Electrical parameters temperature characterization of irradiated GaAsN Schottky Barrier Diodes

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Abstract: Temperature dependent transport parameters of irradiated GaAsN Schottky diodes are investigated in temperature range 110K-290K. Extracted parameters are barrier height, series resistance and Richardson constant. Average barrier heights were found to be 1.02(0.72) eV with standard deviation 0.161 (0.096) in 110K-210K and 210K-290K temperature ranges, respectively. Modified Richardson constant was estimated at 32.03 A/cm\textsuperscript{2}K\textsuperscript{2}. Results indicate an inhomogeneous interface with patches having a double Gaussian distribution of barrier heights.

Key words: GaAsN, Schottky diode, Barrier height, series resistance, Richardson constant

Résumé: Les paramètres de transport dépendant de la température des diodes Schottky GaAsN irradiées sont étudiés dans la gamme de température 110K-290K. Les paramètres extraits sont la hauteur de barrière, la résistance en série et la constante de Richardson. Les hauteurs moyennes des barrières sont de 1,02 (0,72) eV avec un écart type de 0,161 (0,096) dans les plages de température 110K-210K et 210K-290K, respectivement. La constante de Richardson modifiée a été estimée à 32,03 A/cm\textsuperscript{2}K\textsuperscript{2}. Les résultats indiquent une interface non homogène avec des régions ayant une double distribution gaussienne des hauteurs de barrière.

Mots clés: GaAsN, diode Schottky, hauteur de barrière, résistance série, constante de Richardson
1. Introduction

Diluted nitride alloys are obtained by incorporating few percent of nitrogen (N) into GaAs semiconductor to obtain GaAsN alloys. This addition of N change fundamental properties of material such as carriers mobility and band gap width, which make this alloys well suited for solar cells fabrication[1], Infra-red lasers devices [2], Terahertz emitters and detectors[3]. Furthermore, GaAsN devices are expected to be used in environments with high radiation like satellite communications, military weapon and nuclear power generation stations. Radiation produces defects in dilute nitride alloys like non-radiative recombination centers at shallow and deep levels in bandgap of semiconductor material [4]. These defects may be responsible for the degradation of optical and electronic properties of materials and devices.

Several researchers have worked on radiation effects in GaAsN Schottky diodes. Shafi et al. [5] have studied the effect of hydrogen irradiation on deep traps in GaAs$_{1-x}$N$_x$ Schottky diodes. They found that hydrogenation of as-grown GaAs$_{1-x}$N$_x$ epilayers passivated most deep levels. However, for sample with 0.8%N concentration, hydrogen irradiation passivated some defects and reduced the concentration of others; it also created new defects. Alsaqri et al. [6] have investigated gamma irradiation effects on Pt/Au/GaAsN Schottky diode using Laplace Deep Level Transient Spectroscopy (LDLTS). They shown that for samples with N =0.2% - 0.4%, number of traps decreased after irradiation, whereas for samples with N = 0.8% - 1.2 %, number of traps remained the same. Bouiadjra et al. [7] have investigated the electrical properties of Pt/Au/GaAsN Schottky diodes with different N% at room temperature. They found that ideality factor and series resistance increase with increasing N% dilution in GaAs accompanied by a decrease in Schottky barrier height. They also found that interface states density greatly increased when dilute nitride N% is increased.

In our previous work [8]we have characterized electrical properties of Ti/Au/ GaAs$_{1-x}$N$_x$ Schottky diodes at room temperature using I-V and C/G-V-f techniques. Investigated
parameters were ideality factor \((n)\), series resistance \((R_s)\), barrier height \((\Phi_B)\), doping concentration \((N_D)\), relaxation time, and density of interface states \((N_{ss})\). We have shown a significant difference in measured barrier height extracted from current-voltage and capacitance-voltage measurements. Nonlinear \((1/C^2 - V)\) plots made it hard to determine donor density as in DLTS [6]. Previous Schottky contact parameters were evaluated from current-voltage and capacitance-voltage measurement at room temperature. However, investigating these electrical parameters at different temperatures allows to determine dominant current conduction mechanism and degree of homogeneity of Schottky barrier interface.

