Low-Voltage Organic Thin-Film-Transistors on Al_2O_3 Gate Insulators Layer Fabricated by ALD Processing Method

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ALD 방식의 Al_2O_3 게이트 절연막을 이용한 저 전압 유기 트랜지스터에 관한 연구

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Abstract : we fabricated a pentacene thin-film transistor with an Al_2O_3 layer of ALD as a gate insulator and obtained a device with better electrical characteristics at low operating voltages (below 16V). This device was found to have a field-effect mobility of 0.03cm^2/Vs, a threshold voltage of -6V, an subthreshold slope of 1 V/decade, and an on/off current ratio of 10^6.

Keywords : organic thin-film transistor (OTFT), vapor deposition polymerization (VDP), adhesion layer.

1. Introduction

Al_2O_3 is a technologically important material due to its excellent dielectric properties, good adhesion to many surfaces, and thermal and chemical stability. These properties make Al_2O_3 attractive in the silicon microelectronics and thin film device industry as an insulator, ion barrier, and protective coating. Al_2O_3 is being considered as a high k material to replace SiO_2 in microelectronic devices such as DRAMs and MOSFETs[1, 2]. in this paper, nanoscale Al_2O_3 thin films were grown on non-oxidized silicon surface by sequential pulsed exposures to H_2O and trimethylaluminum (TMA), producing OH and Al-(CH_3) terminated surfaces, In this atomic layer deposition, the deposition rate was 1.7Å /cycle. respectively, it was demonstrated that the organic thin film transistors(OTFTs) can be fabricated by ALD processing on the gate insulators. Electron tunneling produces high leakage current and device instability at these low SiO_2 thicknesses [3]. Depositing such thin SiO_2 films uniformly and maintaining the insulating properties has also become increasingly difficult. In response to these problems, high k dielectric materials are currently being investigated to achieve higher capacitances with thicker films to minimize electron tunneling leakage currents.

2. Experimental

All our devices were fabricated on glass substrates using a staggered-inverted structure as shown in Figure 1. In this structure, Cr/Al as a gate electrode was thermally evaporated. Al_2O_3 thin films were grown on non-oxidized silicon surface by sequential pulsed exposures to H2O and trimethylaluminum (TMA), producing OH and Al-(CH3) terminated surfaces, In this atomic layer deposition, the deposition rate was 1.7Å/cycle. respectively, it was demonstrated that the organic thin film transistors (OTFTs) can be fabricated by ALD processing on the gate insulators. To improve the quality of the organic/dielectric surface, polyimide film using as adhesion layer on the Al_2O_3 was co-deposited by high-vacuum thermal-evaporation from 6FDA and ODA at 5×10^{-7} Torr with deposition rate of 4 Å/s, and cured at 150℃ for 1 hr followed by 200℃ for 1 hr in the vacuum oven at 5×10^{-3} Torr. They are characterized by the presence of the imide functionality, a cyclic tertiary amine bound by two carbonyl groups, and either an aliphatic or aromatic group in the main chain[4]. Pentacene as active layer was deposited by thermal evaporation at 7×10^{-7} Torr, deposition rate of 0.3 Å/s, and total thickness of 60 nm. During the deposition of pentacene, the substrates were held at room temperature. The devices were completed by thermal deposition of gold (Au) to form source and drain contacts through a shadow mask.

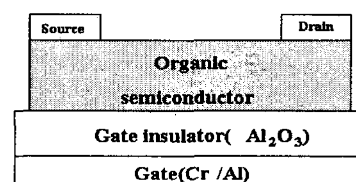
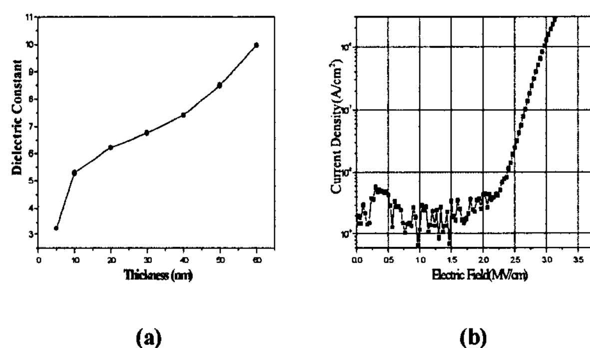


Fig. 1. The structure of OTFTs fabricated in this study.

