THE INVESTIGATION OF THE VOLTAGE AND FREQUENCY DEPENDENT ELECTRICAL CHARACTERISTICS OF Re/n-GaAs SCHOTTKY BARRIER DIODE USING I–V, C–V AND G/ω–V MEASUREMENTS

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The main parameters of Re/n-GaAs Schottky barrier diodes (SBDs) were investigated at room temperature by the forward and reverse bias current–voltage $(I-V)$, capacitance–voltage $(C-V)$ and conductance–voltage $(C/\omega-V)$.The diodes were fabricated by using PLD technique. Characteristics parameters such as potential barrier height (Φ_B), ideality factor (n) and series resistance (R_s) have been calculated by using different methods and compared. Furthermore, the voltage-dependent profile of the resistance (R_i) and shunt resistance (R_{sh}) were obtained for Re/n-GaAs Schottky diodes from the $I-V$ data using Ohm's law. In addition, the influence of frequency on parameters have been investigated. From the reverse bias C^{-2} versus V plots the Fermi energy level E_F, doping concentration N_D and potential barrier height for each frequency have been obtained. The dependence of parameters on frequency due to surface state have been revealed.

Keywords: Re/n-GaAs Schottky barrier diodes (SBDs); Frequency dependence; Series resistance; Surface states, Impedance spectroscopy;
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1. INTRODUCTION

Currently, an important element of most electronic devices are contact structures based on Schottky barriers. In this regard it should be noted that the electrical properties and fabrication of SBDs very interesting both in electronic applications and in understanding other semiconductor devices. It should be noted, that basic parameters of electronic devices depend on technology of fabrication, choice of materials, doping degree and surface states of semiconductor [1-4]. Besides the using of different theoretic and calculation methods also influence on obtained result.

Shottky barrier diodes on the basis of GaAs are an important element in many electronic devices. This is determined largely by the relative ease of the fabrication of metal-semiconductor contacts and some advantages in comparison with p-n junction such as high electron mobility, high voltage electrical breakdown, high radiation resistance. GaAs has a high electrical resistivity as well as a high dielectric constant. Unlike silicon devices, devices on the basis of GaAs are less susceptible to temperature changes and generate less noise when operating at high frequencies. Due to these properties, direct-gap semiconductor GaAs is widely used in semiconductor lasers, some radar systems, in solar batteries, working in space [5-8].

Due to high melting point, chemical resistance, catalytic activity, stability at high temperatures, high stability of films, a low temperature coefficient of resistance, a slight change in resistance with increasing film thickness rhenium is an interesting material [9-13]. However, in the scientific literature there is practically no information on studying the parameters of SBD Re/n-GaAs [14,15]. The aim of this study is investigation of main parameters of Re/n-GaAs on the basis of measured $I-V$, C-V and G/ω-V characteristic at room temperature.

EXPERIMENTAL PROCEDURE

Investigated Re/n-GaAs SBD-s were fabricated using the DSP (double si depolished) method. Single-crystal n-type GaAs (100) with a thickness of 625 μm and carrier concentration (2.2-3.1)10^{18} cm^{-3} was used as a semiconductor substrate. After numerous degreasing and processing steps, the GaAs wafer was thoroughly washed in deionized water with a resistivity of 18,2 MΩ cm. Low ohmic contacts to the n-GaAs wafer were fabricated using high purity (99.999%) Au. In a high vacuum system of about 10^{-6} Torr, Au with a thickness of about 2000 Å was deposited on the entire back side of the n-GaAs wafer. The ohmic contacts were annealed by a temperature treatment at 450 ^{o}C for 5 min [15].

Rectifying contacts with a thickness of about (200-250) nm were deposited by PLD onto the front surface of an n-type GaAs wafer. Rhenium (Re), which was used as the target material, was supplied by Good fellow with a 99.99% purity.

Before starting material deposition, vacuum was pumped down to a base pressure about 1x10^{-7}mbar using a DUO 20M Rotary Vane Pump connected to a HiPace 700 turbo molecular pump, both of them made by Pfeiffer Vacuum. When deposition was started, the chamber pressure was about 1x10^{-6} mbar. To fabrication of rectifying contacts with 1.5 mm diameters a metal shadow mask was used. Deposition time was about 2 hours depending on the required contact material thickness. A sketch of the obtained Schottky diode structure is given in Fig. 1.

