

Reduction of the contact resistance in copper phthalocyanine thin film transistor with UV/ozone treated Au electrodes

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ABSTRACT

Bottom-contact (BC) copper phthalocyanine (CuPc) thin film transistor with UV/ozone treated Au as a source/drain electrode was fabricated and the contact resistance was estimated from the transmission line method (TLM). Comparing the properties of OTFT with untreated Au electrode, the performance of the BC CuPc-TFT with the UV/ozone treated Au electrodes was significantly improved: saturation mobility increased from 4.69×10^{-3} to 2.37×10^{-2} cm²/V s, threshold voltage reduced from -29.1 to -6.4 V, and threshold swing varied from 5.08 to 2.25 V/decade. The contact resistance of the device with UV/ozone treated Au electrodes was nearly 20 times smaller than that of the device with untreated Au electrodes at the gate voltage of -20 V. This result indicated that using the UV/ozone treated Au electrode is an effective method to reduce the contact resistance. The present BC configuration with UV/ozone treated Au electrodes could be a significant step towards the commercialization of OTFT technology.

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1. Introduction

Organic thin film transistors (OTFTs) have attracted considerable attention over the last few decades because of their potential applications in integrated circuits for flexible and ultra-low-cost electronics such as radio frequency identification tags and organic active matrix displays [1–5]. Some studies on OTFTs have made it possible to achieve high performance comparable to those of amorphous silicon (a-Si) TFT [6,7].

Large contact resistance in OTFTs is one of the serious problems for practical application. Recently, some works were done to reduce contact resistance by modifying the source/drain electrodes with thin organic (e.g., tetrafluorotetracyanoquinodimethane (F₄-TCNQ) [8] and 4,4',4''-tris{N-(3-methylphenyl)-N-phenylamino}—Triphenylamine (*m*-MTDATA) [9]) and inorganic material (e.g., MoO₃ [10], FeCl₃ [11]). However, some of the doping materials show problems such as high temperature for evaporation and cross-contamination during evaporation. Cross-contamination is quite fatal to the stability of devices. UV/ozone treatment of Au electrodes can effectively avoid above-

mentioned problems. It has been shown that a thin AuO_x layer was formed by UV/ozone treatment and surface work function of UV/ozone treated Au is increased from 4.7 eV to 5.5 eV compared to air-exposed Au [12]. B. Stadlober et al. [13] have reported that UV/ozone treated Au as S/D electrode can effectively reduce the contact resistance of OTFTs based on pentacene as semiconductor. It is well known that copper phthalocyanine (CuPc) is an important semiconductor material. Low field-effect mobilities of CuPc-TFTs have limited the application. It is interesting that UV/ozone treated Au electrode will be applied to reduce the contact resistance of CuPc-TFTs and enhance the performance of CuPc-TFTs. In addition, most research is focused on top-contact (TC) configurations, less attention is paid to bottom-contact (BC) configurations. Moreover, organic active materials are sensitive to solvents and chemicals, so shadow-mask evaporation is usually used to form S/D electrodes in TC configurations. Such a process, however, is incompatible with large scale integration. Compared with OTFTs with TC structure, OTFTs with BC structure are easily to fabricate using photolithography to define source and drain contacts since depositing the active organic material onto patterned source/drain (S/D) electrodes can avoid or minimize exposure to solvents and chemicals. It is therefore desirable to use a BC configuration, which is compatible with fine lithography processing, for promising applications such as large scale flexible displays.

In this paper, we successfully fabricated BC copper phthalocyanine (CuPc) OTFTs with UV/ozone treated Au as source/drain

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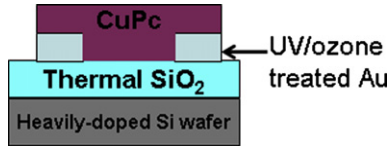


Fig. 1. Schematic cross section of bottom-contact CuPc-TFT with UV/ozone treated Au as source/drain electrodes.

electrodes and compared the electrical properties with that without treated Au electrodes. We found that the performance of devices with UV/ozone treated Au are considerably enhanced and contact resistance is significantly reduced.

2. Experimental details

A cross section of the BC CuPc-TFT is shown schematically in Fig. 1. The devices were fabricated using heavily-doped *p*-type silicon wafers with a 300-nm-thick SiO₂, working as the gate electrode and gate insulator, respectively. Prior to deposition, the wafers were cleaned with acetone, methanol, and de-ionized water in that order. A 50 nm Au (exposed to air) was thermally evaporated as the source and drain electrodes through a metal mask with the same channel width ($W = 2$ mm) and channel lengths (L) in the range of 50–250 μm . Then, 2 h UV/ozone treatment of Au was accomplished using a low-pressure mercury Pen-Ray lamp (UVP, Inc.) under ambient conditions. Finally, a 40 nm CuPc thin film as channel layer was deposited by deposition rate of ~ 0.5 $\text{\AA}/\text{s}$ under a pressure of 10^{-6} Torr.

The current–voltage characteristics of the devices were measured using Agilent E3647A Dual output DC power supply and Keithley 6485 Picoammeter as well as corresponding software. The capacitance measurements were conducted with a HP 4284A Precision LCR meter. All measurements were carried out under dark conditions and at ambient temperature.

