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Thin Solid Films 499 (2006) 415 – 419
thin solid films
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# Organic transistors with indium tin oxide electrodes for driving organic light emitting diode

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Available online 1 August 2005

**Abstract**

The integrated device of the organic field transistor (OFET) based on α,ω-dihexylsexithiophene and the organic light emitting diode (OLED) was fabricated on the same indium tin oxide (ITO)-coated glass substrate by using the photoresist gate insulator with an average surface roughness of 0.2 nm. OFET has a top contact structure with the Au source and drain electrodes. The current and luminance of an OLED were controlled by varying the gate voltage. The field effect mobility of the OFET with non-treated photoresist gate insulator increases with increasing the substrate temperature and is obtained up to about 0.1 $cm^2$/V s at a substrate temperature of 90 °C, while the devices with octadecyltrichlorosilane (OTS)-treated gate insulator are almost independent of the substrate temperature and have up to about 0.1 $cm^2$/V s at the substrate temperature region from 20 °C to 90 °C. The OTS-treated OFET at 60 °C has a highest carrier mobility of 0.137 $cm^2$/V s and a current on/off ratio of $10^5$. The OTS treated gate insulator obviously plays an important role in improving the performance of the OFETs. Current in the order of more than 0.1 μA flows from the semitransparent top contact type OFET utilizing the sputter deposited amorphous carbon nitride /ITO bilayer instead of Au electrode as the source and drain electrodes.


*Keywords:* Organic transistor; Dihexylsexithiophene; Indium tin oxide; Field effect mobility; Organic light emitting diode

## 1. Introduction

Organic semiconductors have attracted a lot of attention due to their simple and low cost processes and potential electronic and optoelectronic applications. Especially, study of organic light emitting diodes (OLEDs), organic field effect transistors (OFETs) and organic photo detectors (OPDs) are very active in this field. Various kinds of organic integrated circuits with OLEDs using OFETs have been demonstrated [1–3]. The thiophene oligomers with high carrier mobility [4–10] are one of the candidates on an active semiconductor layer for realizing all organic circuits.

The electrical characteristics of OFETs depend on the interface states between the organic active layer and the gate insulator. The smooth gate insulator of molecular ordering is one of the determining factors for obtaining the large carrier mobility in OFETs because the carrier transport strongly depends on the overlap between the neighboring grains and also molecules. The surface treatment is also an effective way to improve the performance of OFETs. The polymer gate insulator with smooth roughness is one of the key factors for realizing the flexible devices [7,9,10]. It is very effective to apply the organic self-assembled layer such as octadecyltrichlorosilane (OTS) for channel coating [11–13]. The mobility also depends on the morphology of the organic layer. In the case of the OFETs fabricated on the polymer gate insulator, it is important to focus on improvement of the electrical property of devices due to the change of morphology for the substrate temperature during deposition.

Indium-tin oxide (ITO) electrode is used as the transparent electrode of organic devices such as OLEDs and OPDs. In order to realize the integrated devices with the multilayer structure built up OLEDs and OPDs on OFETs, a transparent electrode is also useful to be applied as the drain and source electrodes.

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0040-6090/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2005.06.080

In this study, we report the results of an investigation of dihexylsexithiophene OFETs with polymer gate insulator and the ITO electrodes for driving the OLEDs.

## 2. Experimental

The device configurations used in this study are shown in Fig. 1. A polished ITO commercially precoated on a glass substrate was used as a gate electrode. The average surface roughness of ITO is estimated to be about 0.5 nm from the atomic force microscope (AFM) image. The gate insulation layer was prepared from a solution of photoresist. The positive tone photoresist of ZWD-6200 series (Zeon Co. Ltd.) suitable for EL-panel processing to make insulator was spun onto a pattered ITO-coated glass substrate and cured at 200 °C in an ambient atmosphere. ZWD-6200 series is an alkaline developable and can be made round pattern profile around the corner of the bank by only baking after fabricating the insulating bank formation on the ITO-coated substrate by photo lithography. The thickness of the gate insulator is 390 nm. Gate leakage was on the order of 1 nA/$cm^2$ at a gate bias of 30 V. A permittivity of 3.5 for the gate insulator was estimated from capacitance measurements.

For the organic active layer, α,ω-dihexylsexithiophene layer with a 30-nm thickness was deposited by organic molecular beam deposition at a background pressure of about $10^{-5}$ Pa. The growth rate was monitored using a quartz crystal oscillator and was on the order of 1 Å/min.

