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Characteristics of Transparent ZnO Based Thin Film Transistors with High-*k* Dielectric Gd_2O_3 Gate Insulators Fabricated at Room Temperature

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1. Introduction

Transparent electronic devices is getting more important due to the demands of new optoelectronic applications. The ZnO based transparent thin film transistor (TTFT) has been widely used to describe the characteristics of transparent electronics due to its great transparency in the visible light range and electrical properties [1,2]. The ZnO thin films deposited under low temperatures not only provide the need of cost down of electronic production but also supply the applications of flexible electronics. In addition, high k dielectric of Gd_2O_3 has been taken as an excellent candidate for replacing the conventional gate oxide in the next generation of nanoelectronics to avoid the high direct tunneling current [3]. Its great thermodynamic stability also provides the wide thermal range during device fabrication processes. In this work, the ZnO based TTFT with gate dielectric of Gd_2O_3 deposited on glass was firstly performed under full room temperature processing.

2. Experimental details

A 200-nm-thick transparent conducting indium tin oxide (ITO) thin films were deposited on 5×5 cm^2 glass substrates under room temperature used by radio frequency (rf) magnetron sputtering in a pure Ar ambient to form the bottom gate electrode. Prior to deposition, the chamber was cryopumped to ~5×10^{-3} mTorr and then sputtered at a reasonable gas pressure of 5 mTorr. Following that, a 140-nm-thick Gd_2O_3 and 150-nm-thick ZnO films were prepared by pulsed laser deposition (PLD) at room temperature in sequence as a gate insulator and active layer of TFT, respectively. Thickness of Gd_2O_3 and ZnO films were chosen to realize the characteristics of reliable TTFT devices. Qualities of deposited Gd_2O_3 and ZnO films were improved by using nearly pure Gd_2O_3 and ZnO targets ablated by a KrF excimer laser. In addition, the targets were rotated at 5 rpm to avoid the formation of pits. Lambda physics of excimer laser was given by λ=248 nm, pulse duration of 25 ns, repetition rate of 3 Hz, and the laser energy of 500 mJ. The distance from target to substrate is 10 cm. The oxygen pressure varied from 2.6 to 14 mTorr to create high quality thin films by using a mass flow controller. After the deposition of active layer of ZnO films and photolithography processes, a 200-nm-thick Al was evaporated to form the source and drain electrodes. Surface morphology of deposited thin films was monitored by the atomic force microscope (AFM) and the crystalline quality of those was analyzed by high resolution X-ray diffraction (XRD) measurement. The I-V and C-V characteristics of TTFT were measured by semiconductor parameter analyzer of HP 4156C and HP4284, respectively.

3. Results and discussion

Figure 1 shows the electrical properties of ZnO films as the function of oxygen pressure. The resistivity of the ZnO films increased with the oxygen pressures ranging from 2.6 to 14 mTorr. The corresponding carrier mobility decreased with the oxygen pressures. Here we propose that the scattering probability of electron reasonably may rise with the increased oxygen interstitials resulting in the reduction of the Hall mobility, even though the carrier concentration remained at about 3×10^{15} cm^{-3} under low oxygen pressure. It has been suggested that the electron trapping centers could be generated by the oxygen interstitials [4]. The carrier concentration is reasonably reduced under high oxygen pressure due to the severe lack of oxygen vacancies. The measured minimum resistivity was approximately 5.2×10^{-3} Ω·cm under low oxygen pressure of 2.6 mTorr, which is consistent with previous work [4].

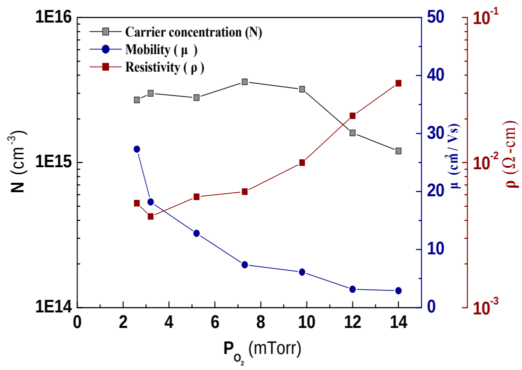
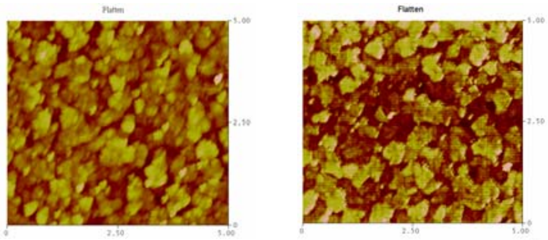


Figure 1. Electrical properties of ZnO films deposited at room temperature as a function of oxygen pressures.

Figure 2(a) and (b) present the crystal sizes of polycrystalline ZnO films measured by AFM for those grown at oxygen pressures of 2.6 and 14 mTorr, respectively. The root-mean-square (RMS) of grain size of ZnO films grown at 14 mTorr is approximately 5.6 nm which is about 2.4 times larger than those grown at 2.6 mTorr. Previous work had evidenced that the crystal size of ZnO films increased with the oxygen pressure regardless of the substrate temperature [4].



(a) (b)

Figure 2. 5×5 μm AFM images of polycrystalline ZnO films performed under an oxygen pressure of (a) 2.6; (b) 14 mTorr.

