since the early 2000s, scientists and engineers have succeeded in applying printing-related techno1ogies to create low-resolution organic electronics devices with micron-sized features [1]. This field of application requires pattern and overlay accuracies down to 20 μm for high-quality reproduction. In particular, screen printing is the collective name for traditional printing, which has been developed as an alternative to conventional methods and as a fabrication technology for microfabrication. This technique uses a printed circuit boards and integrated circuit packaging are popular applications in the electronics industry and is a low-cost process [2, 3].

More recently, a number of techniques and processes including microcontact printing, inkjet printing, gravure printing, offset printing, and screen printing have been introduced for the fabrication of OTFT circuits, flexible displays, and low-cost printed electronics that aim specifically at reducing the fabrication cost [4-6].

In this paper, we report on more detail that a related study in which a printed OTFT was used for the fabrication of printed electrodes and soluble organic semiconductors on poly(ethylenenaphthalate) (PEN), polyethyleneterephthalate (PET), and polycarbonate (PC) plastic substrates. Gate, source and drain electrodes of OTFTs were fabricated by a high-resolution printing technique based on screen printing process by using the low-resistance I-010 (InkTec), D-1502 (Daejoo), and MicroPS-005 (Paru) as Ag screen print paste.

A printed OTFT with a polyvinylphenol (PVP) as polymeric dielectric layer were formed using low temperature process [7], and a bis(triisopropyl-silylethynyl) pentacene (TIPS-pentacene) as an organic semiconductor layer was used in the ink-jet printing [8].

2. Experimental

To fabricate a high-resolution and large-area screen-printed OTFT, the following steps were performed: the design and manufacture of a screen mask and screen printing process. In this work, we fabricated screen mask patterns onto a steel used stainess (SUS) meshed substrate having which dimensions of 320×320 mm^2. The channel lengths (L) of the unit element was split between 30 and 70 μm, and the line widths (W) ranged between 200 μm to and 2 mm on the 150×150 mm^2 screen plate pattern mask, with the pattern mask designed for 40 elements of different channel lengths and line widths to be placed.

We used a PET (Teijin Dupont Films Co.), PEN (Teijin Dupont Films Co.) or PC (i-Component Co.) were used substrates with a thicknesses of 188, 200, and 200 μm and a surface roughnesses of below 11.0, 0.6 and 6.0 nm, respectively [9]. The conductive Ag paste of high-viscosity (~5 Kcps at 22℃), low-density (< 1.08 g/cc) and low-resistance (<0.084 Ω (sq/mil (25 μm)) was printed using the screen mask for the fabrication of electrodes. PVP were used as polymeric dielectric layer. Its dielectric strength is above 5600 (DC volts/mil), its sheet resistance is above 10^{14} (Ω, 23℃, 50%), and its dielectric constants are about 3.3 and 3.1 (60 Hz), respectively. The solution-processable organic semiconductors used for the printed OTFT was TIPS-pentacene which show the highest reported field-effect mobility.

The specifications of the screen mask were made for the screen printing; the mesh tension was 1.00 mm/kgf, emulsion thickness was 5 μm, and the mesh angle was 22.5°by using the 500 mesh net that underwent calendar processing. As the emulsion for plate making, the emulsion was used which was the dual curing type with a high resolution and good anti-solvent quality and to which fluorine resin was added in order to prevent the paste from spreading during printing. Printed electrodes were fabricated by using the BS-150ATC screen printer (Bando Co.) capable of a high-precise alignment.

Fig. 1 shows a schematic fabrication process of printed OTFT by screen printing using low-resistance Ag pastes, polymeric dielectric and semiconductor. We printed gate electrodes of the line width as small as 30μm on PET, PEN or PC substrates. With respect to the printing condition, the flat urethane rubber squeegee of the hardness of 70 ~ 80° was used and the printing pressure was adjusted with the air pressure of 3 ~ 5 kgf/cm^2. The squeegee angle was fixed at 80° during spreading and printing, the separation distance from the plate was set at 0.5 ~ 1.2 mm according to the type of the paste and the size of the printing pattern, the degree of squeegee pushing 0.05 ~ 0.5 mm, and the paste spreading and printing speed 100 ~ 250 mm/sec. As for gate electrodes, the I-010, D-1502 and PS-005 Ag paste containing a high boiling point solvent was made by curing at 110 °C ~ 120 °C for 3min. On the fabricated gate electrodes, polymeric dielectric of 10 wt% PVP was jetted with a inkjet system into the channel area of gate electrodes. In another method, PVP having a thickness between 4000 Å and 10000 Å were formed using spin coating at 3000 rpm for 30 sec ; it was then cured at 80 °C for 10 min. The source and drain electrodes were fabricated by screen printing using three types Ag pastes onto the polymeric dielectric layer with the screen mask designed at the channel lengths of 30, 40, 50, 60 and 70 μm with various line widths. Finally, to form the organic semiconductor layer on the fabricated contact electrodes was ink-jet printing process from a 1 wt% solution of TIPS-pentacene in toluene. The thin-films were formed by annealing at 60 °C for 5 min. in air.

