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Organic Thin Film Transistors for Liquid Crystal Display Fabricated with Poly 3-Hexylthiophene Active Channel Layer and NiO_x Electrodes

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Abstract

We report on the fabrication of P3HT-based thin-film transistors (TFTs) for liquid crystal display that consist of NiO_x, poly-vinyl phenol (PVP),and Ni for the source-drain (S/D) electrodes, gate dielectric layer, and gate electrode, respectively. The NiO_x S/D electrodes of which the work function is well matched to that of P3HT are deposited on a P3HT channel by electron-beam evaporation of NiO powder. The maximum saturation current of our P3HT-based TFT is about 15 μA at a gate bias of -30 V showing a high field effect mobility of 0.079 cm^2/Vs in the dark, and the on/off current ratio of our TFT is about 10^5. It is concluded that jointly adopting NiO_x for the S/D electrodes and PVP for gate dielectric realizes a high-quality P3HT-based TFT.

Key Words : Liquid crystal display, P3HT, PVP, Ni, NiO_x

1. INTRODUCTION

Organic semiconductors have generated considerable interest in the fields of electronic and photonic devices due to wide range of applications, such as thin film transistors (TFTs) and organic light emitting diode (OLED) devices. Among these, organic TFTs (OTFTs) on a thin and flexible substrate have potential advantages of realizing low-cost, large-area, and structural flexible electronic devices[1-9]. Various fabrication techniques are currently used to develop high performance OTFTs, such as spin-coating, ink-jet printing, screen printing, and rubber stamp printing. OTFTs with vacuum deposited organic semiconductors exhibit the highest performance but from the manufacturing cost point of view, solution based technology is more favorable. Therefore, to make use of the full advantages of OTFTs, large area coverage, mechanical flexibility, and low-cost processing, it is necessary to employ polymer gate dielectrics have been reported and some of them exhibited good electronics performance comparable to those with inorganic gate dielectric materials, showing a field effect mobility over 0.08 cm^2/Vs and an on/off ratio over 10^4 although researchers used Au-Cr source-drain (S/D) contacts for the polymer gate dielectrics devices.

In the present study, we report on the fabrication of poly 3-hexylthiophene (P3HT)-based TFTs using the poly-4-vinylphenol (PVP) gate dielectric layer and electron beam evaporated semitransparent NiOx S/D electrodes. Our OTFTs have exhibited field effect mobility of 0.079 cm^2/Vs and on/off current ratio of 10^5 which are quite decent values for TFTs with polymer gate dielectric layer.

2. EXPERIMENTAL

The gate electrode has been made of 100 nm-thick Ni, deposited at room temperature using

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Table 1. Deposited condition of gate electrode.

Conditions	Values
Ar gas flow(sccm)	12
O_2 gas flow(sccm)	0
Target-substrate distance(mm)	10
Pressure(mTorr)	2~3
Power density(Wcm^{-2})	10

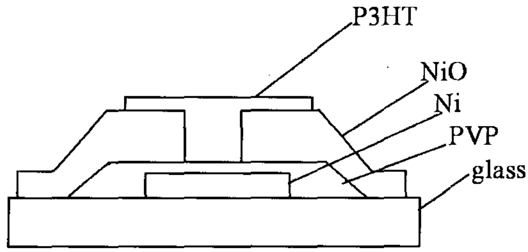


Fig. 1. Cross section of TFT.

RF magnetron sputtering. Table 1 shows condition of RF magnetron sputtering.

PVP is used as a gate dielectric layer, which improves the electrical properties of the OTFTs devices. Prior to the spin-coating of PVP film on gate electrode substrate, the substrate is cleaned with acetone, ethanol, and deionized water in that order. PVP films are then prepared from solution of PVP and poly(melamine-co-formaldehyde), as a cross-linking agent, in propylene glycol momomethyl ether acetate (PGMEA) by spin coating and cross-linking at 150 ℃ in vacuum oven. Final thickness of the PVP film is ~500 nm as measured by Alpha step. NiO powder is evaporated using electron-beam.