The current-voltage $(I\!-V)$ measurements in the range from -5.0 V to +5.0 V with 5 mV steps were performed by using a Keithley 2410 Source Meter at room temperature.

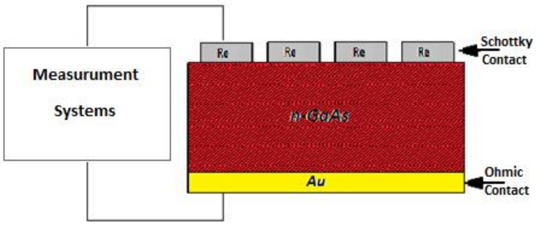


Fig.1. Cross-sectional view of Re/n-GaAs (MS) Schottky diodes/structures.

2. RESULTS AND DISCUSSION

The operation of Schottky diodes is determined mainly by the height of the potential barrier (Φ_B), the ideality factor (n) and series resistance (R_s) . It should be noted that the deviation of the structure from ideality does not allow one to unambiguously determine F and n [16-23]. To accurately determine the barrier height (BH), three factors need to be taken into account: the accuracy of measuring the initial values, the accuracy of the approximation method and the accuracy of determining the current transfer mechanism. In the present work Re/n-GaAs SBD parameters have been calculated by the using of various methods that do not require measurements at different temperatures from measurements of the current-voltage characteristics and compared.

The current-voltage characteristic of Re/n-GaAs SBD measured in the forward and reverse bias regions (±5 V) was previously analyzed based on thermionic emission theory [24]. In the presented article $I-V$ charactersistic has been analized by the depending LnI vs LnV as is shown in Fig.2. [1,16,24,25].

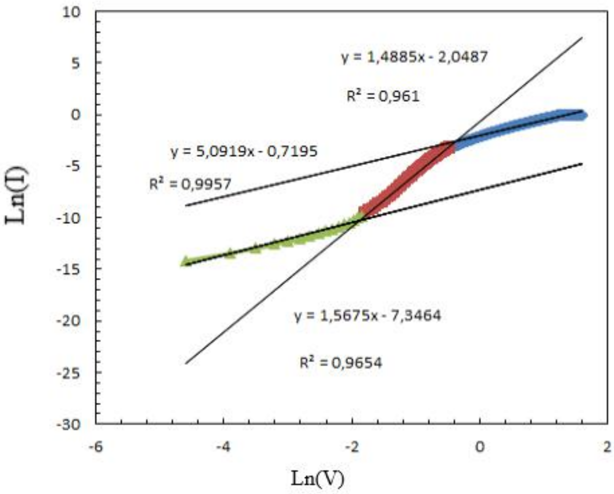


Fig.2. Double logarithmic $I-V$ plot of Re/n-GaAs SBD at forward bias.

The above method is very convenient for calculating the parameters of a diode with a narrow-gap semiconductor (GaAs). As can be seen from the Fig.2. the slope of the characteristic changes. The slope 1.48 of first region of voltage from 0.66 V to 5 V correspond to influence of series resistance. When the voltage varying from 0.17 to 0.65 V above-barrier current transfer is observed and slope is 5.09. In the third section at voltage (0.01÷0.16)V the slope equals 1.56 and can be analyzed by the presence of diffusion current transfer. Changing the slope of the characteristic does not allow to accurately determine the height of the potential barrier, ideality factor and series resistance.

To determine Φ_B and R_s the method (Norde's method) has been used [20]. It is known, that when influence of R_s is great at all values of the applied voltage Norde's functions can presented as:

$$F(V)=\frac{V}{\gamma}-\frac{kT}{q}\left[ln\left(\frac{1}{T^2}\right)-ln(A^*A)\right] \qquad (1)$$

$$\Phi_{BN}=F(V_{min})+\frac{V_{min}}{\gamma}-\frac{kT}{q} \qquad (2)$$

$$R_s = \frac{(\gamma - n)kT}{qI_{min}} \quad (3)$$

where γ is a dimensionless integer greater than n [20]. In this case, to identification of potential barrier height and series resistance at room temperature for the Re/n-GaAs diode was used the minimum point of $F(V)$ vs V plot (Fig.3). The $V_{\min}$, $F(V_{min})$, Φ_{Bn} and R_s values were found to be 0.3 V, 5.88x10^{-1} V, 0.78 eV and 4.13 Ω, respectively.

