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Contact resistance between pentacene and indium–tin oxide (ITO) electrode with surface treatment

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Abstract

Contact resistance between indium–tin oxide (ITO) electrode and pentacene was studied by transmission line method (TLM). Organic solvent cleaned, inorganic alkali cleaned, and self-assembled monolayer (with OTS: octadecyltrichlorosilane) modified ITO electrode structures were compared. Pentacene layer of 300 Å thickness was vacuum deposited on patterned ITO layer at 70 °C with a deposition rate of 0.3 Å/s. Alkali cleaned and SAM modified ITO gave a lower contact resistance of about $6.34 \times 10^4\ \Omega\,cm^2$ and $1.88 \times 10^3\ \Omega\,cm^2$, respectively than organic solvent cleaned ITO of about $6.58 \times 10^5\ \Omega\,cm^2$. Especially with the SAM treatment, the work function of ITO increased closer to the highest occupied molecular orbital (HOMO) level of pentacene, which lowers the injection barrier between ITO and pentacene. It was also believed that pentacene morphology was improved on SAM modified ITO surface due to the lowering of the surface energy. We could obtain the low contact resistance with SAM treatment which is comparable to the measured value of gold–pentacene contact, $1.86 \times 10^3\ \Omega\,cm^2$. This specific contact resistance is still much higher than that of amorphous silicon thin film transistor (0.1–30 $\Omega\,cm^2$).

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Keywords: Contact resistance; Organic thin film transistor; Pentacene; Indium–tin oxide; Work function

1. Introduction

For organic thin film transistors (OTFT), research effort has been focused on improving electrical properties of the semiconductor as well as the gate dielectric and conducting electrodes. The mobility of OTFT with pentacene was improved up to 1.5 cm^2/Vs and on/off ratio was also improved up to 10^5 [1,2]. Despite the considerable progress made in recent years to improve the performance of organic TFTs, many of the design, material, and process parameters are still poorly understood and poorly controlled. One such part is contact resistance between metal electrode and organic semiconductor. With decreasing device dimensions, the contact resistance as a part of the total device resistance will dominate compared with channel resistance and therefore will play an important part

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in device operations. Unlike in field effect transistors based on single-crystalline silicon, polycrystalline silicon, or hydrogenated amorphous silicon, the source and drain contacts in organic TFTs are not easily optimized by conventional processes, such as semiconductor doping or metal alloying. Consequently, the speed of organic integrated circuits may be limited by the contact resistance, not by the intrinsic carrier mobility of the organic semiconductor. Interface properties between electrode and semiconductor are critical factors for good TFT performance and work function modification of the metal surface to lower the barrier and removal of impurities such as native oxide have been studied to lower the contact resistance [3,4]. As a contact metal, gold, silver, calcium and palladium [2,5–7] were studied. It has been known that gold has a work function of 5.1 eV, which is close to the HOMO (highest occupied molecular orbital) level of pentacene, 5.2 eV. Thus the hole injection barrier is expected to be low for gold with pentacene. To date, gold showed best result but the material may not be preferred in real application due to the cost and patterning problem. On the other hand, ITO (indium–tin oxide) is widely used as a transparent conducting material in optical devices like organic light emitting diode and solar cell [8]. In this case, the contact property of ITO with organic layer is also a major concern for efficient carrier injection [9]. As is shown in Figs. 3 and 4, ITO has a work function of 4.5–4.7 eV and the barrier for hole injection to pentacene is higher than gold. To improve contact properties between organic semiconductors and metal electrodes, modification of the drain and source contacts with conductive polymer or charge transfer compounds was proposed [9,10]. Reduction of energy barrier at the electrode interface can be achieved in different ways. One approach is to increase the electrode work function by grafting a self-assembled monolayer (SAM) of molecules that possess a permanent dipole moment onto the ITO surface [7,8]. Enhancement of the carrier injection and the luminescence efficiency in optical device by SAMs was studied [8].

In this work, we measured the contact resistance between ITO and pentacene with TLM (transmission line method) for the first time and compared with gold contact metal. We tried organic solvent cleaned, inorganic alkali cleaned, and self-assembled monolayer (with OTS: octadecyltrichlorosilane) modified ITO electrode structures.

2. Experimental

Octadecyltrichlorosilane (OTS) and pentacene were purchased from Aldrich Chemical Co. and ITO (In_2O_3:SnO_2 = 90:10 wt%) coated glass was supplied by Samsung Corning Co. We used two different sets of processing techniques for treating the surface of the ITO substrates, before the deposition of pentacene active layer by evaporation, wet cleaning and self-assembled monolayer (OTS) deposition. Before the ITO surface treatment, ITO was patterned with photolithography and etching as shown in Fig. 1, with length (d) of 0.1 cm and width of 0.7 cm. For wet cleaning, we adopted two different processes. One is the ultrasonic degreasing where the substrate was washed in an ultrasonic bath of acetone for 30 min, followed by the IPA (isopropyl alcohol) washing for 30 min at room temperature. The other one is washing in a solution of NH_4OH (70 wt%), H_2O_2 (30 wt%) and distilled water in a ratio of 1:4:20 (RCA cleaning SC-1). The substrate was first dipped into the solution at 60 °C for 30 min, and then rinsed twice in distilled water. In order to eliminate the traces of water, we then rinsed in IPA and all substrates were then dried in a flow of nitrogen.

The SAM modified ITO substrates were prepared by the immersion of ITO-glass substrates in octadecyltrichlorosilane (OTS) solutions (concentration of

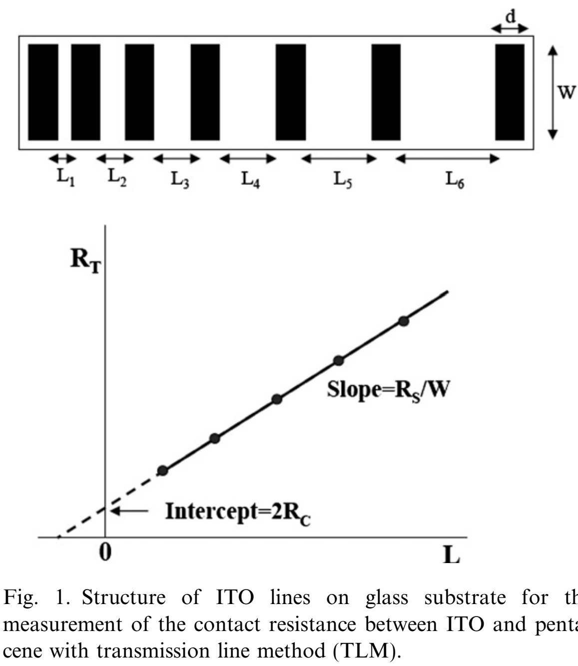

Fig. 1. Structure of ITO lines on glass substrate for the measurement of the contact resistance between ITO and pentacene with transmission line method (TLM).