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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 SiO_2 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 ~500x500 um^2) 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

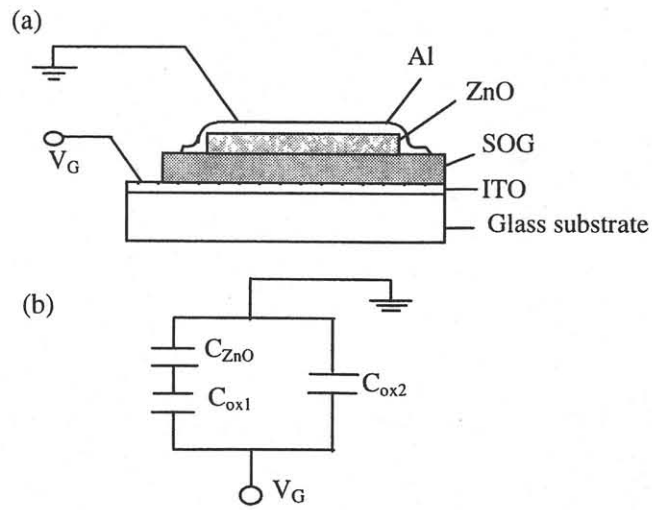

Fig1 (a) A schematic of the sample structure. (b) The equivalent circuit of the MIS diode used in the analysis of the *C-V* data.

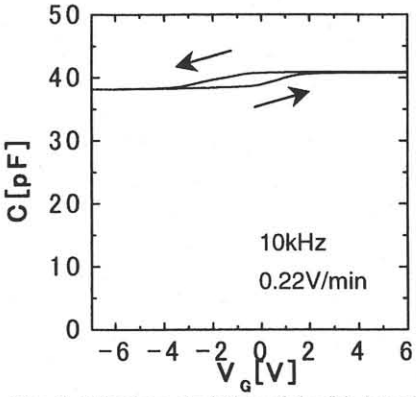

Fig. 2 *C-V* characteristics of the Li-doped ZnO MIS diode.

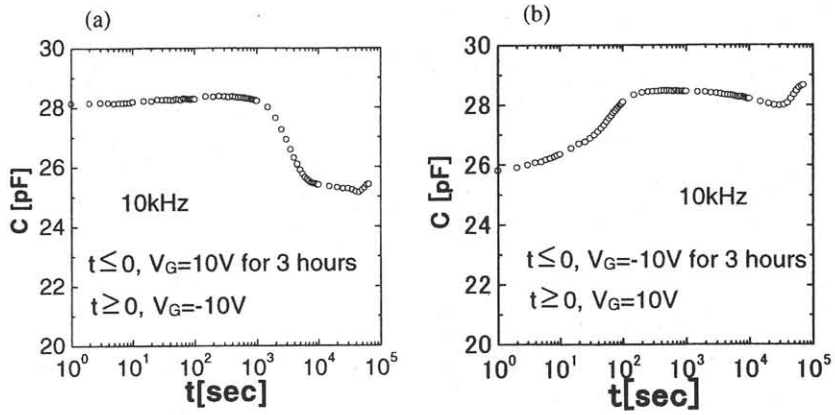

Fig. 3 Transient responses of the undoped ZnO MIS diode capacitance. (a) the bias voltage was changed from 10 to −10 V at t = 0, and (b) −10 to 10 V, respectively.

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 4200A, and that of ZnO is 800 A, 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 $10^2 \sim 10^3$ 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.

Acknowledgement

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