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Influence of molybdenum source/drain electrode contact resistance in amorphous zinc–tin-oxide (*a*-ZTO) thin film transistors

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ABSTRACT

This paper investigates the feasibility of a low-resistivity electrode material (Mo) for source/drain (S/D) electrodes in thin film transistors (TFTs). The effective resistances between Mo source/drain electrodes and amorphous zinc–tin-oxide (*a*-ZTO) thin film transistors were studied. Intrinsic TFT parameters were calculated by the transmission line method (TLM) using a series of TFTs with different channel lengths measured at a low source/drain voltage. The TFTs fabricated with Mo source/drain electrodes showed good transfer characteristics with a field-effect mobility of 10.23 $cm^2/V s$. In spite of slight current crowding effects, the Mo source/drain electrodes showed good output characteristics with a steep rise in the low drain-to-source voltage (V_{DS}) region.

1. Introduction

Since the report by Nomura et al. [1], thin film transistors (TFTs) based on amorphous oxide semiconductors (AOSs) have emerged as a promising technology in several fields. The AOSs are particularly suitable for active-matrix TFT-based backplanes due to their superior electrical performance when compared with conventional amorphous silicon and polycrystalline silicon TFTs. Several groups have demonstrated various AOSs with a $(n-1)d^{10}ns^0$ $(n \geq 5)$ electronic configuration consisting of heavy-metal cations [2] such as indium–zinc-oxide (*a*-IZO) [3,4], indium–gallium–zinc-oxide (*a*-IGZO) [5–8], and zinc–tin-oxide (*a*-ZTO) [9,10]. Among the various AOSs, amorphous indium–gallium–zinc-oxide (*a*-IGZO) TFTs have high field-effect mobilities exceeding that of *a*-Si by a factor of 10^2, a small subthreshold swing, good uniformity attributed to the amorphous structure, a low off current, good stability under electrical stress, and can be processed at low temperatures. However, materials such as indium (In) and gallium (Ga) have some disadvantages, including toxicity, scarcity, and indium extraction in hydrogen plasma [11]. Therefore, there is a need for In-free and Ga-free oxide semiconductors that are inexpensive and non-toxic. Amorphous zinctin-oxide (*a*-ZTO) is regarded as one of the most promising alternative materials for IGZO, as it is inexpensive, non-toxic, exhibits physical robustness, and has a very smooth surface [12–14]. Several research groups have already reported *a*-ZTO-based working devices with remarkable electrical and optical properties. We have recently demonstrated high-performance *a*-ZTO TFTs that exhibit a field effect mobility of μ_{FE} of 14.33 $cm^2/V s$, a subthreshold swing SS of 0.6 V/decade, and an on and off current ratio of I_{ON}/I_{OFF} of 10^9 [15].

Despite recent successes, some outstanding issues related to AOSs electrical performance still remain to be resolved, such as obtaining good electrical contacts between the source/drain (S/D) electrodes. A previous report [6] on the contact resistance of candidate metal electrodes and *a*-IGZO showed that contact resistance decreases with the work function of the metallic electrode. High work function electrodes showed Schottky contacts, while reactive electrodes demonstrated ohmic contacts. However, using reactive metals for an electrical contact requires high process reproducibility.

In this work, we investigate Mo electrodes with the aim of obtaining good contact characteristics in *a*-ZTO-based TFTs. Specifically, we discuss the S/D series resistance and the effects on TFT performance. The TFT S/D series resistance, the intrinsic field effect mobility $\mu_{FE\text{-}i}$, the transfer length L_T, and the effective contact resistance $R_{C\text{-}eff}$ were extracted by the well-known transmission line method (TLM) using a series of TFTs with different channel lengths.

2. Experimental details

Fig. 1 shows a schematic cross-section of a bottom-gate-type *a*-ZTO TFT with staggered structure. Highly doped n-type silicon wafers with a thermally oxidized SiO_2 layer of 100 nm were used.

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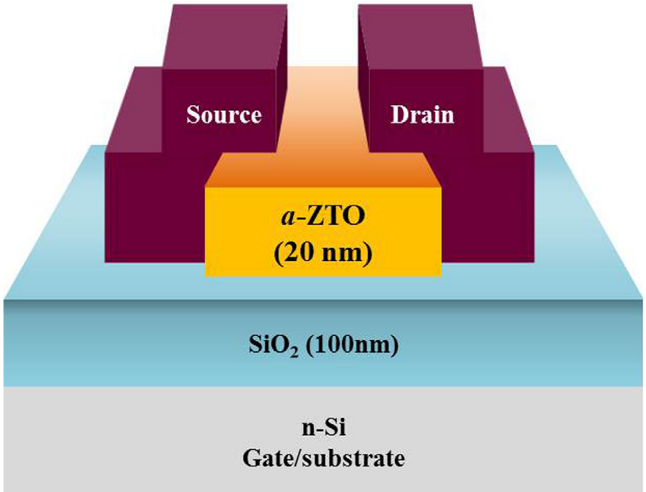

Fig. 1. Schematic cross-section of a bottom-gate-type *a*-ZTO TFT with a staggered structure.

Before depositing the ZTO channel layer, the SiO_2/n-Si substrates were cleaned ultrasonically in acetone and methanol for 10 min each followed by a 10 min rinse in deionized water. Thin films of *a*-ZTO (20 nm thick) were deposited using direct current (DC) magnetron sputtering. The atomic ratio of Zn and Sn in the ZTO targets was maintained at 3:1. Sputtering was performed at room temperature in an argon atmosphere with an oxygen partial pressure of 10%. A 4 in. diameter target was placed 4 cm from the substrate, with a base pressure of 2.7×10^{-4} Pa, a working pressure ($Ar + O_2$) of 6.6×10^{-1} Pa, and a plasma discharge power density of 0.5 W/cm^2. After channel layer deposition, the devices were subjected to thermal annealing at 400 °C for 1 h in ambient air. After annealing the ZTO channel layer, Mo and ITO electrodes were used for the source and drain electrodes, and these were deposited by DC magnetron sputtering at room temperature.

