Physica B xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Physica B

journal homepage: www.elsevier.com/locate/physb

Room temperature current-voltage (I-V) characteristics of Ag/InGaN/n-Si Schottky barrier diode

Erman Erdoğan[a,*], Mutlu Kundakçı[b]

[a] Department of Physics, Faculty of Art and Science, Muş Alparslan University, Muş 49250, Turkey
[b] Department of Physics, Faculty of Science, Atatürk University, Erzurum 25240, Turkey

ARTICLE INFO

Keywords:
Current-voltage characteristics
Ag Schottky contact
InGaN
Room temperature
Schottky barrier diode
Thermionic vacuum arc (TVA)

ABSTRACT

Metal-semiconductors (MSs) or Schottky barrier diodes (SBDs) have a significant potential in the integrated device technology. In the present paper, electrical characterization of Ag/InGaN/n-Si Schottky diode have been systematically carried out by simple Thermionic method (TE) and Norde function based on the I-V characteristics. Ag ohmic and schottky contacts are deposited on InGaN/n-Si film by thermal evaporation technique under a vacuum pressure of 1×10^{-5} mbar. Ideality factor, barrier height and series resistance values of this diode are determined from I-V curve. These parameters are calculated by TE and Norde methods and findings are given in a comparetive manner. The results show the consistency for both method and also good agreement with other results obtained in the literature. The value of ideality factor and barrier height have been determined to be 2.84 and 0.78 eV at room temperature using simple TE method. The value of barrier height obtained with Norde method is calculated as 0.79 eV.

1. Introduction

III-nitrates are materials that have direct and large band gaps and they are suitable for various electronic and optoelectronic applications [1]. They provide several advantages such as; ability to stand wide area of electric field, low loudness generation, high breakdown voltage, high temperature and high power operation due to their large band gaps [2]. InGaN have been broadly investigated for electro-optical devices, solar cells, light emitting diodes (LEDs), high electron mobility transistors (HEMTs) and rectifiers [3].

One of the most widely used rectifying structures are metal semiconductors (MS) or Schottky barrier diodes (SBDs). Schottky contacts with large Schottky barriers and good stabilization at certain temperature are essential to the implentation for electronic based devices. Electrical characteristic of such diodes (Schottky diodes) are affected by several conditions that far away from idealities. For example, the presence of the special distribution of interface states, interfacial oxide layers between metal and semiconductor [4], type of applied voltage, device temperature and the type of semiconductor, series resistance, which is the resistance that against the diode current of the neutral region formed on the side of semiconductor. This effect starts to become the dominant in large voltage, and causes the drop of diode currrent [5].

There is a wide range of carrier transport mechanism in metal semiconductor (MS) strustures, such as; thermionic emission (TE), thermionic diffusion emission (TED), quantum based thermionic field emission, recombination in the neutral and depletion region. TE method in Schottky contacts means that carries gaining enough thermal energy pass from metal to semiconductor or vice versa over the potential barrier. The usual dominant transport mechanism in schottky barriers is basic TE [6]. For the forward bias, by not taking account of the effect of minarity carriers on the $V > 3kT/q$ and the account of the R_s, TE method is valid over InGaN SBDs.

Various experimantal and theoritical studies have been reported about electrical properties of InGaN Schottky diodes using a variety of different contacts and structures in the literature. In these studies, Schottky barrier properties were calculated using current-voltage (I-V) relations. Because of defects occur on surface and getting achivements of high-quality contacts of InGaN materials, diffuculties appear making good InGaN Schottky diodes [7].

Jang et al. [8] studied the electrical properties of Pt/n-InGaN Schottky diodes using current–voltage-capacitance (I-V-C) measurements. They reported that there was a significant change in the Schottky barrier heights acquired by the TE and TFE modes using I–V data. Shao et al. [9] investigated the mechanisms of current transport in InGaN metal–insulator-semiconductor (MIS) structures with two distinctive seperating layers of Si_3N_4 and Al_2O_3. They reported that the photoelectric sensitivity of metal–Si_3N_4–InGaN structure was lower

* Corresponding author.
E-mail address: e.erdogan@alparslan.edu.tr (E. Erdoğan).