P3HT is used after purification process with tetrahydrofuran (THF) and acetonitrile to increase the head-to-tail regioregularity. Later, P3HT is dissolved in chloroform with a concentration of 0.2 wt% and then spin coated or rubber stamp printed on the substrate. Electrical characteristics of the device are measured using Keithley 4200-SCS semiconductor characterization system.

Poor surface characteristics of the substrate leads to inferior dielectric properties of gate dielectric layer and significant degradation in the performance of the resulting organic transistor by more disordered molecular structure of polymer layer on gate dielectric layer. The relationship between the molecular ordering of polymer layer and the electrical characteristics of the device has been investigated. Especially using P3HT as the active layer, there is a direct correlation between the molecular structure and the field effect mobility. Therefore, improvement of surface characteristics of the gate dielectric layer and S/D electrodes should be considered to achieve high field effect mobility. Octadecyl-trichlorosilane (OTS) is used to improve surfaces of the gate dielectric layer and S/D electrodes. In order to increase the region-regularity of P3HT material, a purification process of continuous extraction with tetrahydrofuran (THF) and acetonitrile is carried out, using solubility difference between regio-random and regioregular polymers. The regioregularity of the sample has been increased from 93 % to 98 % after the purification process which is estimated with ^{1}H NMR by comparing the signal intensity that arises from the aromatic region of the spectrum.

Contemporary PH3T-based OTFTs have different designs. One of them is the so-called top S/D contact TFT design, where both S/D contact pads are deposited on top of an active layer through a shadow mask. The top contact TFTs are easiest to fabricate and they show superior characteristics over TFTs of another design. However there is no suitable procedure to pattern the top contact TFT active layer to isolate the devices from each other. TFTs of another design, where S/D contact metal is deposited on the gate dielectric layer and patterned prior to the active layer deposition, are referred to as bottom contact TFTs. Figure 1 shows cross section of a bottom contact OTFT. This structure can be possible to use low-cost processes, such as spin-coating, ink-jet printing and rubber stamp printing and easily be treated.

Here, purified P3HT material with 98 % in regioregularity has been used. Because P3HT is not an oligomer but a polymer, spin coating can be used in condition of a solvent without using vacuum evaporation.

The relationship between microstructure of the P3HT film and the electrical characteristics of field-effect transistor has been intensively studied since after the first investigation by Sirringhaus et al. This study shows that, the field-effect mobility of organic transistor depends on the two-dimensional molecular ordering of the P3HT film and the edge-on structure is more favorable in achieving high mobility rather than the face-on structure.

3. RESULTS AND DISCUSSION

Performance of OTFT is affected by characteristic of a channel, work function of S/D electrodes, interface of electrodes and a channel layer, and interface of a gate dielectric layer and a channel layer. Also, it is well known that the morphology of a gate dielectric layer is an influential factor determining the carrier mobility and insulating properties in OTFT devices. Flatness of a gate dielectric layer has to be good and have no defects to improve performance of OTFT. Figure 2 show an atomic force microscope (AFM) image and statistical distributions of PVP. PVP layer has good flatness in case of using spin-coating method. This is attributed to make uniform channel.

Moreover, molecular ordering of a channel layer is important to modify the surface property of a gate dielectric layer. In relation to molecular ordering of gate dielectric layer, many studies are conducted, such as O_2 plasma treatment, hexamethyldisilazane (HMDS) treatment, self assembly-monolayer (SAM), and α-NMB. However, PVP of the organic gate dielectric layer is damaged using O_2 plasma treatment. HMDS and α-NMB is not suitable for oxide electrodes, because these methods improve only interface of S/D metal electrodes and a gate dielectric layer. Therefore, SAM method is taken using octadecyltrichlorosilane(OTS) due to suitability of both a gate dielectric layer and oxide electrodes. After OTS is treated, P3HT is spread. Figure 3 show good flatness of surface and no defects.

