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Properties of In–Ga–Zn-O thin films for thin film transistor channel layer prepared by facing targets sputtering method

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Abstract

Amorphous indium–gallium–zinc-oxide (a-IGZO) thin films were prepared using the facing targets sputtering (FTS) method as a function of input power at room temperature. The a-IGZO films were used a channel layer for thin film transistors (TFTs). The electrical, optical, and structural properties of a-IGZO thin films were measured by Hall Effect measurement, UV/vis spectrometer and X-ray diffractometer. The performance and device characteristics of the a-IGZO TFTs were measured by using a semiconductor parameter analyzer. The transfer characteristics of a-IGZO TFTs exhibited saturation mobility of 10.83 cm^2/V s and threshold voltage of 5.13 V.
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Keywords: C. Electrical properties; In–Ga–Zn-O; Thin film transistor; Facing targets sputtering

1. Introduction

Recently, the display market has shown accelerated growth due to competition. Among display devices, transparent amorphous oxide semiconductors (TAOSs) have attracted much attention as a superior optical transparent material showing higher mobility than amorphous silicon or organic transistors [1]. TAOSs can be fabricated on plastic substrates at low temperature by physical vapor deposition methods such as the conventional dc sputtering method. The application of various types of TAOS, such as the amorphous indium zinc oxide (a-IZO), amorphous zinc tin oxide, and (a-ZTO) amorphous indium gallium zinc oxide (a-IGZO) in thin film transistors (TFTs) has been reported extensively [2]. The a-IGZO as a channel layer in TFTs, exhibits large field effect mobility (>10 cm^2/V s) at low temperatures (room temperature), which is better than the <1 cm^2/V s of a-Si:H, <2.7 cm^2/V s of a pentacene single crystal and <1.5 cm^2/V s of a pentacene thin film. In addition, a-IGZO TFTs show reasonable on–off ratio and an excellent subthreshold gate voltage swing [3]. In this study, the properties of a-IGZO thin film was investigated using the facing target sputtering method (FTS) for various levels of DC power. Moreover, TFTs deposited with an a-IGZO channel according to DC power were fabricated and the characteristics of these TFTs in relation to the device performance were discussed.

2. Experimental

The a-IGZO thin films were prepared on a glass substrate by using the facing targets sputtering (FTS) method at room temperature. Fig. 1 is the apparatus of the FTS method used in the deposition process. The FTS method was these two targets facing each other when they were arrayed and to form high density plasma between the targets. In the FTS method, the substrate was protected from bombardment by high-energy particles because the substrate was located apart from the plasma. The FTS system can suppress substrate damage caused by high-energy particles, such as electrons and partial ions [4]. The glass substrate was ultrasonically cleaned by using isopropyl alcohol (IPA) and DI-water, and was blown dry in N_2 gas. The chamber was evacuated to 1.0×10^{-4} Pa before the film deposition began at the pressure maintained at 0.13 Pa,

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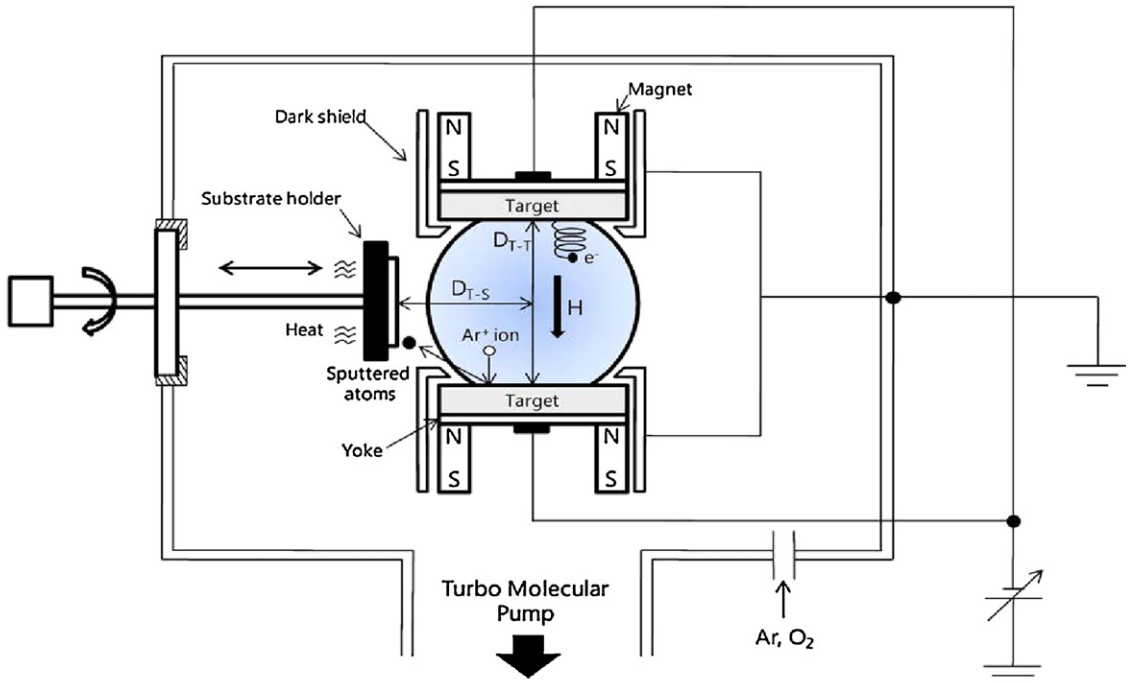

