2006년도 대한전기학회 전기물성·응용부문회 추계학술대회 논문집 (2006. 10. 27 - 28)

1mm의 채널을 갖는 ZnO 투명 박막 트랜지스터

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Transparent ZnO thin film transistor with long channel length of 1mm

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Abstract - Transparent ZnO thin film transistor (TFT) is fabricated on the glass substrates. The device consists of a high mobility intrinsic ZnO as a semiconductor active channel, Ga doped ZnO (GZO) as an electrode, HfO_2 as a gate insulator. GZO and HfO_2 layers are prepared by using a pulsed laser deposition and intrinsic ZnO layers are fabricated by using an rf-magnetron sputtering, respectively. The transparent TFT is highly transparent (> 87 %) and exhibits n-channel, enhancement mode behavior with a field-effect mobility as large as 11.7 cm^2/Vs and a drain current on-to-off ratio of about 10^5.

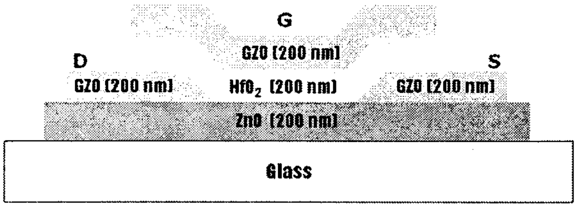
1. Introduction

Transparent electronics have potential opportunities to create next generation optoelectronic devices and invisible computing. The transparent thin film transistor (TFT) is a key device for realizing transparent electronics. In recent years, several ZnO based transparent TFTs have been reported [1-4]. ZnO is one of the most interesting II-VI compound semiconductors with a wide direct band gap of 3.3eV. ZnO normally forms in the hexagonal crystal structure with a = 3.25 Å and c = 5.12 Å [5]. Electron doping in ZnO which is nominally undoped has been attributed to Zn interstitials, oxygen vacancies, or hydrogen. The intrinsic defect levels that lead to *n*-type doping lie approximately 0.01-0.05 eV below the conduction band. Based on these characteristics, transparent TFTs using ZnO as an active channel layers are being explored.

HfO_2 was selected as the gate dielectric as it can be synthesized as thin films at low temperature and exhibits a large band gap sufficient to yield a positive band offset with respect to ZnO [6]. Its wide bandgap (5.68 eV) gives it transparency over a wide spectral range, extending from the ultraviolet to the mid-infrared. The reasons for using high-*k* dielectrics are increasing the physical thickness of the film to reduce electron tunneling and improving a higher permittivity, which would create the capacitance characteristics of a much thinner SiO_2 [7]. Among many candidate materials, HfO_2 is expected to be one of the most promising materials due to its desirable properties: high dielectric constant (~30) and relatively low leakage current [8-9]. In this letter, the fabrication, characterization, and the performance of fully transparent ZnO TFTs with a HfO_2 gate dielectrics is reported.

2. Experimental

Figure 1 shows the structure of coplanar type transparent TFT. The substrates used for these devices were microscope cover glass (Marienfeld). The polycrystalline ZnO channel layer with 200 nm thickness was deposited by using a RF magnetron sputtering in 5×10^{-3} Torr of Ar/O_2 (80 %/20 %) at 500℃. The water-cooled 2-in.-diameter 99.999% pure ZnO target was used. The plasma was activated by a 13.56 MHz and RF power is 100 W. The ZnO thin film exhibits electrical resistivity of 10^4 Ωcm, carrier concentration of 10^{12} cm^{-3}, highly c-axis orientation with a full width at half maximum (FWHM) of 0.22° and smooth surface morphology with a root-mean square (RMS) value below 4 nm. The drain, source and gate are based on highly conductive Ga doped ZnO (GZO) deposited by using pulsed laser deposition (PLD) with a Nd:YAG laser (355 nm, 5 Hz, and FWHM of 6 nm) with a thickness of 200 nm. The target used in this study was the sintered ZnO pellet containing 3 wt. % Ga_2O_3. High quality GZO films with a low resistivity of 3.3×10^{-4} and a transparency above 90 % was able to be formed in oxygen pressure of 30 mTorr at room temperature. HfO_2 deposited by using PLD in oxygen pressure of 100 mTorr at room temperature was selected as the gate dielectric. Shadow masks are used to pattern the ZnO channel and GZO source/drain and gate electrodes. The channel width and length are 8 and 1 mm, respectively, yielding a width-to-length ratio of 10:1.

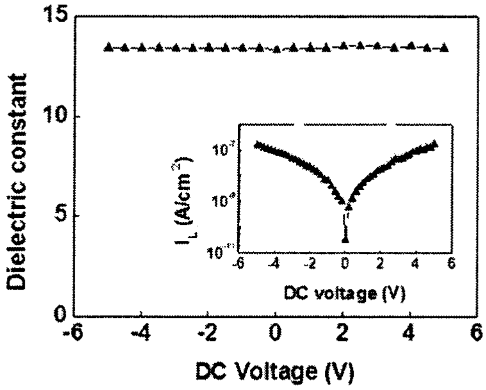


<Fig. 1> Schematic diagram of the coplanar type transparent TFT structure.

