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High-Performance Organic Thin-Film Transistors with Metal Bilayer Electrodes

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메탈 이중층 전극을 이용한 유기 박막 트랜지스터의 성능향상

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초록 : 본 논문은 메탈 이중층 전극을 이용한 유기 박막 트랜지스터를 제작하여 Au 나 Ag 금속만으로 제작한 일반적인 유기 박막 트랜지스터와의 전기적 특성을 비교하였다. 전기적 특성에서 게이트 절연층은 높은 K 값을 갖는 Al_2O_3 를 사용하였고, 유기 반도체층은 펜타센을 사용하였다. 본 실험에서 제작한 유기 박막 트랜지스터는 1.6 x 10^{-1} cm^2 의 포화영역 이동도를 얻을 수 있었으며, 또한 드레인 전압을 -5 V로 하고, 게이트 전압을 3 V에서 -10 V 까지 인가하였을 때 3×10^5의 전멸 비를 얻을 수 있었다.

Keywords : Organic thin-film transistors, atomic layer deposition, Al_2O_3, metal bilayer.

1. Introduction

The thin-film transistors(TFTs) based on organic semi-conductors have received considerable attention because the potential application of nano-scale thin-film structures have been widely researched for large-scale integration industries, e.g. semi-conductors and displays, and great development has been made in this field during the last decade[1-4]. In the past few years, high di-electric constant materials have been widely utilized as gate insulators to enhance the accumulation of carriers under low voltage in organic TFTs(OTFTs.) Atomic layer deposition(ALD) provided noticeable breakthroughs by the use of high k di-electric materials, such as Al_2O_3, HO_2, ZrO_2, etc. ALD allows high step coverage, along with excellent thickness uniformity [5]. However, from the viewpoint of cost, costly

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materials such as Au and Pt have been recognized as matchless metals for the source-drain electrode of pentacene TFTs [6,7]. Moreover, low fabrication cost has recently been one of the most important factors in the fabrication of large area displays. In this work, Ag is suggested as the source-drain electrode with Ni as an adhesion film for a buffer layer and also as a hole injection film to the pentacene layer. Therefore, we focus on the influence of a metal adhesion layer for OTFTs using high k dielectric materials.

2. Experimental

2.1. Fabrication of Organic Thin-Film Transistors

We fabricated bottom-gate (inverted-staggered) transistor as depicted in Fig. 1. All devices were fabricated on glass substrate. Our OTFTs had Al gate electrodes and Al_2O_3 gate insulators, with 20 nm thick Al_2O_3 composite thin films were formed as layered nano-structures using atomic layer deposition (ALD) method. Al_2O_3 thin layers were deposited using TMA (Tri-methyl aluminum) and H_2O as Al and O(oxygen) sources, respectively. The detail was performed following the alternative supply of precursors and purged gases. The growth rate of Al_2O_3 thin films was determined to be in the range of 13 to 18 nm/cycle. Pentacene, which is a p-type semi-conductor layer with 60 nm thickness was evaporated onto the Al_2O_3 insulator layer at room temperature by a thermal evaporator. The source and drain contacts were formed after thermal evaporation of pentacene through a shadow mask to form pristine 60 nm thick Ag and Au single layers respectively, which were used as source(S) and drain(D) electrodes. In order to make a comparative study, 4 nm thick Ni under a 50 nm thick Ag layer was alternatively used as a source and drain and as an adhesion for the bi-layer. The fabricated OTFT has a channel length of 100 μm and width of 300 μm (W/L = 3).

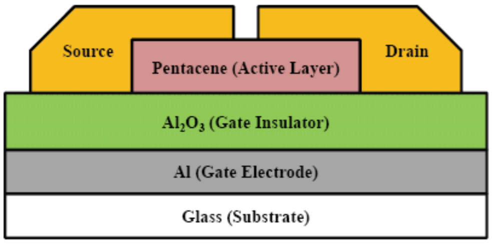

Fig. 1. The inverted-staggered structure of the OTFTs fabricated in this study.

2.2 Measurements

The current-voltage (I-V) characteristics of the fabricated OTFTs were measured by a Keithley 4200 semi-conductor analyzer unit, and the capacitance-frequency (C-F) characteristics were measured by a HP 4192 impedance analyzer. The surface condition was characterized by an atomic force microscope (AFM) and digital instruments nanoscope IV. All measurements were done at ambient conditions.

