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Temperature Dependent Characteristics of Fe/n-GaN Schottky Diodes

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GaN is one of the most important semiconductor materials, for high-speed and many other applications [1]. It also happens to have small spin-orbit coupling, which suggests that spintronic functionality may be effectively integrated on to it. This would require optimized ferromagnet-GaN Schottky contacts for spin injection or detection [2]. We choose iron (Fe) as a high spin polarization material and investigate for the first time the characteristics of Fe/n-GaN Schottky diodes. We have determined Schottky barrier height, barrier inhomogeneity, and ideality factor from current-voltage (I-V) and capacitance-voltage (C-V) characteristics. We have also determined the effect of temperature on these parameters. We have observed barrier height inhomogeneity which is found to match well with a Gaussian Distribution (GD). We have also extracted Richardson's constant for these diodes. Though thermionic emission is found to be the dominant mode of carrier transport under forward bias condition, electron tunneling may contribute significantly under reverse biased condition.

The heterostructure of the sample used in our study is shown in Fig. 1(a). An undoped GaN buffer layer of 7 μm is grown on sapphire (Al_2O_3) substrate by hydride vapor-phase-epitaxy (HVPE). The Si-doped (n-type) GaN layer (2 μm) is then grown by metal-organic-chemical-vapor-deposition (MOCVD) having a doping density of 1-2$\times 10^{18}$ cm^{-3}. The sample is cleaned and native oxide is removed before depositing Ti(20 nm)/Al(150 nm)/Ni(50 nm)/Au(125 nm) metal stack by electron-beam (e-beam) evaporation and annealing at 775 ^{o}C using rapid thermal annealing (RTA) for the annular low resistance ohmic contact. Fe(50 nm)/Ti (6 nm)/Au(125 nm) Schottky contacts 60 μm in diameter are then deposited at the centre by e-beam evaporation. A micro-photograph of the device is shown in Fig. 1(b).

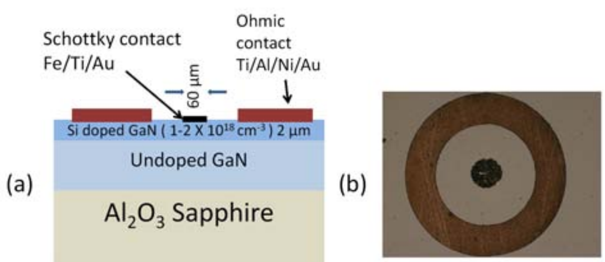

Fig. 1. (a) Schematic heterostructure for Schottky didoes and (b) a micro-photograph of the device are shown.

Capacitance versus reverse bias voltage characteristics of the Schottky diodes are measured at 100 kHz frequency for a temperature (T) range of 300 K to 450 K. The barrier height (Φ_B) and nominal doping density (N_D) are extracted by plotting $1/C^2$ versus V (shown in Fig. 2) and using the expression [3],

$$\frac{1}{C^2} \quad = \quad 2\left(\Phi_B + V - \frac{kT}{q}\right)/(q\epsilon_s A^2 N_D) \qquad (1)$$

where k is the Boltzmann constant, q is the electronic charge, ϵ_s is dielectric constant of GaN, and A is the area. It may be noted that both barrier height (Φ_B = 1.3 eV) and active dopant concentration (N_D = 1.5$\times 10^{18}$ cm^{-3}) change very little with temperature. The active dopant concentration matches well with the nominal doping density 1-2$\times 10^{18}$ cm^{-3}.

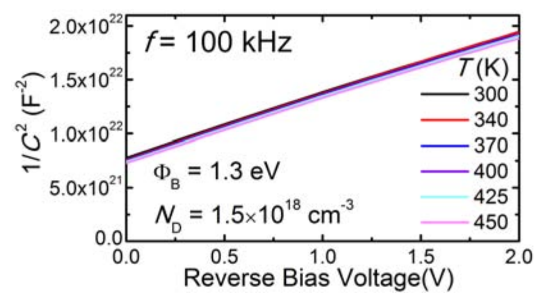

Fig. 2. Capacitance versus voltage characteristics of Fe/n-GaN Schottky diodes under reverse bias condition.

