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RESEARCH ARTICLE

Observation of Space Charge Limited Current in Schottky Diodes with V_2O_5 Interfacial Layer Prepared by Radio Frequency Magnetron Sputtering

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ABSTRACT

Electrical properties of V_2O_5/n-Si Schottky barrier diodes prepared by rf magnetron sputtering of vanadium pentoxide (V_2O_5) on n-Si wafer have been investigated. The current-voltage (*I–V*) and capacitance-voltage (*C-V*) measurements of the diode have been performed in the dark at the room temperature. The saturation current (I_0), ideality factor (*n*), barrier height (Φ_B) values of the diode have been determined as 6.68×10^{-8} A, 1.35, and 0.755 eV, respectively. The series resistance (R_S) values from Norde, Cheung and Nicollian & Brews methods have been determined as 199 Ω, 251 Ω, and 144 Ω, respectively. The energy distribution of interface state density (N_{SS}) was determined, and the values of against the energy values of N_{SS} in the vary between E_C-0.462 eV and E_C-0.713 eV were obtained 4.343x1016 eV^{-1} cm^{-2} and 3.282×10^{15} eV^{-1} cm^{-2}, respectively. The barrier height and metal oxide thickness (δ) values using capacitance-voltage (*C-V*) measurements in the frequency of 1 MHz has also been calculated as 0.949 eV and 37.4 nm, respectively. The prepared diode showed abnormal diode characteristics, indicating the existence of a space-charge limited (SCL) current. From forward bias *I-V* characteristics, the ohmic, trapped filled space charge limited current (TFSCLC) and SCLC conduction behaviors were observed at low, middle, and high voltages, respectively. Experimental results indicated that the prepared V_2O_5 film on n-Si can be utilized in electronic applications.

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Introduction

Thin films of vanadium pentoxide (V_2O_5) have extensively studied due to potential applications in rechargeable lithium ion batteries (Liu et al., 2009), catalysts (Liu et al., 2009), gas sensors (Akande et al., 2015), electrochromic devices (Karaca et al., 2017), optical switching devices (Fateh et al., 2008), and Schotky diodes (Senarslan et al., 2017; Kaya et al., 2021). V_2O_5 is environment friendly (Liu et al., 2018), high energy density (Liu et al., 2011), large and stable reversible capacities (Wang et al., 2011), and low cost (Ihsan et al., 2015) material in the series of transition metal oxide semiconductors (e.g., SnO_2, ZnO, TiO_2). In recent years, diversity of synthesis methods are utilized for synthesis of the films of V_2O_5 such as sol-gel method (Ihsan et al., 2015), sputtering (Luo et al., 2010), thermal evaporation (Al-Kuhaili et al., 2004), and spray deposition (Benkahoul et al., 2017). Magnetron sputtering

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method has advantages such as very good adhesion to the substrate, deposition at a low substrate temperature, produce thin films with repeatable properties, and the control of process parameters such as gas flow and/or pressure ratio (Qiao et al., 2014; Dong et al., 2021).

A metal/insulator/semiconductor (MIS) based Schottky diode mainly depends on added of thin interface layer such as V_2O_5 between semiconductor and metal. These (MIS) based Schottky diodes increase the stability and performance of the device (Akgul et al., 2021). There are reports on the analysis of electrical properties of Schottky diodes with V_2O_5 produced on different semiconductors (Kumar et al., 2016; Senarslan et al., 2017; Balasubramani et al., 2019; Kaya et al., 2021). In these studies, analyzes were made on the current-voltage characteristics of diodes with V_2O_5. As far as we know, much work has not been done on Au/V_2O_5/n-Si Schottky diodes produced by rf magnetron sputtering method. There is a report on the admittance properties of V_2O_5 film formed on p-Si substrate. Şenarslan et al. (2017) reported that the investigation of conductance-voltage (*G-V*) and capacitance-voltage (*C-V*) characteristics of the Al/V_2O_5/p-Si MIS based Schottky diode.

It is recognized that the presence of an interfacial layer between the metal and the semiconductor can affect the transport across the interface. This interfacial layer can also inhibit or induce interfacial chemical reactions (Sigaud et al., 2003). For many diodes, the metal-interfacial layer contacts and interfaces limit charge transport and injection. The injection of charge in the diode depends on several factors such as band bending or Fermi level pinning, chemical reactions, the temperature, the applied electric field, the interface dipoles, and the height of the injection barrier (Yan & Gao, 2002; Bokdam et al., 2011). Although works on the electrical properties of diodes have been introduced broadly, the analyses are still done to determine the current transport mechanism in diodes. A detailed understanding of the transport mechanisms and physical properties governing their electrical action can be determined by investigating the current-voltage characteristics of the device. It was proposed that space charge limited current (SCLC), thermionic recombination, and tunnelling enhanced interface recombination can dominate the current transport in diodes (Yan & Gao, 2002; Sigaud et al., 2003; Bayhan & Bayhan, 2011; Bokdam et al., 2011; Saad & Kassis, 2011; Kumar et al., 2016).