3. Results and Discussion

The transfer and output electrical characteristics of OTFTs were firstly investigated as a function of the insertion of a Ni layer. Some researchers investigated the correlation of the thickness of the grown crystalline pentacene with the surface energy of the di-electric. Fig. 2 shows the capacitance-frequency curves for metal-insulator-metal (MIM) capacitor consist of Al/ 20 nm thick Al_2O_3 as an insulator/Au. It was found that the measured di-electric constant K of the Al_2O_3 ALD films with a thickness of 20 nm was and a breakdown field higher than 5 MV/cm. As shown in Fig. 4 pentacene on the Al_2O_3 ALD film was

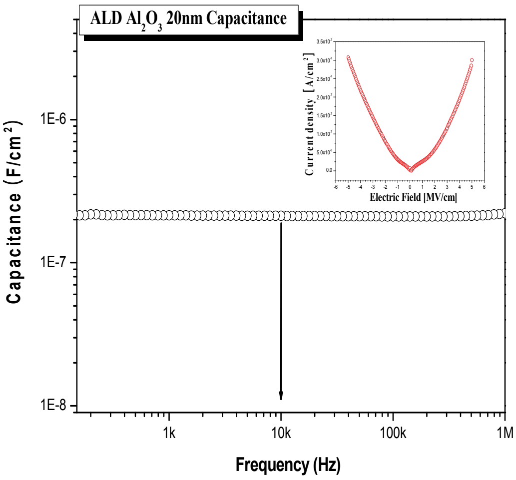

Fig. 2. The capacitance – frequency(C-F) graph of an OTFT using a 20 nm thick Al_2O_3 dielectric layer. Inset shows the current density-electric field (J-E) characteristics.

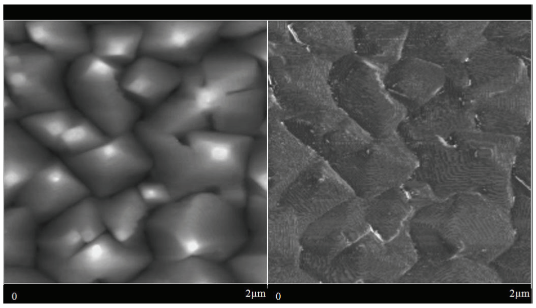

Fig. 3. Atomic force microscopy images of thermally evaporated pentacene films on an Al_2O_3 gate di-electric.

much stronger than other diffraction peaks of the first-order one, which means that the growth of pentacene is highly ordered on the Al_2O_3 films, as shown in the AFM images of Fig. 3 The inset of Fig. 4 shows the contact-angle of water on Al_2O_3 gate insulator. On the Al_2O_3 di-electric surface, the contact angle of 76° means a decrease of the surface energy and polarity. Figure 5 shows transfer and output characteristics of OTFTs, and it was observed that different

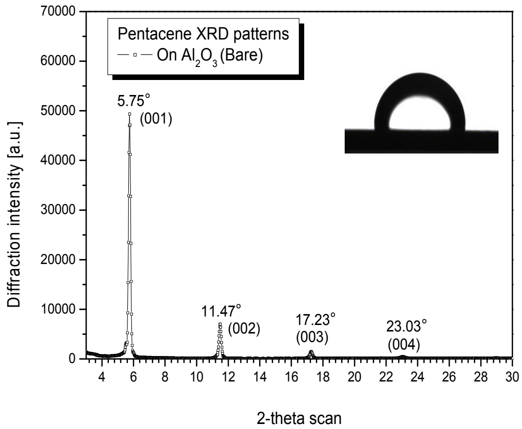

Fig. 4. XRD Patterns for 60 nm thick pentacene film deposited on 20nm thick Al_2O_3 layer and bare Al_2O_3 layer, respectively. Inset shows the contact-angle image on Al_2O_3 gate insulator in this study.

metal electrodes resulted in changes on the electrical characteristics for the OTFTs. As shown in Fig. 5 (a), the OTFTs with Ni/Ag electrodes exhibited much better electrical properties than the OTFTs with pristine Ag electrodes. Figure 5 (b) shows that the OTFTs with Ni/Ag exhibited the typical p-type semiconductor characteristics and good saturation behavior of the device similar to the OTFTs using Au electrodes as shown in Fig. 5 (c). These results indicate that the electrical properties of the OTFTs with bare Ag electrode as shown Fig. 5 (d) were improved by insertion of a Ni adhesion layer. The total TFT ON resistance (R_T) in the linear region $|V_{DS} << V_G|$ was calculated using the equation $R_T = V_{DS}/I_{DS} = 2R_S+R_{ch}$, where R_s is the series resistance both the source and drain contacts, and R_{ch} is the channel resistance. Figure 6 displays I_{DS} versus V_{DS} curves for the fabricated 3 kinds of devices. As compared with TFT using Au electrode, the R_T of that using Ni/Ag electrodes at V_G= −8 V was slightly increased from 0.91 MΩ to 2.04 MΩ. As

