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Transparent Ga and Zn co-doped In_2O_3 electrode prepared by co-sputtering of $Ga:In_2O_3$ and $Zn:In_2O_3$ targets at room temperature

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ABSTRACT

This study examined the characteristics of $Ga:In_2O_3$ (IGO) co-sputtered $Zn:In_2O_3$ (IZO) films prepared by dual target direct current (DC) magnetron sputtering at room temperature in a pure Ar atmosphere for transparent electrodes in IGZO-based TFTs. Electrical, optical, structural and surface properties of Ga and Zn co-doped In_2O_3 (IGZO) electrodes were investigated as a function of IGO and IZO target DC power during the co-sputtering process. Unlike semiconducting $InGaZnO_4$ films, which were widely used as a channel layer in the oxide TFTs, the co-sputtered IGZO films showed a high transmittance (91.84%) and low resistivity (4.1×10^{-4} Ω cm) at optimized DC power of the IGO and IZO targets, due to low atomic percent of Ga and Zn elements. Furthermore, the IGO co-sputtered IZO films showed a very smooth and featureless surface and an amorphous structure regardless of the IGO and IZO DC power due to the room temperature sputtering process. This indicates that co-sputtered IGZO films are a promising S/D electrode in the IGZO-based TFTs due to their low resistivity, high transmittance and same elements with channel $InGaZnO_4$ layer.

1. Introduction

Recently there has been an increasing interest in amorphous oxide electronics such as oxide thin film transistors (TFTs) and memory devices as possible new generation electronic devices and cheap alternatives to Si based traditional devices [1–4]. Among various oxide semiconductors, amorphous $InGa(ZnO)_m$ film has been extensively investigated as a channel layer for transparent TFTs due to its high mobility, transparency and simple fabrication process using sputtering techniques [1–3,5–8]. In transparent oxide TFTs, one of the most important components is the transparent conducting oxide (TCO) electrodes because the electrode contact properties between the source/drain and amorphous IGZO active layer and the transparency of the oxide TFTs are critically dependent on the electrical and optical properties of the TCO electrodes. Until now, amorphous SnO_2-doped In_2O_3 (ITO) and metal (Pt/Ti, Au/Ti, MoW) electrodes have been used widely as a drain/source contact electrode in both academic and industrial laboratories. However, amorphous ITO electrodes and metal electrodes are not desirable as the electrode material for transparent oxide TFTs because of the high resistivity of amorphous ITO and opacity of the metal electrodes [2,7,9–11]. For these reasons, amorphous multi-component oxide electrode, such as Al–Zn–O, Ga–Zn–O, Zr–Zn–O, In–Ga–O, In–Zn–O, In–Ga–Sn–O, In–Al–Zn–O and Zn–In–Sn–O have attracted considerable attention as promising transparent electrode materials to replace conventional ITO electrodes [12–17]. Although the electrical and optical properties of many multi-component TCO electrodes have been reported, there are few reports on the characteristics of Ga and Zn co-doped In_2O_3 (IGZO) electrode, which consists of the same elements (In, Ga, Zn, and O) with the semiconducting $InGaZnO_4$ channel layer. Although the element composition of IGZO electrode film is different from the $InGaZnO_4$ (In_2O_3–Ga_2O_3–ZnO) channel layer, the identical element can provide advantages in a continuous fabrication process of IGZO based transparent TFTs.

This study examined the electrical, optical, structural, and surface properties of the IGZO electrodes on a glass substrate as a function of the $Ga:In_2O_3$ (IGO) and $Zn:In_2O_3$ (IZO) DC power at a constant working pressure of 6.6×10^{-1} Pa, and an Ar flow rate of 15 sccm using a dual target sputtering system on unheated substrate. Using the co-sputtering technique, the relative composition of the Ga and Zn dopants in the IGO co-sputtered IZO films could be changed relatively easily to control the resistivity and transparency.

2. Experimental details

120 nm-thick IGZO electrodes were deposited on a glass substrate using a dual target magnetron DC sputtering system at room temperature in a pure Ar ambient environment without the addition of a reactive oxygen gas [18]. Both the IGO (10 wt.% Ga_2O_3 doped