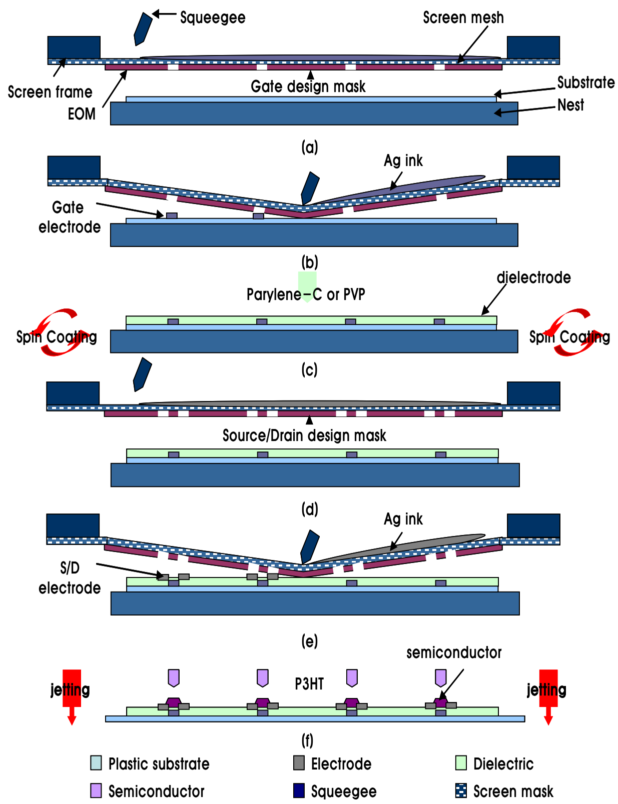


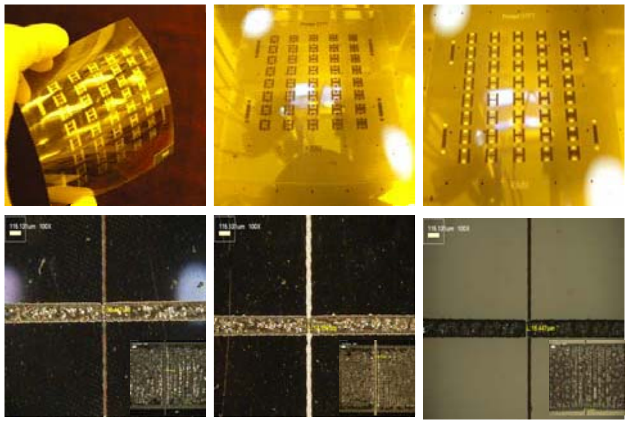
Fig. 1. Fabrication of a printed OTFT using screen printing and soluble process

3. Results and discussion

By the above procedure, which included screen printing using a fine mesh screen mask and low-resistance Ag paste. Fig. 2 shows the respective screen printed OTFTs with channel lengths between 13 (16) and 39 (62) μm and channel widths between 211 (244) and 1995 (1962) μm, with various gate electrode patterns. Fig. 2 shows result of depositing organic semiconductor onto printed OTFTs at the prefabricated source and drain electrodes using three types conductive Ag pastes with a low-resistance on the 150×140 mm^2 PEN, PET or PC substrates without pattern defects. Fig. 2(a) shows that the printed OTFTs with A-Ag paste has a replicated pattern exactly corresponding to the master pattern and has a high accuracy of filling and releasing on PEN substrate. Also, Fig. 2(a) as a performance characteristic, by measuring the wettability, resistance, and density, it was demonstrated that the printed electrodes were hydrophilic with a contact angle of 31.3 ~ 33.5° (O_2 plasma and SAM), a sheet resistance of 0.052 and 0.0211 Ω/□, and mean deviation of resistance was shown very low. Fig. 2(b) shows the result for printed OTFTs with A-Ag paste on PET substrate, and it was ascertained that all patterns correspond to the master in shape and that the space between a line and another line was exactly divisible, however that the center printed OTFTs were a some trapezoid, i.e., its top face was different in size from its bottom face. Fig. 2(c) shows an optical microscope image of a printed OTFT array using PVP as the gate dielectric layer, B-Ag paste as the gate, A-Ag paste as source and drain electrodes, and a 1 wt.% solution of P3HT in high-purity chloroform was ink-jet printed on PC substrate and then cured at 60 °C for 5 min. on a hot plate in air. Fig. 3 shows a graph of the measurement results of variation characteristics including the designed channel lengths versus the printed channel lengths for screen-printed OTFTs. which corresponds to a device at 30, 40, 50, and 60 μm as the channel lengths, and 200, 500, 1000, 1500, and 2000 μm as the line widths. Fig. 3 also shows that the screen-printed electrodes have a transferred pattern exactly corresponding to the engraved plate and they have a higher accuracy of printing onto plastic substrates. The screen-printed electrodes exhibited high fidelity and good reproducibility above 40 μm. The channel length deviations for 40 to 70 μm patterns were less than –10 %. However, the channel lengths for 30 μm pattern increased by -20 ~ -30 % due to Ag paste diffusion and shrinkage, which occurred during printing and curing between the Ag paste electrode and polymeric dielectric layer or plastic substrate interface.