http://dx.doi.org/10.1016/j.physb.2016.11.005
Received 18 July 2016; Received in revised form 17 October 2016; Accepted 7 November 2016
Available online xxxx
0921-4526/

than the metal–Al_2O_3–InGaN one. Reddy et al. [10] studied properties pertaining to structure of Ir/n-InGaN Schottky diodes as a temperature dependent. Arslan et al. [11] investigated the current-transport mechanism in the Pt/p-InGaN and Pt/n-InGaN Schottky contacts. They found that the prevailing system of the charge transport through the Pt/p-InGaN and Pt/n-InGaN Schottky contacts were electron tunneling to deep levels within the wide temperature range of 80–360 K. Another study have been investigated by Padma et al. [12] revealed that annealing effects play a key role on the electrical and structural properties of Ir/Ru Schottky contacts to n-InGaN. Chen et al. [13] reported that the thermionic emission is a usual current transport mechanism at the Pt/n-InGaN interface. Jun-Jun et al. [14] fabricated Au/Pt/$In_{0.2}Ga_{0.8}N$/GaN heterostructure Schottky solar cell, reported that the thermionic emission is a prevailing mechanism of current carriers at the Pt/InGaN interface. Reddy et al. [15] studied the detailed electrical properties of very quickly annealed Ir and Ir/Au Schottky contacts on n-InGaN. They found that 300^0 C was the optimum annealing temperature for both Ir and Ir/Au Schottky contacts on n-InGaN. T.T.A. Tuan et al. [16] investigated temperature dependent transport behavior of n-InGaN/p-Si heterojunction diode by means of I-V measurement. They calculated the barrier height, ideality factor and series resistance of diodes using simple TE and Cheung's methods. J.W. Ager et al. [17] studied MBE-grown InGaN films and they fabricated two types of junctions with diffrent substrates. Ohmic junctions are formed with p-type Si and schottky junctions are formed with n-type Si. They reported that InGaN devices with AlN buffer layer have lower series resistance compared to others. Li et al. [18] characterized InGaN schottky photodiode with oxidized Ir contact. They found that oxidation process plays an important role for performance of the photodiode by enhancement the barrier height and improvement of schottky contact transmittance. M.Kumar et al. [19] fabricated InGaN/Si hetero structures and analyzed current-density-voltage characteristics as a function of temperature. They suggested that thermionic field emission can be valid for current transport in these heterojunctions. T.T Anh Tuan and D.-H. Kuo [20] studied n-InGaN/p-GaN junction diode and they used TE method, Cheung's method and Norde function to analyze temperature dependent I-V measurements.

The aim of the present study is to investigate the electrical properties of Ag/InGaN/n-Si Schottky diode using current–voltage (I–V) measurements at room temperature. Basic TE and Norde method were used to characterize the Ag/InGaN/n-Si Schottky diode.

2. Experimantal details and electrical measurements

The Ag/InGaN/n-Si structure was used in this research work. InGaN film on Si substrate was grown by thermionic vacuum arc (TVA), a plasma deposition technique, with very short production time being 40 s. The film was deposited at 10^{-6} *torr* working pressure, 18 *A* filament current. Plasma was produced at 200 *V*, 0.6 *A* plasma current. Microstructure of sample was analyzed by X-ray diffractometer (XRD). The structure and surface morphology of deposited InGaN thin film were determined by scanning electron microscopy (SEM). Compositional analysis was done by energy dispersive X-ray spectroscopy (EDAX). The elemental analysis results showed that In composition is 10.92% in the InGaN alloy. The thickness of deposited InGaN film was measured using an interferometer and the thickness measurement system Filmetrics F20. The average thickness of the thin film was found to be about 250 nm. Properties of thin film of InGaN mentioned above have been already published [21]. The InGaN film on Si substrate was first ultrasonically cleaned with acetone and methanol for 5 min each. Before ohmic contact formed on the film, the sample was dipped in dilute [HF:H_2O=1:5] for about 5 min to remove the surface oxides and then rinsed in deionized (DI) water and dried with high purity nitrogen and inserted into the deposition chamber immediately after cleaning. Ag was deposited on one side top portion of the InGaN/Si as ohmic contact using thermal evaporation system under a vacuum pressure of 1×10^{-5} mbar. The sample was then annealed at 300 ^{0}C in N_2 ambient for 3 min. Ag was deposited through shadow mask on top of the InGaN/Si for Schottky contact by thermal evaporation technique at 1×10^{-5} mbar. The current-voltage (I-V) characteristic of Ag/InGaN/n-Si Schottky contact was measured using Keithley 2400 source. The cross-sectional wiew of the fabricated Ag/InGaN/n-Si diode is shown in Fig. 1.

