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Electrical Properties of TiO_2 Thin Film and Junction Analysis of a Semiconductor Interface

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Abstract

To research the characteristics of TiO_2 as an insulator, TiO_2 films were prepared with various annealing temperatures. It was researched the currents of TiO_2 films with Schottky barriers in accordance with the contact's properties. The potential barrier depends on the Schottky barrier and the current decreases with increasing the potential barrier of TiO_2 thin film. The current of TiO_2 film annealed at 110°C was the lowest and the carrier density was decreased and the resistivity was increased with increasing the hall mobility. The Schottky contact is an important factor to become semiconductor device, the potential barrier is proportional to the hall mobility, and the hall mobility increased with increasing the potential barrier and became more insulator properties. The reason of having the high mobility in the thin films in spite of the lowest carrier concentration is that the conduction mechanism in the thin films is due to the band-to-band tunneling phenomenon of electrons.

Index Terms: Carrier, Hall mobility, Potential barrier, Schottky contact, Tunneling, ZnO

I. INTRODUCTION

The TiO_2 films are extensively studied because of their physical, chemical, electrical and transparent optical properties. TiO_2 is a high bandgap semiconductor. The TiO_2 is transparent to visible light and has excellent optical transmittance [1-3]. The TiO_2 has high refractive index and good insulating properties, and as a result it is widely used as anti-reflective (AR) coatings, gas sensors, electrochromic displays and memory/logic device [4, 5]. It is usually known that the improvement of mobility of semiconductors was done by the trapping and tunneling effect owing to the high doping at the channel materials [6]. Recently, it was reported the tunneling phenomenon in the depletion layer, which was low dielectric constant insulator as high degree of amorphous structure [7, 8]. The tunneling phenomenon is essential to make a sensor required the high sensitivity [9].

In this study, it was discussed the electrical characteristics and Schottky barrier of TiO_2 films as the high dielectric constant materials to understand of the enhancement of the electrical characteristics by a Schottky barrier at the depletion layer. Specifically, it was researched the annealing effect and potential barriers at an interface for the optimization condition of TiO_2 film to progress the conductivity.

II. EXPERIMENTAL METHODS

The TiO_2 thin films were prepared with an oxygen gas flow rate of 30 sccm by the radio frequency (RF) magnetron sputtering system, and the as-deposited TiO_2 were annealed at various temperatures in a vacuum for 10 minutes. The electrical properties were measured by using the structure of metal/TiO_2/n-type Si wafer. The hall measurement was pre-

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pared to observe the relationship between the potential barrier and contact mechanism.

III. RESULTS

Fig. 1 is the hall mobility of TiO_2 in accordance with the various annealing temperatures. The electrical properties of TiO_2 with various annealing temperatures was researched to discover the relationship between the conductivity of TiO_2 and the annealing temperature.

The hall mobility of the TiO_2 that annealed at 110°C is about $\times 10^4$ cm/V^2. The mobility decreased as the field increased; the mobility of the TiO_2 that annealed at 110°C had the highest mobility.

Fig. 2 is the resistance of TiO_2 in accordance with the various annealing temperatures. Most samples had a resistivity under 2 Ω·cm. The TiO_2 that annealed at 110°C had the highest resistivity (near 4 Ω·cm), as the field that was applied increased from 1000 gause to 5000 gause. The carrier concentration was the lowest when the TiO_2 annealed at 110°C.

Fig. 3 is the carrier concentration of TiO_2 in accordance with the various annealing temperatures. The carrier concentration increased as the annealing temperature increased. When 4000 gause was applied, the carrier concentration was the highest in the TiO_2 that annealed at 150°C. The mobility of the TiO_2 that annealed at 150°C was the lowest, as shown in Fig. 1, and the resistance of the TiO_2 that annealed at 150°C was the lowest as seen in Fig. 2. The high carrier concentration (in um) in the condition of the space limitations is the reason for decreased mobility despite the lower resistivity.

Fig. 4 shows the mobility variation of TiO_2 that annealed at 150°C; the lowest mobility occurred when 4000 gause was applied, despite the high carrier concentration. To observe the variation of the optical properties of TiO_2, photoluminescence (PL) spectra were analyzed.