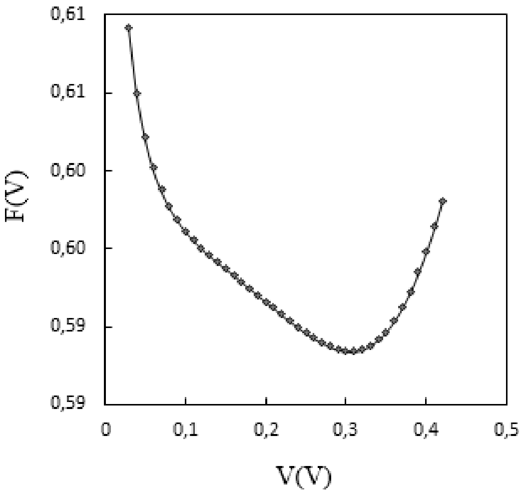


Fig.3. F(V) vs. V(V) plot of Re/n-GaAs SBD.

On the other hand, this method, along with its advantages, has some disadvantages. The difference between the ideality factor and unity affects the calculation results. Besides, according to this technique, the calculation is performed at one point of the $I - V$ characteristic, which can negatively affect the calculation accuracy.

Another way to solve the identified problem is to use the method developed by Cheung [21]. The method has been used in order to compute Re/n-GaAs SBD parameters like the Φ_B, n and R_s [16,21]. Cheung's functions can be obtained as follows

$$\frac{dV}{d(\ln I)} = n\left(\frac{kT}{q}\right) + IR_s \quad (4)$$

$$H(I) = V - n\frac{kT}{q}ln\left(\frac{I}{AA^{*}T^{2}}\right) = n\Phi_{B0} + R_s I \quad (5)$$

$$H(I) = V - n\frac{kT}{q}ln\left(\frac{I}{AA^{*}T^{2}}\right) \quad (6)$$

Here, IR_s is the voltage drop across the series resistance of the Re/n-GaAs SBD. The plots $dV/d(lnI) - I$ and $H(I) - I$ are presented in Fig.4 Using the slope of $dV/d(lnI) - I$ has been obtained R_s and n as 3.27 Ω and 1.43, respectively by using Eq.(4). $I - V$ data was analyzed by the well-known equation at forward bias Eq. (5). On the basis of $H(I) - I$ plot's has been calculated R_s with the value of 4.04 Ω and potential barrier height Φ_{BCh}= 0.74 eV (Fig.4).

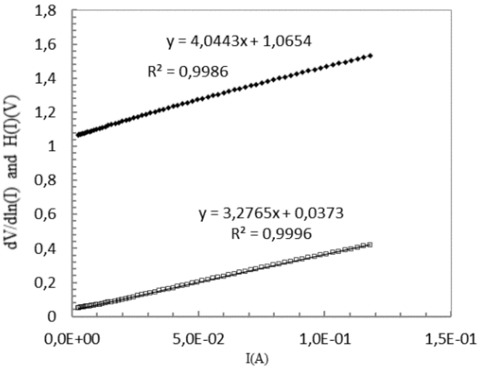


Fig.4. The plots of $dV/dlnI$ versus I and $H(I)$ versus I at room temperature.

