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Tunneling condition at high Schottky barrier and ambipolar transfer characteristics in zinc oxide semiconductor thin film transistor

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ABSTRACT

This study investigates the behavior of SiOC as gate dielectric materials for zinc-based oxide semiconductor thin film transistors (TFTs). The SiOC with a high potential barrier due to a low ionic energy at a Poole–Frenkel (PF) contact was suitable for use as a gate dielectric material to support tunneling in ZnO/SiOC TFTs. The performance of the ZnO TFTs for the low-polarization SiOC improved by introducing a direct tunneling phenomenon in the minority carriers of the SiOC depletion layer due to the decrease in the activation energy and the very high Schottky barrier (SB) of the SiOC material. PF emission was achieved at a non-polar SiOC with a high SB, and the mobility-stability of the TFTs with the PF contact dramatically improved. The TFT of the PF contact with a high SB was free from a shift in the threshold voltage with a decrease of the drain voltage.

1. Introduction

The zinc based oxide semiconductor transistor has a potential to be used in electronic devices including the thin film transistor (TFT) backplanes for flexible displays or transparent active matrix organic light emitting diode displays [1–4], because of they offer high conductivity, low resistivity and high transparency in the visible region. However, the oxide semiconductor exhibits the voltage bias stress instability and low mobility compared with conventional polycrystalline Si TFTs. The instability of oxide TFTs has been influenced by the mechanisms of charge trapping or defects located at the localized state. But the conduction mechanism is still ambiguous understanding of TFT's instability. Generally, the reported TFT instability of oxide semiconductor might be related to the environmental effect [5–7], and impurity doping effect [8–10]. The trap electrons in channel layers and deep trap states at a dielectric interface result in the threshold voltage shift during the gate bias voltage. Therefore, the oxide semiconductor transistor has been controlled by the passivation or gate bias stress [11]. Zinc based oxide semiconductor has the characteristics dominated by oxygen vacancies (V_O) and zinc interstitials (Zn_i). Zinc based oxide is usually doped with group three elements such as gallium, aluminum and indium. Impurity doped zinc oxide improved the electrical–optical characteristic [12–15]. Recently, to improve the transistor for optical–electronic applications, it has been reported Schottky and Ohmic contacts of oxide semiconductors by many researchers [16–18]. Understanding of an interface between a channel and a gate dielectric to increase a mobility of TFTs is a key factor to decrease the sheet resistance.

This work provides the correlation between the Schottky contact and PF contact in zinc oxide semiconductor transistor used on SiOC as a gate insulator. To research the Schottky contact between SiOC insulator and channels, the gradient of I_{DS}–V_{GS} curve of TFTs and capacitance of ZnO/SiOC were analyzed. The difference of SB and PF contact was observed from analysis of I_{DS}–V_{GS} curve of ZnO TFTs. To make a Schottky contact at the interface of gate insulator and channel, SiOC was prepared using by various oxygen gas flow rates.

2. Experiment details

ZnO film was deposited at room temperature by RF magnetron sputtering, and SiOC as gate insulators was prepared using different oxygen gas flow rates on p-type Si substrates by RF magnetron sputtering at room temperature [15]. The ZnO targets (99.99% purity) were supplied by ANP Co., Ltd. Al source/drain electrodes were evaporated by a thermal evaporator. The I_{DS}–V_{DS} and I_{DS}–V_{GS} were measured using MIS (metal/SiOC film/Si) structure and mask pattern with diameter of 200 μm. Aluminum was used as the electrode source. The zinc oxide semiconductor can be used as the conducting channel for field effect transistor applications with a variety of gate configuration. The ZnO TFTs was made with backgate configuration on p-doped Si stubstrate and 250 nm thick SiOC. The main advantage of using back-gate

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configuration is the utilization of top surface of zinc oxide for conduction modulation. Electrical characteristics of current versus voltage were measured by the semiconductor parameter analyzer (4155A). Measurements were carried out in dark conditions, in air. Fig. 1 shows the structure of an ZnO/SiOC transistor.

3. Results and discussion

ZnO channel TFTs were prepared on a SiOC dielectric layer to investigate the behavior of the interface between the dielectric and channel materials of the ZnO/SiOC TFTs according to variations in the oxygen flow rates during deposition of the SiOC-film gate insulators. The spatial structure of the Schottky barrier (SB) that forms between the channel and the dielectric layer in a junction device is important to understand the jumping effect of the high mobility transistors.

Fig. 2 shows the capacitance of SiOC for various oxygen flow rates on an n-type Si substrate. In an MIS structure, most samples showed n-type characteristics that depend on the n-type Si substrate due to the presence of amorphous SiOC. The lowest capacitance was obtained for the SiOC sample with 18 sccm of O_2. The reduction in the capacitance was a result of the Schottky barrier (SB) providing a high potential difference that supported the depletion region due to electron–hole recombination. The increase in the SB is related to the reduction in the capacitance of SiOC with the decrease in polarity depending on the oxygen flow rate.

Fig. 3 shows the photoluminescence (PL) spectra of SiOC fabricated with various oxygen flow rates. All of the SiOC were observed to have a main peak at 465 nm, but the intensity varied according to the polarity as a result of the combination of opposite sites generated by a reaction between the oxygen gas and the target source. In particular, the intensities for SiOC 12 and SiOC 20 were observed to increase. The electron emissions were influenced by the ionic bonding strengths and the polarization, resulting in variations in the PL intensities. Therefore, the ionic bonding for SiOC 12 and SiOC 20 can be estimated to have become stronger than that of the others due to the strength of the ionic bonding carriers. The SiOC 14–SiOC 18 samples with low PL intensities were consequently revealed to have a relative decrease in polarity.

