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Feasibility of ZnO:Al/Ag/ZnO:Al multilayer source/drain electrode to achieve fully transparent HfInZnO thin film transistor

Jun Li [a,b], Jian-Hua Zhang [b,*], Xue-Yin Jiang [a], Zhi-Lin Zhang [a,b]

[a] School of Material Science and Engineering, Shanghai University, Jiading, Shanghai 201800, PR China
[b] Key Laboratory of Advanced Display and System Applications, Ministry of Education, Shanghai University, Shanghai 200072, PR China

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ABSTRACT

We fabricated fully transparent hafnium indium zinc oxide (HfInZnO) thin film transistors (TFTs) with ZnO:Al(AZO)/Ag/ZnO:Al multilayer source/drain (S/D) electrodes. The effect of Ag interlayer thickness on the electrical and optical properties of AZO(60 nm)/Ag/AZO(60 nm) multilayer films was investigated. The AZO(60 nm)/Ag(10 nm)/AZO(60 nm) multilayer film shows a low sheet resistance of 10.5 Ω/square and a transmittance of 87%. Compared with HfInZnO-TFT with AZO electrode, the performance of the device with AZO/Ag/AZO multilayer electrode was significantly improved. The field effect mobility increased from 3.2 to 5.8 cm^2/V s, and the threshold voltage reduced from 2.3 to 0.1 V. The improvement was attributed to the lower resistivity of AZO/Ag/AZO multilayer film. The result indicates that AZO/Ag/AZO multilayer electrode is a promising S/D electrode for fully transparent HfInZnO-TFTs.

1. Introduction

Fully transparent displays have attracted increasing attention for the vision of science fiction movies and head-mounted displays. Realization of fully transparent active-matrix displays requires both transparent light-emitting devices and transparent thin film transistors (TFTs). Transparent metal oxide (ZnO, InGaZnO) thin film transistors have been extensively studied as a driving device for active-matrix organic light-emitting diodes, liquid crystal displays, and transparent displays because of its high mobility and excellent optical transmission [1–3].

In order to fabricate fully transparent TFTs with better electrical performance, it is essential to obtain the source/drain (S/D) electrodes with a low resistivity and a high transparency. Conventional transparent S/D electrodes such as indium tin oxide (ITO), gallium zinc oxide, and indium zinc oxide have been reported for fabricating InGaZnO-TFTs [4–6]. However, the electrical properties of InGaZnO-TFTs with conventional transparent S/D electrodes are obviously inferior to that with metal S/D electrodes (Cu [7,8], Ni/Au [9], Al [10], Mo [11]). The major reason is that the electrical resistivity of conventional transparent electrodes is much higher than that of metal electrodes. To realize the S/D electrode with the high transparency and low resistance, a sandwich structure electrode (metal oxide/metal/metal oxide) was proposed to effectively solve the contradiction between transparency and resistivity.

Hafnium indium zinc oxide (HfInZnO) semiconductor is currently considered to be one of the most promising channel materials for thin film transistors. It has excellent characteristics such as high mobility, low-temperature process, good uniformity, and excellent bias-stress stability [12–13]. Most of works have focused on the InGaZnO semiconductor, less attention is paid to the HfInZnO active layer. In addition, silver is a metal which is widely used in low emissivity (low-e) coatings. A continuous layer of silver has low absorption and very good electrical conductivity. In present work, HfInZnO-TFT with AZO/Ag/AZO multilayer film as S/D electrode was firstly fabricated and investigated. Compared with HfInZnO-TFT with AZO electrode, the electrical properties of HfInZnO-TFT with AZO/Ag/AZO multilayer S/D electrode were significantly improved. The purpose of the work is to demonstrate the feasibility of using AZO/Ag/AZO multilayer film as the S/D electrode in fully transparent HfInZnO-TFT.

