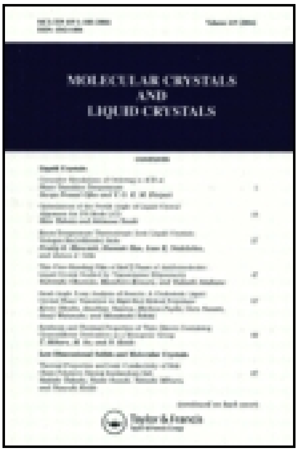

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Oxygen Gas Dependence of IGZO Thin Film for TFT Channel Layer

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Amorphous indium-gallium-zinc-oxide (a-IGZO) thin films on glass were prepared using facing target sputtering (FTS) methods by different oxygen flow rates at room temperature. The a-IGZO films were used as 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 semiconductor parameter analyzer. The transfer characteristics of a-IGZO TFTs saturation exhibited mobility of 19.42 cm^2/V.s and the threshold voltage of 4.18 V.

Keywords a-IGZO; TFTs; FTS

Introduction

Recently, transparent amorphous oxide semiconductors (TAOSs) are being investigated in many laboratory due to overcome defects of existing materials used in transparent electronic devices. Amorphous Indium gallium zinc oxide (a-IGZO) is most interesting material for superior optical transparent material with high mobility in comparison to amorphous silicon or organic transistors [1–2]. TAOSs can be p on plastic substrates at low temperature by physical vapor deposition methods such as the ordinary dc sputtering method. The application of TAOSs, 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 [3–4].

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 for a-Si:H, <2.7 cm^2/V.s for a pentacene single crystal and <1.5 cm^2/V.s for a pentacene thin film [1].

a-IGZO TFTs shows also reasonable on-off ratio and an marvelous Subthreshold gate voltage swing [5]. We investigated the properties of a-IGZO thin film using the facing target sputtering method (FTS) for oxygen gas flow. Furthermore, we fabricated TFTs with an a-IGZO channel deposited according to DC power and discussed the characteristics of these TFTs in relation to the device performance.

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Experimental

The a-IGZO thin films were prepared on a glass substrate by the facing targets sputtering (FTS) method at room temperature. Figure 1 is an instrument of the FTS method used in the deposition process. The FTS method was designed to array two targets facing each other and to form high density plasma between the targets. The FTS method was able to reduce the bombardment of the substrate by high-energy particles because the substrate's position was located apart from the plasma. Thus, the FTS system can suppress substrate damage caused by high-energy particles, such as electrons and partial ions [6–8]. The glass substrate was ultrasonically cleaned by using isopropyl alcohol (IPA) and DI-water. Then glass substrate was dried by N_2 gas. The chamber was evacuated to 1.0×10^{-4} Pa before the film deposition began with the pressure maintained at 0.13 Pa throughout the process. Before the deposition, the IGZO (In_2O_3:Ga_2O_3:ZnO = 1:1:1 mol%, 2 inch) targets was pre-sputtered in pure Argon atmosphere for 10min to remove the natural surface oxide layer of the targets. The thickness of the grown a-IGZO films was 100 nm. Figure 2 shows structure of the TFT using the a-IGZO film as a channel layer. A 100-nm-thick SiO_2 insulator of the TFTs was grown on low resistivity boron doped Si gate electrode. A 50-nm-thick a-IGZO channel layer was deposited by the FTS method at input power of 55 W and oxygen flow rate of 0.8 sccm. The 100-nm-thick source/drain electrodes (Al) were deposited by the FTS method on top of the a-IGZO film. The TFT structures were defined by photolithography and lift-off process. The channel width (W) was 1000μm and the channel lengths (L) were 100 μm, respectively. More details about the sputtering conditions are given in Table 1. The thickness of the a-IGZO film was measured by surface profiler (Alpha-step). The electrical properties of the film were measured by Hall Effect

