4" E-ink Active-matrix Displays based on Ink-jet Printed Organic Thin Film Transistors

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Keywords : OTFT, pTFT, Ink-jet printing, E-paper

Abstract

We demonstrate 4-in QVGA active-matrix electrophoretic display based on ink-jet printed organic transistors on glass substrates. Our TFT array had a bottom-gate, bottom-contact device architecture. The organic semiconductor and gate dielectric were solution processed. The field-effect mobility of the printed devices, calculated in the saturation region, was 0.1~0.3cm^2/Vs at Vg=-20 V.

1. Introduction

Flexible displays are commercially competitive due to their flexibility and light weight. The use of thin flexible substrates for TFT arrays will significantly reduce the weight of displays and provide the ability to bend or roll a display into any desired shape.To achieve these purposes, much effort has been focused on materials and process methods.

Organic thin film transistors (OTFTs) are attracting much attention to the special applications such as flexible display, smart card, and RF tag which are difficult to be achieved by the conventional Si devices due to the solid property of Si and/or the cost of fabrication. To date, OTFTs are under worldwide investigation particularly on improvement of field effect mobility. The field effect mobility has been impressively increased year by year by improving the processes or applying a new organic material as the active layer.

There are two types of organic semiconductors for the channel materials; one is polymeric material and the other is small molecule material.[1] The merit of the polymeric material is compatibility with solution processes but the challenge is to purity the polymeric materials. Since the solid state structure of small molecular material has basically high crystallinity, it has relatively high mobility, compared to the polymeric material. The challenging issue is its processibility. The small molecular semiconductors generally have poor solubility and the films are formed by a vacuum-process. As a result, the trade-off relationships between a good processibility and a high mobility.

In this paper we demonstrate 4-in QVGA active-matrix electrophoretic display based on solution processed organic thin film transistors on glass substrates. Inkjet printing, especially DOD-IJP (drop on- demand Inkjet printing), an attractive patterning technique was used for active layer. The material we used as an channel material was Poly alkyl(thiophene-thiazole)s and solution-processible organic-inorganic hybrid dielectric material used as a gate insulator.

A field-effect mobility as high as 0.1cm^2/Vs can usually be obtained and this number can be improved up to 0.3cm^2/Vs with surface treatments and changes in annealing conditions.

2. Experimental

The glass substrate was cleaned using normal cleaning process and deposited 200nm MoW by sputtering. The MoW layer was employed as a gate metal. After patterning the gate metal, a organic-inorganic hybrid gate insulator layer was spin- coated to a thickness of 400nm and annealed at 200°C for 2 h. The gate via holes were formed by reactive-ion etching (RIE) using a gas mixture of CF_4 and O_2 in rate of 2:1.

A 70nm Au layer was deposited by e-beam at room temperature to serve as a source and drain metal and patterned by a photo lithography method.

Banks for ink-jet printing were subsequently formed by spin coating method and patterned by photo lithography and annealed at 180°C for 1 h. The material for banks was fluorine-added PVA. After annealing, fluorinated side groups move to surface and the surface becomes hydrophobic. The surface contact angle was measured to be about 100° to 110°.

After forming bank layer, we treated the gate insulator surface with O_2 plasma and deposited self assembled mono layer (SAM) to improve surface condition between gate insulator and semiconductor layer.

The semiconductor ink of Poly alkyl(thiophene-thiazole)s, dissolved in 1,2,3,4-Tetrahydronaphthalene (THN) in 0.01wt%, was printed to a thickness of 30nm to 50nm and annealed at 150°C for 1 h under nitrogen atmosphere. Then the 1um thick passivation layer was spin coated and annealed at 120°C for 1 h. Finally, the e-ink film was laminated on fabricated TFT array plate.

The structure of OTFT was bottom gate-bottom contact and W/L ratio for these transistors was 120um/10um. Fig. 1. shows cross-section of the integrated device.

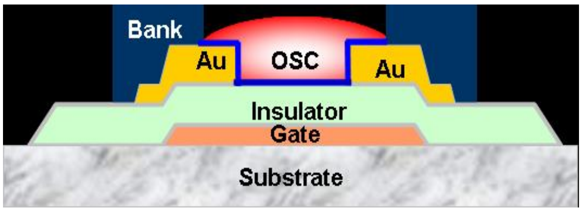


Fig. 1. Cross-section of OTFT fabricated using ink-jet printing

3. Results and discussion

Electrical characteristics of OTFTs were measured using a Keithly 4200 Semiconductor Characterization System. Fig. 2 shows I_D–V_D and I_D–V_G characteristics of OTFTs. It produced p-type FET characteristics, and the good gate-controllability.

The performance of OTFTs was calculated by using equations and methods recommended on “IEEE Standard for Test Methods for the Characterization of Organic Transistors and Materials.”