Another method for the obtaining of series resistance and ideality factor is Verner's method [22]. In this method differential conductance ($L = dI/dV$) of real diode at $V > 3kT/q$ is described by the relation (Fig.5):

$$\frac{L}{I} = \frac{q}{nkT}(1 - R_s L) \quad (7)$$

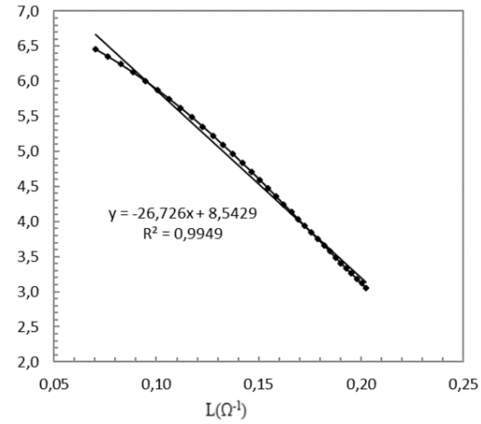


Fig.5. The plots of L/I versus L for Re/n-GaAs SBD at room temperature

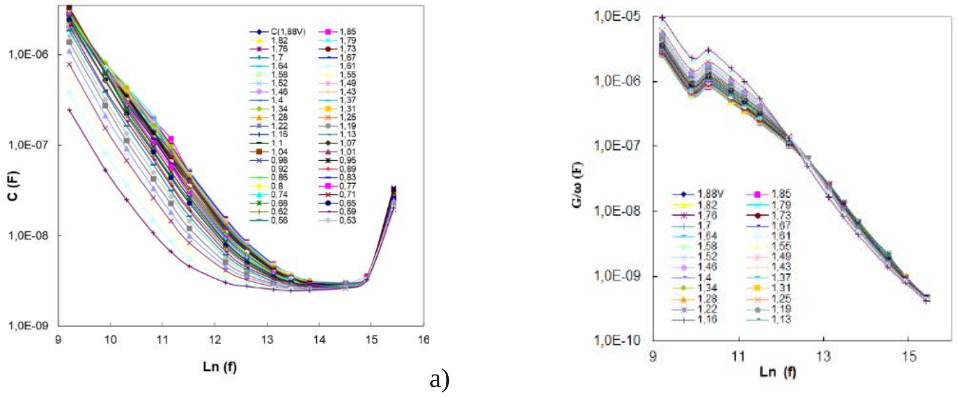
Eq.7 shows that a plot of L/I versus L yields a straight line with slop R_s. From y-axis intercept one can determine the ideality factor n. We have compared the result of different methods to tested of the characteristic parameters of Re/n-GaAs SBD on the basis of experimental $I - V$ curve measured at room temperature. One can see that the different techniques give almost similar meanings of the parameters. Exception is n determined by Verner's method.

The calculated values of characteristic parameters (Φ_B, I_o, n and R_s) of Re/n-GaAs SBD experimentally obtained at room temperature are given in Table 1.

Table 1.

Φ_{B0} (eV)	n	R_s (Ω)	R_{sh}(Ω)	Norde		Cheung dV/dlnI		Cheung H(I)		Verner	
				Φ_{BN} (eV)	R_{sN} (Ω)	R_{sCh1} (Ω)	n	R_{sCh2}(Ω)	Φ_{BCh}(eV)	R_{sv}(Ω)	n
0,61	1,84	3,92	2,19E+1	0,78	4,13	3,28	1,43	4,04	0,74	3,13	4,52

The obtained result indicates the difference between the selected and ideal model. To explain the obtained results, it should be taken into account that the ratio of the lattice parameters of the metal and semiconductor plays a significant role in the formation of a contact [26]. It is known, that lattice parameters are a = 0.565nm for GaAs and a=2.761nm, c=4.456 nm for Re, respectively [27]. Due to lattice mismatch between the metal and GaAs in the subsurface region of semiconductor elastic stresses can be appear. At metal deposition on the semiconductor surface is possible a mutual diffusion of metal and semiconductor atoms, which affects the formation of a barrier and surface states [28-30]. The obtained difference between values of parameters Φ_B, n and R_s, calculated with the using of different methods can be attributed to formation of barrier and surface states due to influence of lattice mismatch between Re and GaAs. In connection with this goal, the Re/n-GaAs SBD were studied by the impedance method at frequencies of the test signal (50 mV) 10 kHz - 5 MHz. So, figure 6 shows for Re/n-GaAs SBD the dependence of C(a) and G/ω (b) value vs. frequency at fixed voltage and room temperature. It should be noted, that decreasing of values of C and G/ω at height frequencies can be attributed to the carrier charges at surface states/traps and their relaxation time (τ).



a) b)

Fig. 6. The dependence of C(a) and G/w(b) value vs. frequency at fixed voltage for Re/n-GaAs SBD (T=300K).