2. Experimental details

Two configurations of the bottom gate thin film transistors with AZO source/drain electrode and AZO/Ag/AZO multilayer source/drain electrode were fabricated as Fig. 1(a and b), respectively. Both devices were deposited on indium tin oxide (ITO)-coated glass substrates. ITO glass substrates were cleaned in an ultrasonic bath with acetone, methanol, and de-ionized water, respectively. 250 nm AlO_x thin film was deposited on ITO glass substrates by 150 W radiofrequency (rf) sputtering of Al_2O_3 target (~99.999%) at room temperature. 40 nm of HfInZnO was deposited at room temperature via radiofrequency (rf) magnetron sputtering

* Corresponding author.
E-mail address: jhzhang@staff.shu.edu.cn (J.-H. Zhang).

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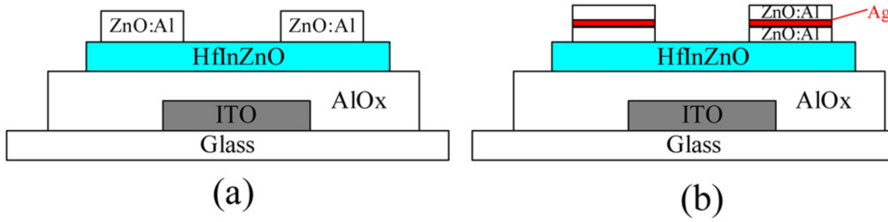

Fig. 1. The schematic cross-sectional configuration of bottom gate HfInZnO-TFT with (a) AZO source/drain electrode and (b) AZO/Ag/AZO multilayer source/drain electrode.

to form the active layer. The sputtering was carried out in an argon (Ar) atmosphere at 1.2 Pa and a power of 50 W using a ceramic HfInZnO target (In_2O_3:HfO_2:ZnO = 1:1:1 mol%). The growth rate of HfInZnO film was about 0.15 nm/s. For the device with AZO source/drain electrode (called "device A"), AZO electrode was prepared using magnetron sputtering system at room temperature under optimized growth conditions. A sintered ceramic target with a mixture of ZnO (purity: 99.9%) and Al_2O_3 (purity: 99.99%) was used as source material. The content of Al_2O_3 added to the ZnO target was 3 wt%. The pressure of Ar was maintained at 1 Pa, and the forward power was 100 W. The growth rate of AZO film was about 0.1 nm/s and the thickness of AZO film was 120 nm. Ag film was sputtered by high pure Ag target (99.999% purity) using a forward power of 30 W. The growth rate of Ag films was 0.05 nm/s in this condition. The thicknesses of Ag films were controlled by the deposition time. The distance between the target and the substrate was about 9.5 cm. For the device with AZO/Ag/AZO multilayer source/drain electrode (called device B), the bottom AZO, Ag, and top AZO layers were continuously sputtered. The growth condition is same as above. The thickness of bottom and top AZO layers are both 60 nm.

The optical transparency of the AZO and AZO/Ag/AZO multilayer films was examined using a UV/visible spectrometer. The current–voltage characteristics of the devices were measured using an Agilent E3647A Dual-output DC power supply and a Keithley 6485 Picoammeter. The capacitance measurements were conducted with an HP 4284A Precision LCR meter. The film thickness was determined by a surface profiler (Alpha-Step IQ). All measurements were carried out in air ambiance at room temperature.

3. Results and discussion

For AZO/Ag/AZO multilayer source/drain electrode, an ultimate goal is to gain the multilayer film having lower sheet resistances and higher transmission. Ag film is a good conductor, and the sheet resistance of AZO film is much higher than that of Ag film. It is known that the sheet resistance of the multilayer film is mainly effected by the electrical properties of Ag film. So optimizing the thickness of Ag film is very important for obtaining a multilayer film with low resistivity and high transmission. To study the influence of Ag interlayer on optical and electrical properties of multilayer electrode, we fabricated a series of AZO/Ag/AZO multilayer electrodes with Ag layer thickness from 7 to 15 nm. The AZO/Ag/AZO thin films were deposited on glass substrate (corning eagle 2000 glass). To investigate the true transmittance of AZO/Ag/AZO multilayer, the transmittance measurements are calibrated using bare glass substrate. The transmittance spectra as a function of wavelength in the range of 300–800 nm for multilayer with different thickness of Ag layers are shown in Fig. 2. The transmittance of 120 nm AZO film is greater than 80% over the entire range of visible-light wavelength region and have a peak near 420 nm. When Ag film is inserted into the AZO layer, the average transmittance of multilayer electrode reduces slightly with increasing the thickness of Ag film. When the thickness of Ag film is 10 nm, the transmission peak reaches a maximum value of 87% at the wavelength of 553 nm.