All electrical measurements of the printed OTFTs were carried out in air without any encapsulation. The electrical measurements and characterization of the printed OTFTs were conducted using 4200-SCS semiconductor characterization system (Keithley).

Printed OTFT devices were fabricated by a room-temperature process and characterized in air. Figs. 4 show the measurement results for the transfer and output characteristics. Fig. 4(a) shows a typical plot of drain current I_{DS} versus drain voltage V_{DS} output characteristics at various gate voltages V_{GS}, which corresponds to a device using a TIPS-pentacene semiconductor, a PVP dielectric, an Ag paste printing as the gate, source and drain electrodes. Fig. 4(b) shows a graph of the transfer characteristics including an I_{DS} versus V_{GS} plot and an $|I_{DS}|^{1/2}$ versus V_{GS} plot. The figure corresponds to a printed OTFT with a channel length of L=16 μm (designed L=30 μm), a width of W=477 μm (designed W=500 μm), a 1 wt.% P3HT as the semiconductor, a 5000 Å coating of PVP as the gate dielectric layer, an Ag paste gate, source and drain electrodes. As a result of evaluating the printed OTFT fabricated by the proposed process using low-resistance Ag pastes and a screen mask with high-resolution mesh, the following parameters were obtained: a mobility of 0.08(±0.02) cm^2/Vs, an I_{on}/I_{off} current ratio of 10^3, an I_{off} current of 1.2×10^{-10} A, a subthreshold slope of 2.53 V/decade, and a threshold voltage of -3.54 V.



(a) (b) (c)

Fig. 2. Images of fabrication of screen-printed OTFTs using three types Ag paste on flexible PEN, PET or PC substrates .

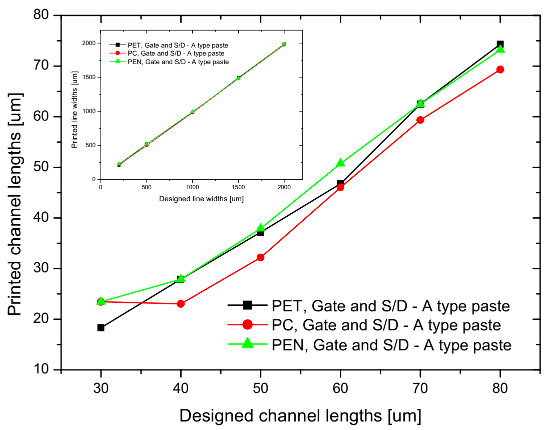
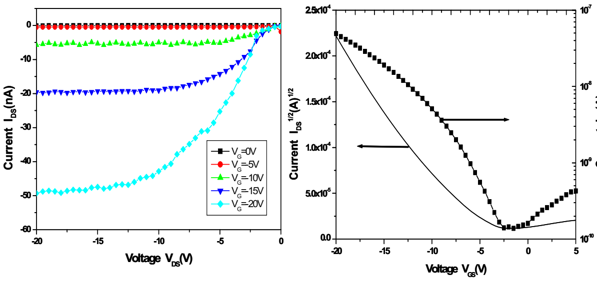


Fig. 3. Variation characteristics of designed line widths versus printed channel lengths for source and drain electrodes of printed OTFTs. designed

line widths versus printed line widths for gate electrodes are shown in the inset.)



(a) (b)

Fig. 4. Device characteristics for a printed TIPS-pentacene OTFT on PEN substrate in the screen printing: (a) output characteristics, (b) transfer characteristics.

4. Conclution

Direct screen printing using an high-mesh screen mask, low-resistance conductive Ag paste, polymer dielectrics, and soluble semiconductors, made it possible to fabricate printed OTFTs with channel lengths down to 13 μm on the 150×150 mm^2 PEN, PET and PC substrates without pattern defects, which had been hardly patterning in the previous traditional printing. The number of steps in the fabrication process was reduced by 20 steps compared with conventional fabrication techniques, there were no need for exposure, develop, and remove processes. Since the fabrication process was done in near room temperature, there was no appeared such as pattern shrinkage, pattern transformation and bending problem. This technology of using printed electrodes and soluble organic semiconductors combined with large-area inking and printing techniques is believed to have the potential to reduce manufacturing costs is by eliminating the need for conventional technology.

5. References

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