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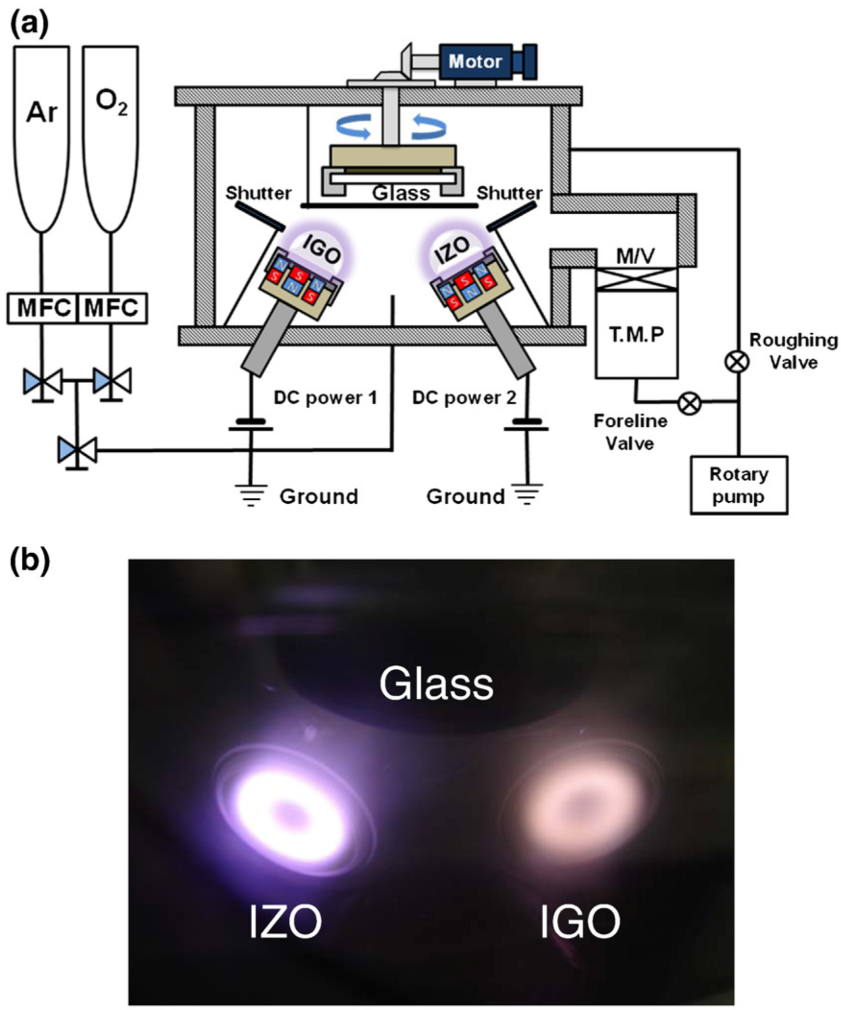

Fig. 1. (a) Schematics diagram and (b) picture of dual target sputtering for co-sputtering of IGO and IZO targets.

In_2O_3) and IZO (10 wt.% ZnO doped In_2O_3) targets, as co-sputtering sources, were loaded on a tilted cathode gun placed 100 mm from the glass substrate center, as shown in Fig. 1(a) and (b). The picture in Fig. 1(b) shows the plasma simultaneously formed on the IGO and IZO targets during the IGO and IZO co-sputtering process. The IGZO electrodes were deposited on a 25×25 mm^2 glass substrate at a constant total DC power (DC power of IGO + DC power of IZO) of 100 W. Table 1 lists the DC power applied to each target. The Ar flow rate and working pressure were maintained at 15 sccm and 6.6×10^{-1} Pa, respectively. For simplicity, the samples are referred to as 'X-IGZO' where X denotes the DC power applied to the IGO target. For example, 10 W-IGZO means that 10 W IGO and 90 W IZO DC power were supplied to the targets simultaneously. The thickness of the IGZO electrode as a function of the IGO and IZO DC power was measured using a stylus profilometer (Tencor Alpha-step 250). The resistivity, mobility, carrier concentrations, and sheet resistance of the IGZO electrodes were measured using Hall measurements with a van der Pauw geometry at room temperature. In addition, a UV/visible spectrometer was used to measure the optical transmittance of the IGZO electrodes. The structure of the IGZO electrodes was examined by X-ray diffraction (XRD, D/Max 2000) using Cu K_α ($\lambda = 1.54059$ Å) radiation in a Rigaku diffractometer (SWXD). The microstructure of the optimized IGZO electrode was examined by high-resolution electron microscopy (HREM; JEM-2100F) and transmission electron diffraction (TED). The surface smoothness and morphology of the IGZO electrode were analyzed by field emission scanning electron microscopy (FESEM; JSM-6500F) with an operating voltage of 15 kV and atomic force microscope (AFM-D3100). The existence of Ga and Zn dopants and the binding energy of each element in the IGZO electrode were examined by X-ray photoelectron spectroscopy (XPS-PHI5200) using an Al K_α radiation source (1486 eV) with an operating power of 400 W in an ultra high vacuum system with a base pressure of ~1.3×10^{-8} Pa. The extent of IGO incorporation into the IZO film was characterized by Auger electron spectroscopy (AES) depth profile using a PHI 670 Auger microscope with an electron beam of 10 keV and 0.0236 μA.

Table 1
Deposition conditions of IGO co-sputtered IZO electrode as a function of the IGO and IZO DC power.

	10 W IGZO	25 W IGZO	50 W IGZO	75 W IGZO	90 W IGZO
Base pressure			6.6×10^{-4} Pa		
Working pressure			6.6×10^{-1} Pa		
Ar flow rate			15 sccm		
IGO power	10 W	25 W	50 W	75 W	90 W
IZO power	90 W	75 W	50 W	25 W	10 W
Total DC power	100 W				