In this study, we studied the current-voltage (*I-V*) and capacitance-voltage (*C-V*) characteristics of Au/V_2O_5/n-Si Schottky diode prepared by the rf magnetron sputtering method. Furthermore, the values of the ideality factor (*n*), barrier height (Φ_B), series resistance (R_S) and interface state density (N_{SS}) from *I-V* measurements were investigated at room temperature. Moreover, the barrier height (Φ_B) and metal oxide thickness values using capacitance-voltage (*C-V*) measurements in the frequency of 1 MHz has also been determined. Barrier height values determined from *I-V* and *C-V* measurements were also compared. The forward bias *I-V* properties showed that the Au/V_2O_5/n-Si Schottky diode had the ohmic, trapped filled space charge limited current (TFSCLC), and SCLC (space charge limited current) conduction behaviors were observed at low, middle, and high voltages, respectively.

Materials and Methods

In this work, the n-type Si wafer grown by CZ method with P-doped has 10 Ω-cm resistivity, 300 µm thickness, and (100) orientation. Before forming the contacts, the silicon crystal was washed with the RCA method (Akgul et al., 2021) to remove the unwanted structures such as oxide on the surface of the silicon crystal. In order to create ohmic contact, 150 nm gold (Au) metal was deposited on the unpolished surface of the silicon crystal at $1x10^{-6}$ Torr pressure in a vacuum and by heating it on a tungsten plate under the same pressure, the Au metal was precipitated. The V_2O_5 film was prepared on the polished part of n-Si crystal by RF magnetron sputtering at the 100 W sputtered power. The base and working pressures were maintained of the order $6x10^{-5}$ Pa and $5x10^{-1}$ Pa in argon gas atmosphere (purity 99.99%) during the sputtering process, respectively. The distance between the sputtered target (V_2O_5 target, 2-inch diameter, 0.125-inch thickness, and 99.99% purity) and the n-Si crystal and the sputtering time were fixed at 30 cm and 20 minutes, respectively. The deposited film was annealed in the oven at 400 ºC for 10 minutes to form V_2O_5. Figure 1 shows the fabrication of V_2O_5 thin film by the RF magnetron method. After V_2O_5 film coating was made on n-Si, 150 nm gold (Au) metal was deposited on V_2O_5 using 2 mm diameter circular masks at the same pressure in vacuum. In this way, Schottky rectifier contacts were created. Finally, Au/V_2O_5/n-Si/Au Schottky diode structure was produced. The contact area of the produced diode is equal to 0.0314 cm^2. For electrical characterization, Figure 2 shows the cross-sectional representation of the Au/V_2O_5/n-Si/Au diode. Figure 3 shows the energy band diagram of Au/V_2O_5/n-Si Schottky diode in thermal equilibrium after contact. In order to examine the electrical properties of the produced diode, current-voltage (*I-V*) and capacitance-voltage (*C-V*) measurements were taken at room temperature. *I-V* and *C-V* measurements of Au/V_2O_5/n-Si/Au Schottky diode were carried out by means of a Keithley 2410 SourceMeter and Keysight E4990A impedance analyzer in 1 MHz frequency, respectively.

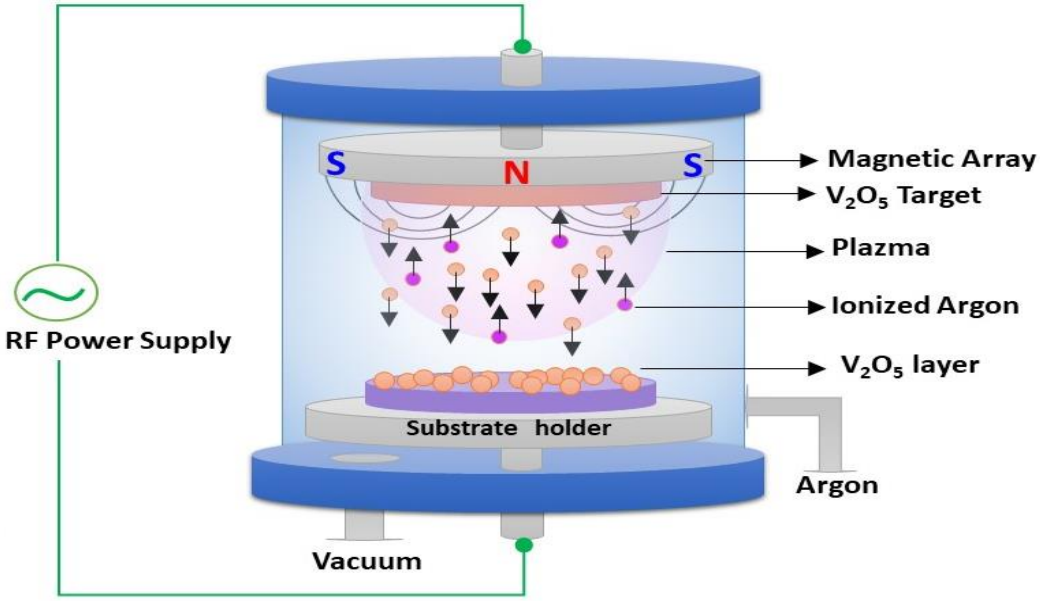

Figure 1. Schematic diagram of preparation of V_2O_5 thin film on n-Si by RF magnetron method.