Fig. 1. Apparatus of the FTS method used in the deposition process.

which was maintained throughout the process. Before the deposition, the a-IGZO targets were pre-sputtered in pure Argon atmosphere for 10 min to remove their natural surface oxide layers. The thickness of the as-grown a-IGZO films was 100 nm. Fig. 2 shows cross section that the TFT deposited by using FTS method. A 100 nm-thick SiO_2 insulator for the TFTs was grown on a low resistivity boron doped Si gate electrode. A 50 nm-thick a-IGZO channel layer was deposited on the SiO_2 insulator at input power of 55 W and oxygen flow rate of 0.1 sccm. Source/drain electrodes (Al) of 100 nm in thickness were deposited by using the FTS method on top of the a-IGZO film. The TFT structures were defined by photolithography and the lift-off process. The channel width (W) was 1000 and the channel lengths (L) were 100 μm and 70 μm. More details about the sputtering conditions are given in Table 1. The thickness of the a-IGZO film was measured by using a surface profiler (Alpha-step, TENCOR, USA). The electrical properties of the film were measured with a Hall Effect measurement system (HMS-3000, Ecopia, Korea). The optical and the structural properties were measured by using an UV–vis spectrometer (HP8453, Hewlett–Packard, USA), and an X-ray diffractometer (RINT 2000series, Rigaku, Japan). The performance and device properties of the a-IGZO TFTs were measured by using a semiconductor parameter analyzer (4156C, Agilent, USA).

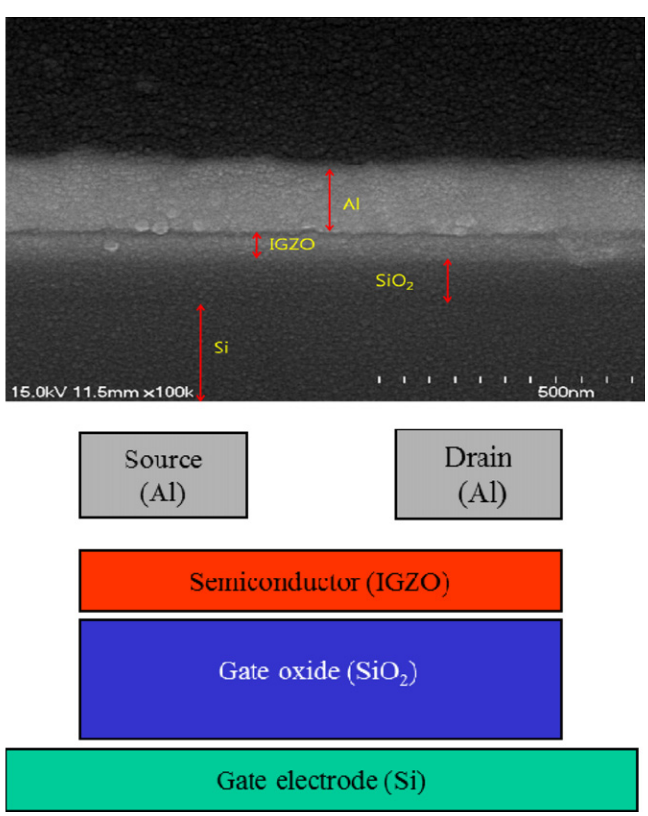

Fig. 2. Cross section of TFT deposited by FTS method.

Table 1
Sputtering conditions of a-IGZO thin films.