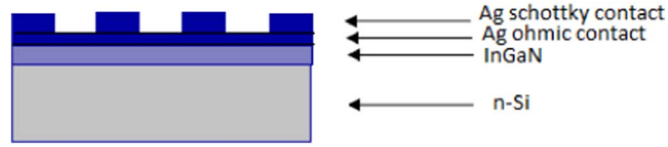

Fig. 1. Schematic cross-sectional wiew of the Ag/InGaN/n-Si MS diode.

The current through Ag/InGaN/n-Si structure with the series resistance in the forward bias is given by thermionic emission theory (TE) [22],

$$I=I_0 exp\left(-\frac{q\phi_{bn}}{kT}\right)\left[exp\left(\frac{q(V-IR_s)}{nkT}\right)\right] \tag{1}$$

where T is thetemperature in terms of Kelvin, k is the Boltzman's constant, n is the ideality factor, V is the voltage, q is the electronic charge and the I_0 is the saturation current and is given below,

$$I_0=AA^*T^2exp\left(-\frac{q\phi_{bn}}{kT}\right) \tag{2}$$

Where ϕ_{bn} is the barrier height, A is the diode area, A^* is the Richardson constant, which is 112,5 cm^{-2} K^{-2} for n-type Si. ϕ_{bn} is defined as,

$$\phi_{bn}=\frac{kT}{q}ln\left(\frac{AA^*T^2}{I_0}\right) \tag{3}$$

Saturation current I_0 from Eq.(2), is determined by extrapolating the linear region of the curve to zero voltage and the barrier height is determined from Eq.(3).

The ideality factor is important parameter for diode characteristic calculated from the slope of the linear region of the I-V forward bias characteristics and is given as,

$$n=\frac{q}{kT}\left(\frac{dV}{dlnI}\right) \tag{4}$$

Another method used in this study to obtain diode parameters is Norde method [23]. Using this method series resistance and barrier height can be determined.

$$F(V)=\frac{V}{\gamma}-\frac{kT}{q}ln\left(\frac{I(V)}{AA^*T^2}\right) \tag{5}$$

where γ is the first integer value gerater than n, I(V) is current obtained from I-V characteristics. Schottky barrier height can be calculated after finding minimum value of the F versus V plot. Barrier height can be determined via below equation,

$$\phi_b=F(V_0)+\frac{V_0}{\gamma}-\frac{kT}{q} \tag{6}$$

where $F(V_0)$ is the minimum point of F(V), and V_0 is the minimum voltage which corresponds to $F(V_0)$. Series resistance is given,

$$R_s=\frac{kT(\gamma-n)}{qI_0} \tag{7}$$

where I_0 is current of minimum point of F(V) value.

3. Results and discussion

Fig. 2 depicts ln I-V curve of our Ag/InGaN/n-Si rectifying device at

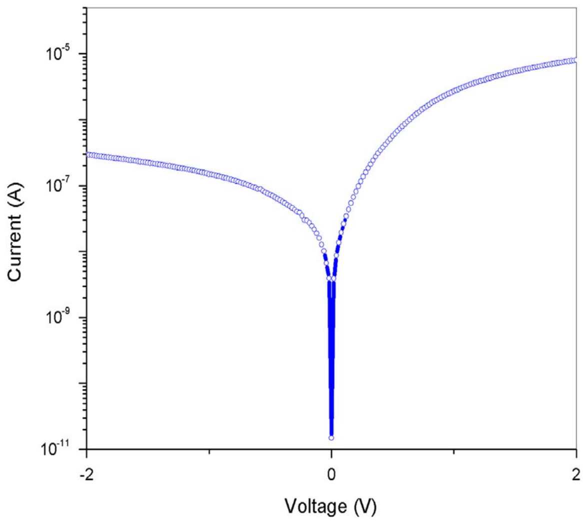

Fig. 2. I-V characteristic of the Ag/InGaN/n-Si Schottky diode.

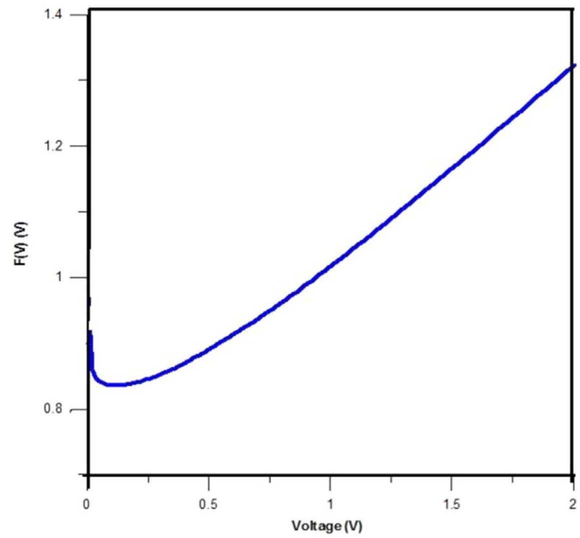

Fig. 4. F(V) versus V plot of the Ag/InGaN/n-Si diode.

room temperature and in the dark. As can be seen from Fig. 2, the diode exhibits rectifying behavior. Ideality factor of this schottky structure is larger than one because of the series resistance that dominates the current curve in forward bias. High values of n can be referred to barrier non-homogeneties, interfacial oxide layers and etc.