The mobility and threshold voltage values were measured from the transfer characteristics to be 0.1~ 0.3cm^2/Vs and 10V respectively. The on/off ratio and sub-threshold slope were 10^6 and 1.2V/decade respectively.

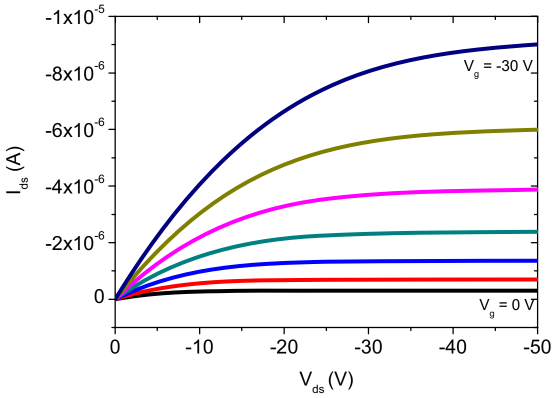
These OTFT performance was much depends on surface treatment conditions including plasma treatment time, ink concentration and annealing conditions.

Another factor determining the performance of OTFTs is contacts between semiconductors and source/drain electrodes. Among metals, Au has been used for source/drain electrodes in most of the work done to date because of a work function close to the HOMO of p-type organic materials. Despite its work function advantages, Au may not be a good candidate for the source/drain electrodes in active-matrix TFT arrays because its expensive, shows poor adhesion properties, poor etching properties and is not a common metal in TFT fabrication process.

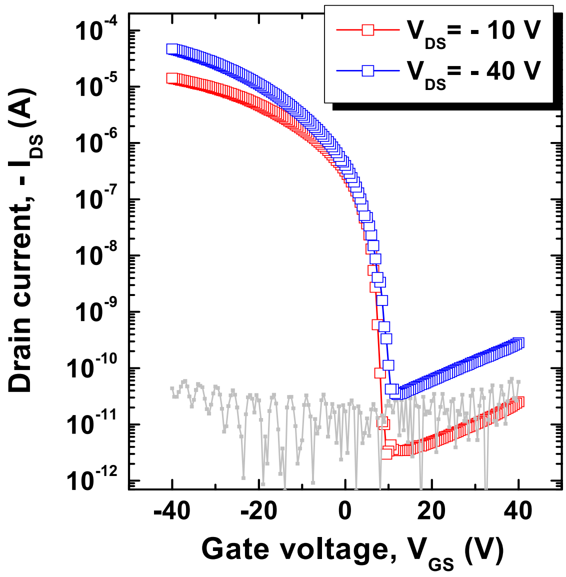
As an alternative to Au for source/drain electrodes, we have investigated the possibilities of using other metals such as Nickel (Ni), Molybdenum (Mo) and Indium tin oxide (ITO). In case of Ni and Mo, the surface oxide layer prevents carriers from being effectively injected. The work function of ITO was measured to be ~4.8eV, but Choi et al. showed that oxygen plasma treatment increased the work function up to 5.1eV, which probably provides ohmic contact with organic semiconductors.[2] Table 1. lists the performance of OTFTs various electrode materials.

TABLE 1. Performance of OTFTs various electrode materials

Electrode materials	Work function (eV)	Mobility (cm^2/Vs)
Gold (Au)	5.1	0.3
Nickel (Ni)	5.15	0.001
Molybdenum (Mo)	4.6	0.002
Indium tin oxide(ITO)	4.8	0.1



(a) Output characteristics of an IJP OTFT



(b) Transfer characteristics of an IJP OTFT

Fig. 2. (a) I_D–V_D, and (b) I_D–V_G characteristics of ink-jet printed OTFTs

After passivation, laminating e-ink film and PCB bonding, we developed 4-in QVGA e-ink active-matrix displays based on ink-jet printed organic thin film transistors (Fig. 3.).

Fig. 3. 4" QVGA e-ink active-matrix displays

4. Summary

We investigated the effects of various processes conditions on performance of OTFTs. The surface condition of gate insulator is the most important factor to determine the performance of OTFTs, because the ordering of organic semiconductor thin film depends on the surface property.[3]

We also demonstrated 4-in QVGA active-matrix e-ink display based on solution-processed (ink-jet printed) organic transistors on glass substrates.

5. References

1. Sangyun Lee, Bonwon Koo, Jaegeun Park, Hyunsik Moon, Jungseok Hahn and Jongmin Kim, *MRS BULLETIN,* Vol. 31, p455 (2006)
2. J.H. Choi, E.S. Lee, S.H. Choi, H.K. Baik, K.M. Song, Y.S. Lim and S.M. Lee, *J. Vac. Sci. Technol.* A23, p1479 (2005)
3. Chung-Kun SONG, Bonwon Koo, Sang-Back LEE and Do-Hyun KIM , *Jpn. J. Appl. Phys.,* Vol. 41, p2730–2734 (2002)