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Electrode metal penetration of amorphous indium gallium zinc oxide semiconductor thin film transistors

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ABSTRACT

Penetration effects of various electrode materials, namely Al, Au, and Cu, on the physical and electrical characteristics of amorphous oxide semiconductor thin film transistors (TFTs) were investigated. Amorphous indium gallium zinc oxide (a-IGZO) TFTs were fabricated with conventional staggered bottom gate structures on a p-type Si substrate. X-ray photoemission spectroscopy (XPS) analysis under the electrode deposition area revealed variations in the oxygen bonding states and material compositions of the a-IGZO layer. Field-emission scanning electron microscopy (FE-SEM) with the line scan of energy dispersive spectroscopy (EDS) showed lateral penetration by the electrode metal. To compare the electrical characteristics of the tested TFTs, the initial current–voltage (I–V) transfer characteristics were examined. In addition, the tested TFTs fabricated using various electrode materials were tested under bias stress to verify the correlations between variations in TFT characteristics and both the metal work function and penetration-induced oxygen vacancies in the channel around the contact area.
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1. Introduction

Amorphous InGaZnO (a-IGZO) thin-film transistors (TFTs) have attracted interest for use in next-generation display devices because of their high mobility, good uniformity, and flexible and transparent characteristics [1,2]. Despite recent successes [3], however, some issues still need to be overcome. One of these issues is the influence of the source and drain electrode materials on resistance, contact area, and parasitic capacitance [4]. Although Cu has been studied as an electrode material to reduce the RC delay because of its low sheet resistance, it has not been used in the mass production of active matrix liquid crystal displays (AMLCDs) or active matrix organic light emitting diodes (AMOLEDs). In a previous study, the effect of incorporating Cu to reduce the sheet resistance of metal was investigated [5], because the electrical properties of a-IGZO TFTs are dependent on the electrode material. However, the effects of metal penetration by various electrode materials, which can impact TFT characteristics, have not previously been reported. Therefore, in this paper, we analyze the effect of the lateral and vertical metal penetration around electrodes using X-ray photoemission spectroscopy (XPS) and energy dispersive spectroscopy (EDS). In addition, the results can be verified using the positive gate/drain bias stress test by monitoring the drain current.

2. Experiments

In this work, a-IGZO TFT test structures with a conventional staggered bottom gate on p-type Si substrate were fabricated as shown in Fig. 1. The doping concentration of the Si substrate used in the gate was 8.0×10^{19} cm^{-3} and the resistivity was 1.0×10^{-3} Ω cm. The SiO_2 gate insulating layer was deposited with a thickness of 300 nm using thermal oxidation. The a-IGZO channel layer was deposited by RF sputtering on a SiO_2/p-Si substrate at a RF power of 150 W at room temperature and O_2/Ar gas flow of 5/45 sccm at a working pressure of 5×10^{-3} Torr for 6 min. Source and drain electrodes with a thickness of 100 nm were deposited by shadow mask using thermal evaporation at room temperature at a working pressure of 5×10^{-6} Torr. Source and drain electrode materials with a fixed channel width (W) of 1000 μm and channel length (L) of 200 μm were fabricated using three types of metals (Al, Au, and Cu). The transfer characteristics and stress instability of the a-IGZO TFTs were measured using a Keithley 236 source measurement unit (SMU) at room temperature. The oxygen contents of a-IGZO TFTs

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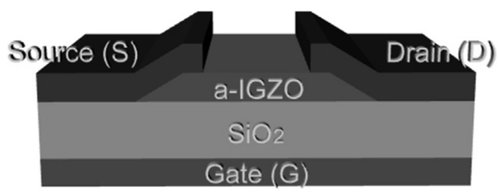

Fig. 1. Schematic diagram of a-IGZO TFTs.

were analyzed by X-ray photoemission spectroscopy (XPS; Thermo VG, U.K.) with Ar ion etching (ion beam: 1 kV, 2.0 μA) using a filtered Al X-ray source ($h\nu = 1486.6$ eV). Here, the spectrometer was calibrated by the photoemission line of Si. The chemical composition of a-IGZO TFTs was also analyzed by the line scan of energy dispersive spectroscopy (EDS) using a field-emission scanning electron microscope (SEM; JEOL-7001F) with a Schottky-type field-emission gun.

3. Results and discussion

Fig. 2 shows the transfer characteristics of a-IGZO TFTs with Al, Au, or Cu source and drain electrodes. Parameters used to assess the performance of TFTs are the threshold voltage (V_{th}), field effect mobility (μ_{FE}), and subthreshold gate swing (S_{SUB}). V_{th} is determined by the gate voltage (V_{GS}), which is defined as the value when the drain current (I_D) is 10 nAxL/W at a drain voltage (V_{DS}) of 5.1 V. Because the threshold voltages for the Al, Au, and Cu cases were different, the applied V_{GS} was determined differently for the same ($V_{GS} - V_{th}$) sweep range, i.e., −30 V–30 V. Field effect mobility (μ_{FE}) was determined by

