C-V Characteristics of ZnO Thin-Film Field Effect Transistor Structures Formed on Glass Substrates

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1. Introduction
A wide-gap semiconductor ZnO has attracted considerable attention as promising material for ultraviolet light emitting devices [1]. An even wider area of applications is expected if switching devices can be made of a transparent semiconductor ZnO and integrated with light emitting devices. Quite recently, an invisible thin-film ZnO field effect transistor (FET), which is made on a glass substrate and uses highly conductive transparent materials as gate or ohmic electrodes, has been successfully fabricated [2]. Although these FET's showed a number of advantages besides its high transparency, it is necessary to understand the interface properties of metal-insulator-semiconductor (MIS) structures in order to make them suitable for practical applications. In this work, we investigated the capacitance-voltage (C-V) characteristics of the thin-film ZnO MIS diode to evaluate the properties of the MIS structure.

2. Experimental Method
Sample Structure
Figure 1(a) shows the cross-sectional view of the sample structure. We used ITO (Indium-Tin-Oxide)-coated glass substrate. The ITO is used as a buried transparent gate electrode. On the substrate, a SiO₂ insulating film is formed by using spin-on glass (SOG) (TOKYO OHKA KOGYO: OCD T-7) in advance. The substrate was then loaded into a vacuum chamber, and a polycrystalline ZnO film was deposited by laser ablation method using a KrF excimer [1]. We prepared two kinds of MIS diodes: one is of undoped ZnO which is unintentionally n-doped, while the other is of Li-doped ZnO with high resistivity. An Al electrode (typical size of ~500×500 μm²) was formed to make an ohmic contact to ZnO, and using it as a mask, the rest of the ZnO film was removed by wet-chemical etching. Note that a fringe of the Al electrode touches to the SOG directly as a result of side-etch effect. In the analysis of the result of the C-V characteristics, we took it into account. Finally, a part of the SOG film was removed in order to make contact with ITO. The thickness of each film was measured by a Dektak stylus profiler.

C-V Measurements
The capacitance of the Al/ZnO/SOG/ITO MIS diode was measured by using an impedance analyzer (Hewlett Packard: HP4194A) at room temperature (see Fig. 1). In the C-V measurements, the bias voltage was swept from -7 to 6 V and vice-versa at the sweep-rate of ±0.1–0.22 V/min. The frequency ranged from 100 Hz to 10 MHz. In the transient measurements, we measured C as a function of passed time t after the bias voltage was changed from 10 to -10 and -10 to 10 V, respectively. Before the transient measurements, the

![Figure 1](image_url)
sample was kept biased for a few hours which is long enough to settle the MIS structure in a steady state.

3. Results and Discussion

Figure 2 shows the C-V curve of the Li-doped ZnO MIS diode. For this sample, the thickness of SOG is 4200 Å, and that of ZnO is 800 Å, respectively. It can be seen that C increases when a positive bias $V > 0$ is applied. We observed almost no frequency dependence in the C-V characteristics (not shown). Since it was confirmed that the Li-doped ZnO becomes conductive as $C$ was increased in a FET structure [2], we regarded the saturated capacitance at $V > 0$ as the accumulation capacitance $C_{acc}$. Using the experimental value of $C_{acc}$, we calculated the dielectric constant of SOG and found it to be ~5.5. When $V$ is negative, the Li-doped ZnO film is insulating. Assuming that the ZnO film is fully depleted under the negative bias condition where $C$ reaches its minimum, we estimated the dielectric constant of the ZnO film to be ~ 6.3, which is somewhat smaller than the value (8–9) reported in literature [3].

One notices in Fig. 2, on the other hand, that the C-V curve exhibits a clear hysteresis loop: although the C-V curve does not depend on the frequency above 100 Hz, it depends sensitively on the bias sweeping rate. Similar hysteresis loop was also observed in the C-V curves of undoped ZnO MIS diodes. The direction of the trace of C-V curve suggests the existence of mobile charges in the insulator, rather than deep levels at the ZnO/SOG interface.

The time-constant of the hysteresis in the C-V curve was evaluated by measuring the transient change of $C$ of the undoped ZnO MIS diode. In Fig. 3(a), $C$ is plotted as a function of $t$ in the case when $V$ is changed from 10 to $-10$ V at $t = 0$, and in Fig. 3(b) is plotted $C$ when $V$ is changed from $-10$ to 10 V, respectively. It can be seen that the time constant depends on the change of the polarity of $V$, but in both polarities the MIS capacitor reaches its steady state after $10^7$–$10^8$ s. This also suggests that the hysteresis of C-V characteristics originates from mobile ions in the insulator.

3. Conclusion

In conclusion, we carried out the C-V and C-t measurements of the ZnO MIS structures formed on glass substrates. The features of the C-V curves clearly indicate that the charge accumulation occurs at the ZnO/SOG interface. The hysteresis of the C-V trace with long time constant reveals the existence of mobile charge in SOG, which should be improved for practical FET applications.

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Reference