Deposition parameter	Sputtering conditions
Targets	IGZO (In_2O_3:Ga_2O_3:ZnO = 1:1:1 mol%, 2 in.)
Substrate	Glass
Base pressure	1.3×10^{-4} Pa
Working pressure	0.13 Pa
Film thickness	100 nm
Substrate temperature	Room temperature
Input DC power	30–55W
Oxygen flow rate	0.1 sccm

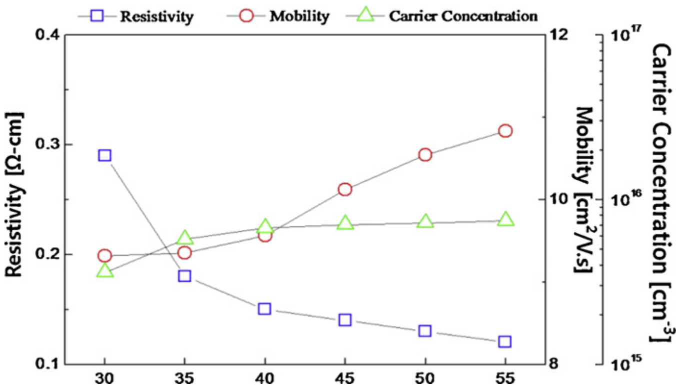

Fig. 3. Electrical properties of a-IGZO films as a function of input power.

3. Results and discussion

Fig. 3 shows the electrical properties of a-IGZO films as a function of input power. The carrier concentration of the a-IGZO films ranged from 3.62×10^{15} cm^{-3} to 7.43×10^{15} cm^{-3} with the increase of input power (from 30 W to 55 W). The mobility of the a-IGZO films ranged from 9.32 cm^2/V s to 10.83 cm^2/V s with the increase of input power (from 30 W to 55 W). The resistivity of the a-IGZO films decreased from 0.29 Ω cm to 0.12 Ω cm with the increase of the input power (from 30 W to 55 W). The resistivity depends on the mobility and the carrier concentration. The decreasing resistivity of the thin films was due to the increasing carrier concentration and mobility [5].

$$\rho = \frac{1}{ne\mu} \quad (1)$$

where ρ is the resistivity [Ω cm], n is the carrier concentration [cm^{-3}], e is the charge of an electron (1.6021×10^{-16} C) and μ is the mobility [cm^2/V s].

Fig. 4 shows the optical transmittance of the a-IGZO films in the visible range as a function of input power. The transmittance of all a-IGZO films was above 80% without as a function of input power. The optical transmittance in the visible range slightly decreased with increasing input power. The reduction of transmittance with increasing input power can be associated with a metal-like optical behavior, strongly controlled by oxygen vacancies. The oxygen removal mechanism competes with the oxidation phenomenon. This causes the formation of a more stoichiometric oxide with higher transmittance but lower carrier concentration [6]. Fig. 5 shows the X-ray diffraction patterns of a-IGZO thin films as a function of input power. No peaks were found in any of the deposition conditions. It seems that the as-deposited a-IGZO thin films had insufficient energy for crystallization.

Fig. 6(a) and (b) shows the transfer characteristics of a-IGZO TFTs at input power of 55 W and W/L (1000/100 μm and 1000/70 μm). Gate voltage from −20 V to 20 V was applied to make a graph of the transfer characteristics. At W/L of 1000/100 μm, the on/off ratio was a maximum 3.77×10^6, and the threshold voltage was 5.13 V from a graph of $V_g - (I_d)^{1/2}$. At W/L of 1000/70 μm, the on/off ratio was a maximum 6.19×10^6, threshold voltage was 5.11 V from the graph of $V_g - (I_d)^{1/2}$. The saturation mobility was calculated from the by mutual transfer conductance by the transfer characteristics equation for a standard linear field.

$$I_{ds} = \frac{W\mu_{sat}C_i}{2L}(V_{gs} - V_{th})^2 \quad (2)$$

where μ_{sat} was saturation mobility, V_{th} was threshold voltage, and C_i was capacitance per unit area of the gate insulator. The saturation mobilities of TFTs were 10.83 cm^2/V s and 9.83 cm^2/V s for W/L of 1000/100 μm and 1000/70 μm. Similar results of saturation mobility, have been reported previously for narrow channels and long device. On the other hand, devices with lower W/L ratio tended to have fast mobility. With increasing input power, the saturation mobility of TFTs increased with decreasing threshold voltage because of the carrier concentration in the TFT channel increased. Hosono and co-workers [7,8] reported that the carrier concentration in crystalline and amorphous IGZO is proportional to mobility. For general crystalline silicon semiconductors, mobility was decreased with increases of scattering and carrier concentration. However, the a-IGZO was amorphous structure. Therefore,

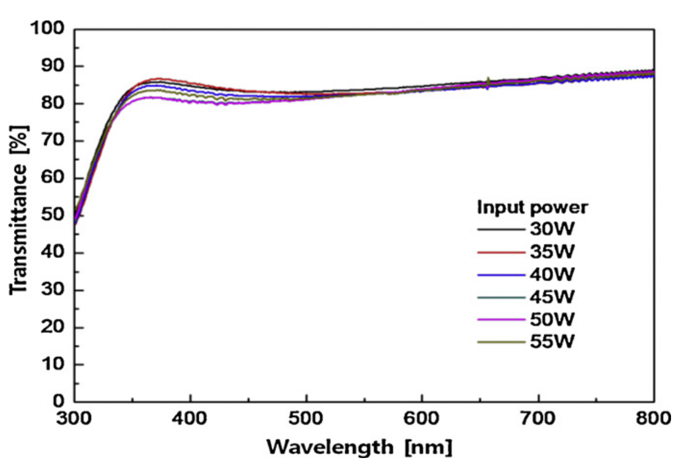

Fig. 4. Transmittance of a-IGZO films in the visible range as a function of the input power.