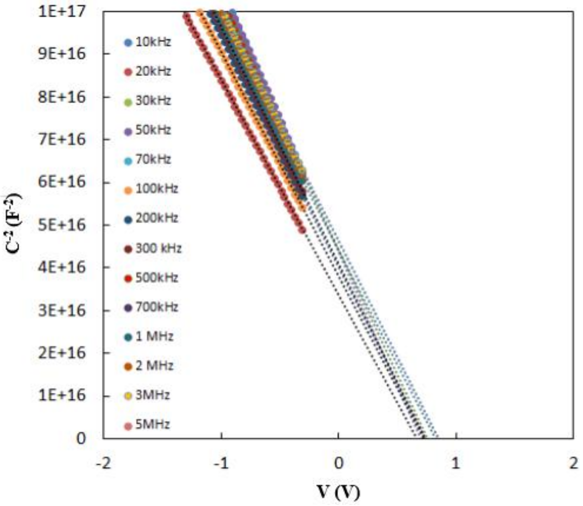


Fig.7. C^{-2}–V plot of Re/GaAs Schottky diode at various frequencies (10kHz-5MHz).

Table 2.

Various parameters for Re/GaAs Schottky diode obtained on the basis of the of C-V and G/ω –V characteristics measured at the frequencies in the range of from 10kHz to 5MHz (50mV)

f, x10^3 Hz	**V_0 (V)**	**N_Dx 10^{17} (cm^{-3})**	**E_Fx10^{-2} (V)**	**$Φ_B$ (eV)**	**V_{max}, (V)**	**G/$ω_{max}$ (F)**	**C_m, (F)**	**N_{ss}, (eV^{-1} sm^{-2})**	**$R_{s\ max}$, (Ω)**
10	0,61	1,68	2,43	0,63	0,23	1,90E-5	2,30E-6	6,48E+13	3,01
20	0,67	2,18	1,77	0,68	0,25	3,01E-6	6,35E-7	3,18E+13	6,64
30	0,63	1,82	2,23	0,65	0,26	3,60E-6	2,68E-7	2,04E+13	5,33
50	0,69	1,75	2,32	0,72	0,28	2,12E-6	1,00E-7	8,25E+13	14,02
70	0,71	1,95	2,15	0,72	0,29	1,09E-6	6,20E-8	4,41E+13	11,46
100	0,72	2,09	1,88	0,74	0,35	5,42E-7	3,00E-8	1,83E+12	15,94
200	0,73	1,98	2,01	0,75	0,41	1,45E-7	1,06E-8	7,02E+11	20,95
300	0,73	1,98	2,01	0,75	0,53	1,66E-8	6,50E-9	4,73E+11	38,57
500	0,75	1,88	2,14	0,77	0,54	2,38E-8	4,11E-9	3,39E+11	38,5
700	0,77	1,93	2,07	0,79	0,56	1,22E-8	3,42E-9	2,74E+11	38,30
1000	0,82	2,06	1,91	0,84	0,58	6,66E-9	2,91E-9	3,14E+11	32,7
2000	0,83	1,72	2,37	0,85	0,63	1,89E-9	2,74E-9	2,30E+11	17,83 (≠f(V)
3000	0,85	2,02	1,97	0,86	0,68	9,1E-10	3,42E-9	1,84E+11	5,28 (≠f(V)
5000	0,83	1,81	2,23	0,85	0,74	4,62E-10	2,21E-8	1,21E+11	0,21 (≠f(V)

The procedure of investigation of parameters Re/n-GaAs SBD by considering the R_s and N_{ss} effect begins by looking for V_0, E_F N_D, $\Phi_B$values that can be extracted from dependence of capacitance on voltage [31-35]

$$\frac{d(1/C^2)}{dV} = \frac{2}{\varepsilon_s \varepsilon_0 q N_{Dapp} A^2} \tag{8}$$

where ε_s is the permittivity of the semiconductor (12,9 for GaAs), ε_0 is the permittivity of free space charge (ε_0= 8.85x10^{-14} F/cm). N_D is the concentration of doping (charge concentration) of the semiconductor (GaAs), A is the contact area of the diode.

