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Jin Woo Lee [b], Jin Woo Han [a], Sang Kuk Lee [a], Jeong Min Han [a], Byung Moo Moon [b], Dae Shik Seo [a] & Jae Hyung Kim [c]

[a] Department of Electrical Engineering, Yonsei University, Seoul, Korea

[b] Department of Electrical Engineering, College of Engineering, Korea University, Seoul, Korea

[c] Department of Physics, Inje University, Kimhae, Kyungnam

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Jin Woo Lee[2], Jin Woo Han[1], Sang Kuk Lee[1], Jeong Min Han[1], Byung Moo Moon[2], Dae Shik Seo[1], and Jae Hyung Kim[3]
[1]Department of Electrical Engineering, Yonsei University, Seoul, Korea
[2]Department of Electrical Engineering, College of Engineering, Korea University, Seoul, Korea
[3]Department of Physics, Inje University, Kimhae, Kyungnam

We report on the fabrication of soluble pentacene-based thin-film transistors (TFTs) that consist of NiO_x, poly-vinyl phenol (PVP), and Ni for the source-drain (S/D) electrodes, gate dielectric, and gate electrode, respectively. The NiO_x S/D electrodes of which the work function is well matched to that of soluble pentacene are deposited on a soluble pentacene channel by sputter deposited of NiO target and show a moderately low but still effective transmittance of $\sim 65\%$ in the visible range along with a good sheet resistance of $\sim 40\,\Omega/\square$. The maximum saturation current of our soluble pentacene-based TFT is about $15\,\mu A$ at a gate bias of $-30\,V$ showing a high field effect mobility of $0.03\,cm^2/Vs$ in the dark, and the on/off current ratio of our TFT is about 10^4. It is concluded that jointly adopting NiO_x for the S/D electrodes and PVP for gate dielectric realizes a high-quality soluble pentacene-based TFT.

Keywords: NiO_x; organic TFT; PVP; soluble pentacene

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,

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Address correspondence to Prof. Dae Shik Seo, Department of Electrical Engineering, Yonsei University, Seoul 120-749, Korea (ROK). E-mail: dsseo@yonsei.ac.kr

large-area, and structural flexible electronic devices [1–4]. Various fabrication techniques are currently used to develop high performance OTFTs, such as vacuum deposition, ink-jet printing, screen printing, and rubber stamp printing [6]. 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 $0.025\,m^2/Vs$ and an on/off ratio over 10^4 although researchers used Au-Cr source-drain (S/D) contacts for the polymer gate dielectrics devices [1].

In the present study, we report on the fabrication of soluble pentacene based TFTs using poly-4-vinylphenol (PVP) gate dielectrics and RF (radio frequency) sputtered semitransparent NiO_x S/D electrodes. Our OTFTs have exhibited field effect mobility of $0.03\,cm^2/Vs$ and on/off current ratio of 10^4 which are quite decent values for TFTs with polymer gate dielectrics.

EXPERIMENTAL

The gate electrode has been made of 100 nm-thick Ni, deposited at room temperature using RF magnetron sputtering. Table1 shows condition of RF magnetron sputtering.

PVP is used as a gate dielectric, 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°C in

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)	$2\sim3$
Power density (Wcm^{-2})	10

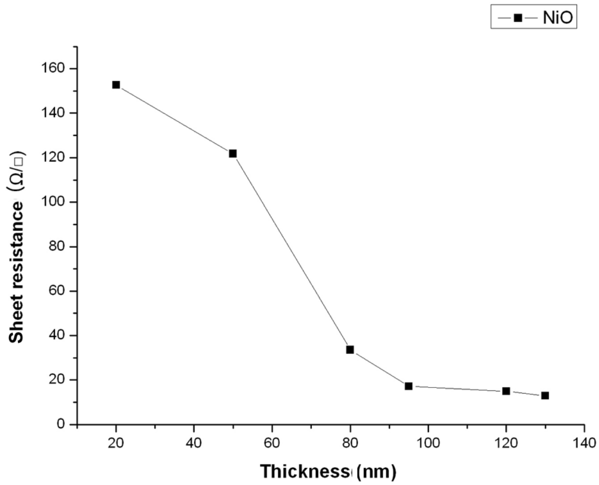

FIGURE 1 Resistance per square of NiO.

vacuum oven [5]. Final thickness of the PVP films is ~500 nm as measured by Alpha step. NiO target is deposited by sputter. After deposition, the resistance per square of this material is measured as Figure 1.

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. The relationship between the molecular ordering of polymer layer and the electrical characteristics of the device has been extensively investigated recently. Especially using soluble pentacene 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 and source/drain electrode should be considered to achieve high field effect mobility. Octadecyltrichlorosilane (OTS) is used to improve surface of electrodes and gate dielectrics.

Contemporary soluble pentacene organic TFTs have different designs [4]. One of them is the so-called top source and drain contact TFT design, where both source and drain contact pads are deposited on top of an active layer through a shadow mask. The top contact TFTs are easiest to fabricate and they showed superior characteristics over TFTs of other designs. However there is no suitable procedure to

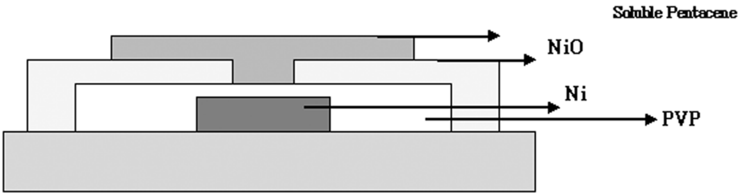

FIGURE 2 Cross section of TFT.

pattern the top contact TFT active layer to isolate the devices from each other. TFTs of another design, where drain and source contact metal is deposited on the gate dielectric and patterned prior to the active layer deposition, are referred to as bottom contact TFTs.

