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Characterization of magnesium oxide gate insulators grown using RF sputtering for ZnO thin-film transistors

Jong Hoon Lee [a], Hong Seung Kim [a,*], Sang Hyun Kim [b], Nak Won Jang [b], Young Yun [c]

[a] Department of Nano Semiconductor Engineering, Korea Maritime University, Busan 606-791, Republic of Korea
[b] Division of Electrical and Electronics Engineering, Korea Maritime University, Busan 606-791, Republic of Korea
[c] Department of Radio Communication Engineering, Korea Maritime University, Busan 606-791, Republic of Korea

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ABSTRACT

A ZnO thin-film transistor (TFT) with an MgO insulator was fabricated on a silicon (100) substrate using a radiofrequency magnetron sputtering system. The MgO insulator was deposited using the same deposition system; the total pressure during the deposition process was maintained at 5 mTorr, and the oxygen percentage of $O_2/(Ar + O_2)$ was set at 30%, 50%, or 70%. The process temperature was maintained at below 300 °C. The dielectric constant of the MgO thin layer was approximately 11.35 with an oxygen percentage of 70%. This ZnO TFT displayed enhanced transistor properties, with a field-effect mobility of 0.0235 $cm^2\ V^{-1}\ s^{-1}$, an I_{ON}/I_{OFF} ratio of $\sim 10^5$, and an SS value of 1.18 V $decade^{-1}$; these properties were superior to those measured for the MgO insulators synthesized using oxygen percentages of 30% and 50%.

1. Introduction

Oxide semiconductor devices have attracted attention as a replacement for conventional silicon-based devices, and ZnO-based oxide materials are emerging as the next generation of oxide semiconductor materials. ZnO has higher mobility than amorphous silicon-based thin-film transistors (TFTs), and ZnO-based TFTs are suitable for applications that require transparent devices, due to their wide band gap ($E_g = 3.37$ eV). High-dielectric constant (k) materials have been suggested for ZnO TFTs, to allow a sufficient number of charges to accumulate, and reduce the operating voltage [1,2]. The k of MgO is approximately 9.8 [3]. This value can be affected by the growth conditions; specifically, the presence of interstitial oxygen can increase the dielectric constant [4]. MgO thin films grown in an oxygen-rich environment show more oxygen than Mg ions in their composition [4,5]. The Chen group [4] reported the improved mobility of ZnO TFTs, and explained that the reduction of grain boundaries in the ZnO film on the MgO insulator with the excess oxygen ions. Motivated by this, we attempted MgO deposition using RF (radiofrequency) magnetron sputtering, aiming to develop a large-scale process. The maximum process temperature was set not to exceed 300 °C. We also controlled the oxygen percentage in the reactive gas mixtures to induce the reaction between the Mg ions and the O_2.

2. Experimental

The MgO thin layer was deposited on an n-type and low-resistivity (0.005 Ω cm) Si (100) substrate using an RF magnetron sputtering system. Prior to deposition, the silicon substrate was cleaned using acetone and methanol, where each was applied for 5 min in the ultrasonicator. The native oxide (SiO_2) on the Si substrate was removed via the application of a buffered oxide etchant for 5 min. Finally, the sample was rinsed using deionized water, and blown dry using N_2 gas. The working pressure was 5 mTorr. Mixed Ar and O_2 was flowed into the chamber, and was controlled using a mass flow controller. The total amount of gas ($Ar + O_2$) was 20 sccm. The total pressure was maintained at 5 mTorr, and the injected gas mixture was changed by varying the O_2 gas flow, with oxygen percentages of 30% [i.e., $O_2/Ar + O_2$ ratio = 6 sccm/(14 sccm + 6 sccm)], 50%, and 70%. A commercial MgO target (4 inch) was used; the target was sputtered for 10 h using an RF power of 300 W and the deposition temperature set at 300 °C. In general, the deposition method for MgO thin film is difficult to use general RF-sputter system due to MgO has great tolerance for ion bombardment [6]. Moreover, the deposition rate is very slow at low deposition temperature. To overcome this problem, several researches proposed reactive magnetron sputtering or high density

* Corresponding author.
E-mail address: hongseung@hhu.ac.kr (H.S. Kim).

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inductively coupled plasma for deposition of MgO thin film [7,8]. However, in our experiment, even though we used RF magnetron sputtering system, the deposition temperature of 300 °C was too low to get the moderated deposition rate.

The ZnO was deposited on the MgO/Si substrate using RF magnetron sputtering for 30 min. To make the channel region, the ZnO was patterned using a metal mask. The deposition temperature was 300 °C, with an Ar amount of 20 sccm, and a pressure of 5 mTorr. The ZnO thickness was ~60 nm. Ti (10 nm)/Au (50 nm) were deposited using e-beam evaporation, and were patterned using the lift-off technique, as shown in Fig. 1(b). Ag metal was attached on the back side of the Si substrate. With this Au/Ti/MgO/Au/Ti structure, a metal–insulator–metal (MIM) structure was formed on the Corning glass substrate using the same deposition conditions as those used for MgO; the pattern is shown in Fig. 1(c).