Fig. 4 shows the PL of the ZnO deposited on SiOC with various oxygen gas flow rates. All of the ZnO samples were concurrently prepared under the same conditions via RF magnetron sputtering. The main band had a broad band from 350 to 850 with a peak of 650 nm. The peak at 440 nm disappears with a decrease in the polarity of the SiOC, such as for ZnO/SiOC 14, ZnO/SiOC 16, and ZnO/SiOC 18. In particular, the ZnO/SiOC 18 with a PF contact showed a main peak shift from 650 nm to 580 nm. In addition, the PL intensity of ZnO/SiOC 18 abruptly decreased, and the extension in the diffusion currents as minority carriers caused a reduction in the peak at 440 nm and a lower shift in the main peak from 650 nm to 580 nm. The effect of the drift and diffusion currents could be induced from the difference in the SiOC and ZnO/SiOC films analyzed by the PL spectra. The peaks at 440 nm increased when the drift current increased, and the peak at 440 nm decreased only due to the increase in the diffusion current, as shown in Fig. 4(e). The diffusion currents of the ZnO/SiOC 18 film with the lowest capacitance of SiOC exhibited a strong effect, and the PL spectra were found to be proportional to the current density quantified between the drift currents in the ZnO channel and the diffusion currents due to the minority carriers that are ionized in the depletion layer as a result of the electron–hole recombination.

Fig. 5 shows the capacitance of the ZnO/SiOC samples, and the capacitance curve indicates a dependence on the characteristics of the SiOC. In spite of the fact that ZnO was deposited under the same conditions, the capacitances exhibited a variation from that of an n-type to a p-type semiconductor due to the polarization of the SiOC according to the oxygen flow rates and structural mismatch at the interface between ZnO and SiOC. The capacitance of the ZnO/SiOC exhibited n-type characteristics on SiOC with 12 and 14 sccmand p-type characteristics on SiOC with 18 and 20 sccm. The capacitance for ZnO on SiOC 16 showed ambipolar characteristics, as shown in Fig. 5(d). The capacitance for ZnO/SiOC with 14, 16, and 18 sccm was lower than that of the others, and these results were the same as those for the PL intensity, as shown in Fig. 3(c)–(e). For ZnO/SiOC at 18 sccm (Fig. 5(e)), a change from n-type to p-type was observed, and the capacitance with a low width from the top to bottom was the lowest in comparison to that of the other samples. The width from the top to bottom of the ZnO/SiOC capacitance with 20 sccm was higher than that at 18 sccm, and this result means that the ZnO/SiOC capacitance with 20 sccm had a higher polarity than the sample with 8 sccm. The threshold voltage of the zinc-based oxide semiconductor is a critical component that defines the stability for transparent, flexible applications. In general, the shift in the threshold voltage of the oxide semiconductor TFTs limits their applicability. Current technology requires several driving transistors per pixel to compensate for the shift in the threshold voltage, and the use of amorphous SiOC decreases the mismatch rates for the growth of ZnO deposited on SiOC. The Poole–Frenkel contact of amorphous SiOC with a high SB admits tunneling conduction through the diffusion currents of minority carriers in order to improve the performance of the devices [19].

Fig. 6 presents schematic diagrams of the semiconductor contacts and the potential differences (V_p) that depend on the drift as the majority carriers in the ZnO channel and the diffusion currents as the minority carriers in the depletion layer. The depletion layer is formed by diffusion currents and minority carriers, resulting in electron–hole recombination between the

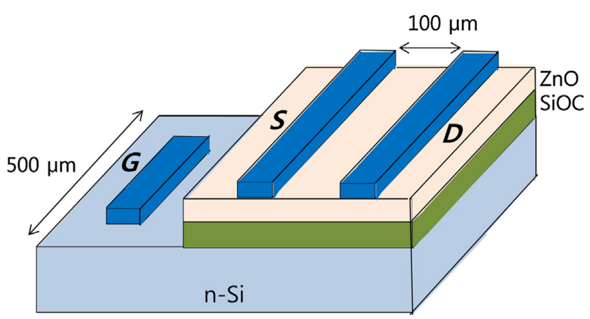

Fig. 1. Schematic diagram of IGZO/SiOC TFTs.

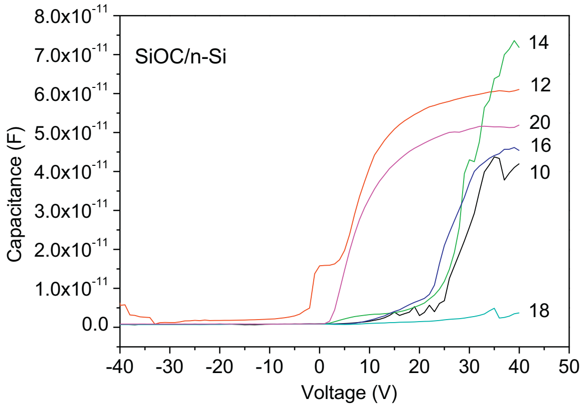

Fig. 2. Capacitance of SiOC with various oxygen gas flow rates.