Figure 2 shows cross section of TFT. Pattern formation is difficult due to characteristic of polymer, before S/D is evaporated. So, bottom contact TFT structure is used. This structure can be obtained using low-cost processes, such as spin-coating, ink-jet printing and rubber stamp printing and easily be treated.

Here, purified soluble pentacene material has been used.

RESULTS AND DISCUSSION

Figure 3 shows the gate electrodes of fabricated TFTs. The size of the island pattern is $700 \times 900\,\mu m$ and the thickness of the film is 60 nm.

The capacitance of gate dielectric layer is the most important factor to determined performance of TFT. Figure 4 shows C-V curve of PVP. PVP has good electrical insulating properties.

Moreover, molecular ordering of channel is important to modify the surface property of 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,

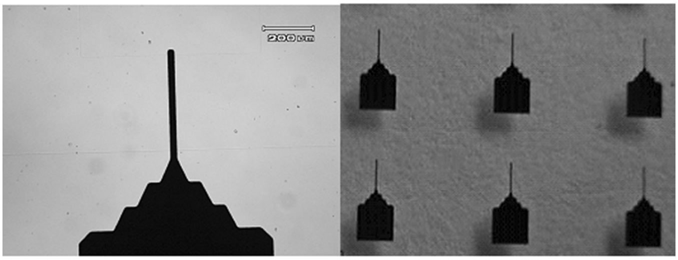

FIGURE 3 The gate electrodes of TFT.

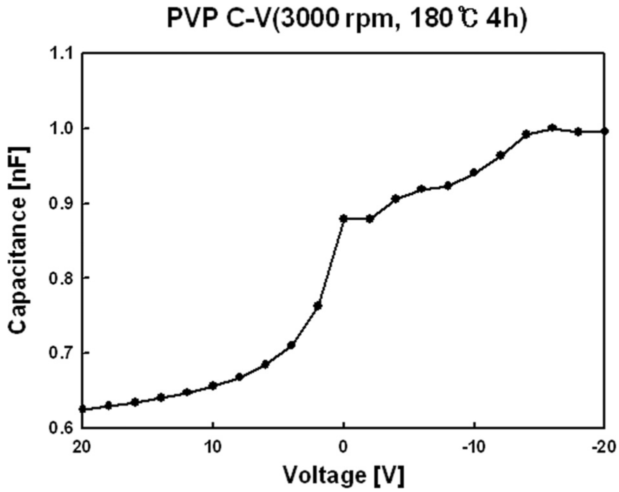

FIGURE 4 The capacitance per area of the PVP gate dielectric.

self assembly-monolayer (SAM), and a-NMB. PVP of organic gate dielectric layer is damaged using O_2 plasma treatment. HMDS and a-NMB is not suitable for oxide electrodes, because these methods improve only interface of S/D metal electrodes and gate dielectric

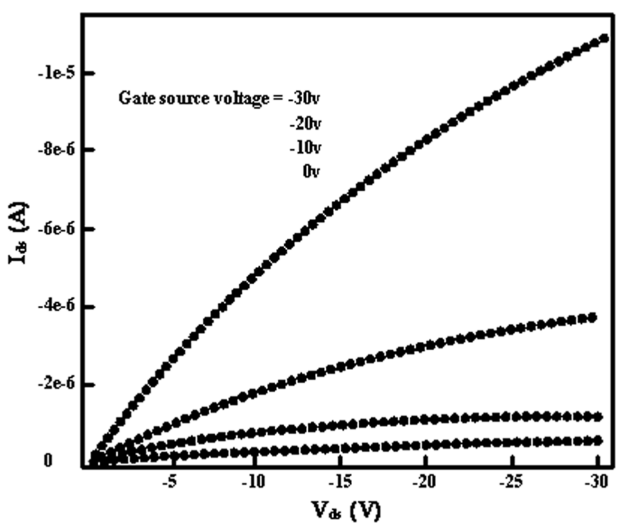

FIGURE 5 I-V characteristics of polymer thin-film transistors with soluble pentacene materials.

layer [7]. Therefore, SAM method is taken using octadecyltrichlorosilane (OTS) due to suitability of both a gate dielectric layer and oxide electrodes. After OTS is treated, soluble pentacene is spread.

Figure 5 show the transfer characteristics of organic transistors fabricated with surface treatment materials. Here, the active channel is spin-coated. With non surface treatment, the field-effect mobility is found to be $0.025\,cm^2/Vs$ and the on/off ratio was $10^2 \sim 10^3$. However with surface treatment, the field-effect mobility increases to $0.03\,cm^2/Vs$ and the on/off ratio also increases to $10^4 \sim 10^5$ in Figure 5. Consequently, using surface treatment, field-effect mobility and on/off ratio are improved by factors of 10^3 and 10^2, respectively.

CONCLUSIONS

In this study, we report on the fabrication of soluble pentacene based TFTs using PVP gate dielectrics and sputtered semitransparent NiO_x S/D electrodes. Our OTFTs have exhibited field effect mobility of $0.03\,cm^2/Vs$ and on/off current ratio of 10^4 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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