The electrical properties were measured by using the four-point probe method. X-ray diffraction (XRD) (Cu Kα) and atomic force microscopy (AFM) were used to characterize the structural properties of the films. The optical transmission measurements were performed using a UV-near IR grating spectrometer (Cary 5G; 175~3300 nm). The current-voltage (I-V) characteristics were measured with a semiconductor parameter analyzer (HP 4145) and capacitance-voltage (C-V) measurements were made with a RLC meter (HP 4284).

3. Results and discussion

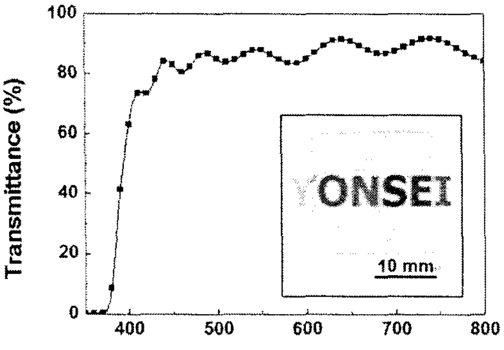
In order to investigate the electrical properties of HfO_2 thin film, we fabricated the metal-insulator-metal (MIM) capacitor on glass substrate. Figure 2 shows the dielectric constant of HfO_2 transparent MIM capacitor.



<Fig. 2> Dielectric constant vs bias voltage for HfO_2 transparent MIM capacitor. The inset shows the J-V characteristics.

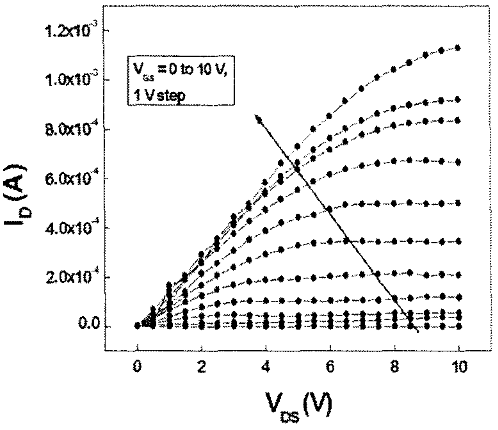
The bottom electrode was made with GZO thin films deposited on glass substrate. HfO_2 thin film was grown for dielectric and the 300-μm-radius GZO dot were patterned with shadow mask for the top electrodes. All the layers were deposited by using PLD at room temperature, and the thicknesses of each layer are 200 nm, respectively. The C - V measurements were performed at 1MHz frequency by sweeping the gate voltage from -5 to +5V. The dielectric constant of this GZO/HfO_2/GZO capacitor measured is about 13. The inset of Fig. 2 shows the leakage current density versus voltage characteristics of this MIM capacitor. The leakage current at 3 V is 4.35×10^{-8} A/cm^2.

Figure 3 shows the optical transmittance spectrum through the entire TFT. The average optical transmittance in the visible region is 87.14 %. The figure inset shows a 2 cm×2 cm glass substrate with four transparent TFTs placed on the background text.



<Fig. 3> Optical transmittance spectrum of a transparent TFT. The inset shows the photograph of the device placed on a background text.

The drain current curves (I_D) as a function of source-drain voltage (V_{DS}) for gate voltages (V_{GS}) between 0 and 10 V are shown in Fig. 4. The output characteristics exhibit clear current saturation and pinch of behavior, as evidenced by the fact that the slope of each I_D curves is flat for large V_{DS}. This indicates that the entire thickness of the of the ZnO channel can be depleted of free electrons [1]. These characteristics are useful for circuit applications that employ this device. The off-currents less than 10^{-9} A is observed and the I_{DS} is increased by the positive V_{DS}. These results support that this transparent TFT operates as an n-channel enhancement mode (normally-off) device. The positive threshold voltages (V_T) were 2~8 V and the on-to-off current ratio is about 10^5.



<Fig. 4> Drain current-drain voltage characteristics for a transparent TFT.

The field effect mobility (μ_{FE}) can be determined from the transconductance value using [10]

$$I_D = \frac{W}{L}\mu_{FE}C_{OX}(V_{GS} - V_T)V_{DS} \qquad (1)$$

where W is the channel width, L is the channel length, and C_{OX} is the capacitance of gate oxide. The obtained field effect mobility is 11.7 cm^2/Vs. Further improvements in device performance are expected to result from the higher quality, intrinsic ZnO thin film and the improved channel-insulator interface.

4. Conclusion

In conclusion, coplanar type transparent ZnO TFT is successfully fabricated on the glass substrates with HfO_2 gate insulator. An n-channel enhancement mode device was realized. The field effect mobility and on-to-off current ratio were 11.7 cm^2/Vs and 10^5, respectively. The average optical transmittance of the in the visible portion is 87.14 %. This improvement in the performance of transparent TFTs may serve as a key technology for realizing invisible electronics.

Acknowledgment

This work was supported by grant No.R01-2004-000-10195-0 (2006) from the Basic Research Program of the Korea Science & Engineering Foundation.

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