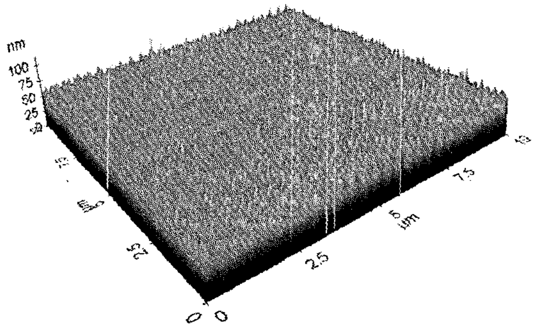


Fig. 2. AFM image and statistical distribution of PVP surface.

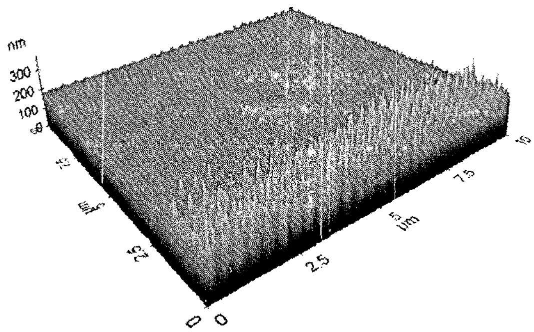
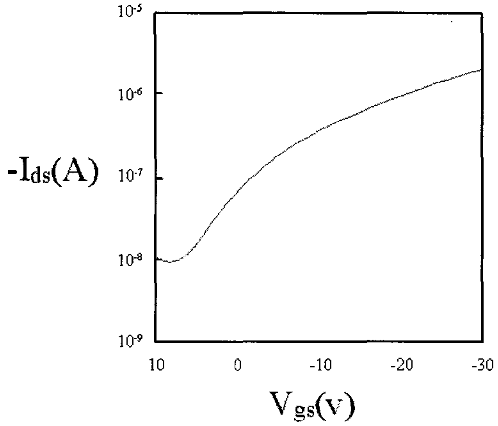
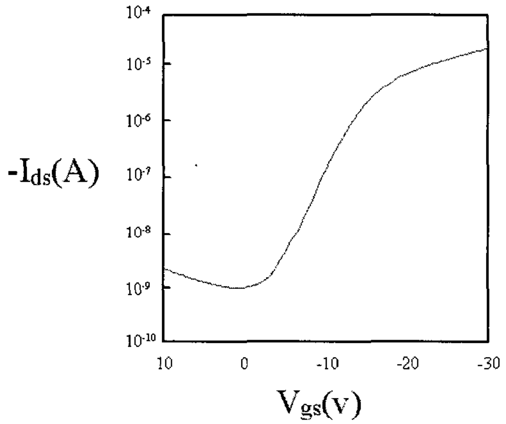


Fig. 3. AFM image and statistical distribution of P3HT surface.

Figure 4(a) and 4(b) show the transfer characteristics of organic transistors fabricated with as-received (93 % in regioregularity) and purified (98 % in regioregularity) P3HT materials. Here, the active channel is spin-coated. With low regioregular material (93 %), the field-effect mobility is found to be 0.025 cm^2/Vs and the on/off ratio was 10^2 ~ 10^3 in Fig. 4(a). However with purified material (98 %), the field-effect mobility increases to 0.079 cm^2/Vs with a maximum value of 0.1 cm^2/Vs and the on/off ratio also increases to 10^4 ~ 10^5 in Fig. 4(b). Consequently using higher regioregular P3HT, field-effect mobility and on/off ratio are improved by factors of $10^3$and 10^2, respectively.



(a) as-received(93 % in regioregularity)



(b) purified(98 % in regioregularity) P3HT materials.

Fig. 4. I-V characteristics of polymer thin-film transistors with.

4. CONCLURION

In this study, we report on the fabrication of P3HT-based TFTs using PVP gate dielectrics and electron beam evaporated semitransparent NiOxS/D electrodes. Our OTFTs have exhibited field effect mobility of 0.079 cm^2/Vs and on/off current ratio of 10^5 which are quite decent values for TFTs with polymer gate dielectrics. The fabrication of organic devices on extremely cheap polymer substrates may be important for realizing future applications in flexible and disposable electronics.

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