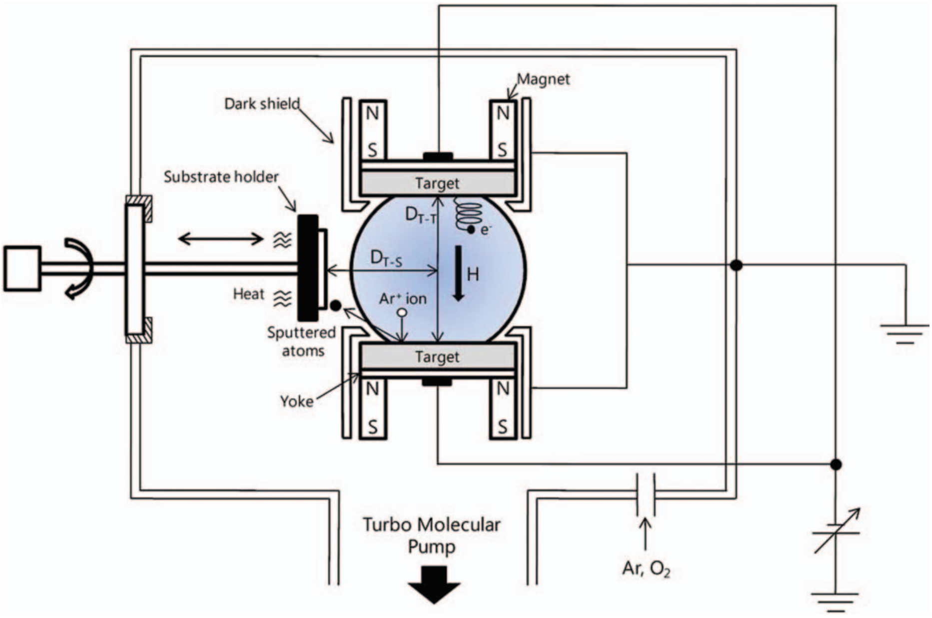

Figure 1. An apparatus of the FTS method used in the deposition process.

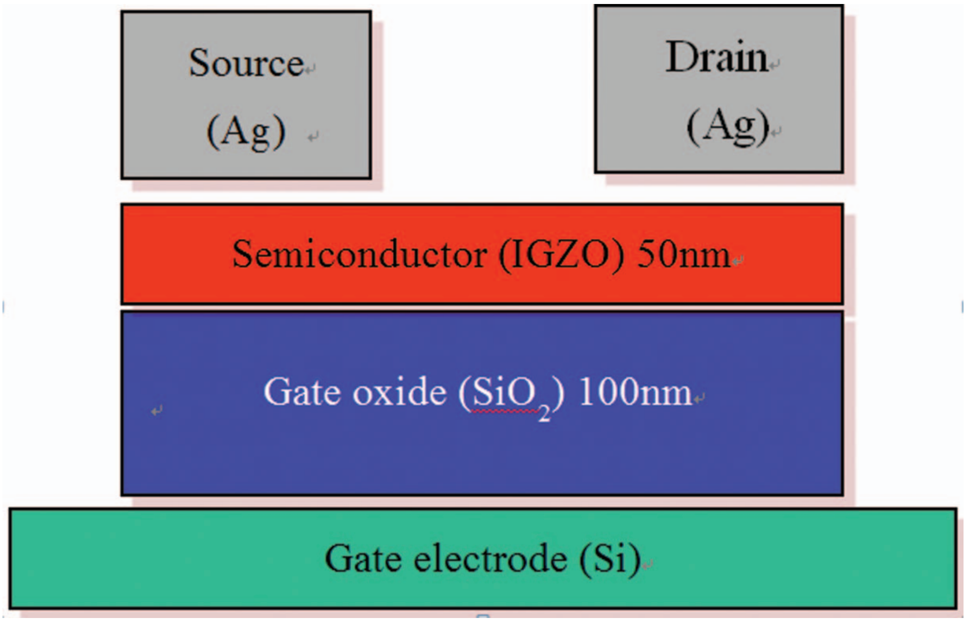

Figure 2. Structure of the TFT using the a-IGZO film as a channel layer.

measurement system. The optical and the structural properties were measured by UV-VIS spectrometer, and X-ray diffractometer. The performance and device properties of the a-IGZO TFTs were measured by a semiconductor parameter analyzer.

Results and Discussion

Figure 3 show the electrical properties of a-IGZO films in proportion as function of Oxygen gas flow. The mobility of the a-IGZO films ranged from 24.33 V·s to 60.47 V·s with the increase of the oxygen gas flow from 0.2sccm to 0.8sccm. The resistivity depends on the mobility and the carrier concentration. The decreasing resistivity of the thin films was due

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 inch),
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	55 W
Oxygenflow rate	0.0~0.8 sccm

