Characteristics of Transparent ZnO Based Thin Film Transistors with High-κ Dielectric Gd₂O₃ 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-κ dielectric of Gd₂O₃ 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 Gd₂O₃ 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 cm² 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 bottom gate electrode. Prior to deposition, the chamber was cryopumped to ~5×10⁻³ mTorr and then sputtered at a bottom gate electrode.

Figure 1 shows the electrical properties of ZnO films deposited at room temperature as a function of oxygen pressures. 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 3×10¹⁵ 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 Ωcm under low oxygen pressure of 2.6 mTorr, which is consistent with previous work [4].

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 oxygen pressures of 2.6 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].
Table 1 shows the electrical properties of gate dielectric of Gd$_2$O$_3$ 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$_2$O$_3$/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$_2$O$_3$ thin films decrease with increasing oxygen pressure for samples regardless of annealing temperatures.

![AFM images of polycrystalline ZnO films](image)

**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. Characteristics of ZnO/Gd2O3/ITO capacitor

<table>
<thead>
<tr>
<th>PO$_2$ (Torr)</th>
<th>Temp. (℃)</th>
<th>Thick (Å)</th>
<th>Leakage (at 1V/cm)</th>
<th>C (μF/cm$^2$)</th>
<th>K</th>
</tr>
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<tbody>
<tr>
<td>1×10$^{-2}$</td>
<td>RT</td>
<td>612</td>
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<tr>
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<td>560</td>
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<td>8.9</td>
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</tbody>
</table>

![Optical transmittance spectrum](image)

**Figure 3.** (a) XRD measurements of the Gd$_2$O$_3$ films deposited under different oxygen pressures; (b) Optical transmittance spectrum of ZnO based TTFT fabricated at room temperature. It appear obviously the saturation regions of current and pinch off behavior for gate voltage (V$_{so}$) 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 ($\mu_{FE}$) was estimated to be about 2.0 V and 1.12 cm$^2$/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$_2$O$_3$ gate oxide was successfully fabricated at room temperature.

![Drain current curves](image)

**Figure 4.** (a) $I_{DS}$ verse $V_{GS}$ 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$_2$O$_3$ 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 cm$^2$/V-s, respectively.

**References**