In this work, effects of \(\gamma\)-ray irradiation on electrical properties of GaAsN Schottky diodes over a wide temperature range \([110K-290K]\) is investigated. Phenomena that contribute to electronic transport in gamma irradiated Pt/Au/GaAsN Schottky diodes are investigated using current-voltage-temperature \((I-V-T)\) measurements. By assuming a Gaussian spatial distribution of barrier height at Au/Ti/GaAsN interface, temperature dependent barrier height, effective ideality factor, Richardson constant, and series resistance are deduced.

2. Experimental details

Schottky diodes are made of an n-GaAs substrate on top of which is grown a 0.1\(\mu\)m thick Si-doped \((2.10^{18}\text{cm}^{-3})\) epitaxial buffer layer of GaAsN followed by a 1\(\mu\)m thick Si-doped \((3.10^{16}\text{cm}^{-3})\) epitaxial active layer of GaAsN. At this stage, structures were ion irradiated at room temperature in a gamma cell Cobalt irradiator at a dose of 50 kGy with a 5.143 kGy/h dose rate. Then devices are processed in the form of circular mesas with different diameters for electrical characterization. A Ge/Au/Ni/Au sandwich layer was evaporated and alloyed to form an Ohmic contact to the bottom of n- GaAs substrates. Schottky contacts were formed by evaporation of Ti/Au on top of doped epilayer. Current-voltage \((I-V-T)\) measurements were carried out using an Agilent precision semiconductor parameters
Analyzer (4156C). Device temperature was changed using an ARS Closed Cycle Cryostat.

3. Results and discussion

Fig.1 shows semi-logarithmic current-voltage characteristics of irradiated GaAsN Schottky diodes in 110K to 290K temperature range. It can be seen from Fig.1 that irradiated GaAsN Schottky diodes have a good rectifying property at studied temperature range. Both forward and reverse currents are temperature dependant. These plots clearly depict linearity over several order of current. Further, they progressively become non-linear when temperature is decreased. Deviation from linear current rise at low bias voltage indicates inhomogeneous metal-semiconductor behavior at low bias and low temperature. Such behavior can be explained by electrons being able to surmount lower barriers at low temperature and thus current transport will be dominated by current flowing through patches corresponding to lower barrier height. As temperature increases, more and more electrons have sufficient energy to surmount higher barriers leading to reverse current density, at −1V, going from $1.76 \times 10^{-5}$ Acm$^{-2}$ to $2.71 \times 10^{-4}$ Acm$^{-2}$ when temperature changed from 110K to 290K.

![Fig.1: I-V characteristics temperature dependence of irradiated Ti/Au/ GaAsN Schottky diode.](image-url)
According to thermionic emission theory [8], current can be expressed as [9]:

\[ I = I_0 \left( e^{q(V - R_s I)/nkT} - 1 \right) \]  

(1)

Where \( n \) is ideality factor, \( R_s \) is series resistance, and \( I_0 \) is saturation current given by:

\[ I_0 = A_{eff} A^* T^2 e^{-q\bar{\phi}_0/nkT} \]  

(2)

Where \( A_{eff} \) is diode area \((1.25 \times 10^{-3}\, \text{cm}^2)\), \( k \) is Boltzmann constant \((1.381 \times 10^{-23} \, \text{J/K})\), \( A^* \) is modified Richardson constant \((A^* = \frac{4\pi q k^2 m^*}{h^3} = 48.06 A/cm^2 K^2)\) with \( m^* = 0.04m_0 \) [8]. \( A^* \) is assumed constant after irradiation. \( T \) is temperature in Kelvin. A Matlab program has been written to extract Schottky diode parameters such as barrier height (\( \bar{\phi}_0 \)), ideality factor (\( n \)) and series resistance (Rs).

Extrapolating linear part of semi logarithmic I-V plots to current axis gives reverse saturation current value. From slopes of equation (1) and (2) we can get ideally factor and barriers height, respectively. Series resistance is deduced from equation (1) at high voltage.

Fig.2 shows ideality factor and barrier height variations with temperature. Ideality factor \( n \) decreases with increasing temperature from 13.17 at 110K to 2.74 at 290K. Zero-bias barrier height increases from 0.18eV to 0.51eV when temperature increases from 110K to 290K. Fig.3 shows variation of series resistance as a function of device temperature. \( R_s \) values are found to decrease with increasing temperature.