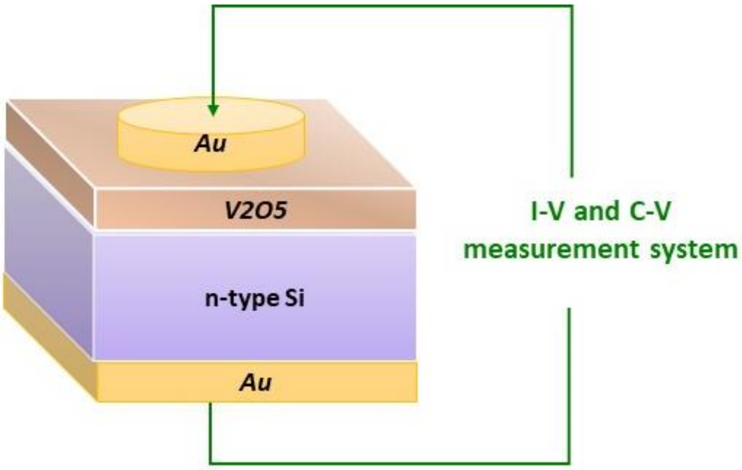

Figure 2. Schematic diagram of Au/V_2O_5/n-Si/Au Schottky diode.

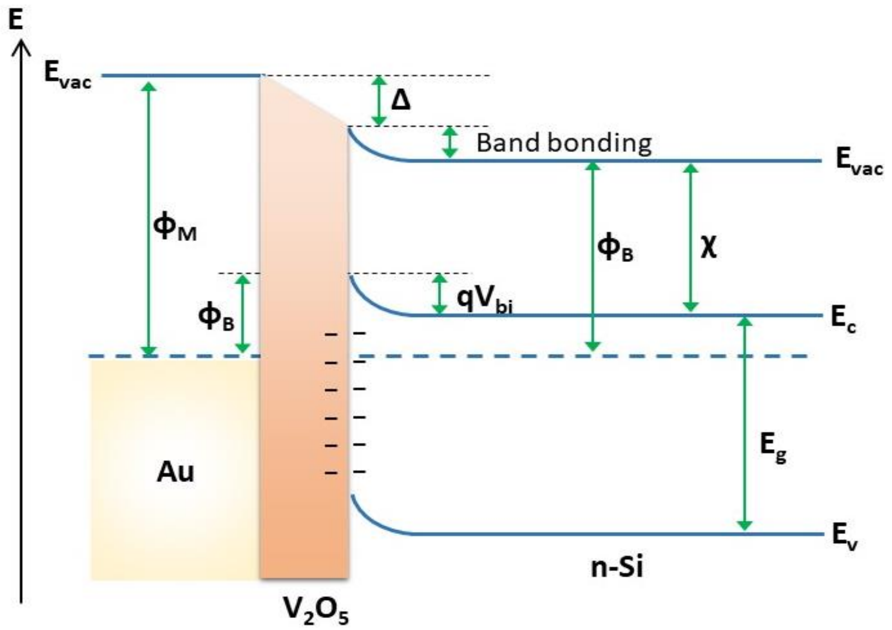

Figure 3. The energy band diagram of Au/V_2O_5/n-Si Schottky diode after contact.

Results and Discussion

We have prepared the Au/n-type Si Schottky contacts with vanadium pentoxide (V_2O_5) interfacial layer by rf magnetron sputtering method. Current-voltage (*I-V*) measurements were taken at dark and at room temperature. From *I-V* measurements of the Au/V_2O_5/n-Si Schottky diodes and the thermionic emission theory, saturation current (I_0), ideality factor (n), and barrier height (Φ_B) values can be obtained from following equations

$$I_0 = AA^*T^2 \exp\left(-\frac{q\Phi_B}{kT}\right) \quad ; \qquad (1)$$

$$n = \frac{q}{kT}\left(\frac{dV}{d\ln I}\right) \quad ; \qquad (2)$$

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

where T is the absolute temperature, k is Boltzmann constant, A is the Schottky contact area, q is the electronic charge, and A^* is the effective Richardson constant.