The experimental values of barrier height and ideality factor were calculated from the straight line fit in current axis and the slope of the linear region using Eqs. (3) and (4), respectively. The value of ideality factor and barrier height have been determined to be 2.84 and 0.78 eV at room temperature using simple TE method. Ideality factors and barrier heights were determined to be 2.90 and 0.62 eV for as-deposited Pt contact on InGaN [8]. n value of this structure is so closed to our result. n=1.60, ϕ_b=0.79 eV for as-deposited Ir contact on n-InGan [10]. Barrier height value of this diode is completely consistent with the result calculated here. n=1.93, ϕ_b=0.61 eV for as-deposited Ir/Ru contacts on n-InGaN [12], n=1.6, ϕ_b=0.79 eV for Ir contact and n=1.53, ϕ_b=0.70 eV for Ir/Au contact on *n*-InGaN [15].

In reverse bias of I-V characteristics, the current through the diode is contanst for a large value of applied voltage. The diode rectification ratio is computed from the ratio of forward and reverse current at a certain voltage value. This ratio is proportional of quality of diode. Fig. 3 exhibits rectification ratio versus voltage (RR-V) curve of Ag/InGaN/n-Si structure.

Series resistance gives favourable informations about electrical behavior of Schottky diodes. Thus, we used Norde function as an efficient method to evaluate barrier height and series resistance of our diode. Fig. 4 shows the F(V)-V plot of the our Ag/InGaN/n-Si rectifying diode. In the calculations for our Schottky diode, F(V_0), minimum point of F(V), is found to be 0.7772. V_0 is correspondes to this V value and found to be 0.12 V. The value of barrier height obtained with the help of these values and from Eq. (6) is calculated as 0.79 eV, which is very good agreement with value of barrier height obtained using simple TE method. For as-deposited Ir/Ru contacts on n-InGaN, barrier height was found to be 0.63 eV using Norde function [12]. For as-deposited Ir contact on n-InGaN, ϕ_b=0.81 eV, which is in good agreement with that calculated by us. In same study, for as-deposited Ir/Au contact ϕ_b=0.73 eV [15]. Series resistance in Norde method is determined using Eq. (7). For our diode, for 0.21 V, I_0 is calculated to be 3.446×10^{-8} A and using these values series resistance is determined to be 120 kΩ. Obtained parametes are given in Table1. The large value of series resistance can be attributed to non-ideality of the ohmic contact. Current transport of metal-semiconductor structure is dependent the temperature. At room temperature, electrons flow across with low barriers with high ideality factor. If temperature increases, barrier height will increase, this corresponds to decreasing of free charge carriers.

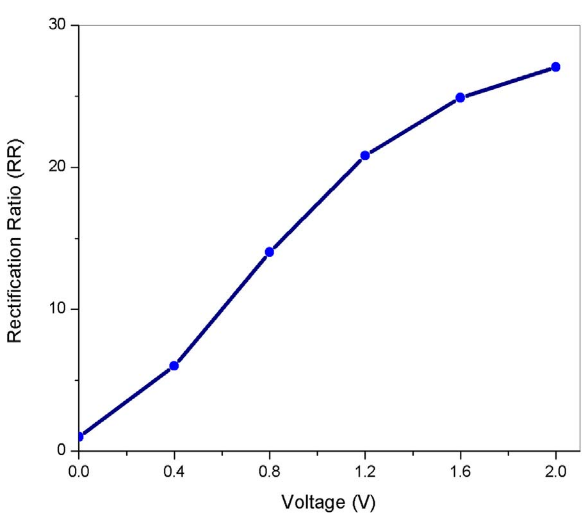

Fig. 3. RR-V characteristic of the Ag/InGaN/n-Si Schottky diode.