Fig.2: Ideality factor and zeros barrier height Vs T plots of irradiated Ti/Au/ GaAsN Schottky diodes.
Fig. 3: Series resistance temperature dependence of irradiated Ti/Au/GaAsN Schottky diodes

These barrier height and ideality factor abnormal behaviors with temperature indicate an inhomogeneous interface and may be explained on the basis of a double Gaussian distribution of barrier height. In this case, apparent barrier height is given as [10]:

$$\phi_{b0}(T) = \bar{\phi}_{b0}(T) - \frac{q\sigma_0^2}{2kT}$$  \hspace{1cm} (3)

Where $\bar{\phi}_{b0}(T)$ and $\sigma_0$ are the average barrier height and the standard deviation of barrier height distribution, respectively.

Fig. 4 shows experimental apparent barrier versus $q/2kT$ drawn from experimental data of Fig. 1. There are two lines instead of single one with transition occurring at 210K, which indicates the presence of two Gaussian distributions at contact area. Standard deviation value $\sigma_0$ was found to be 0.161 in 110-210K temperature range and 0.096 in 210-290K temperature range. Average barrier height value was found to be 1.02 eV in 110-210K range and 0.62 eV in 210-290K range. 0.62eV barrier height value is in good agreement with early work [6] undertaken at room temperature. Temperature dependant apparent ideality factor can be expressed as [11]:

$$n^{-1} - 1 = -\rho_1 + \frac{q\rho_2}{2kT}$$  \hspace{1cm} (4)

Where $\rho_1$ and $\rho_2$ are voltage deformation coefficients of barrier height distribution.
Fig. 4 shows the graph of the zeros barrier height and $1/n - 1/2kT$ Vs $2/2kT$ plots of irradiated GaAsN Schottky diodes.

Extracted voltage deformation coefficients of barrier height are $\rho_1 = -0.0021$ and $\rho_2 = -0.81$ in 110-210K range, and $\rho_1 = -0.0093$ and $\rho_2 = -0.25$ in 210-290K range. These voltage deformation coefficients values indicate that Schottky diode interface is more complex than that taken in thermionic emission theory.

Fig.5a shows conventional Richardson constant change with temperature. It shows a great nonlinearity. For a Gaussian distribution of barrier height, conventional Richardson plot can be modified as [12]:

$$ln\left(\frac{I_0}{T^2}\right) - \left(\frac{q^2 \sigma^2}{2k^2T^2}\right) = ln(AA^*) - \left(\frac{q\phi_B}{kT}\right)$$

(5)

Fig.5 shows the graph of Richardson plot and modified Richardson plot of irradiated GaAsN Schottky diodes.

Fig.5B shows modified Richardson constant change with temperature. The presence of two linear regions can be explained by lateral inhomogeneity of barrier height and potential fluctuations at interface that consists of low and high barrier areas [11].

From plot straight lines, mean zero bias barrier heights...
were obtained and are 1.08 eV in 110K-210K temperature range and 0.70 eV in 210K-290K range. Intercepts give Richardson constant, respectively, $21.46 \times 10^{-2} A/cm^2K^2$ and 32.03 $A/cm^2K^2$ in 110K-210K and 210K-290K temperature ranges. $A^*$ is found to be lower than theoretical value of $48.06 A/cm^2K^2$ . This is believed to be due to electrically inactive defects at low temperature [13], traps being passivated when contact is exposed to gamma radiation and/or increase in effective mass due to N incorporation[14].

4. Conclusion

Current transport mechanism of irradiated GaAsN Schottky diode has been investigated using current-voltage-temperature (I-V-T) measurements in temperature range (110K-290K). Schottky barrier height, ideality factor, series resistance and modified Richardson constant parameters were all found to be temperature dependant. Barrier height increased and ideality factor decreased with increasing temperature showing the existence of an inhomogeneous interface. This inhomogeneity can be described by a double Gaussian distribution of barrier heights with an average barrier height of 1.02(0.72) eV and standard deviation of 0.161 (0.096) in 110-210K and 210-290K temperature ranges, respectively. In addition, modified Richardson constant was estimated at 32.03 $A/cm^2K^2$. Non ideal I-V characteristic behavior in forward bias could successfully be explained in term of thermionic emission with double Gaussian distribution of barrier height.

References


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