The Effect of Microstructure on *I-V* Properties in Si/SiO_2 Film

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ABSTRACT

Si/SiO_2 films were deposited on P-type Si (100) wafers with 8~11 $\Omega \cdot cm$ resistivity using the radio frequency reactive magnetron sputtering technique. Subsequently, ohmic contacts were formed by evaporating Al films onto the backside of all samples and then annealed at 400 ℃ for 30 min in N_2 ambience. Semitransparent circular Au dots with diameters 2mm were deposited using a mask onto the front surface of the samples. Thus, Au/ (Si/SiO_2)/p-Si structures were formed. All *I-V* measurements of nano-size Si/SiO_2 films were performed at room temperature, the experimental results indicated that these kinds of films have rectifying properties, and the reason what reflects on the films presenting this properties was analyzed through experimental results, respectively. We conclude that the nano-structure of the multi-layer films and the thickness of the SiO_2 layer are the primary factors that affect on the *I-V* properties in Si/SiO_2 film.

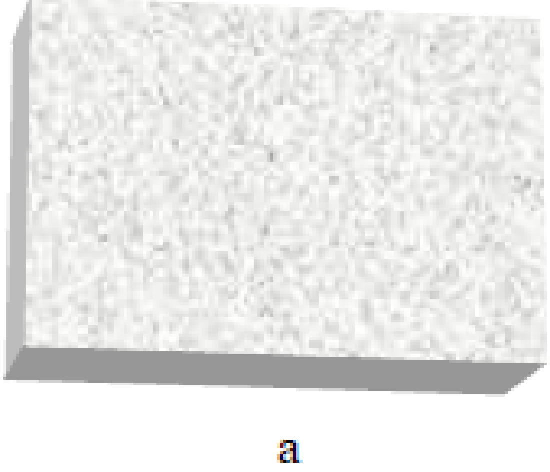
Keywords: R.F magnetron sputtering, nano-size Si/SiO_2 film, *I-V* properties

1 INTRODUCTION

Applications in optoelectronic devices have made the nano-scale Si-based films a field of particular interest in recent years [1-6] since Dimaria *et. al.* [7] fabricated Au/ SiO_2/Si-rich SiO_2 /n-Si structure using the chemical vapor deposition technique. Subsequent to Dimaria, SiO_2 films are being widely used in Silicon integrated circuits as passivation layers and electrical insulation layers. At same time, current carrier study from the SiO_2 films embedded nm silicon particles has recently gained much interest [8]. However, the current carrier mechanism of Si/SiO_2 films need to be further studied.

2 EXPERIMENTS

Si/SiO_2 films were deposited on P-type Si (100) wafers using the radio frequency reactive magnetron sputtering technique. Just before Si/SiO_2 films were deposited, the native oxide layers on Si substrates were removed using 5% hydrofluoric acid, after blow drying by N_2. In order to remove other leftover metal ions and impurity on the surfaces of the substrates, we put it into a hot H_2SO_4:H_2O_2 (1:4) liquor and allow it to cook for approximately 10 min. The Si substrates were then put into the magnetron sputtering device (JGP560B), and three kinds of Si/SiO_2 films were fabricated on these substrates using the R.F magnetron sputtering technique. (a) Si-SiO_2 composite target having a one-fifth area ratio of Si to SiO_2 was adopted, and 10nm thickness of nano-size Si/SiO_2 film was prepared. (b) The Si/SiO_2 film was obtained using the two-target alternation by R.F magnetron sputtering technique. The alternation targets are the high purity polycrystal Si target and the high purity SiO_2 target. In this kind of film, thickness of the SiO_2 and Si are 8 nm and 2 nm, respectively. (c) The four periods Si/SiO_2 films were taken using the two-target alternation by R.F magnetron sputtering technique. A double target was made up of the high purity polycrystal Si target and the high purity SiO_2 target. In this kind of multi-layer films, thickness of the SiO_2 and Si are 2 nm and 0.5nm in one period. During the film fabrication process, the background vacuum of the device was lower than 10^{-5} Pa and Argon and Nitrogen were used as sputtering gases and were introduced in the chamber with a gas flow of 10 ml/min and 6 ml/min. The substrate temperature was fixed at 400 ℃. The thicknesses of the layers were controlled by sputtering power and time, respectively. Fig. 1 presents their profile structures. Subsequently, ohmic contacts were formed by evaporating Al films onto the backside of all samples and then annealed at 400℃ for 30 min in a N_2 ambience. Semitransparent circular Au dots with diameters 2 mm were deposited using a mask onto the front surface of the samples at last. Thus, three Au/ (Si/SiO_2)/p-Si structures were formed. All *I-V* measurements of nano-size Si/SiO_2 films were performed at room temperature.