Fig. 3 shows the dependence of sheet resistance of AZO(60 nm)/Ag/AZO(60 nm) multilayer electrode on the thickness of Ag interlayer. It is well known that the sheet resistance of AZO(60 nm)/Ag/AZO(60 nm) multilayer electrode results from the three resistances of single layers coupled in parallel connection.

$$\frac{1}{R_{total}} = \frac{2}{R_{ZnO:Al}} + \frac{1}{R_{Ag}} \quad (1)$$

The sheet resistance of AZO film deposited at room temperature is about 150 Ω/square. For AZO(60 nm)/Ag/AZO(60 nm) multilayer electrode, the sheet resistance reduces as the Ag film thickness increases. The sheet resistance of AZO/Ag/AZO film is mainly dependent on the thickness of Ag film. When the thickness of Ag thin film on AZO surface reaches 10 nm, the sheet resistance of AZO(60 nm)/Ag/AZO(60 nm) multilayer film is about 10.5 Ω/square. As the Ag thickness increases, the sheet resistance reaches a constant value. It is reported that Ag film does not show high conductivity until its thickness exceeds a specific thickness when it becomes continuous [14]. A specific value of Ag thickness is closely correlated with fabrication process and the substrate. Thus, it is supposed that 11 nm thickness Ag film on AZO surface is continuous. The similar work was reported by Zhang et al. [15].

A figure of merit is proposed to weigh the performance of a film [16]. Figure of merit (φ) can be expressed as follows:

$$\varphi = \frac{T^{10}}{R_{total}} \quad (2)$$

where T is the optical transmittance and R_{total} is the sheet resistance. A highest φ (0.02 Ω^{-1}) of multilayer film is obtained for 10 nm Ag film. It indicates that AZO(60 nm)/Ag(10 nm)/AZO(60 nm) multilayer film shows better performance simultaneously low sheet resistance and high transmittance.

The above results reveal that AZO(60 nm)/Ag(10 nm)/AZO(60 nm) multilayer film shows better optical and electrical performance. The multilayer film simultaneously high transmittance and low sheet resistance as source/drain electrode, it is favorable to achieve high-performance

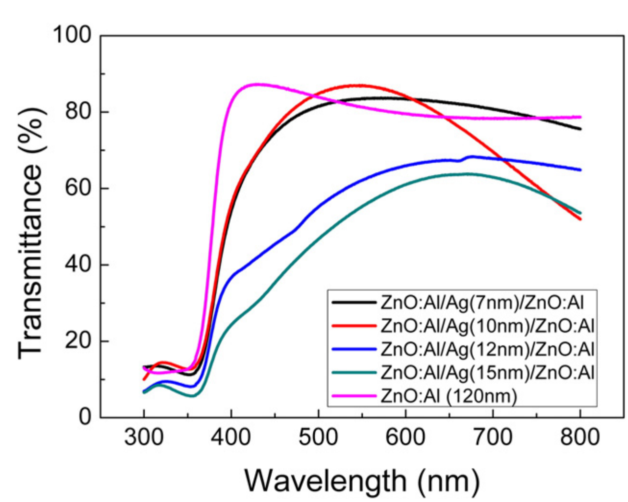

Fig. 2. Dependence of transmittance of AZO(60 nm)/Ag/AZO(60 nm) multilayer electrode on the thickness of Ag interlayer.