With the using Eq.8 the experimental value of N_d has been calculated for low (10kHz) and high values (5MHz) of frequency (Fig.7)

$$N_d = \frac{2dV}{\varepsilon_s \varepsilon_0 q d(A^2/C^2)} \tag{9}$$

For Re/n-GaAs SBD by the using the intercept C^{-2}-V plot the value of potential barrier height (Φ_B) has been calculated at room temperature (500kHz, 50mV) [31-36]

$$\Phi_B = q(V_0 + E_F) \tag{10}$$

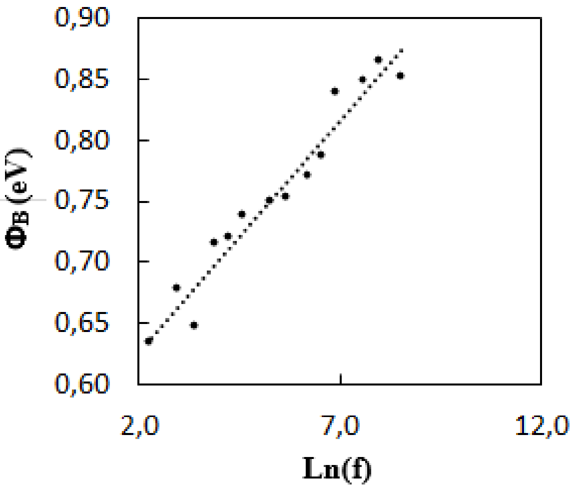


Fig.8. The dependence of potential barrier height (Φ_B) on frequency for Re/GaAs SBD.

Where V_0 is diffusion potential, the value of which from intersection of linear part of $(1/C)^2-V$ characteristics was determined. Besides, the Fermi energy level (E_F) in the neutral region of n-GaAs was obtained as:

$$E_F = V_n = \frac{kT}{q} ln\left(\frac{N_c}{N_D}\right) \qquad (11)$$

N_c is the effective density of states in non-degenerated conductance band of GaAs,

$$N_c = 2{,}5\text{E} + 19 * (T/300)^{3/2}\left(\frac{m_e^*}{m_0}\right)^{3/2} \qquad (12)$$

where m_e^* =0,068m$_0$ is the effective mass of the electron in GaAs [2,3] and m$_0$ (9.1×10^{-31} kg) is the rest mass of the electron.

The values of the barrier height obtained from the dependence C^{-2}-V differ from the values obtained from the $I-V$ characteristic. This discrepancy can be explained by the existence of an interfacial layer or surface states.

As is shown from Fig.8 the value of the potential barrier height dependent on frequency of test signal. Apparently, this dependence is due to the influence of the recharging of surface states [36].

CONCLUSION

The main parameters of the diode were studied based on the I-V, C-V and G/w-V characteristics measured at room temperature. The dependence I-V was measured in the voltage range ± 5V, the dependence of capacitance and conductance on voltage have been measured in the frequency range 10kHz-5MHz.The basic characteristics parameters such as Φ_B, n and R_s, R_i , R_{sh} have been calculated by using different methods (Cheung's, Norde's and Verner's methods) at room temperature and compared. The values of the parameters calculated by using different methods are slightly different, which indicates the difference between the selected and ideal model. Obtained result was attributed to the influence of lattice mismatch between the Re and GaAs on the formation of the barrier and surface states. On the basis of the $C-V$ and $G/\omega-V$ characteristics measured in a bias voltage 2V÷+5V and wide frequency range of test signal from 10kHz to 5000 kHz (50 mV) has been determined E_F, N_D , Φ_B, R_s N_{ss} and dependence on frequencies. It was revealed the contribution of surface states at low frequencies.

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[1] *E.H. Rhoderick, R.H. Williams.* Metal–Semiconductor Contacts, Clarendon Press, Oxford, 1988.

[2] *V.I. Strikha.* Theoretical Bases of Metal-Semiconductor Contact Work, Naukova Dumka, Kiev, (1974) (in Russian).