Figure. 3(a) shows the temperature dependent $I-V$ characteristics of the diode. While the forward bias characteristics is a strong a function of temperature, the reverse bias current is relatively insensitive to changes in temperature. This indicates

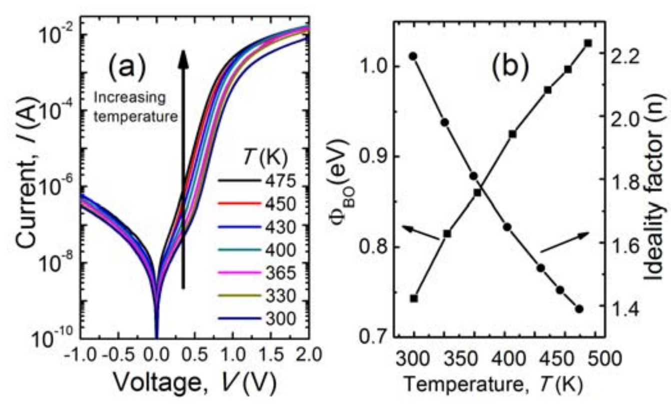

Fig. 3. (a) Temperature dependent current versus voltage characteristics under forward and reverse bias conditions; and (b) zero bias barrier height and ideality factor as a function of temperature for Fe/n-GaN Schottky diodes.

that thermionic emission is the dominant mechanism for electron transport in forward bias and electron tunneling may be dominant process under reverse bias condition. Zero voltage barrier height and ideality factor (Fig. 3(b)) are determined as a function of temperature by considering thermionic emission under forward bias condition as

$$I = \left[AA^{*}T^{2}\exp\left(-\frac{q\Phi_{B0}}{kT}\right)\right]\exp\left[\frac{q(V-IR)}{nkT}\right] \times\left(1-\exp\left[-\frac{q(V-IR)}{kT}\right]\right) \qquad (2)$$

where A^{*} is the Richardson's constant, Φ_{B0} is the zero voltage barrier height, R is the series resistance due to the semiconductor, and n is the ideality factor. The voltage independent prefactor in Eq. 2 corresponds to the reverse saturation current I_0. Φ_{B0} and n as determined from experimental data and Eq. 2 show a strong variation with temperature varying from 0.75 eV to 1.02 eV and 2.2 to 1.4, respectively, as the temperature increases from 300 K to 475 K. The nonideal behavior and smaller barrier height at lower temperature regime indicate the possibility of other mechanism for electron transport and/or the presence of barrier inhomogeneity. In the presence of barrier inhomogeneity, the current will flow mostly through the regions of lower barrier height at low temperature where electrons having lower energy spread can surmount such barrier. This may explain the increasing barrier height and ideal Schottky diode behavior at higher temperatures.

Fig. 4(a) shows the conventional Richardson's activation energy plot i.e ln(I_0/T^2) versus q/kT which should give a straight line. The data in Fig. 4(a) deviates from linearity because of the temperature dependence of both Φ_{B0} and n which arises possibly from barrier inhomogeneity and potential fluctuations at Fe-GaN interface that consists of low and high barrier regions [4,5]. The value of A^{*} extracted from Fig. 4(a) is 1.8×10^{-7} A $\mathrm{cm}^{-2}\mathrm{K}^{-1}$ which is far away from the theoretically predicted value of 26.4 A $\mathrm{cm}^{-2}\mathrm{K}^{-1}$.

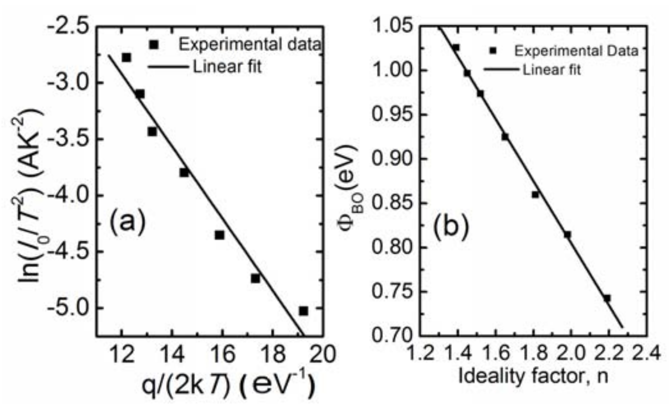

Fig. 4. (a) Determination of barrier height and Richardson's constant for Fe/n-GaN Schottky diodes; and (b) zero-bias barrier height as a function of ideality factor.