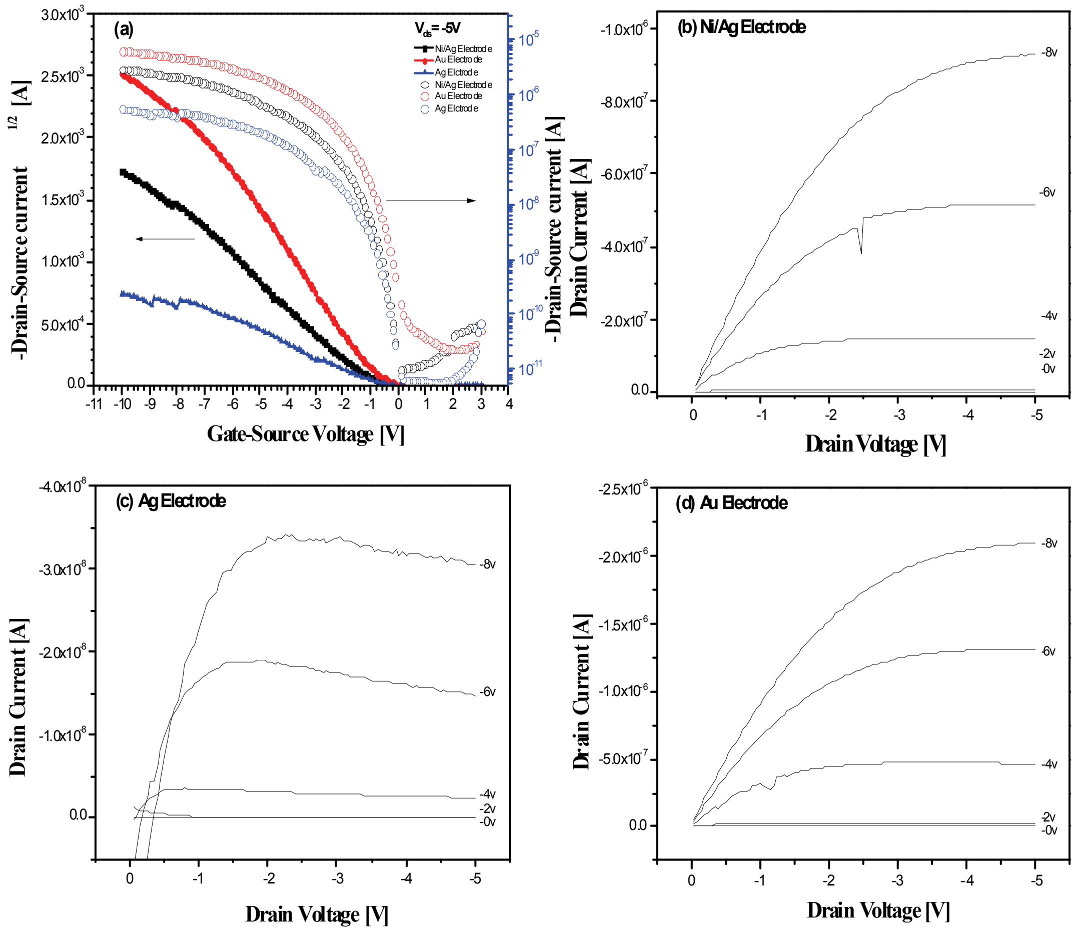

Fig. 5. Transfer characteristics and output characteristics of OTFTs with Ag, Ni/Ag, and Au Source-Drain electrodes.

Table 1. Summary of Electrocal Properties on the fabricated TFTs

Electrical Properties \ Electrode	Ag	Ni/Ag	Au
Threshold voltage [V]	-0.8	-1	-0.7
Subthresoldslop [V/decade]	0.4	0.3	0.4
On/off current ratio	7×10^{4}	3×10^{5}	8.5×10^{4}
Mobility [cm^{2}/Vs]	3.4×10^{-2}	1.6×10^{-1}	3×10^{-1}
Off current [A]	7.8×10^{-12}	9.5×10^{-12}	7.4×10^{-11}

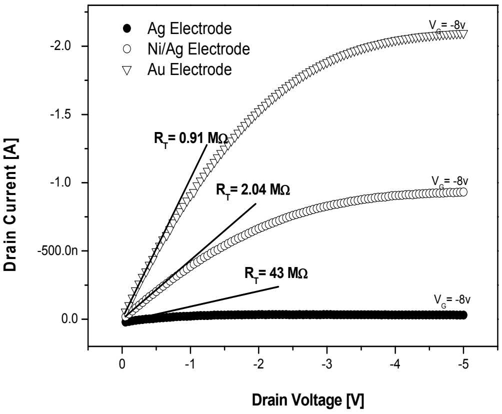

Fig. 6. I_{DS}-V_{DS} characteristics of devices with Ag, Ni/Ag and Au source-drain electrodes at V_G= -8 V. Tangent lines on different source-drain electrodes represent the total resistance.

compared to Ag Source-Drain electrodes, the Ni/Ag Source-Drain electrodes are good enough to carry holes, because the holes are easily injected from the Ni adhesion electrode directly into pentacene by being matched between the work function of Ni and the highest occupied molecular orbital (HOMO) of pentacene[8-11]. Further electrical properties of each device are summarized in Table I.

4. Conclusions

In this paper, we have demonstrated that an Ag electrode itself as an Source-Drain electrode for an OTFT, did not show good electrical characteristics. However, the insertion of the Ni layer between the pentacene and Ag layer conspicuously improved the electrical characteristics of the OTFT, such as the transfer and output characteristics. It was also found that inexpensive Ag with Ni as source and drain electrodes can be applicable for fabricating pentacene TFTs which have good electrical characteristics.

Acknowledgment

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