[3] *S.M. Sze.* Physics of Semiconductor Devices, John Wiley & sons, New York, 1981.

[4] *I.M. Afandiyeva, Ş. Altındal, L.K. Abdullayeva, A.İ. Bayramova*. Self-assembled patches in PtSi/n-Si (111) diodes, Journal of Semiconductors, 2018,v.39,№5,pp.054002-1-7.

[5] F. Taghizadeh, van Rensburg, P.J. Janse, K. Ostvar, et al. Electronic properties and transformation kinetics of two prominent metastable defects introduced in GaAs during sputter deposition of Au Schottky contacts/Materials science in semiconductor processing/ 2019, v.99, pp.23-27.

[6] *B. Kirezli, M. Ahmetoglu (Afrailov), A. Kara.* Electrical and optical properties of photodiode structures formed by surface polymerization of [P (EGDMA-VPCA)-SWCNT] films on n-GaAs/Journal of molecular structure, 2019,vol.1192, pp. 258-263.

[7] *Vezzoli, Andrea; Brooke, Richard J. Ferri, Nicolo et al.* Charge transport at a molecular GaAs nanoscale junction/Faraday Dıscussıons, 2018, vol. 210, pp. 397-408.

[8] *Chatterjee, Abhishek; K. Khamari, Shailesh ; S. Porwal.* Effect of Co-60 gamma-irradiation on the nature of electronic transport in heavily doped n-type GaN based Schottky photodetector/, 2018, vol.123, is.16, 161585.

[9] *B.S. Danilin.* Vakuum evaporation of thin films,M.Energiya, 1967, 312p.

[10] *Contelot, Fanny, Thomas, J. Robert, Seaman, John C.* Using porous iron composite (PIC) material to immobilize rhenium as an analogue for technetium. Environment InternationaL, 2019, vol. 128, pp. 379-389.

[11] *Littleton, A.H. Joshua Secco, A. Richard, Yong, Wenjun* et.al. Electrical resistivity and thermal conductivity of W and Re up to 5 GPa and 2300 K/Journal of Applied Physics,2019, 125,is.13,135901.

[12] *Tian, Bian; Yu, Qiuyue; Zhang, Zhongkai* et.al. Effect of magnetron sputtering parameters on adhesion properties of tungsten-rhenium thin film thermocouples Ceramics International , 2018, vol.4 p15-18.

[13] *Hasanli, Nijat; Gauquelin, Nicolas; Verbeeck, Johan*. Small-moment paramagnetism and extensive twinning in the topochemically reduced phase $Sr_2ReLiO_{5.5}$ Dalton Transactions, 2018, vol.47, is.44, pp.15783-15790.

[14] *Chia-Chien Lin.* Electrical and structural properties of Re/GaAs Schottky diodes/Journal of Applied Physics 85, 3893, 1999.

[15] *Durmus, H Yildirim, M., Altindal, S* .On the possible conduction mechanisms in Rhenium/n-GaAs Schottky barrier diodes fabricated by pulsed laser deposition in temperature range of 60-400K/ journal of materıals scıence-materıals ın electronıcs/ 2019,vol. 30, is.9, pp. 9029-9037.

[16] *Ya.Ya. Kudryk, V.V. Shynkarenko, V.S. Slipokurov* et al. /Determination of the Schottky barrier height in diodes based on Au–TiB_2–n-SiC 6H from the current-voltage and capacitance-voltage characteristics/ Semiconductor Physics, Quantum Electronics & Optoelectronics, 2014. V. 17, N 4. P. 398-402.

[17] *S.O. Tan, H. Uslu, O.C. Tecimer.* Electrical characterizations of Au/ZnO/n-GaAs Schottky diodes under distinct illumination intensities/J Mater Sci: Mater Electron. 2016, DOI 10.1007/s10854-016-4843-4.

[18] *Abdulkerim Karabulut.* Barrier height modification in Au/Ti/n-GaAs devices with a HfO2 interfacial layer formed by atomic layer deposition/ *Bull. Mater. Sci.* (2019) 42:5.