Figure 4 displays the experimental ln*I-V* measurement of the fabricated Au/V_2O_5/n-Si Schottky diodes at ±2V and at room temperature. From Figure 4, the experimental measurement of the diode displays the behavior of good rectification. The rectification ratio (*RR*) [$RR = I(+2V)/I(-2V)$] of the produced diode was quite high and was determined as approximately 3940. Using the thermionic emission (TE) theory (Rhoderick & Williams, 1988; Ongun et al., 2021; Tezcan et al., 2021), the values of the ideality factor (n), the saturation current (I_0), and the barrier height (Φ_B) for the prepared Au/V_2O_5/n-Si Schottky diode are obtained from the slope of the linear region of plot and the current axis intercept as 1.35, 6.68×10^{-8} A and 0.755 eV, respectively. Mahato et al. (2017) deposited V_2O_5 powder on n-Si substrate by thermal evaporation system and obtained Au/V_2O_5/n-Si structure and n and Φ_B values of the structure were reported as 2.04 and 0.83 eV. Kaya et al. (2021) produced vanadium pentoxide by sputtering technique on (100) oriented n-type silicon crystal to produce Au/V_2O_5/n-Si diode. They determined n and Φ_B values as 2.68 and 0.72 eV from current-voltage measurements. In another study by Kaya et al. (2020), vanadium pentoxide was produced by sputtering technique on (100) oriented n-type silicon crystal to produce Ti/V_2O_5/n-Si diode. They determined n and Φ_B values as 1.39 and 0.76 eV from current voltage measurements. Balasubramani et al. (2019) produced vanadium pentoxide by sputtering technique on (100) oriented n-type silicon crystal to produce Cu/V_2O_5/n-Si diode. They determined n and Φ_B values as 5.26 and 0.46 eV from current-voltage measurements.

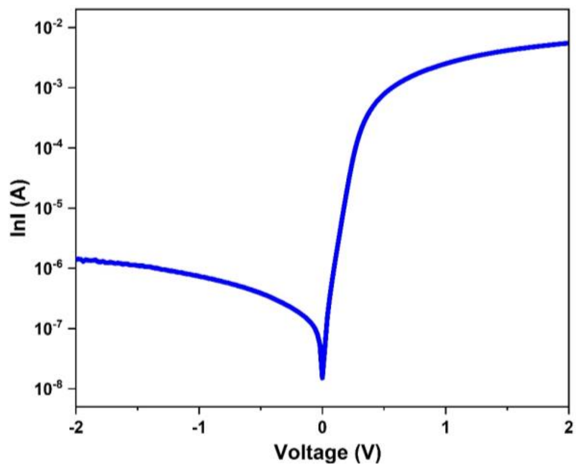

Figure 4. Current-voltage graph of the Au/V_2O_5/n-Si Schottky diode.

Series resistance behaviour is another one of the main characteristics that analyze the electrical measurements of the Schottky barrier diode. Using the voltage dependence of the *F(V)* function introduced by Norde (1979), series resistance (R_S) and barrier height Φ_B values can be found by the following relations:

$$F(V) = \frac{V}{a} - \frac{1}{\beta}\ln\left(\frac{I(V)}{AA^*T^2}\right) \qquad (4)$$

$$\Phi_B = F(V_{min}) + \frac{V_{min}}{a} - \frac{1}{\beta} \qquad (5)$$

$$R_S = \frac{(a-n)}{\beta I_{min}} \qquad (6)$$

Where β is equal to q/Kt and a is a constant bigger than ideality factor. Figure 5 shows the $F(V)$ vs. bias voltage (V) of the Au/SnO_2/n-Si/Au Schottky barrier diode. From Figure 5, the Φ_B and R_S values were obtained as 0.750 eV and 199 Ω from calculating the minimum in a *F(V)* versus *V* curve, respectively.

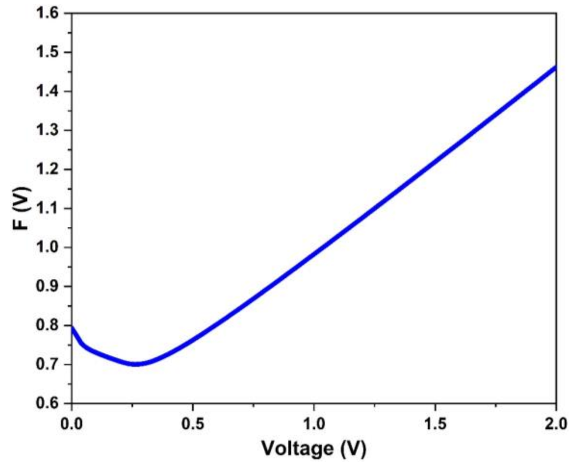

Figure 5. Curve of $F(V)$ vs. bias voltage (V) of the Au/V_2O_5/n-Si Schottky barrier diode.