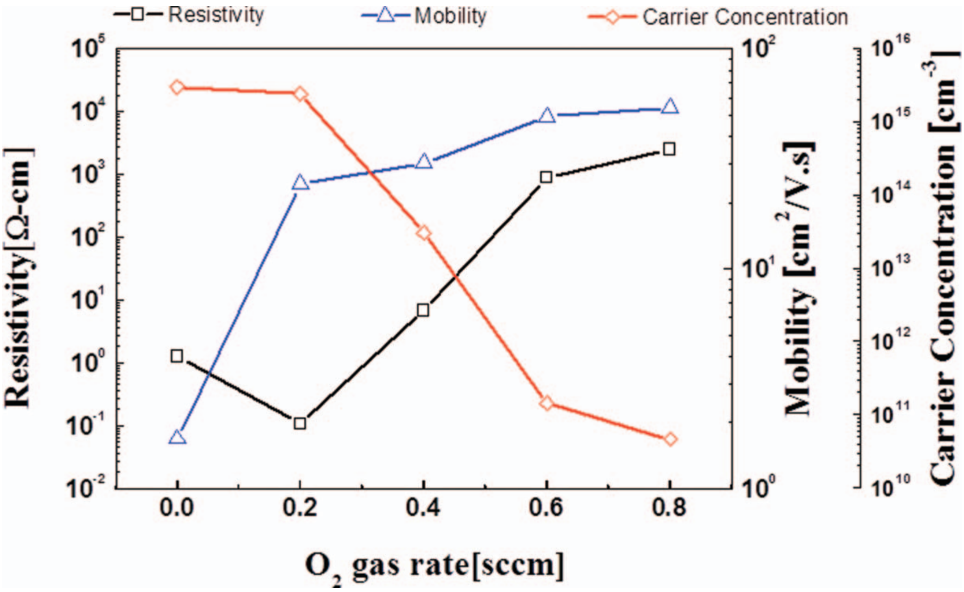

Figure 3. The resistivity and mobility according to Oxygen gas flow rate.

to the increasing carrier concentration and mobility [9].

$$\rho = \frac{1}{ne\mu} \tag{1}$$

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} coulombs) and μ is the mobility [$\text{cm}^2/\text{V}\cdot\text{s}$].

The coordination numbers of the O ions around In, Zn, and Ga in a-IGZO are reduced from those in the crystalline phase, which consequently reduces the cation coordination numbers around an O ion to maintain charge neutrality. InO_6 and GaO_6 octahedra coexist with less numbers of InO_5 and GaO_5 pentahedra. The low coordination number structures such as InO_5 and GaO_5 do not have oxygen vacancy sites, but have additional oxygen ions coordinated at longer distances, which causes the reduced average coordination number and large electron mobility in *a*-IGZO [10].

Figure 4 shows the optical transmittance of the a-IGZO films in the visible range as a function of the oxygen gas flow rate. The transmittance of all oxygen added a-IGZO films was above 80% for wavelength of 55 0nm and optical transmittances in the visible range slightly increase with increasing oxygen gas flow.

Figure 5 shows the X-ray diffraction patterns of a-IGZO thin films for different oxygen gas flow. No peaks were found in any of the deposition conditions. It seemed that the as-deposited a-IGZO thin films have not sufficient energy for crystallization. Some of In-O polyhedra maintain the edge-sharing network structures such as in the IGZO crystal, but the other In-O polyhedra are connected by corner sharing. Therefore, a-IGZO thin films have not sufficient energy for crystallization [10].

Figure 6-(a)(b) show the transfer characteristics of a-IGZO TFTs at input power of 55 W, Oxygen gas flow 0.8 sccm and W/L (1000/100 μ). We applied gate voltage from −20 V to 20 V would make a graph of transfer characteristics. As W/L of 1000/100 μ,

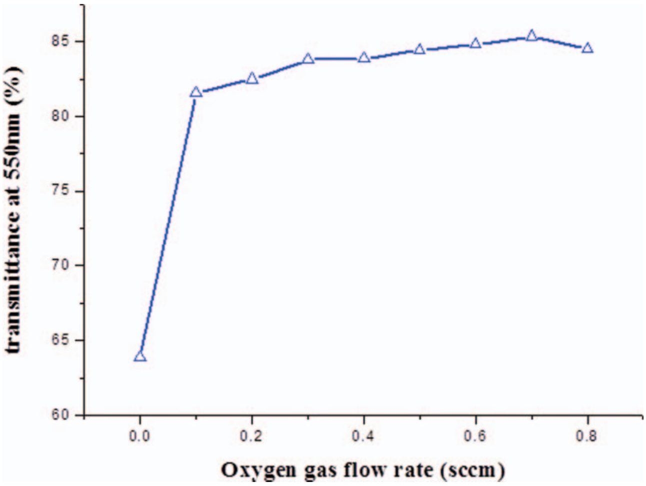

Figure 4. The optical transmittance of the a-IGZO films at 550nm for different oxygen gas flow.

On/off ratio was a maximum 2×10^6, threshold voltage was 4.06 V from a graph of V_g-$(I_d)^{1/2}$. The saturation mobility was calculated by mutual transfer conductance from transfer characteristics equation in a standard linear field.

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

where μ_{sat} was saturation mobility, V_{th} was threshold voltage, and C_i was capacitance per unit area of gate insulator. The saturation mobility of TFTs were 19.42 $cm^2/V\cdot s$ with W/L of 1000/100 μm that it was Investigated by linear section.