[19] *K. Bouzidi, M. Chegaar, M. Aillerie.* Solar cells parameters evaluation from dark I-V Characteristics/ Energy Procedia 18 (2012) 1601 – 1610.

[20] *H. Norde.* A modified forward I-V plot for Schottky diodes with high series resistance, *J. Appl. Phys.*1979:50;5052-5053S.

[21] *S.K. Cheung, N.W. Cheung.* Extraction of Schottky diode parameters from forward current-voltage characteristics. Appl. Phys. Lett. 49(2), p. 85-87. (1986).

[22] *J.H Werner.* Schottky barrier and pn-junction I/V plots -Small signal evaluation, Appl Phys A, 1988, 47:291-300.

[23] *N. Şimşir, H. Şafak, ÖF Yüksel, M. Kuş.* Investigation of current–voltage and capacitance–voltage characteristics of Ag/perylene-monoimide/GaAs Schottky diode. Curr Appl Phys 2012; 12: 1510-1514.

[24] *I.M Afandiyeva, R.F Babayeva.* The potential barrier height and profile of surface states of Re/n-GaAs Schottky barrier diode, Proc. of the 7th Int. Conf. MTP-2021: Modern Trends in Physics, dec. 15-17, 2021, BSU, Baku, Azerbaijan, pp.97-103.

[25] *A. Kaya, E.Marıl, Ş. Altındal, İ. Uslu.* The comparative electrical characteristics of Au/n-Si (MS) diodes with and without a 2% graphene cobalt-doped $Ca_3Co_4Ga_{0.001}O_x$ interfacial layer at room temperature/Microelectronic Engineering 149 (2016) 166–171.

[26] *P.N. Krylov.* Physical models of thermo-processed contact metal–semiconductors. Journal of Udmurt University, 2006, 4: 125.

[27] *M P. Shaskolskaya.*Crystallography. Moscow, Visshaya shkola, 1984.

[28] C. Calandra, Giorgio Santoro. Surface states of the (110) surface of GaAs,Journal of Physics C Solid State Physics 8(6):L86. 2001.

[29] *Erman Erdoğan*[a], *MutluKundakçı*[b] Room temperature current-voltage (I-V) characteristics of Ag/InGaN/n-Si Schottky barrier diode/ Physica B: Condensed Matter, Vol.506, 1 February 2017, p. 105-108.

[30] *Haziret Durmuş and Ülfet Atav.* Extraction of voltage-dependent series resistance from I-V characteristics of Schottky diodes/ Appl. Phys. Lett. 99, 093505 (2011).

[31] *O.A. Soltanovich, N.M. Shmidt, E.B. Yakimov.* Frequency and temperature dependences of capacitance–voltage characteristics of InGaN/ GaN light-emitting structures with multiple quantum wells. Semiconductors, 2011, 45(2): 221.

[32] *S.J. Moloi, M. McPherso.* Capacitance–voltage behaviour of Schottky diodes fabricated on p-type silicon for radiation-hard detectors. Radiation Physics and chemistry, 2013, 85:73.

[33] *I.S. Yahiya, H.Y. Zahran, F.H. Alamri, M. Aslam.* Microelectronic properties of the organic Schottky diode with pyronin-Y: Admittance spectroscopy, and negative capacitance. Physica B: Condensed Matter, 2018, 543: 46.

[34] *G. Ersöz, ˙I. Yücedağ, Y. Azizian-Kalandaragh, I. Orak, S. Altındal.* Investigation of Electrical Characteristics in Al/CdS-PVA/p-Si (MPS) Structures Using Impedance Spectroscopy Method/ IEEE transactıons on electron devıces, v. 63, № 7, July 2016, p.2948-2955.

[35] *F. Parlakturk, S. Altındal, A. Tataroğlu, M. Parlak, A. Agasiev.* On the profile of frequency dependent series resistance and surface states in Au/$Bi_4Ti_3O_{12}$/SiO_2/n-Si(MFIS) structures,p.81-88.

[36] *E.H. Nicollian and J.R. Brews.* MOS (Metal Oxide Semiconductor) Physics and Technology. New York, USA: Wiley, 1982, pp. 117–129.

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