Another method in series resistance calculations is the Cheung method (Cheung & Cheung, 1986). There are two functions in the Cheung method. These functions are given in the equations below:

$$\frac{dV}{d\ln(I)} = \frac{nkT}{q} + IR_S \quad (7)$$

$$H(I) = V - \left(\frac{nkT}{q}\right)\ln\left(\frac{I}{AA^*T^2}\right) = n\Phi_B + IR_S \quad (8)$$

Figure 6 shows the $dV/d(\ln(I))$ and $H(I)$ vs. current (I) of the Au/SnO_2/n-Si Schottky barrier diode. From $dV/d(\ln(I))$-I , the R_S and n values were found as 275 Ω and 1.132, respectively. From $H(I)$-I, the R_S and Φ_B values were found as 251 Ω and 0.801 eV, respectively. In classical I-V method and Norde method, diode parameter calculations are made over voltage dependent graphics. In these methods, since the calculation region is at low voltages, the barrier height values are determined close to each other. For the diode produced, these values are 0.750 eV and 0.755 eV for the I-V method and the Norde method, respectively. However, the reason why the 0.801 eV value obtained from the Cheung method is different is due to the fact that this method is calculated at high voltages.

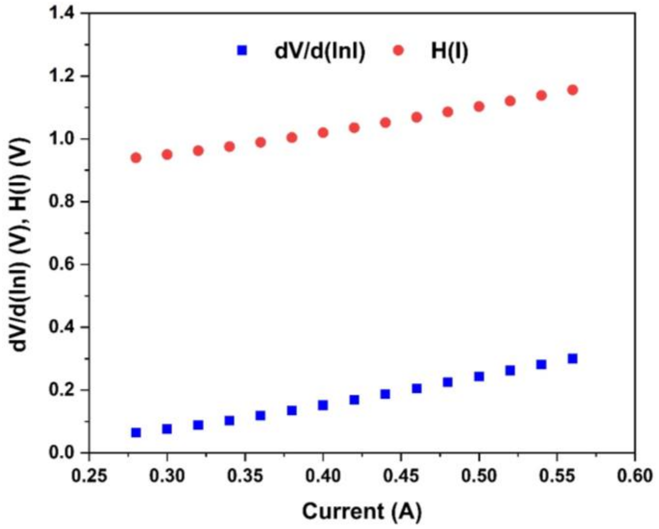

Figure 6. Plot of $dV/d(\ln(I))$-I and $H(I)$-I for the Au/V_2O_5/n-Si Schottky barrier diode.

Figure 7 shows the double logarithmic forward bias I-V curves of the Au/V_2O_5/n-Si Schottky barrier diode. According to Figure 7, at low-voltage part, the current conduction in the Au/V_2O_5/n-Si Schottky diode obeys Ohm's law. At the middle and high-voltage parts, the charge transport phenomenon dominates to be trapped filled space-charge-limited current (TLSCLC) and space-charge-limited current (SCLC), respectively.

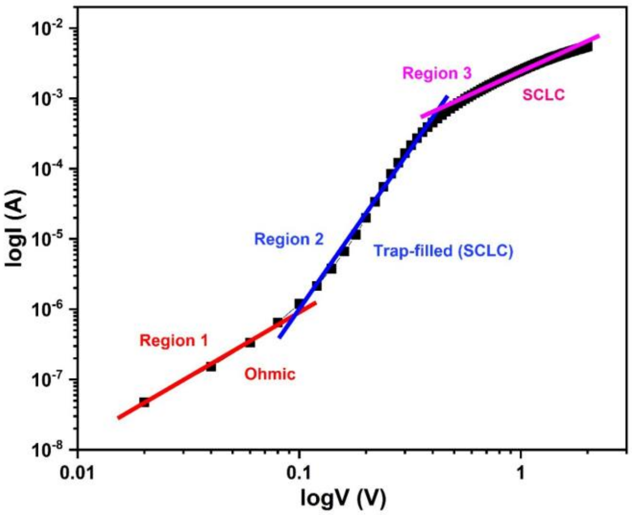

Figure 7. The log (I)-log (V) graph of Au/V_2O_5/n-Si Schottky barrier diode.

According to the method proposed by Card and Rhoderick (1971), the change in the energy band gap of the interface states (N_{SS}) in the case of the interface states being in equilibrium with the n type semiconductor is found by the following equations (Card & Rhoderick, 1971; Tuğluoğlu & Karadeniz, 2012):

$$N_{SS} = \frac{1}{q}\left(\frac{\varepsilon_i}{\delta}(n(V) - 1) - \frac{\varepsilon_s}{W_D}\right) \quad (9)$$

$$E_c - E_{ss} = q(\Phi_e - V) \quad (10)$$

where δ is the thickness of the V_2O_5 interface layer, E_C and E_{SS} are the energy of the interface states and conduction band, respectively. The permittivity of silicon semiconductor and V_2O_5 are $\varepsilon_s = 11.8\varepsilon_0$ and $\varepsilon_i = 12\varepsilon_0$, respectively. Figure 8 shows the interface state density (N_{SS}) vs. energy distribution (E_C - E_{SS}) curve of the Au/V_2O_5/n-Si Schottky barrier diode. From Figure 8, in the vary between E_C - 0.462 and E_C - 0.713 eV, the N_{SS} values for Au/V_2O_5/n-Si Schottky diode were determined to change from 4.34x10^{16} to 3.28x10^{15} eV^{-1} cm^{-2}, respectively.

