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Frequency Dependent Dielectric Properties of ZnSe/p-Si Diode

Araştırma Makalesi / Research Article

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ABSTRACT

The study on electrical and dielectric properties of the ZnSe/p-Si diode have been investigated using admittance measurements in the frequency range of 50 kHz - 1 MHz at room temperature. The experimental values of dielectric constant and dielectric loss are found in decreasing behavior with increase in frequency due to the characteristics of the interface capacitance in the diode and so that the similar behavior was observed in loss tangent. With the contribution of the series resistance, the results of the electrical conductivity analysis indicated direct proportionality to the frequency change. Additionally, electric modulus was discussed to represent the dielectric relaxation process in the diode structure.

Keywords: E-beam evaporation, dielectric properties, frequency effect.

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ÖZ

ZnSe/p-Si diyot yapısının elektrik ve dielektrik özellikleri oda sıcaklığında 50 kHz - 1 MHz frekans aralığında yapılan admitans ölçümleri kullanılarak incelendi. Deneysel olarak elde edilen dielektrik sabiti ve dielektrik kaybı değerlerinin, diyot yapısındaki arayüz kapasitans karakteristiğine bağlı olarak frekans artışı ile azalan bir davranışta olduğu görüldü, ve benzer davranış kayıp tanjantında da gözlemlendi. Elektriksel iletkenlik analizinde, seri direnç katkısı ile frekans değişimi ile doğrusal orantılı olarak bir değişim bulundu. Ayrıca, diyot yapısındaki dilelektrik relaksasyon davranışı, elektrik modülüsler kullanılarak tartışıldı.

Anahtar Kelimeler: E-demeti buharlaştırma, dielektrik özellikler, frekans etkisi.

1. INTRODUCTION (GİRİŞ)

With the current interest in the optoelectronic applications of heterojunctions, II-VI compounds have been employed with Si based heterojunction as a promising materials for photodetector and also photovoltaic diodes [1-4]. This type of diode structure associates the advantageous properties of the highly transparent, direct-band gap ZnSe window layer and the high mobility, tractable properties of Si layer [5]. In the previous work, the authors presented the material properties of the e-beam deposited ZnSe thin film layer and the results of the current-voltage measurements on the ZnSe/p-Si diode [6]. From the systematic studies of the ZnSe film, it was found in stoichiometric and polycrystalline in structure and homogeneous in surface morphology. With the high transparency characteristics for the visible region, the fundamental band gap value was obtained as about 2.8 eV. The experimental forward current-voltage (I–V) characteristics of the diode was modelled by the Gaussian distribution in the barrier height and the current behavior was assumed to be dependent on especially interfacial layer, interfaces states and series resistance. In addition to this electrical analysis of ZnSe/p-Si diode, the frequency dependent capacitance-voltage ($C-V$) and conductance-voltage ($G/\omega-V$) characteristic were investigated under the indication of interfacial states. Therefore, the objective of the present work on $C-V$ and $G/\omega-V$ characteristics as a function of frequency is to obtain information about the effects of the interface states and electrical parameters under the effect of localized electronic states. From these analysis, the effects of the frequency and the bias voltage on the dielectric properties were investigated and the main dielectric parameters were calculated with the presence of the interfacial layer.

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2. MATERIAL and METHOD (MATERYAL VE METOD)

The polycrystalline ZnSe thin film layer was deposited on the (111) oriented p-type (B-doped) crystalline Si wafer with the resistivity value of 1-10 (Ω-cm) by e-beam deposition technique to fabricate the ZnSe/p-Si diode structure [6]. The back metal contact on the Si wafer was formed by elemental Al evaporation onto the whole back surface of the wafer and subsequent annealing treatment at 450°C under the nitrogen atmosphere to achieve the ohmic contact behavior. Additionally, top ohmic contact was deposited by thermal evaporation of In elemental source through shadow mask in circular dot contact shape of 2 mm diameter onto ZnSe film surface. The complete structure was annealed at 100°C under the nitrogen atmosphere to enhance the ohmicity of the contact. The $C-V$ and $G/\omega-V$ characteristics were analyzed by using Hewlett Packard 4192A LF model impedance analyzer at room temperature and dark condition.

3. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

The $C-V$ and $G/\omega-V$ plots of the ZnSe/p-Si diode structure for different frequencies at room temperature were discussed in the previous work [6]. According to these plots, $C-V$ behavior was found to be in a less sensitive to the frequency variation and $G/\omega-V$ plot showed a characteristic peak profile for each measured frequency. With increasing applied frequency, both capacitance (C) and conductance (G/ω) values decrease, and the peak value of the G/ω also decreases under the effect of series resistance of the diode [7]. However, frequency affects these measured values strongly at low frequencies and this can be attributed to the presence of interfacial oxide layer and the particular distribution of interface states [8-10]. Assuming the total diode capacitance as a sum of junction and interface state capacitance, exchanges of the carriers can contribute to the total diode capacitance by the fact that at relatively low frequencies the interface states can follow the applied ac signal [11, 12]. Therefore, C of the interfacial layer in the ZnSe/p-Si inhomogeneous diode evaluated as in a series combination of the junction capacitance can be the reason of this observed frequency dispersion [13].