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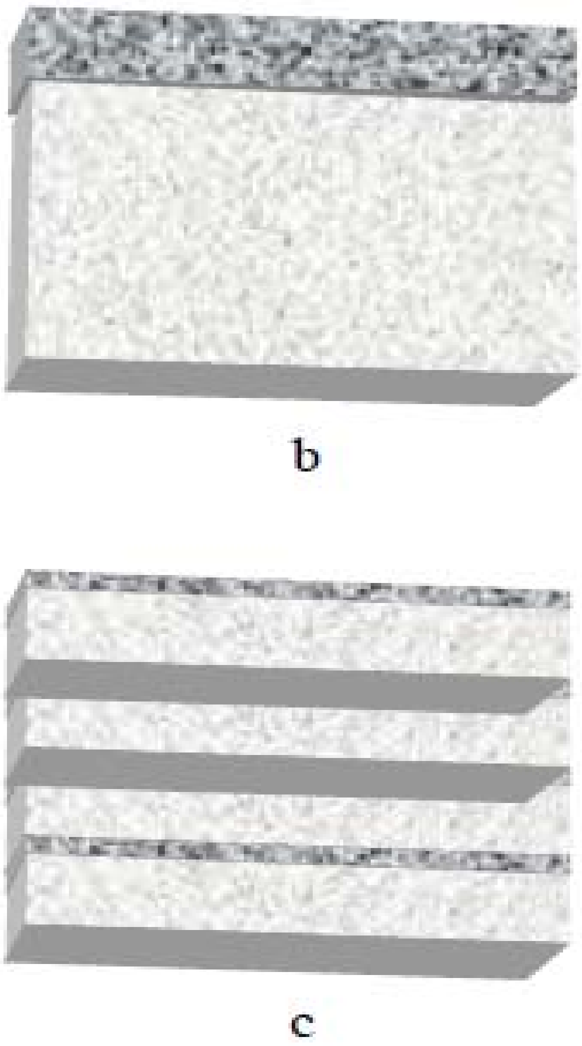

Figure 1: The profile structures of samples.

3 RESULTS AND DISCUSSION

The current-voltage (I-V) dependence was measured using a digital multi-meter. Under forward bias, a positive polarity was applied on the p-type silicon substrate and the gold electrode was negative. The (I-V) characteristics of the Au/ (Si/ SiO_2)/p-Si structures are shown in Fig. 2. The structure has good rectifying properties. All the Au/ (Si/ SiO_2)/p-Si structures contained a periodical SiO_2 layer, so an SiO_2 oxide layer will be formed in the samples. In generally, current tunneling model including Fowler-Nordheim (F-N) tunneling model, direct tunneling model, Frenkel-Poole (F-P) emission model, Schottky emission model, space charge confinement current, ion carrier and ohmic carrier current and so on. In order to understand the behavior better for positive voltage, the above models are employed to explain the current information.

There are five linear tunneling mechanisms:

(1) F-N tunneling model which is assisted by the electric field:

$$\ln\left[\frac{I}{V^2}\right] \propto \frac{1}{V} \tag{1}$$

(2) F-P emission model which is assisted by defect:

$$\ln\left[\frac{I}{V}\right] \propto \frac{1}{V^2} \tag{2}$$

(3) Schottky emission model exists between semiconductor and insulation interferes:

$$\ln I \propto \frac{1}{V^2} \tag{3}$$

(4) Space charge confinement current model:

$$I \propto V^2 \tag{4}$$

(5) Ohmic carrier current model:

$$I \propto V \tag{5}$$

At a forward voltage of V>6V, the F-P emission model, Schottky emission model and F-N tunneling model are consistent with *I-V* properties of Au/ (Si/ SiO_2)/p-Si structures. Experimental results are shown in Fig. 3.

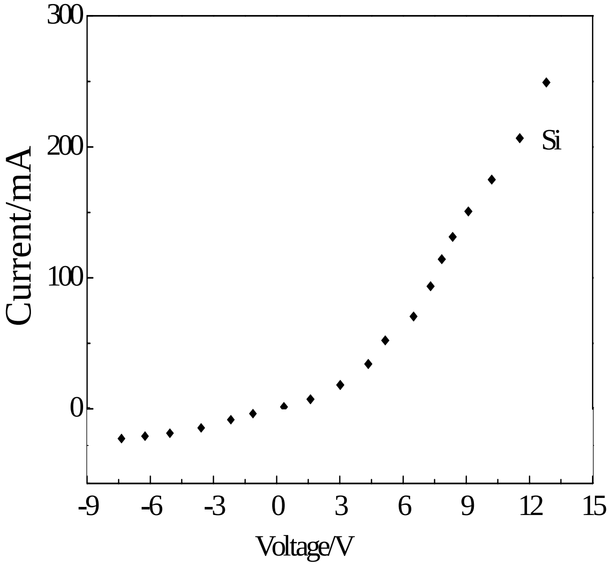

Figure 2: I-V characteristics of the Au/ (Si/SiO_2)/p-Si structures.