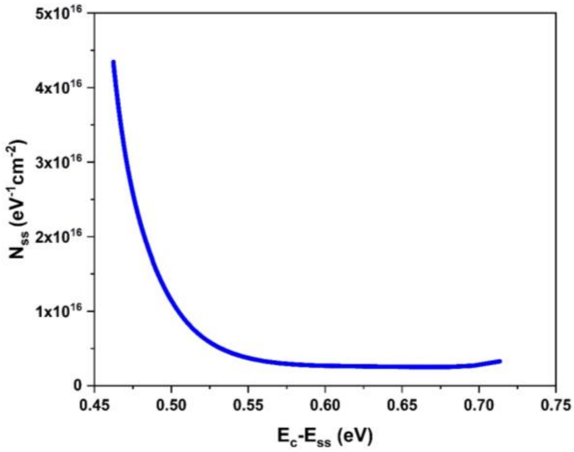

Figure 8. The variation N_{SS} values with E_C - E_{SS} in Au/V_2O_5/n-Si Schottky diode.

Figure 9 displays the capacitance-voltage (*C-V*) and $1/C^2$ characteristics of the produced Au/V_2O_5/n-Si diode at 300 K, at 1 MHz and at ±3V. The thickness (δ) of V_2O_5 is found capacitance-voltage (*C-V*) measurement in accumulation region by means of the relation for V_2O_5 oxide layer capacitance ($C_{ox} = \varepsilon_{ox}\varepsilon_0 A/d_{ox} = 8.91\text{x}10^{-10}F$), where $\varepsilon_{ox} = 12\varepsilon_0$ and ε_0 are the permittivity of the V_2O_5 thin film and free space. The value of V_2O_5 thickness for Au/V_2O_5/n-Si diode was determined as 37.4 nm. The curve of $1/C^2$ inferred from capacitance-voltage (*C-V*) measurement can yield knowledge about barrier height Φ_B of the produced Schottky diode. From the slope of $1/C^2$ - *V* plot, the value of Φ_B is calculated as 0.948 eV in Au/V_2O_5/n-Si diode.

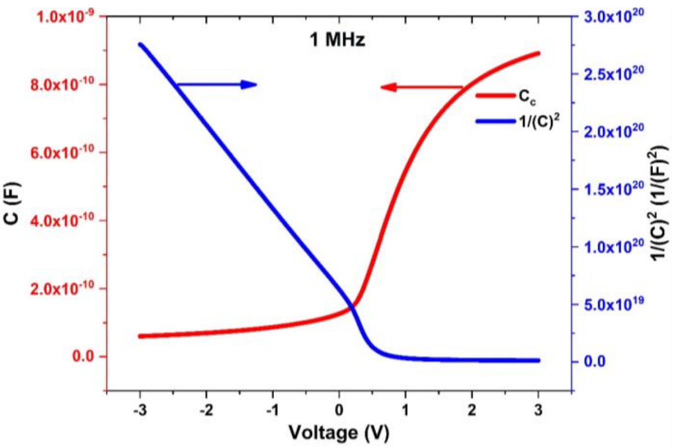

Figure 9. Capacitance-voltage (*C-V*) and $1/C^2$ - *V* characteristics of the Au/V_2O_5/n-Si Schottky diode.

Conclusion

For investigation the electrical properties of Au/V_2O_5/n-Si/Au Schottky diode, forming V_2O_5 thin films on n-Si wafer were fabricated by the RF magnetron sputtering. The rectification ratio of the produced diode was quite high and was determined as approximately 3940. The ideality factor of the diode was low and was determined as 1.35. The values of barrier height were found as 0.755 eV and 0.984 eV from *I-V* and *C-V* characteristics of the diode, respectively. This difference in value is due to the difference in measurement techniques. Space charge limited current (SCLC) in the current transport of the diode was also observed. The *logI* - *logV* curves of the dioded indicated three parts. At low voltage, the ohmic conduction mechanism referred to the charge carrier tunneling at the interfaces in region. At middle and high voltages, a TFSCLC and SCLC mechanism is the dominant current transport mechanism in II and III parts, respectively. In conclusion, the *I-V* and *C-V* results introduced that the Au/V_2O_5/n-Si/Au Schottky diode are useful different device applications.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

Akande, A. A., Mwakikunga, B. W., Rammutla, K. E., & Machatine, A. (2015). Larger selectivity of the V_2O_5 nano-particles sensitivity to NO_2 than NH_3. *Sensors & Transducers*, *192*(9), 61-65.