Fig. 5 shows the PL spectra of TiO_2 thin films with various annealing temperatures. The PL intensity increased as the annealing temperature increased. The half-width of the TiO_2 films that annealed at 150°C and 170°C changed. The half-width of the TiO_2 annealed at 90°C and 110°C are similar to each other, and the highest peaks are located at the similar

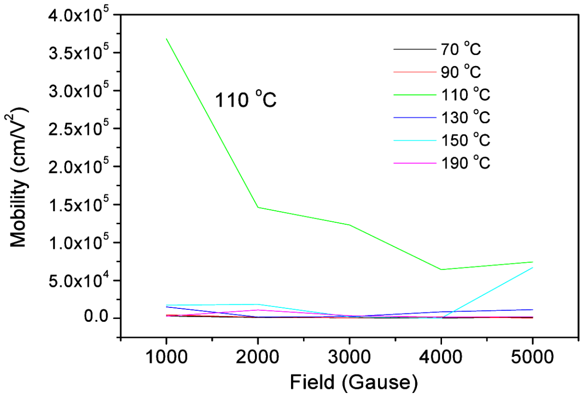


Fig. 1. Mobility of TiO_2 thin films with various annealing temperatures.

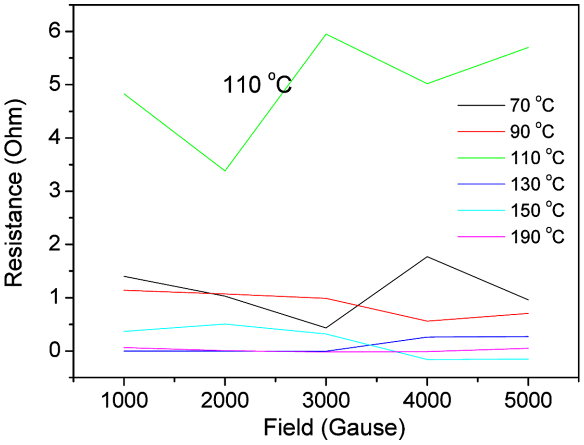


Fig. 2. Resistance of TiO_2 thin films with various annealing temperatures.

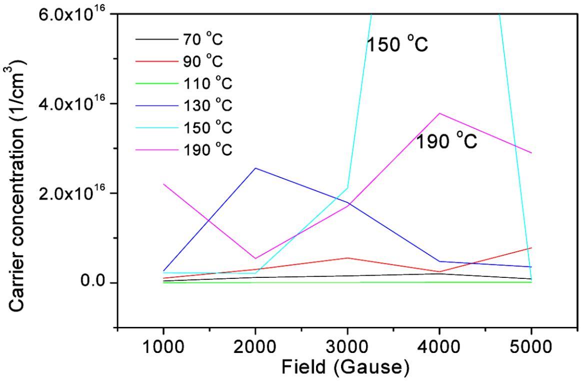


Fig. 3. Carrier concentration of TiO_2 thin films with various annealing temperatures.

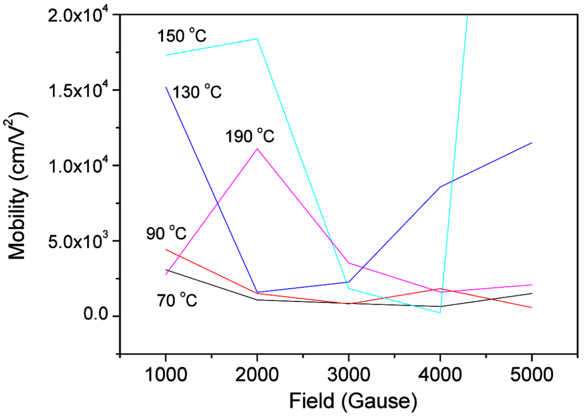
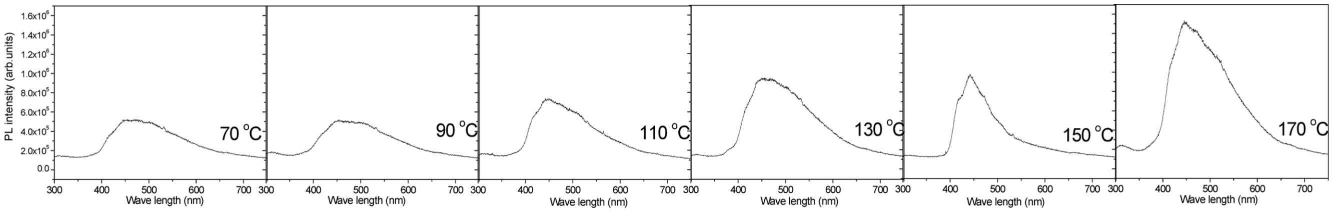


Fig. 4. Mobility variation of TiO_2 thin film that annealed at 150°C.