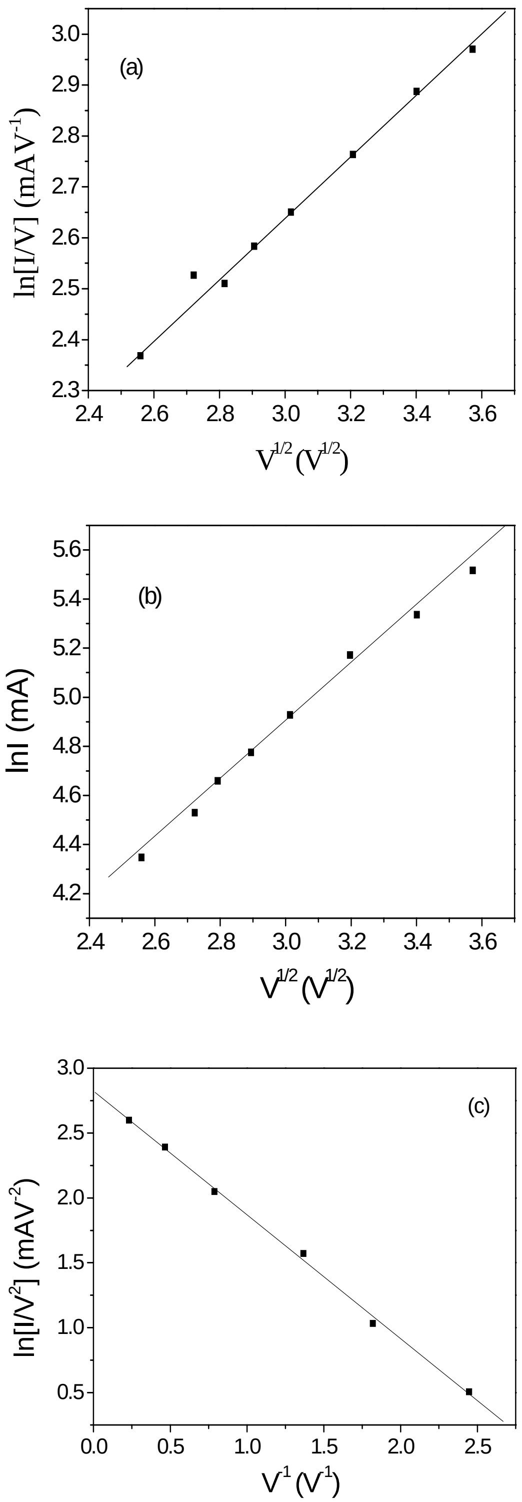

Figure 3: The relationship of linear tunneling model and I-V characteristics at a higher forward voltage.

The main reason is that the sample usually contains various defects, so it is easy to satisfy F-P emission. In addition, the barrier between Si and SiO_2 interfere decreases with the increasing positive voltage, which contributes to Schottky emission current. Finally, the intensity of the electric field is strong for a large forward voltage. The condition of the F-N tunneling is satisfied easily.

At a forward voltage of V<6 V, the F-N tunneling model is consistent with the *I-V* properties of Au/ (Si/ SiO_2)/p-Si structures. Experimental results are shown in Fig. 4.

Direct tunneling is relative to the thickness of oxide layer [9], i.e., the direct tunneling effect is obvious when the thickness of SiO_2 layer is under 2 nm. In this paper, thickness of the SiO_2 and Si is 2 nm and 0.5nm in one period, four periods' multi-layer films are 10 nm. So the direct tunneling effect will be limited. However, the SiO_2 layer is a periodic structure, electron of gold electrode and cavity of p-type Si substrate tunnel by F-N model across SiO_2 layer to form the current.

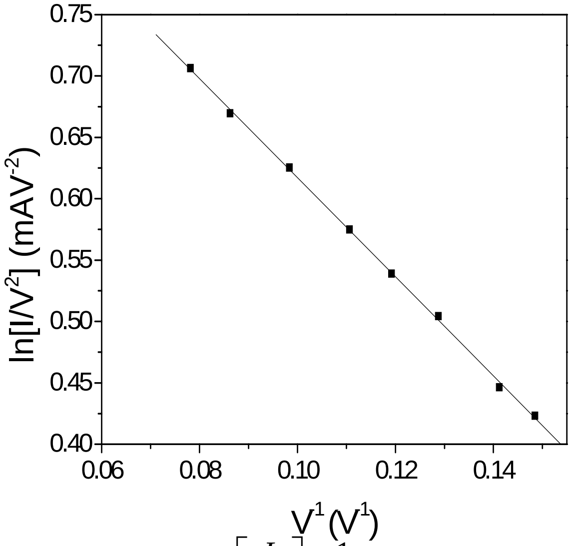

Figure 4: The $\ln\left[\frac{I}{V^2}\right]-\frac{1}{V}$ relationship at a lower forward voltage.

4 CONCLUSIONS

The results indicated that a variety of factors affect the *I-V* properties. The single current carrier model could not explain the *I-V* properties of Si/SiO_2 multi-layer films. The nano-structure of the multi-layer films and the thickness of the SiO_2 layer are the primary factors affecting the *I-V* properties. At a forward voltage of V>6 V, the F-P emission model, Schottky emission model and F-N tunneling model are consistent with the *I-V* properties of Au/ (Si/ SiO_2)/p-Si structures. At a forward voltage of V<6 V, the F-N tunneling model is consistent with *I-V* properties of Au/ (Si/ SiO_2)/p-Si structures.

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