3. Results and Discussion

The electrical properties of Al_2O_3 ALD films grown at 200 °C were investigated vs. film thickness. Al_2O_3 films grown on the moderately doped n-Si(100) substrates for thicknesses ranging from 50 to 600 Å. a decrease in current density with increasing film thickness. This decrease is consistent with decreased leakage and tunneling currents for larger film thicknesses. In addition, part of this decrease is also attributed to smaller charging currents associated with the smaller capacitances of the thicker films.

The dielectric constants of the Al_2O_3 ALD films were measured versus film thickness. Results are showed in Fig. 2.(a) for Al_2O_3 ALD films grown at 200 °C on moderately doped n-type Si(100), the measured dielectric constant was k~9, therefore 40nm thickness of Al_2O_3 used by the gate insulator layer, The current density was measured by dividing the measured current by the area of the electrode (0.00038 cm2). Fig. 2.(b) shows that the leakage current density was about 5×10^9 A/cm^2 at 2 MV/cm.



(a) (b)

Fig. 2. (a) Dielectric constants as a function of thickness in Al_2O_3 thin films. (b) Leakage current density of 40nm thickness in Al_2O_3.

As shown in Fig. 3.(a), the drain current also didn't flow in the channel and flow into gate dielectric because of the disordering pentacene molecules and the interstitial defects at the corner of Al_2O_3 and source electrode. However, the pentacene OTFTs show the typical p-type characteristics and good saturation behavior in the case of applying adhesion layers as shown in Fig. 3.(b). In the transfer characteristic curve shown in Fig. 3(c). we have performed an experimental and theoretical investigation of the grain size and the energy barrier dependence of the OTFTs electrical characteristics. The OTFT with top-contact configuration showed the typical accumulation enhancement mode and the transfer characteristic curve. We have obtained a mobility value of about 0.03 cm^2/Vs as saturation mobility. The on-off current ratio (Ion/off) is about 10^6 in a gate voltage span between 2 and -16V while the drain

4. Conclusions

we have demonstrated that the potential of using thin layers of Al_2O_3 as gateinsulators for organic semiconductors by preparing a high-performance device with low-voltage operation. We have also shown that Al_2O_3 gate insulators can be used to obtain pentacene thin-film-transistors with good electrical properties. We have obtained a The leakage current density was about 5×10^9 A/cm^2 and field effect mobility value of about 0.03 cm^2/Vs as saturation mobility. The on-off current ratio (Ion/off) is about 10^6 in a gate voltage sweep between 2 and -16 V while the drain voltage set at -10 V.

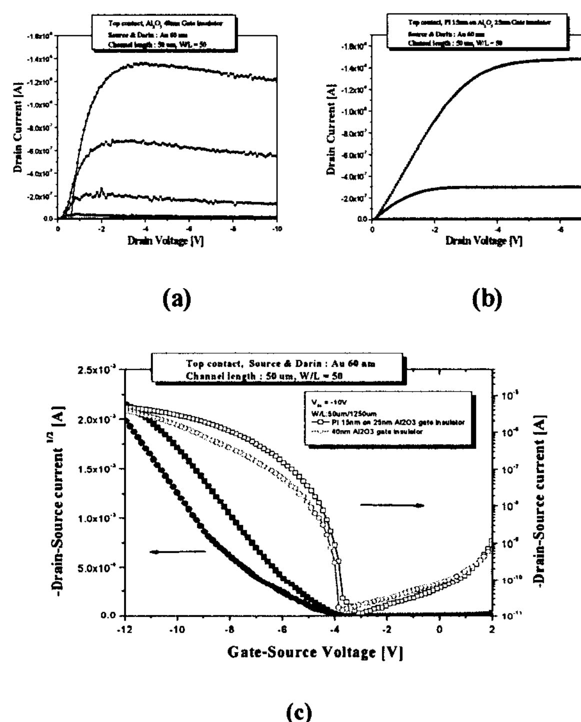


Fig. 3. (a) Output characteristic of OTFTs with Al_2O_3 gate insulator. (b) Output characteristic of OTFTs With polyimide adhesion layer. (c) Transfer characteristics of OTFTs.

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