(a) (b) (c) (d) (e) (f)

Fig. 5. PL spectra of TiO_2 thin films with various annealing temperatures. (a) 70°C, (b) 90°C, (c) 110°C, (d) 130°C, (e) 150°C, and (f) 170°C.

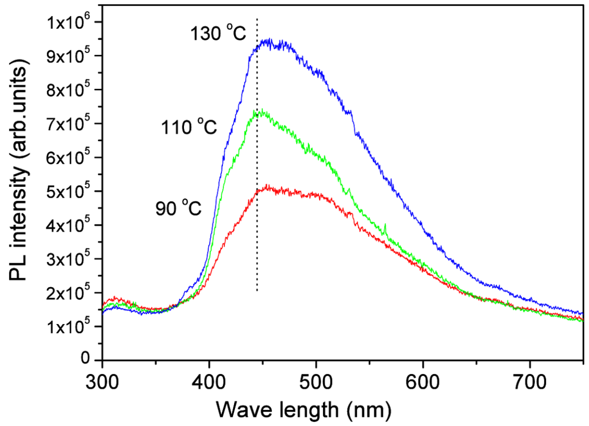


Fig. 6. PL spectra of TiO_2 thin film annealed at 90°C, 110°C, and 130°C.

peak despite the different intensities. However, the full width half maximum (FWHM) of the TiO_2 annealed at 130°C abruptly increased, and the intensity also increased as shown in Fig. 6. The mobility (in um) of thin films is in inverse proportion to the carrier concentration. Finally, for the increment the mobility, the carrier concentration must be decreased.

Fig. 7(a) shows the Schottky contacts of the TiO_2 films near 0 V observed in accordance with the annealing temperatures. It was researched the electrical characteristics of the TiO_2 thin films to understand the contact properties at the interface. The TiO_2 films that annealed at 70°C and 110°C showed low currents as the Schottky barrier, and the TiO_2 films that annealed at 90°C were mostly Ohmic contacts near zero voltage as shown in Fig. 7(b). In Fig. 7(c), in the region of -10 V < voltage < +10 V, the properties of good insulators were shown by the TiO_2 films that annealed at 110°C, which has the Schottky contact.

In Fig. 8, the currents of the TiO_2 films over 130°C with increasing the annealing temperatures increased in regards to the electrical characteristics, though currents under 110°C had a tendency to decrease as temperatures increased. These properties are similar to the PL spectra in that the optical characteristics of the TiO_2 films changed at the annealing temperature of 130°C.

The TiO_2 films that annealed at 110°C showed the characteristics of good insulators. The carrier concentration was