To ascertain the presence of barrier inhomogeneity, zero voltage barrier height is plotted as a function of ideality factor (Fig. 4(b)). The linear dependency confirms the presence of barrier inhomogeneity [6]. To estimate the degree of barrier inhomogeneity, we have considered a Gaussian distribution for barrier height having a mean value of $\bar{\Phi}_{B0}$ and standard deviation σ_s. It can be shown that Eq. 2 is then modified as,

$$I_0 = \left[AA^{*}T^{2}\exp\left(-\frac{q}{kT}\left(\bar{\Phi}_{B0}-\frac{q\sigma_s^{2}}{2kT}\right)\right)\right] \qquad (3)$$

where $\bar{\Phi}_{B0}$ is the zero bias mean barrier height. Fig. 5(a) shows that the zero-bias barrier height is linearly dependent on temperature, which is indicative of the presence of barrier inhomogeneity. $\bar{\Phi}_{B0}$ and σ_s as determined from the plot are found to be 1.52 eV and 0.2 eV, respectively. The modified

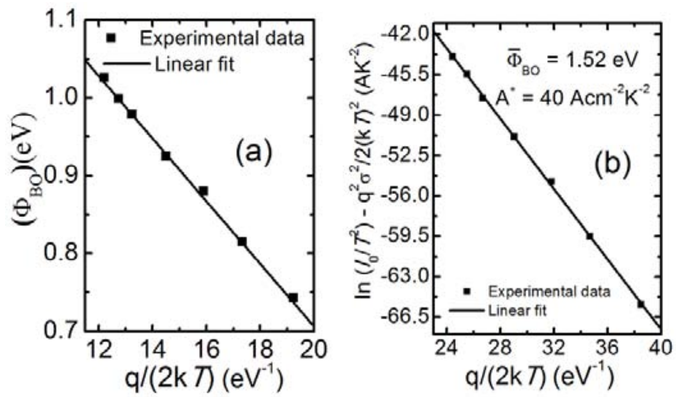

Fig. 5. (a) zero bias barrier height as a function of temperature for Fe/n-GaN Schottky diodes including the effect of barrier inhomogeneity. A linear dependency confirms the presence of such inhomogeneity and (b) Determination of zero bias mean barrier height and Richardson's constant from modified activation energy plot.

plot to determine Richardson's constant including the effect of barrier inhomogeneity is shown in Fig. 5(b). The value for A^{*} is found to be 40 A $\mathrm{cm}^{-2}\mathrm{K}^{-1}$, which is closer to the predicted value. The value of $\bar{\Phi}_{B0}$ extracted here is 1.52 eV which is reasonably close to the value obtained from C-V analysis (Fig. 2).

In summary, we have investigated both experimentally and theoretically Fe/n-GaN Schottky diodes. We have measured I-V and C-V characteristics of these devices. We have observed that the zero-bias barrier height increases and ideality factor comes closer to unity with increasing temperature. We find that barrier inhomogeneity at the interface causes deviation from ideal characteristics. We have extracted the mean barrier height and Richardson's constant by considering the Gaussian distribution in the barrier heights. The estimated Richardson's constant is found to be close to the theoretically predicted value.

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References

[1] *International Technology Roadmap for Semiconductors* (ITRS), 2010. [Online]. Available: http:// www.itrs.net/
[2] J. D. Albrecht and D. L. Smith, Phys. Rev. B 66, 113303 (2002)
[3] S. M. Sze, *Physics of Semiconductor Devices*, 2nd ed. (Willey, New York, 1981)
[4] S. Chand, J. Kumar, Apply. Phy. A, 65 (1995)
[5] M. Siva Pratap Reddy, A. Ashok Kumar, V. Rajagopal Reddy, Thin Solid Films 519 (2011)
[6] R.F. Schmitsdorf, T.U. Kampen, W. Monch, Surf. Sci. 342 (1995)