Electrical characterization of Au/ZnO thin film Schottky diode on silicon substrate

Lintu Rajan, C. Periasamy, Vineet Sahula

Malaviya National Institute of Technology, Jaipur, India

Received 28 February 2016; accepted 26 March 2016
Available online 2 April 2016

KEYWORDS
Zinc oxide; Gold; Thin film; Schottky diode; Electrical characterization

Summary
An array of Gold (Au) schottky contacts have been deposited on RF Sputtered nanocrystalline Zinc Oxide thin film. A systematic analysis on the electrical parameters of the Schottky diode with the help of current–voltage (I–V) and capacitance-voltage (C–V) measurements has been done, which confirmed its excellent rectifying characteristics. To incorporate the influence of series resistance in the determination of Schottky diode parameters (barrier height, ideality factor and saturation current), Cheung’s method along with thermionic emission model has also used. The discrepancy in the value of barrier height determined from C–V characteristics throws light into the presence of interface states.

Introduction

The distinct properties of ZnO such as large band gap (3.3 eV), high exciton binding energy (60 meV), good chemical and thermal stability, high mobility of conducting electrons, etc., makes it an excellent candidate for diverse electronic devices applications like gas sensors, lasers, solar cells, photo detectors, LEDs, nano-generators, etc (Neville and Mead, 1970; Tsiarapas et al., 2014; Yadav et al., 2014). ZnO thin film can form excellent Schottky or rectifying contact with high work function noble metals like Pt, Au and Pd and an investigation on the electrical parameters of ZnO thin film Schottky diodes is very crucial to understand the controllability of metal-semiconductor contacts, in the context of its intensive use in electronic device applications (Neville and Mead, 1970; Tsiarapas et al., 2014; Yadav et al., 2014; Aydogan et al., 2009; Periasamy and Chakrabarti, 2009, 2011; Sze, 1981).

The ZnO Schottky contact was first published by Neville and Mead (1970). Yadav et al. (2014) reported the Pd Schottky contact on ZnO using sol–gel technique. Aydogan et al. (2009) used electro-deposition technique to fabricate Au/n-ZnO Schottky diodes on n-type silicon substrate, and investigated its electrical characteristics. Periasamy et al. has studied Pt contact on ZnO thin film using vacuum evaporation and thermal evaporation technique (Periasamy and Chakrabarti, 2009, 2011). We have fabricated an array of Au Schottky contacts on RF sputtered ZnO thin film and have
analyzed Au/ZnO Schottky diode parameters, through $I-V$ and $C-V$ characterization, which can be a potential candidate for many electron device applications.

**Experimental**

The ZnO thin film was deposited on n-Si by RF sputtering system equipped with high purity ZnO target (99.99% pure). The deposition parameters fixed during thin film deposition is given in Table 1.

The deposited ZnO thin film has undergone rapid thermal annealing at 450 °C for 10 min. Au Schottky diodes were then fabricated on ZnO thin film by E-beam evaporation technique, whereas ohmic contact is realized using thermal evaporation of Al on the back side of Silicon substrate. Forward bias and reverse bias $I-V$ and $C-V$ characteristics were obtained by Agilent B1500A semiconductor device analyzer.

<table>
<thead>
<tr>
<th>Table 1 Deposition parameters.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition parameter</td>
</tr>
<tr>
<td>Target to substrate distance</td>
</tr>
<tr>
<td>Vacuum pressure</td>
</tr>
<tr>
<td>Deposition pressure</td>
</tr>
<tr>
<td>RF power</td>
</tr>
<tr>
<td>Argon gas concentration</td>
</tr>
<tr>
<td>Deposition time</td>
</tr>
</tbody>
</table>

**Results and discussions**

$I-V$ characterization

Schematic diagram for the proposed device, used for $I-V$ characterization is shown in inset of Fig. 1(a), whereas Fig. 1(a) shows the $I-V$ characteristics for Au/ZnO Schottky diode, which indicates the Schottky nature of the diode with rectification ratio ($I_f/I_b$) of 93. We have analyzed the $I-V$ characteristics of the proposed Schottky diode using conventional thermionic emission theory, where the empiric parameters of Schottky diode, like ideality factor and barrier height are assumed to be independent of voltage.

The $I-V$ relation is given by (1) (Sze, 1981)

$$I \approx I_0 \left[ \exp \left( \frac{q(V - IR_s)}{kT} \right) \right]$$

where $I_0$ is the saturation current given by $I_0 = AA^*T^2 \exp(-\frac{q\phi_b}{kT})$, $q$ is the electronic charge, $\phi_b$ is the effective barrier height at zero bias, $V$ is the applied voltage, $A$ is the diode area, $A^*$ (32 cm$^2$ K$^2$) is the Richardson constant, $k$ is the Boltzmann constant and $\eta$ is the ideality factor.