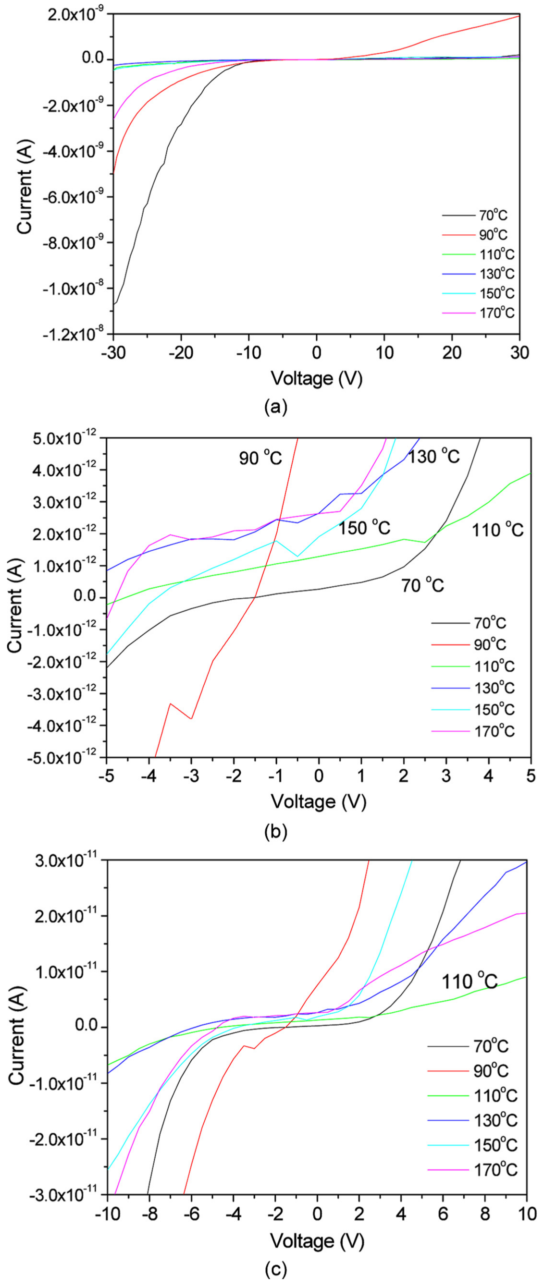


Fig. 7. Electrical characteristics of TiO_2 thin films with various annealing temperatures. (a) Long range, (b) short range, and (c) TiO_2 thin film that annealed at 110°C had the lowest current.

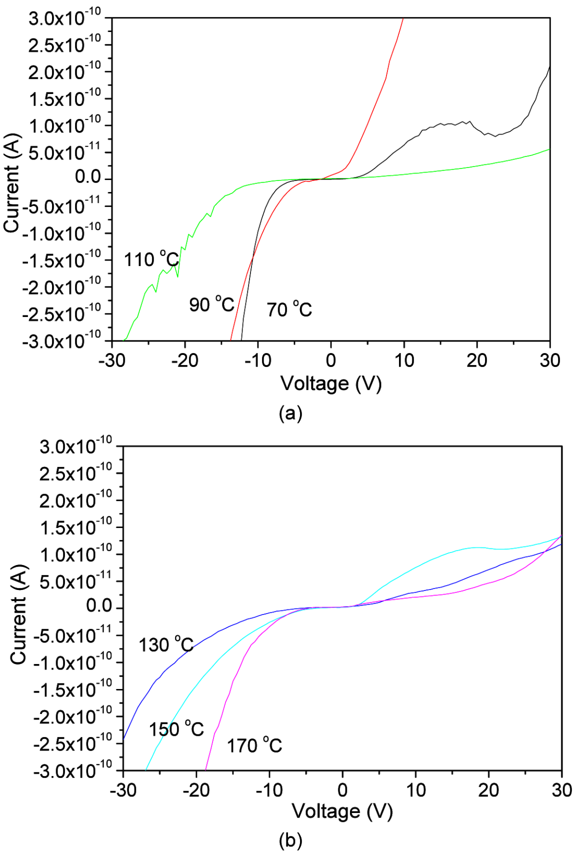


Fig. 8. Electrical characteristics in the negative voltage.

low and the resistivity increased, and therefore, the hall mobility increased. The TiO_2 that annealed at 130°C increased the carrier concentration as shown in Fig. 8(b), had low resistivity, and low hall mobility. The hall mobility depends on the Schottky barrier. The high potential barrier is easily shown in the insulator. Therefore, a low carrier concentration and a high resistivity have the advantage in insulators as dielectric materials [7, 8].

IV. DISCUSSION AND CONCLUSION

To research the electrical properties of TiO_2 in accordance with the junction and contact of semiconductors, the TiO_2 thin films were annealed from 70°C to 170°C in order to make the Schottky contact and depletion layer by the electron-hole (e-h) pair pair recombination. The hall mobility increased at the TiO_2 thin film with low carrier concentrations. The TiO_2 with high hall mobility decreased the current and gained more insulator characteristics due to the high potential barrier. The high carrier concentration in the thin films caused interference of the conductivity because of the space's limitation. It was confirmed that the high potential barrier was due to the Schottky contact, and was the reason for the of hall mobility.

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