In case of saturation mobility, similar to results have been reported previously, about narrow channel and long length device. In the other hands, the lower W/L ratio devices had a fast mobility tendency. Increasing input power, the saturation mobility of TFTs

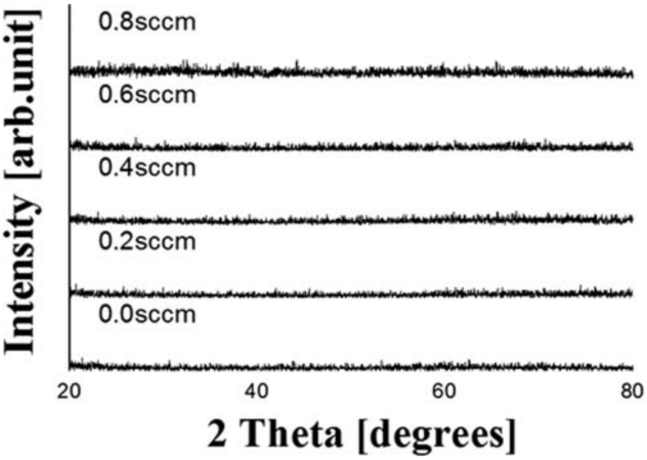

Figure 5. The X-ray diffraction patterns of a-IGZO thin films for different oxygen gas flow.

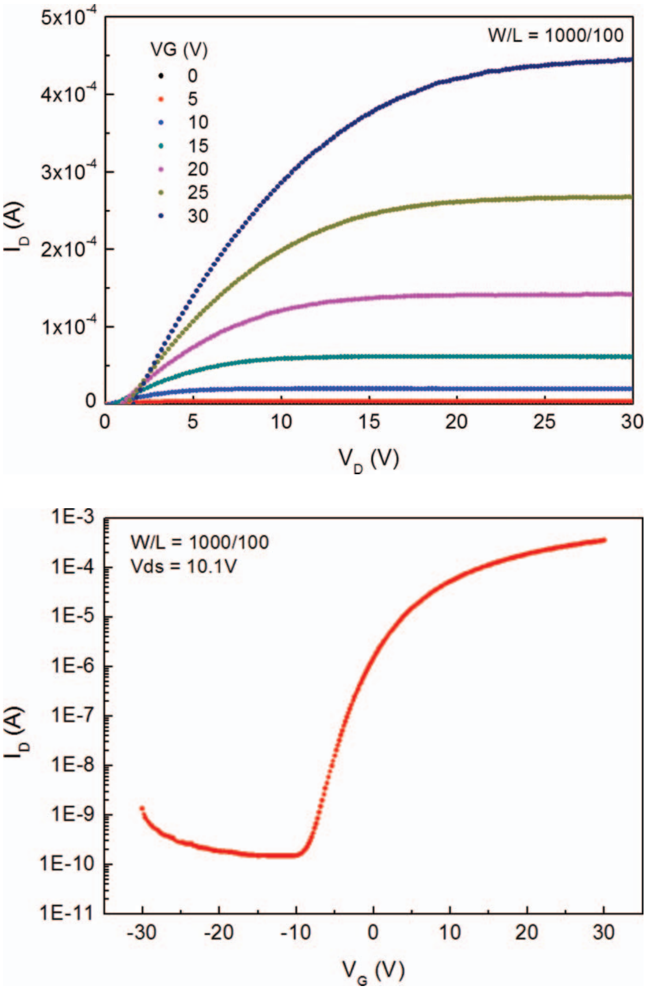

Figure 6. **(a) (b)**. transfer characteristics of a-IGZO TFTs at input power of 55 W, Oxygen gas flow 0.8 sccm and W/L (1000/100 μ).

increased with decreasing threshold voltage because of the carrier concentration in TFT channel increased. H. Hosono *et al.* [11–12] reported, the carrier concentration was proportional to mobility in crystalline and amorphous IGZO. As the general crystalline silicon semiconductor, the mobility was decreased by increasing scattering with increasing carrier concentration. However, the a-IGZO had a structural disorder with amorphous structure. Therefore, percolation conduction was caused by that potential barrier distributed irregular to conduction band edge, and mobility was increased by decreasing activation energy with increasing carrier concentration.

Conclusions

An a-IGZO film which can be used as a channel layer was deposited by FTSsystem at room temperature according to oxygen gas flow. The optical properties indicated that an a-IGZO film can be used as TFTs. The mobility of the a-IGZO films fabricated at increasing oxygen gas flow rates 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 1.75 V decade^{-1}, on/off ratio of 2×10^6, threshold voltage of 4.18 V and saturation mobility of 19.42 cm^2/V·s. The fabricated TFTs exhibited good performance.

Acknowledgment

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