Akgul, F. D., Eymur, S., Akin, U., Yuksel, O. F., Karadeniz, H., & Tugluoglu, N. (2021). Investigation of Schottky emission and space charge limited current (SCLC) in Au/SnO_2/n-Si Schottky diode with gamma-ray irradiation. *Journal of Materials Science: Materials in Electronics*, *32*(12), 15857-15863. https://doi.org/10.1007/s10854-021-06138-4

Al-Kuhaili, M. F., Khawaja, E. E., Ingram, D. C., & Durrani, S. M. A. (2004). A study of thin films of V_2O_5 containing molybdenum from an evaporation boat. *Thin Solid Films*, *460*(1), 30-35. https://doi.org/10.1016/j.tsf.2004.01.076

Balasubramani, V., Chandrasekaran, J., Marnadu, R., Vivek, P., Maruthamuthu, S., & Rajesh, S. (2019). Impact of annealing temperature on spin coated V_2O_5 thin films as interfacial layer in Cu/V_2O_5/n-Si structured Schottky barrier diodes. *Journal of Inorganic and Organometallic Polymers and Materials*, *29*(5), 1533-1547. https://doi.org/10.1007/s10904-019-01117-z

Bayhan, H., & Bayhan, M. (2011). A simple approach to determine the solar cell diode ideality factor under illumination. *Solar Energy*, *85*(5), 769-775. https://doi.org/10.1016/j.solener.2011.01.009

Benkahoul, M., Zayed, M. K., Solieman, A., & Alamri, S. N. (2017). Spray deposition of V_4O_9 and V_2O_5 thin films and post-annealing formation of thermochromic VO_2. *Journal of Alloys and Compounds*, *704*, 760-768. https://doi.org/10.1016/j.jallcom.2017.02.088

Bokdam, M., Cakir, D., & Brocks, G. (2011). Fermi level pinning by integer charge transfer at electrode-organic semiconductor interfaces. *Applied Physics Letters*, *98*(11), 113303. https://doi.org/10.1063/1.3565963

Card, H. C., & Rhoderick, E. H. (1971). Studies of tunnel MOS diodes I. interface effects in silicon Schottky diodes. *Journal of Physics D: Applied Physics*, *4*(10), 1589. https://doi.org/10.1088/0022-3727/4/10/319

Cheung, S. K., & Cheung, N. W. (1986). Extraction of Schottky diode parameters from forward current-voltage characteristics. *Applied Physics Letters*, *49*(2), 85-87. https://doi.org/10.1063/1.97359

Dong, X., Su, Y., Wu, Z., Xu, X., Xiang, Z., Shi, Y., Chen, W., Dai, J., Huang, Z., Wang, T., & Jiang, Y. (2021). Reactive pulsed DC magnetron sputtering deposition of vanadium oxide thin films: Role of pulse frequency on the film growth and properties. *Applied Surface Science*, *562*, 150138. https://doi.org/10.1016/j.apsusc.2021.150138

Fateh, N., Fontalvo, G. A., Cha, L., Klunsner, T., Hlawacek, G., Teichert, C., & Mitterer, C. (2008). Synthesis-structure relations for reactive magnetron sputtered V_2O_5 films. *Surface & Coatings Technology*, *202*(8), 1551-1555. https://doi.org/10.1016/j.surfcoat.2007.07.010

Ihsan, M., Meng, Q., Li, L., Li, D., Wang, H., Seng, K. H., Chen, Z., Kennedy, S. J., Guo, Z., & Liu, H.-K. (2015). V_2O_5/mesoporous carbon composite as a cathode material for lithium-ion batteries. *Electrochimica Acta*, *173*, 172-177. https://doi.org/10.1016/j.electacta.2015.05.060

Karaca, G. Y., Eren, E., Alver, C., Koc, U., Uygun, E., Oksuz, L., & Oksuz, A. U. (2017). Plasma modified V_2O_5/PEDOT hybrid based flexible electrochromic devices. *Electroanalysis*, *29*(5), 1324-1331. https://doi.org/10.1002/elan.201600631

Kaya, M. D., Sertel, B. C., Sonmez, N. A., Cakmak, M., & Ozcelik, S. (2020). Thickness-dependent physical properties of sputtered V_2O_5 films and Ti/V_2O_5/n-Si Schottky barrier diode. *Applied Physics A: Materials Science & Processing*, *126*(11), 830. https://doi.org/10.1007/s00339-020-04023-1

Kaya, M. D., Sertel, B. C., Sonmez, N. A., Cakmak, M., & Ozcelik, S. (2021). The current-voltage characteristics of V_2O_5/n-Si Schottky diodes formed with different metals. *Journal of Materials Science: Materials in Electronics*, *32*(15), 20284-20294. https://doi.org/10.1007/s10854-021-06534-w

Kumar, N. S., Raman, M. S., Chandrasekaran, J., Priya, R., Chavali, M., & Suresh, R. (2016). Effect of post-growth annealing on the structural, optical and electrical properties of V_2O_5 nanorods and its fabrication, characterization of V2O5/p-Si junction diode. *Materials Science in Semiconductor Processing*, *41*, 497-507. https://doi.org/10.1016/j.mssp.2015.08.020