$$\mu_{FE} = \frac{G_m}{\left(\frac{W}{L}\right) C_i V_{DS}} \quad (1)$$

where G_m and C_i are the transconductance and gate capacitance per unit area, respectively [6]. The subthreshold gate swing (S_{SUB}) was determined by

$$S_{SUB} = \frac{dV_{GS}}{d(\log I_D)} \quad (2)$$

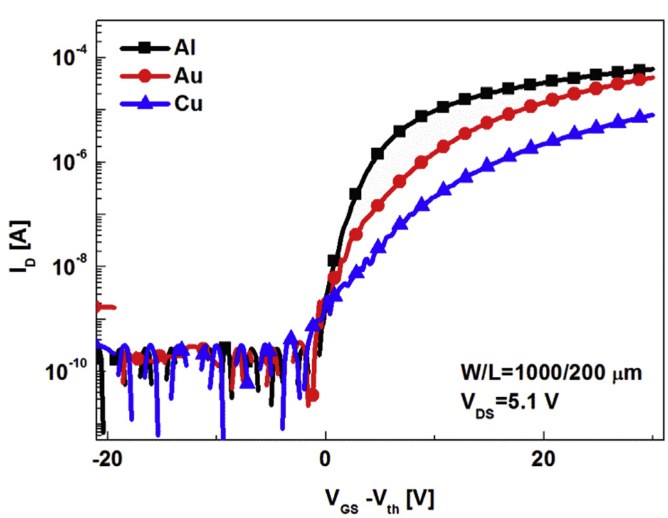

Fig. 2. Transfer characteristics (W/L = 1000/200 μm, V_{DS} = 5.1 V) of the tested a-IGZO TFTs.

Table 1
Comparison of various parameters of a-IGZO TFTs fabricated with three electrode materials. (W/L = 1000/200 μm, V_{DS} = 5.1 V).

Parameters	Type of metal electrode		
	Al	Au	Cu
V_{th} [V]	−0.8	8.2	12
u_{FE} [cm^2/V s]	8.5	6.7	1.3
S_{SUB} [V/dec]	0.73	1.19	2.32

The electrical properties of the a-IGZO TFTs with different source and drain electrodes are summarized in Table 1. TFT performance was better when S_{SUB} was smaller and μ_{FE} was larger. Thus, Al exhibited better performance than Cu and Au.

Previous studies reported that the TFT characteristics of a-IGZO were related to the work functions of the source and drain metal electrodes [2,5]. As shown in Fig. 2, the TFT with an Al electrode had the highest I_D due to the lowest work function. The work function of the Au electrode was higher than that of the Cu electrode; however, the Au electrode had a higher I_D than the Cu electrode. It was previously reported that the metal work functions of Al, Au, and Cu are 4.06–4.26 eV, 5.1–5.47 eV and 4.53–5.1 eV, respectively. In other words, it is found that the work function of Al is much smaller than the work functions of Au and Cu and the work function of Au is slightly larger than the work function of Cu. Thus, in order to analyze the relationship between the work function and device characteristics of Au and Cu, we performed additional physical experimental analysis of the metal contact.

At first, XPS results for the electrode materials were analyzed to examine the physical characteristics. XPS spectra of the O 1s peak in the a-IGZO active area under the contact area with the electrodes

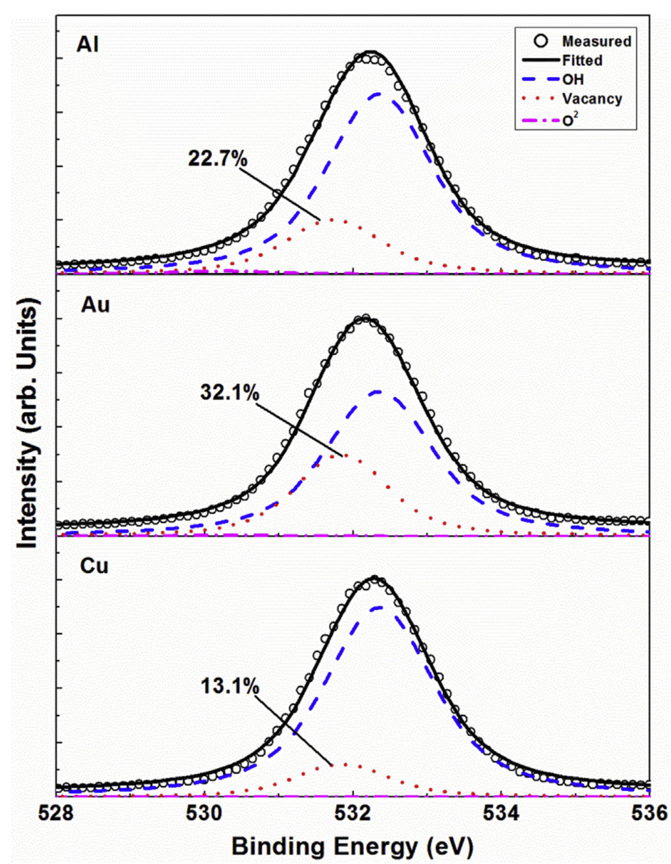

Fig. 3. XPS curve-fits of the O 1s peak of a-IGZO film under the contact area.

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