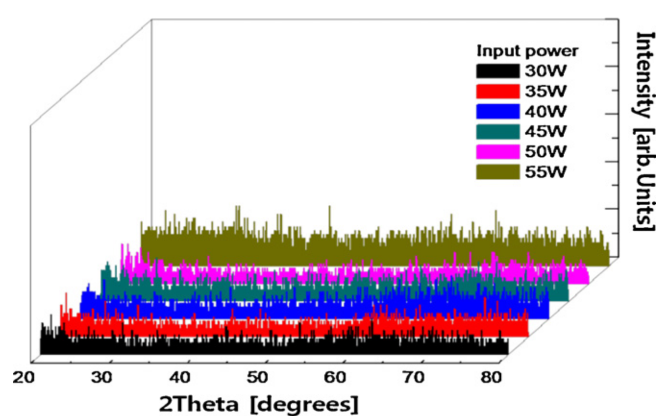

Fig. 5. X-ray diffraction patterns of a-IGZO thin films as a function of input power.

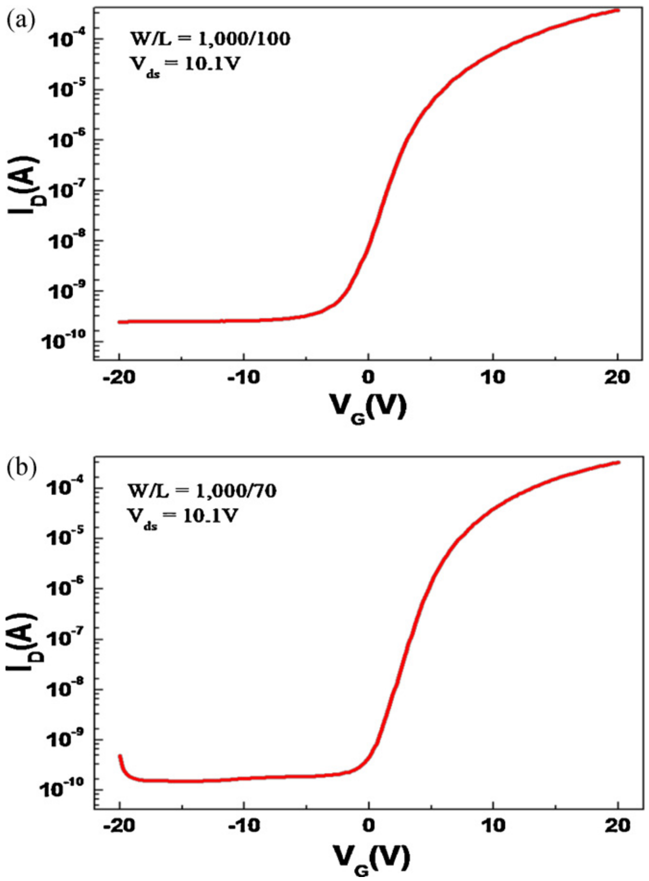

Fig. 6. Transfer characteristics of a-IGZO TFTs at input power of 55 W and *W/L* (a)1000/100 μm (b) 1000/70 μm.

percolation conduction occurred due to the irregular distribution of the potential barrier at the conduction band edge, and mobility was increased with decrease of activation energy and increase of carrier concentration. As the carrier concentration in the TFT channel increased, the threshold voltage decreased due to low gate voltage.

4. Conclusions

An a-IGZO film, which can be used as a channel layer, was deposited at room temperature according to input power by FTS. The optical properties indicated that an a-IGZO film can be used as TFT. The carrier concentration and mobility of the a-IGZO films fabricated at increasing input power were suitable for application to TFT devices. The TFTs ($W/L = 1000/100$) with the a-IGZO channel layer exhibited a subthreshold slope value of 1.35 V decade^{-1}, on/off ratio of 3.77×10^6, threshold voltage of 5.11 V and saturation mobility of 10.83 cm^2/V s. In addition, the TFTs ($W/L = 1000/70$) with the a-IGZO channel layer exhibited a subthreshold slope value of 1.26 V decade^{-1}, on/off ratio 6.198×10^6, threshold voltage of 5.13 V and saturation mobility of 9.83 cm^2/V s. Therefore, the fabricated TFTs exhibited good performance.

Acknowledgments

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