3. Results and discussion

Fig. 2 shows the θ–2θ XRD pattern for the fabricated TFT film transistor. A weak MgO (200) peak was observed at $2\theta = 44.4°$. The MgO (200) peak intensities were similar, in spite of the different oxygen percentages. Chen et al. [9] reported that the crystallinity of MgO thin films was affected by the oxygen partial pressure, showing improved crystallinity at low O_2 pressures. However, our results suggested the formation of an amorphous state under low-temperature conditions. The peaks at $2\theta = 34.4°$ and $2\theta = 38.2°$ corresponded to ZnO (002) and Au (111), respectively.

Fig. 3 shows the transmittance of the MgO insulator layer on the glass substrate. The transmittance of the MgO was over 80% in the wavelength range of 300–800 nm. This result revealed the superior transparency in the visual region, regardless of the different oxygen-to-argon percentage deposition conditions.

Fig. 4 shows an AFM image of the MgO film grown on the n^+-Si substrate using an oxygen-to-argon percentage of 70%. The root-mean-square (RMS) surface roughness of the MgO thin films grown on the n^+-Si substrate using oxygen percentages of 30%, 50%, and 70% were measured as approximately 3.42, 3.48, and 3.38 nm, respectively. All of the MgO films grown were relatively smooth. The MgO thin film grown with an oxygen percentage of 70% showed the lowest RMS value.

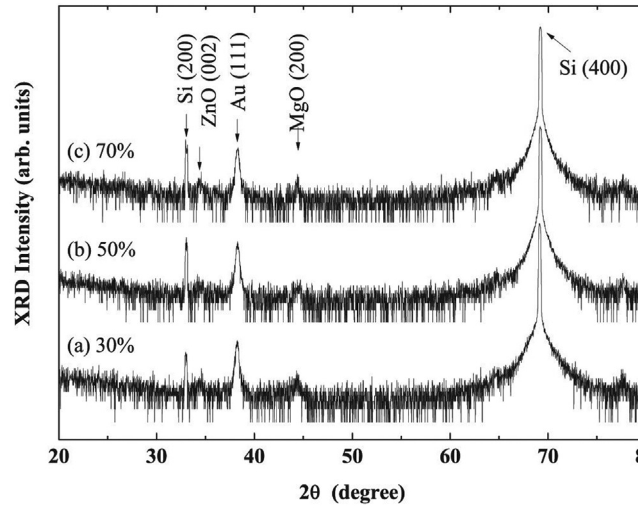

Fig. 2. XRD Θ-2Θ spectra for the ZnO TFT with MgO gate insulators grown with oxygen percentages (in the reactive gas mixture) of (a) 30%, (b) 50%, and (c) 70%.

The thickness of the deposited MgO layer was measured using a surface profiler. The measured thicknesses of the MgO thin films grown using oxygen percentages of 30%, 50%, and 70% were 167, 175, and 207 nm, respectively. These results showed that the interaction between Mg^{2+} and O^{2-} was more active in an oxygen-enrich environment, which explains the increase in the MgO thickness.

Fig. 5 shows the capacitance C–f curve for the MIM structure. At frequencies from 1 kHz to 1 MHz, the capacitance remained almost constant. The capacitance (C) was obtained using an LCR meter (HP4284A), which was controlled using LabVIEW. To investigate

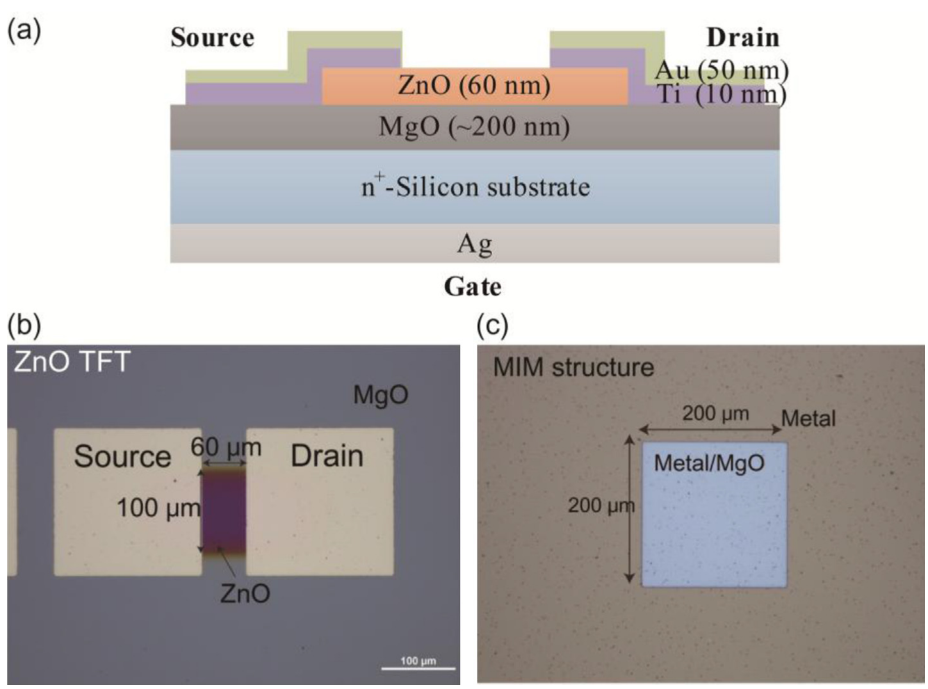

Fig. 1. (a) Schematic of the ZnO TFT, (b) top-view optical image of the ZnO TFT, and (c) MIM structure with a square pattern (w = 200 μm).