4. Conclusions

In this study, Ag/InGaN/n-Si diode structure is formed using ohmic and schottky contacts using thermal evaporation system under a vacuum pressure of 1×10^{-5} mbar. Basic electrical properties of our diode, such as; ideality factor, barrier height and series resistance are determined with the help of linear region of the I-V curve. Findings demonstrated that our diode shows rectifying behavior by means of I-V characteristics. Barrier height and ideality factor of obtained diode were found to be 0.78 eV and 2.84, respectively. Values of the barrier height and series resistance belongs to our diode calculated the method have been developed by Norde method. Obtained barrier height and series resistance values were found to be 0.79 eV and 120 kΩ, respectively. These results show that the barrier height value obtained

Table 1
Electrical parameters of Ag/InGaN/n-Si obtained from F(V)-V characteristics.

Diode	V_O	F (V_O)	I_O (A)	R_s (kΩ)	Φ_b (eV)
Ag/InGaN/n-Si	0.12	0.77	3.44×10^{-8}	120	0.79

by Norde method is good agreement with the that of calculated using simple TE method.

References

[1] C.F. Huang, W.Y. Hsieh, B.C. Hsieh, C.H. Hsieh, C.F. LinTan, Characterization of InGaN-based photovoltaic devices by varying the indium contents, Thin Solid Films 529 (2013) 278–281.
[2] M. Patrick, LED for Lighting Applications, ISTE Ltd, John Wiley & Sons, London, New Jersey, 2010.
[3] H. Morkoç, Handbook of Nitride Semiconductors and Devices, Materials Properties, Physics and Growth, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2009.
[4] S. Aydogan, K. Çınar, H. Asıl, C. Coskun, A. Türüt, J. Alloy. Compd. 476 (2009) 913.
[5] S.M. Sze, Physics of Semiconductor Devices, 2nd ed., Willey, New York, 1981.
[6] E.H. Rhoderick, R.H. Williams, Metal-Semiconductor Contacts, Clarendon, Oxford, 1988.
[7] S.X. Li, Phys. Rev. B 71 (2005) 161201.
[8] J.S. Jang, D. Kim, T.-Y. Seong, J. Appl. Phys. 99 (2006) 073704.
[9] Z.G. Shao, D.J. Chen, B. Liu, H. Lu, Z.L. Xie, R. Zhang, Y.D. Zheng, J. Vac. Sci. Technol. B 29 (2011) 051201.
[10] V. Rajagopal Reddy, R. Padma, M. Siva Pratap Reddy, C.-J. Choi, Phys. State Solid A 209 (2012) 2027.
[11] E. Arslan, H. Cakmak, E. Ozbay, Microelctron. Eng. 100 (2012) 51.
[12] R. Padma, B. Prasanna Lakshmi, M. Sivapratap Reddy, V. Rajagopal Reddy, Superlattices Microstruct. 56 (2013) 64.
[13] D.J. Chen, Y. Huang, B. Liu, Z.L. Xie, R. Zhang, Y.D. Zheng, Y. Wei, V. Narayanamurti, J. Appl. Phys. 105 (2009) 063714.
[14] X. Jun-Jun, C. Dun-Jun, L. Bin, X. Zi-Li, J. Ruo-Lian, Z. Rong, Z. Yon-Dou, Chin. Phys. Lett. 26 (2009) 098102.
[15] V. Rajagopal Reddy, B. Prasanna Lakshmi, R. Padma, J. Metall. (2012) 1.
[16] T.T.A. Tuan, Dong-Hau Kuo, Kaifan Lin, Guan-Zhang Li, Thin Solid Films 589 (2015) 182–187.
[17] J.W. Ager, L.A. Reichertz, Y. Cui, Y.E. Romanyuk, D. Kreier, S.R. Leone, K.M. Yu, W.J. Schaff, W. Walukiewicz, Phys. Status Solidi C 6 (2009) 413–416.
[18] B. Li, L. Zhang, Z. Wu, G. Wang, H. Jiang, IEEE Photonics Technol. Lett. 27 (2015) 2300–2303.
[19] M. Kumar, B. Roul, M.K. Rajpalke, T.N. Bhar, A.T. Kalghatgi, S.B. Krupanidhi, Curr. Appl. Phys. 13 (2013) 26–30.
[20] T.T. Anh Tuan, D.-H. Kuo, Mater. Sci. Semicond. Process. 32 (2015) 160–165.
[21] E. Erdogan, M. Kundakci, A. Mantarci, J. Phys.: Conf. Ser. 707 (2016) 012019.
[22] S.M. Sze, K. Ng Kwok, Physics of Semiconductor Devices, 3rd ed., John Wiley & Sons, New Jersey, USA, 2007, pp. 362–390.
[23] H. Norde, J. Appl. Phys. 50 (1979) 5052–5053.