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Fabrication of Sol-Gel Alumina Dielectric for Low-Voltage Operating Pentacene Transistor

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1. Introduction

Organic thin film transistors (OTFTs) have attracted much attention because of their large applications for flexible electronics and economical processibility. Wet device fabrication process, especially for organic transistors, is a major key process for low cost fabrication. Thus, spin-coatable polymer dielectrics have been extensively explored such as polymethyl methacrylate (PMMA) [1], polyvinylphenol (PVPh) [2], and others [3] in OTFTs. However, these polymer dielectrics have problems. Poor electrical characteristics, such as threshold voltage shift [4], hysteresis problem [5], and high operating voltage, are shown when polymer dielectrics are used. On the other hand, inorganic dielectrics of transistors are generally free from hysteresis problem.

To use a sol-gel material is a solution for taking advantage of the merits of both the inorganic dielectric and the solution processing. Sol-gel material is solution processible and can be an inorganic dielectric when it is sintered or cured. Such attempt and result were made with solution processible spin-on-glass (SOG) [6] and extended to photodefinable sol-gel material [7]. A sol-gel for barium-strontium-titanium oxide was recently used for pentacene TFTs [8]. The current leakage was relatively high though the dielectric constant was large.

In here, we use a sol-gel based alumina dielectric for OTFTs. The pentacene TFTs fabricated with the alumina dielectric allows OTFTs to operate at low voltage and is stable against the bias stress. The off-state current is also stable and it is insensitive to the off-state voltage.

2. Experimental

The alumina sol-gel film was prepared according to the early introduced method. Aluminum tri-sec-butoxide is utilized as a precursor and mixed with nitric acid and acetylacetone as catalyst and chelating agent, respectively [9, 10]. As shown in Fig. 1, bottom gate and top contact pentacene transistor was used. A flat glass is used as a substrate and aluminum gate electrode (70 nm thick) was defined by thermal evaporation through a shadow mask.

The alumina solution was prepared by the hydrolysis and it was spin-coated on the aluminum gate electrode at a speed of 1400 rpm for 30 s. It was heated for 30 mins at 80 ℃ and then annealed for 30 mins at 150 ℃ on a hot plate. For thicker alumina film, these coating and annealing process was repeated several times.

To decompose the organics for the alumina formation, the alumina film was cured at 400 ℃ for one hour. Pentacene (Aldrich, 97%) (100 nm thick) was thermally evaporated onto the dielectric layer as received in vacuum at a rate of 0.05 nm s^{-1}. The device fabrication was made by thermal evaporation of gold through a shadow mask to fabricate the source and drain electrodes (70 nm thick). The channel length and the width of electrode are 120 μm and 3 mm, respectively. Spin-coating and heating processes were done under air environment and the measurements of the completed devices were carried out in the argon-purged glove box.

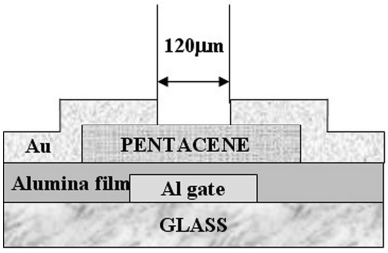

Fig. 1 Schematic illustration of the organic transistor with alumina dielectric

3. Results and Discussion

The current-voltage (I-V) characteristic curves of the devices for thin (33 nm) and thick (70 nm) alumina layer are shown in Fig. 2. The effective mobility, μ_{eff}, in the saturation region was calculated as follows;

$$\mu_{eff} = \frac{2I_d L}{CW(V_g - V_{th})^2} \qquad (1)$$

where W and L are the channel width and length, respectively. C is the insulator capacitance, I_d is the drain current density, V_g and V_{th} are the gate and threshold voltage, respectively.