The ideality factor, is being measured using the slope of linear region of $I-V$ characteristics, using the relation $\eta = \frac{(dV/d\ln(I))}{I}$, and its value is obtained as 6.28. The large divergence of ideality factor from the ideal value 1, strongly suggests the presence of interfacial layer between metal and semiconductor, current conduction mechanisms other than thermionic emission, like tunnelling, recombination, etc., and presence of barrier inhomogeneities (Aydogan et al., 2009; Sze, 1981). The intercept of $\ln I-V$ curve at the y axis provides the value of saturation current as $1.37 \times 10^{-10}$ A. Effective Barrier height of the Schottky junction is found to be 0.804 eV. It is to be noted that empiric parameters of the Schottky diode were calculated using thermionic emission model, from the low voltage region (linear region) of current–voltage characteristics without incorporating the effect of series resistance. Cheung has derived an alternate method to obtain the Schottky diode parameters, incorporating the effect of series resistance (Aydogan et al., 2009).

Cheung’s functions can be given

$$\frac{dV}{d(\ln I)} = \frac{\eta kT}{q} + IR_s$$

$$H(I) = V - \frac{\eta kT}{q} \ln \left( \frac{I}{AA^*T^2} \right)$$

$$H(I) = \eta \phi_b + IR_s$$

![Figure 1](image-url) (a) In $I-V$ characteristics of Au/ZnO Schottky diode, inset shows schematic diagram of Au/ZnO Schottky diode on Si substrate (b) $dV/d\ln I$ vs. $I$ plot and $H(I)$ vs. $I$ plot.
across frequencies, corresponding in van der Pauw—van der Merwe measurement.
The series resistance $R_s$ has obtained from the slope of $dV/d\ln(I)$ curve and is obtained as $118 \Omega$, where as the Y axis intercept of $H(I)$ vs. $I$ curve will provide the barrier height according to (4) and is obtained as 0.61 eV. The relative difference between the value of barrier heights obtained from the thermionic emission model and Cheung's method suggests the occurrence of series resistance and interface states across metal and semiconductor.

$C−V$ characterization

Fig. 2 elucidates the $C−V$ characteristics of Au/n-ZnO thin film Schottky diode on Si substrate, at three different frequencies. It is clear from the graph that, value of capacitance reduces with the rise in frequency. This can be considered as a proof for the existence of interface states. Interface states, will yield excess capacitance at lower frequencies, since it can easily follow the ac signal at lower frequencies, whereas at higher frequencies, ac signal cannot be easily followed by charge at interface states, resulting in lower capacitance value (Tsiarapas et al., 2014; Aydogan et al., 2009; Sze, 1981).

The $C−V$ characteristics can be investigated by using $C−V$ characteristics of the diode at reverse bias and the corresponding plot at various frequencies depicted in inset of Fig. 2. The depletion layer capacitance, $C$ across the Schottky junction can be expressed as,

$$C^2 = \frac{2(V_{bi} - V - (kT/q))}{q\varepsilon_0\varepsilon_0^2N_d} \tag{5}$$

where $V_{bi}$ is the built-in potential, $\varepsilon_0$ the dielectric constant of the semiconductor ($9\varepsilon_0$ for ZnO), $\varepsilon_0$ is the dielectric constant of vacuum ($8.85 \times 10^{-12}$ F/m), $N_d$ is the concentration of ionized donors and $A$ is the diode area. The slope of $C^2−V$ curve, will provide the carrier concentration, $N_d$ using Eq. (5) and found to be $2.13 \times 10^{13}$ cm$^{-3}$.

Conclusion

We have fabricated Au Schottky diodes on RF sputtered ZnO thin film deposited on n-Si substrate and investigated its electrical characteristics through $I−V$ and $C−V$ characterizations. The $I−V$ characteristics shows the rectifying nature of the diode, with rectifying ratio of 93, ideality factor of $\sim$ 6, barrier height of 0.804 eV and saturation current of $1.37 \times 10^{-10}$ A, which were obtained by assuming thermionic emission model of the Schottky diode. We have also calculated the diode parameters using Cheung’s method incorporating the effect of series resistance. The $C−V$ measurements showed decreasing capacitance with increase in frequency, which was due to the presence of interface states.

Acknowledgments

Authors acknowledge CeNSE, IISc Bangalore where the part of the reported work (fabrication/characterization) was carried out under INUP which have been sponsored by DIT, MCIT, Govt. of India. Authors also acknowledge Materials Research Centre, MNIT Jaipur.

References