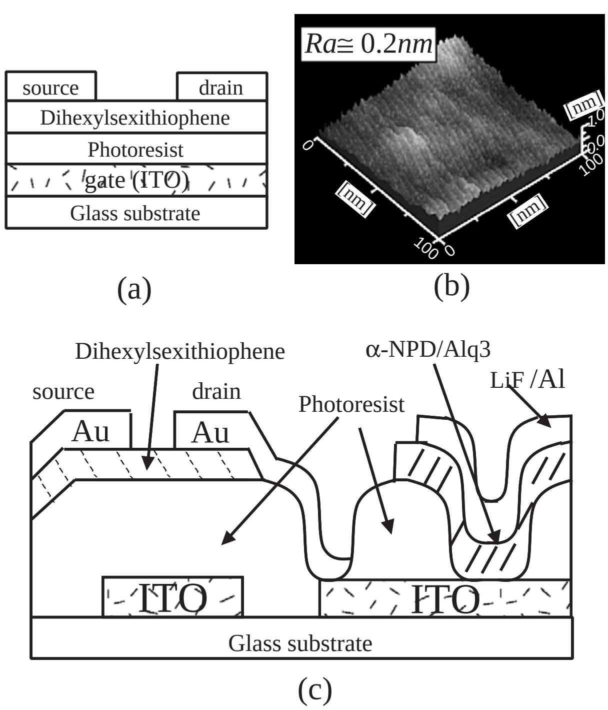


Fig. 1. The device configurations used in this study and an AFM image of the surface of the photoresist gate insulator spin-coated on the ITO-coated glass substrate.

Dihexylsexithiophene was purchased from H.C. Starck-V TECH Ltd. The source and drain Au electrodes with a 30-nm thickness were evaporated at a background pressure of about $10^{-4}$ Pa. The channel length and width are 0.1 mm and 2 mm, respectively. All measurements of the electrical characteristics of OFETs are carried out in a vacuum chamber at a background pressure of about $10^{-1}$ Pa.

ITO electrodes were deposited by using a sputtering system (Thin-Film Process Soft Inc., Japan) of the facing targets type. Using the sputtering system, high-quality ITO film without annealing process of the deposited film can be obtained. The ITO film has a resistivity of about $4 \times 10^{-4}$ Ω cm. The total pressure during the sputtering process was kept at $2 \times 10^{-1}$ Pa under a pure 45 sccm for Ar and 0.7 sccm for $O_2$ flow. The sputtering rate was 8 nm/min. An amorphous carbon nitride (a-C:N) buffer layer with flexibility and good conformity for organic materials was deposited using the same sputtering system. The gas flow rate was 45 sccm for Ar and 20 sccm for $N_2$. The a-C:N film used in this study has a resistively in the order of $10^5$ Ω cm.

The typical OLED device consists of a 50-nm-thick 4,4′-bis[*N*-(naphthyl)-*N*-phenyl-amino]-biphenyl (α-NPD) layer as a hole-transporting layer and 50-nm-thick tris (8-hydroxyquinoline) aluminum ($Alq_3$) layer as an emissive layer, terminated with LiF/Al bilayer cathode. After fabrication, the device, as shown in Fig. 1(c) was covered with a glass plate and encapsulated by epoxy resin in argon atmosphere to prevent oxidation of the cathode and organic layers.

## 3. Results and discussion

The OFET based on dihexylsexithiophene and the green OLED with $Alq_3$ as an emitting layer were fabricated on the same glass substrate as shown in Fig. 1(c). The ITO electrodes and the photoresist insulator were pattered by standard photolithography. For fabricating a round pattern profile, it is easy to be pattered and cured the ITO-coated glass substrate by using the photoresist gate insulator. It is well-known that the electrical properties of OFETs are strongly affected by the surface roughness of the gate insulator. The average surface roughness of a gate insulator spin-coated on the ITO-coated glass substrate is estimated to be about 0.2 nm from an AFM image as shown in Fig. 1(b). The AFM image of a gate insulator indicates homogeneous and smooth images. Fig. 2 shows gate voltage dependence of current and luminance for the integrated device with an OLED of ITO/α-NPD (50 nm)/$Alq_3$ (50 nm)/LiF (0.5 nm)/Al with an active area of 0.5 mm diameter circle, where the value of voltage at −30 V is applied on the LiF/Al cathode electrode. The organic active layer of the OFET is deposited at a substrate temperature of 20 °C. The current and luminance of an OLED were controlled by varying the gate voltage. The luminance of the OLED proportionally increases with increasing the current density as shown in