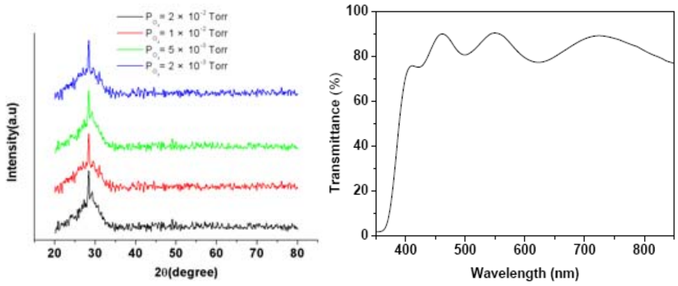
Table 1 shows the electrical properties of gate dielectric of Gd_2O_3 thin films performed by PLD in the metal-oxide-metal (MIM) capacitor on glass substrate at different anneal temperatures and oxygen pressures. The top and bottom electrodes were performed with Al and ITO thin films, respectively. The leakage current in the $ZnO/Gd_2O_3/ITO$ capacitor is much smaller in samples annealed at temperature of 200°C than in those fabricated at room temperature. However, severe leakage current was occurred for samples annealed at higher temperatures. Both of dielectric constant and capacitance constant of Gd_2O_3 thin films decrease with increasing oxygen pressure for samples regardless of annealing temperatures.

Table 1. Characteristics of ZnO/Gd2O3/ITO capacitor

P_{O2} (Torr)	Temp. (℃)	Thick (Å)	Results		
			Leakage (at 1MV/cm²)	C_i (nF/cm²)	K
1×10^{-2}	RT	612	1.34×10^{-7}	100	10.2
5×10^{-3}	RT	560	1.54×10^{-7}	148	12
2×10^{-3}	RT	668	5.55×10^{-7}	131	11.5
1×10^{-2}	200	660	6.44×10^{-9}	120	11.2
5×10^{-3}	200	550	2.61×10^{-8}	156	12.3
2×10^{-3}	200	670	9.44×10^{-8}	140	12
1×10^{-2}	300	610	3.43×10^{-6}	95	9.3
5×10^{-3}	300	580	6.37×10^{-6}	122	11.3
2×10^{-3}	300	660	1.02×10^{-5}	101	8.9

Figure 3(a) evidenced that the deposited Gd_2O_3 films is amorphous independently of the oxygen pressure. The reduction of leakage current for samples annealed at 200°C with a high oxygen pressure is attributed reasonably to the improvement in the quality of Gd_2O_3 film. Consequently, the leakage current density is increased with increasing the leakage paths during the crystallization process of thin film for samples annealed at higher temperature. Development of room temperature fabrication of TTFT is worthy to realize due to the demands of cost down and flexible applications in the microelectronic manufacturing. Figure 3(b) shows the optical transmittance spectrum of the ZnO based TTFT fabricated at room temperature with Gd_2O_3 gate dielectric. The average optical transmittance is about 82.8% in the visible region.

Figure 4(a) illustrates the drain current (I_{DS}) versus source-drain voltage (V_{DS}) of an n-channel TTFT device. The selected oxygen pressures of the deposited ZnO active layer and Gd_2O_3 gate dielectric thin films by PLD were 2.6 and 10 mTorr, respectively. The output characteristics appear obviously the saturation regions of current and pinch off behavior for gate voltage (V_{GS}) ranging from 0 to 4 V. It is observed the off-current less than 10^{-9} A. The corresponding dc transfer characteristics are portrayed in Fig. 4(b). Here the width and length of this reported TTFT were designed to be 500 and 120 μm, respectively. The ratio of on-to-off current was extracted to be approximately 6.7×10^4 for device operated in the saturation region. By fitting the data of the square root of I_{DS} verse V_{GS} in the saturation region, the threshold voltage (V_{th}) and the filed effect mobility (μ_{FE}) was estimated to be about 2.0 V and 1.12 cm²/V-s. The subthreshold swing of gate voltage was calculated to be about 0.4 V/decade. The acceptable electrical characteristic of the ZnO based TFT with a Gd_2O_3 gate oxide was successfully fabricated at room temperature.



(a) (b)

Figure 3. (a) XRD measurements of the Gd_2O_3 films deposited under different oxygen pressures; (b) Optical transmittance spectrum of ZnO based TTFT fabricated at room temperature.

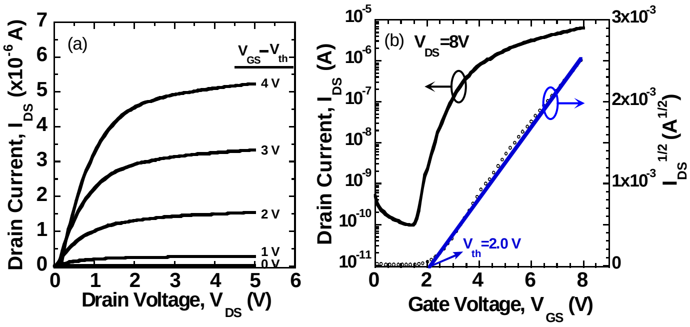


Figure 4. (a) I_{DS} verse V_{DS} characteristic curves and (b) transfer characteristics of the proposed TTFT devices

4. Conclusions

Oxygen pressures influenced on the qualities of thin film has been elucidated in detail. Room temperature fabrication of ZnO TTFT with high k dielectric of Gd_2O_3 has been performed successfully on the glass substrates. The estimated on/off ratio current and field effect mobility were approached to be 10^5 and 1.12 cm²/V-s, respectively.

References

[1] R.L. Hoffman, B.J. Norris and J.F. Wager, Appl. Phys. Lett. **43** (2003) 733.

[2] H.-C. Cheng, C.-F. Chen and C.-C. Lee, Thin Solid Films, **498** (2006) 142.

[3] A. Laha, A Fissel and H. J. Osten, Appl. Phys. Lett. **90**, p.113508 (2007).

[4] P.-K. Shin, Y. Aya, T. Ikegami and K. Ebihara, Thin Solid Films, **516** (2008) 3767.