Liu, H. M., Wang, Y. G., Wang, K. X., Hosono, E., & Zhou, H. S. (2009). Design and synthesis of a novel nanothorn VO_2(B) hollow microsphere and their application in lithium-ion batteries. *Journal of Materials Chemistry*, *19*(18), 2835-2840. https://doi.org/10.1039/b821799h

Liu, Y. Y., Clark, M., Zhang, Q. F., Yu, D. M., Liu, D. W., Liu, J., & Cao, G. Z. (2011). V_2O_5 nano-electrodes with high power and energy densities for thin film Li-ion batteries. *Advanced Energy Materials*, *1*(2), 194-202. https://doi.org/10.1002/aenm.201000037

Liu, X. Y., Zeng, J. H., Yang, H. N., Zhou, K., & Pan, D. (2018). V_2O_5-Based nanomaterials: Synthesis and their applications. *RSC Advances*, *8*(8), 4014-4031. https://doi.org/10.1039/c7ra12523b

Luo, Z., Wu, Z., Xu, X., Du, M., Wang, T., & Jiang, Y. (2010). Impact of substrate temperature on the microstructure, electrical and optical properties of sputtered nanoparticle V_2O_5 thin films. *Vacuum*, *85*(2), 145-150. https://doi.org/10.1016/j.vacuum.2010.05.001

Mahato, S., Biswas, D., Gerling, L. G., Voz, C., & Puigdollers, J. (2017). Analysis of temperature dependent current-voltage and capacitance-voltage characteristics of an Au/V_2O_5/n-Si Schottky diode. *AIP Advances*, *7*(8), 085313. https://doi.org/10.1063/1.4993553

Norde, H. (1979). A modified forward I-V plot for Schottky diodes with high series resistance. *Journal of Applied Physics*, *50*(7), 5052-5053. https://doi.org/10.1063/1.325607

Ongun, O., Tasci, E., Emrullahoglu, M., Akin, U., Tugluoglu, N., & Eymur, S. (2021). Fabrication, illumination dependent electrical and photovoltaic properties of Au/BOD-Pyr/n-Si/In Schottky diode. *Journal of Materials Science: Materials in Electronics*, *32*(12), 15707-15717. https://doi.org/10.1007/s10854-021-06122-y

Qiao, Y., Chen, J., Lu, Y., Yang, X., Yang, H., & Xu, K. (2014). Fabrication of low phase transition temperature vanadium oxide films by direct current reactive magnetron sputtering and oxidation post-anneal method. *Infrared Physics & Technology*, *67*, 126-130. https://doi.org/10.1016/j.infrared.2014.07.016

Rhoderick, E. H., & Williams, R. H. (1988). *Metal-semiconductor contacts*. Clarendon Press.

Saad, M., & Kassis, A. (2011). Current-voltage analysis of the record-efficiency $CuGaSe_2$ solar cell: Application of the current separation method and the interface recombination model. *Solar Energy Materials and Solar Cells*, *95*(7), 1927-1931. https://doi.org/10.1016/j.solmat.2011.02.022

Senarslan, E., Guzeldir, B., & Saglam, M. (2017). Influence of anodic passivation on electrical characteristics of Al/p-Si/Al and Al/V_2O_5/p-Si/Al diodes. *Journal of Materials Science: Materials in Electronics*, *28*(11), 7582-7592. https://doi.org/10.1007/s10854-017-6450-4

Sigaud, P., Chazalviel, J. N., Ozanam, F., & Lahlil, K. (2003). Increased hole injection in organic diodes by grafting of dipolar molecules on indium-tin oxide. *Applied Surface Science*, *218*(1-4), 54-57. https://doi.org/10.1016/s0169-4332(03)00580-4

Tezcan, A. O., Eymur, S., Tasci, E., Emrullahoglu, M., & Tugluoglu, N. (2021). Investigation of electrical and photovoltaic properties of Au/n-Si Schottky diode with BOD-Z-EN interlayer. *Journal of Materials Science: Materials in Electronics*, *32*(9), 12513-12520. https://doi.org/10.1007/s10854-021-05886-7

Tuğluoğlu, N., & Karadeniz, S. (2012). Analysis of current-voltage and capacitance-voltage characteristics of perylene-monoimide/n-Si Schottky contacts. *Current Applied Physics*, *12*(6), 1529-1535. https://doi.org/10.1016/j.cap.2012.04.027

Wang, S. Q., Li, S. R., Sun, Y., Feng, X. Y., & Chen, C. H. (2011). Three-dimensional porous V_2O_5 cathode with ultra high rate capability. *Energy & Environmental Science*, *4*(8), 2854-2857. https://doi.org/10.1039/c1ee01172c

Yan, L., & Gao, Y. L. (2002). Interfaces in organic semiconductor devices. *Thin Solid Films*, *417*(1-2), 101-106, https://doi.org/10.1016/s0040-6090(02)00586-2