3. Results and discussion

Fig. 2(a) and (b) show the source-drain current (I_D) versus source-drain voltage (V_{DS}) of the OTFTs with Au and UV/ozone treated Au as the source and drain electrodes, respectively. The saturation current of the device with UV/ozone treated Au electrode attained a value of -6.8 μA at $V_{GS} = -60$ V, which is much larger as compared with the device with untreated Au electrodes. The transfer characteristic of the devices with Au and UV/ozone treated Au as S/D electrodes measured at the saturation region with $V_{DS} = -60$ V are shown in Fig. 3(a) and (b), respectively. The saturation mobility (μ) of these devices were calculated at the saturation region from the following equation:

$$I_{DS} = \frac{W}{2L} \mu C_i [(V_{GS} - V_{th})^2], \quad (1)$$

Where I_{DS} is the drain-source current, W is the width of channel, L is the length of channel, C_i is the capacitance per unit area of the insulator layer ($C_i = 10.0$ nF/cm²), V_{GS} is the gate voltage and V_{th} is the threshold voltage. For the device with untreated Au electrodes, the saturation mobility and the threshold voltage are 4.69×10^{-3} cm²/V s and -29.1 V, respectively. However, the saturation mobility is improved to 2.37×10^{-2} cm²/V s and the threshold voltage is reduced to -6.4 V for the device with UV/ozone treated Au electrodes. It can be easily seen that the improvement is attributed to the reduction of contact resistance for device with UV/ozone treated Au electrodes. More details are discussed in the later.

The gate voltage swing (S), defined as the voltage required to increase the drain current by a factor of 10, is given by

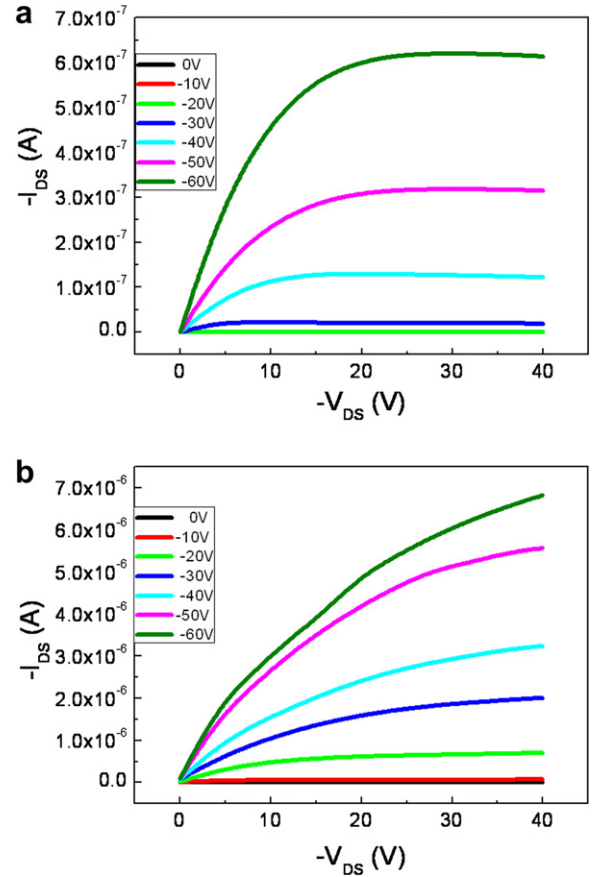


Fig. 2. I_{DS} versus V_{DS} curves for BC CuPc-TFTs with (a) untreated Au electrodes and (b) UV/ozone treated Au electrodes.

$$S = \frac{dV_{GS}}{d(\log I_{DS})}, \quad (2)$$

S is given by the maximum slope in the transfer curve. From the Eq. (2), the gate voltage swing for device without and with UV/ozone treated Au electrodes are 5.08 and 2.25 V/decade, respectively. The gate voltage swing can also be expressed as [14]: $S \approx (kT/q) \ln 10 (1 + ((C_{int} + C_{it} + C_D)/C_{ox}))$, where C_{int} , C_{it} and C_D are the capacitances due to the contact interface, the semiconductor/insulator interface and the semiconductor depletion layer, respectively. k is the Boltzmann constant, and T is temperature. A thin AuO_x layer was presented after the UV/ozone treatment of Au [12], which narrows the energy difference between Femi energy of Au and the highest occupied molecular orbit (HOMO) of CuPc, resulting in a reduction in C_{int} . The lower gate voltage swing is therefore produced by the reduction in C_{int} .

The transmission line method is a standard approach for the extraction of the contact resistance of transistor by fitting the total resistance (R_{tot}) as a function of the channel length (L). In the linear region of operation, it can be assumed that the total resistance is a series connection of the channel resistance (R_{ch}) and the contact resistance (R_C). Assuming that the contact resistance is independent of L , R_{tot} can be defined as [15]:

$$R_{tot} = \left. \frac{\partial V_{DS}}{\partial I_{DS}} \right|_{V_{DS} \rightarrow 0}^{V_{GS}} = R_{ch} + R_S + R_D \approx \frac{L}{W \mu_{ch} C_i (V_{GS} - V_{TI})} + R_C, \quad (3)$$

Where $R_C = R_S + R_D$, μ_{ch} and V_{TI} are intrinsic mobility and intrinsic threshold voltage of CuPc-TFTs, respectively. Eq. (3) shows that the

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