The effective mobility in the saturation region of the device was calculated to be 5.0×10^{-3} cm^2 V^{-1} s^{-1} (Fig. 2(b) with 70 nm thickness of alumina). The threshold voltage is

-1.3 V and the saturated current at -3 V is 2.6×10^{-8} A. The on/off ratio was determined to be 3.1×10^{3}. The capacitance of the alumina film at the frequency of 100 kHz is 205 nF cm^{-2}. The subthreshold voltage is 150 mV $decade^{-1}$. As determined by ellipsometry, the thicknesses of alumina film for the devices in Fig. 2(a) and 2(b) were 33 nm and 70 nm, respectively. The leakage current density at the gate voltage of -3 V was 1.0×10^{-7} A cm^{-2} for six times coated alumina film and a smooth surface (0.6 nm of root-mean-square roughness) was measured by atomic force microscopy (AFM). There are no differences of output characteristic in the saturation region at the gate bias of -3 V between the devices with thin and thick alumina film. With the increase of the thickness of the dielectric layer, the current-voltage curves are stabilized and smooth curves are shown in the off-state current (Fig. 2).

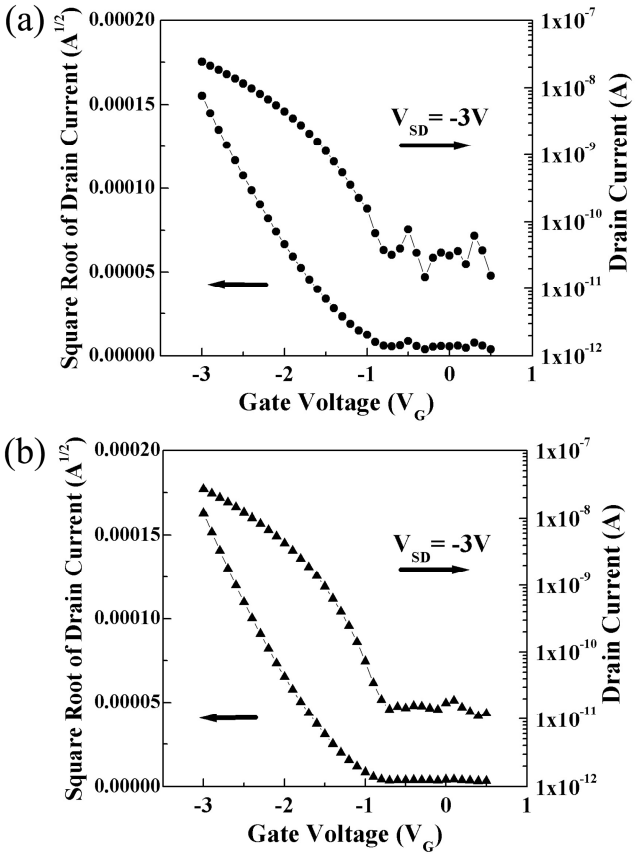

Fig. 2 Transfer characteristics of pentacene/alumina TFTs. (a) four times coated device (33 nm) (b) six times coated device (70 nm)

Inorganic dielectrics such as metal oxide and silicon nitride show less mobile impurities than organic dielectrics. For the result, the thin film transistor with inorganic dielectric shows more stable performances than the one with organic dielectric layer in hysteresis and threshold voltage shift. Although not shown in Fig. 2, the current output showed a little or no hysteresis.

It is not well known for organic TFT with sol-gel based alumina dielectric. Furthermore, we can compare the devices with the alumina dielectric film that is either formed by plasma oxidation [11] of aluminum or anodization [12]. The dielectric thicknesses of oxidized and anodized aluminum are 3.9 nm and 6.5 nm, respectively. Due to the thin dielectric, the OTFTs with these dielectrics show unstable off-state performance. However, spin-coating of sol-gel alumina precursor in this work allows to control the alumina film thickness and these dielectrics can be used to make stable low-voltage organic transistor.

4. Conclusions

In conclusion, a spin-coatable alumina dielectric based on a sol-gel process has been introduced. The alumina dielectric combines the merit of a polymer dielectric, which can be fabricated economically, and the merit of an inorganic dielectric, stable device. By using spin-coatable alumina dielectric, the low voltage pentacene thin film transistor is fabricated and thus fabricated device is free from the threshold voltage shift problems and the hysteresis. Furthermore, the dielectric thickness of the device can be easily controlled by multi-coating and the low voltage device can be fabricated insensitive in the off state voltage range.

Acknowledgements

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