The channel layer and S/D electrodes were defined using a lift off process, and the resulting transistors had a fixed width (W) of 100 μm, whereas the channel length (L) varied from 10 to 50 μm. All electrical characterizations were conducted with a semiconductor parameter analyzer (Agilent HP 4145B) at room temperature in the dark without a passivation layer.

3. Results and discussion

The transfer characteristics and field effect mobilities of *a*-ZTO-based TFT with ITO and Mo electrodes are shown in Fig. 2 for devices with L = 40 μm and W = 100 μm, which were measured at drain-to-source voltages, V_{DS}, of 10 V. The TFTs with ITO and Mo electrodes showed an SS factor of 0.5 and 0.9 V/decade, a turn-on voltage V_{ON} of 0.5 and 1.5 V, and I_{ON}/I_{OFF} of about 10^7 and 10^8 at V_{DS} = 10 V, respectively. Fig. 2 also shows the extraction of the linear mobility from the linear region for the ITO and Mo electrode, which were 4.02 and 10.23 cm^2/V s, respectively. Because Mo has a much lower resistivity ($4.85 \times 10^{-6}\,\Omega$ cm) than that of ITO ($\approx 10^{-4}\,\Omega$ cm [16]), Mo-contact TFT mobilities are larger than that of ITO-contact TFTs.

Fig. 3 shows the output characteristics of a TFT with Mo S/D electrodes and their differentials. The TFT showed excellent drain current characteristics with a steep rise in the low V_{DS} region. The differential conductance decreased linearly with V_{DS}, showing a little current crowding. This behavior is known to be due to the nonohmic contact between the S/D electrodes and the channel. In the TFTs, Mo thin films with a work function (Φ_{Mo}) of ~4.57 eV were used as the S/D electrodes, while the ZTO channel layer had a

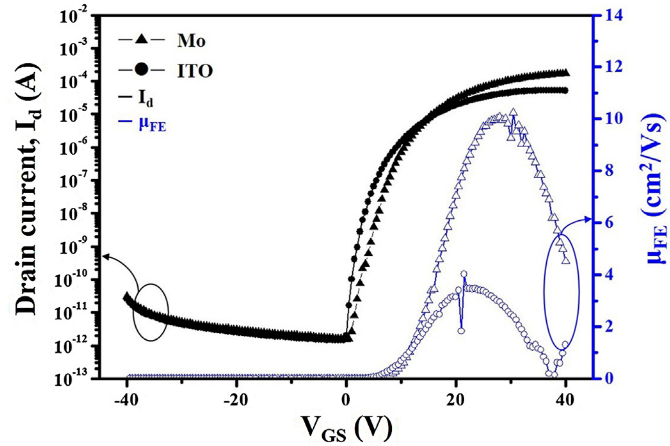

Fig. 2. Transfer characteristics and field effect mobility extracted from the transconductance of *a*-ZTO TFTs with Mo and ITO S/D electrodes. Devices with W/L = 100/40 μm and V_{DS} = 10 V.

work function (Φ_{ZTO}) of ~4.35 eV [17], and thus, nonohmic contact may be involved.

To evaluate the intrinsic properties of *a*-ZTO using a Mo electrode, the contact resistances were extracted. For a low V_{DS}, the total TFT ON resistance (R_T) can be expressed as

$$R_T = \frac{V_{DS}}{I_{DS}} = r_{ch}L + R_{S/D} (= R_S + R_D) \quad (1)$$

where r_{ch} is the channel resistance per channel length unit, $R_{S/D}$ is the total source/drain resistance, and R_S and R_D are the source and drain resistances, respectively. Using the basic transistor equation from the gradual channel approximation, we can express the channel resistance as a function of the intrinsic field effect mobility $\mu_{FE\text{-}i}$ and the intrinsic threshold voltage $V_{th\text{-}i}$, and thus, represent the conduction channel material without the influence of the contact series resistance as

$$r_{ch} = \frac{1}{\mu_{FE-i} C_{OX} W (V_{GS} - V_{th-i})}. \quad (2)$$

As illustrated in Fig. 4, R_T was plotted as a function of channel length for different V_{GS}, and the experimental values were fitted with linear curves for each V_{GS}. This allowed us to obtain the TFT total series resistance ($R_S + R_D$) from the intercept with the *y*-axis and r_{ch} from the slope. When the reciprocal of r_{ch} is plotted as a

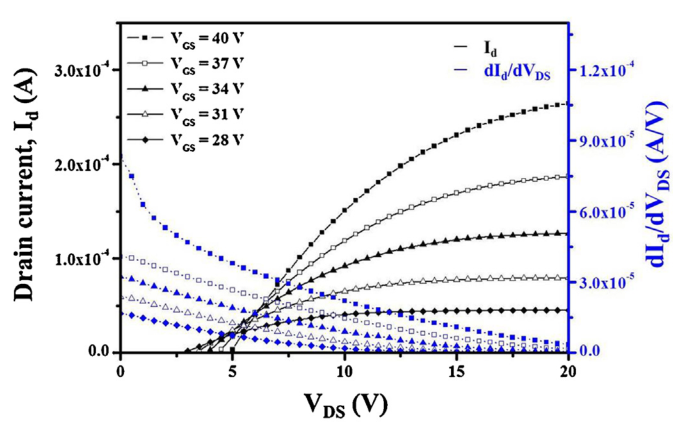

Fig. 3. Output characteristics and corresponding differential conductance.