Electrical characterization of Au/ZnO/Si Schottky contact

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Abstract. In this study, temperature dependent current-voltage (I-V) and capacitance-voltage (C-V) measurements have been performed on Au/ZnO/Si Schottky barrier diode in the range 150 – 400K. The room temperature values for ideality factor and barrier height found to be 2.68 and 0.68 eV respectively. From the temperature dependence of I-V, the ideality factor was observed to decrease with increasing temperature and barrier height increased with increasing temperature. The observed barrier height trend was disagreeing with the negative temperature coefficient for semiconductor. A deep defect with activation energy 0.57 eV below the conduction band was observed using the saturation current plot and deep level transient spectroscopy.

1. Introduction

ZnO is very important material for short wavelengths electronic and optoelectronic devices due to its amazing properties of wide band gap of 3.37 eV and exciton binding energy of 60 meV at room temperature [1]. ZnO finds applications in ultraviolet light emitting devices (UVLED), photo-detectors, sensors, thin film transistors and solar cells [2-4]. Most of these ZnO based devices employed Schottky contacts to use them in practical applications. But good rectifying contacts have been difficult to achieve due to the presence interface states [5] between film and metal. Furthermore room temperature I-V and C-V measurements could not explain the transport phenomena. Therefore study on the quality of metal semiconductor junction is very important and needs to be understood thoroughly.

In this study, the transport properties of Au Schottky contacts fabricated on ZnO have been investigated with the help of temperature dependent I-V and C-V characteristics. The measured values of ideality factor and barrier height for Au/ZnO/Si diode were found to be 2.68 and 0.68 eV respectively. The saturation plot was drawn to calculate the activation energy of deep level defects with energy 0.57 eV below the conduction band. Deep Level Transient Spectroscopy (DLTS) measurements were also performed to confirm deep level defect.

2. Experimental

ZnO thin film is grown on p-type silicon wafer by MBE. The detail of growth can be seen elsewhere [6]. After growth Au metal was evaporated by e-beam evaporation to form metal contacts of diameter 1 mm.

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3. Results and discussion

Current in the Schottky barrier diode due to the thermionic emission, neglecting series resistance is given as [7],

\[ I = I_S \exp \left( \frac{qV}{nkT} \right) - 1 \]  \hspace{1cm} (1)

Where \( n \) is the ideality factor and \( I_S \) is the reverse saturation current given by the relation,

\[ I_S = A^*A e^{\frac{-q\phi_0}{kT}} \]  \hspace{1cm} (2)

Where \( A \) is the contact area, \( A^* \) is the Richardson constant and its value is \( 32 \text{ A K}^{-2} \text{ cm}^{-2} \) for \( \text{ZnO} \) [8]. \( T \) is temperature in Kelvin, \( k \) is the Boltzmann’s constant (\( k=1.38 \times 10^{-23} \text{ J/K} \) or \( 8.617 \times 10^{-5} \text{ eV/K} \)), \( q \) is the electric charge and \( \phi_0 \) is the barrier height.

![Figure 1. Current-voltage characteristics of Au/ZnO/Si Schottky diode at different temperatures.](image)

Figure 1 shows the semilogarithmic plot of Au/ZnO Schottky contacts at room temperature. By fitting the linear part of this plot and using intercept and slope, we obtained the value of ideality factor and barrier height using following equations

\[ n = \frac{q}{kT \times \text{slope}} \]  \hspace{1cm} (3)

\[ \phi_{0(1-v)} = \frac{kT}{q} \ln \left( \frac{AA^*T^2}{I_S} \right) \]  \hspace{1cm} (4)
Where \( k = 8.617 \times 10^{-5} \text{eV/K} \), \( T \) is the temperature in Kelvin, \( A \) is the contact area = 0.0314 \( \text{cm}^2 \) and \( A^* \) is the Richardson constant having value 32 \( \text{A K}^{-2} \text{cm}^{-2} \) for ZnO [8, 9].

The measured room temperature value of ideality factor 2.68 and the corresponding barrier height value was 0.68 eV respectively. The value of the ideality factor is greater than unity. High values of \( n \) can be attributed to the presence of the interfacial thin native oxide layer at Au and ZnO interface, a wide distribution of low-Schottky barrier height (SBH) patches (or barrier inhomogeneities), to the series resistance effect and to the voltage dependence of the SBH [10-12].

![Graph between ideality factor versus temperature and barrier height versus temperature of Au/ZnO/Si Schottky diodes.](image)

Figure 2 shows that ideality factor decreased with increasing temperature for both diodes. These decreasing values of \( n \) with increasing temperature, shows that the thermionic transport mechanism is strongly affected in low temperature region or trapped assisted tunneling is responsible for transport mechanism [13, 14].

The plot of temperature versus barrier height \( \phi_{\text{B(1-v)}} \) at the temperature 150 to 400K is shown in figure 2. Like the ideality factor, \( \phi_{\text{B(1-v)}} \) is also seemed to be a strong function of temperature. This is attributed to the fact that ZnO readily forms interfacial layer of thickness of one to two monolayer on its surface which is resulted in the existence of abundant surface states on ZnO [15].
Figure 3. Richardson plot for Au ZnO/Si Scottky diode in the temperature range 150-400K.

Figure 3 show the Richardson plot for the temperature range 150-400K. The value of Richardson constant was found to be 10 AK\(^{-2}\)cm\(^{-2}\). The deviation of Richardson constant from the theoretical value, 32 AK\(^{-2}\)cm\(^{-2}\) is due to the barrier height inhomogeneity effect. The barrier height consists of low and high barrier area at interface. Due to these potential fluctuations at the interface, the current of diode will flow preferentially through the lower barriers in the potential distribution [16].

Figure 4. Saturation plot for Au/ZnO/Si Scottky diode in the temperature range 150-400K.
Figure 4 is the saturation plot in the temperature range 145 to 400K. The activation energy of deep level defect that traps the carrier and can be found by the gradient of linear fit to following equation

\[ I_s = I_o \exp(-E_a/kT) \]  

(5)

Where \( I_s \) is saturation current measured at different temperatures, \( E_a \) is the activation energy of the defect. The activation energy was found to be 0.58eV below the conduction band. To confirm this, we have performed DLTS measurements. Fig. 5 is the DLTS spectra of Au/ZnO/Si Schottky diode. The spectra show one peak with activation energy 0.57 eV below the conduction band.

**Figure 5.** DLTS spectra for Au/ZnO/Si Schottky diode.

4. Conclusion

In this paper, we have investigated the transport properties of Au/ZnO/Si Schottky diode with the help of current-voltage characteristics in the temperature range of 150-400K. From the temperature dependence of I-V, the ideality factor was observed to decrease with increasing temperature and barrier height increased with increasing temperature. The observed barrier height trend was disagreeing with the negative temperature coefficient for semiconductor material that C–V barrier height decreases with temperature. A deep level defect with activation energy 0.57 eV below conduction band was observed from saturation plot and deep level transient spectroscopy.

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