Based on the impedance/admittance technique, the conductance losses from the exchange of majority carriers at the junction interface can be discussed to determine the dielectric parameters and their frequency dependencies [14, 15]. Therefore, in this work, the frequency effects of dielectric constant (ε'), dielectric loss (ε''), loss tangent ($tan\delta$), ac electrical conductivity (σ_{ac}) and electric modulus (M' and M'') are investigated from the room temperature measurements under applied frequency interval of 50kHz-1MHz [16, 17]. In this case, a complex capacitance (C^*) can be defined to derive a real capacitance in the application of ac bias voltage, and it can be given as $C^*=Y^*/i\omega$ which is related to the complex admittance Y^* at angular value of ω [18]. From this relation, the complex relative permittivity $\varepsilon^*=\varepsilon'-i\varepsilon''$ can be used to describe the dielectric properties of the diode [19, 20]. At various frequencies, the real part of ε^* named as dielectric constant (ε'), and the imaginary part as dielectric loss (ε'') are calculated using the measured capacitance (C_m) and conductance (G_m/ω) values at the strong accumulation region as [11, 21, 22],

$$\varepsilon'=\frac{C_m d_i}{\varepsilon_0 A}=\frac{C_m}{C_0} \quad (1)$$

and

$$\varepsilon''=\frac{G_m d_i}{\omega\varepsilon_0 A}=\frac{G_m}{\omega C_0} \quad (2)$$

where C_0 is the capacitance of an empty capacitor as $C_0=\varepsilon_0 A/d_i$ with diode active area, A, interfacial layer thickness, d_i and permittivity of free space, ε_0. The calculated frequency dependent ε' and ε'' values are shown in Fig.1 and these values are found in decreasing behavior with increase in frequency, whereas ε' shows a frequency independent nature of the parameter in the negative voltage region. Since C and G/ω are sensitive to the interface properties and also parasitic resistances, this inverse relation can be explained with the change in the response time of the interfacial dipole orientation to the applied field [21, 23]. The increase of the capacitance depends on the ability of the charge carrier concentration to follow the applied ac signal [11] and so that these carriers at the localized interface states can hop between a pair of these centers having different dipole orientations. However, as decreasing in the polarization at high frequencies, dipoles could not follow this action of the ac field without having enough time to relax in equilibrium and therefore to give a response to the ac signal [23]. The dispersion behavior shown in Fig.1 can be due to the inhomogeneity in the diode with the effect of accumulation of the charges at the boundary of less conducting regions and interfacial polarization [11, 20, 24]. In addition, the interfacial oxide layer thickness was calculated from $C-V$ characteristics using the basic concept of parallel plate capacitor and it was estimated as about 4 nm [25-27].

In addition to the analysis of real and imaginary components of ε^*, the results can also be discussed using the loss tangent, $tan\delta=\varepsilon''/\varepsilon'$, $tan\delta=G_m/\omega C_m$ which indicates the amount of energy that is dissipated in the dielectric when an electric field is applied across it [18, 22]. Fig. 2 shows the characteristics of $tan\delta$ with a peak behavior at each frequency and this behavior can be related to the frequency dependence of ε' and ε'' values. As shown in Fig.1(b) and Fig.2, ε'' and $tan\delta$ have peaks for each frequency and the peak position shifts toward lower voltages with decreasing frequency. The decrease in the magnitude of the peaks with increasing frequency may be due to the presence of interface traps [28, 29]. Furthermore, the interface state density, the series resistance of the diode, and the thickness of the interfacial insulator layer can be responsible for this behavior of $tan\delta$ [9, 21, 23].

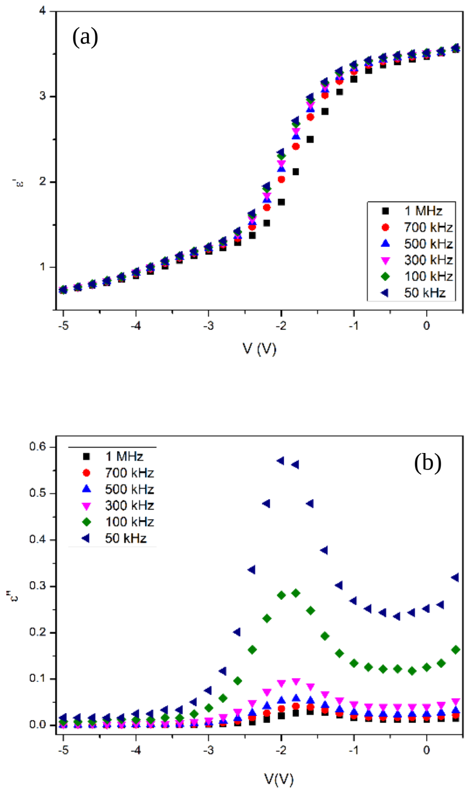

Figure 1. Frequency dependent room-temperature ε' (a) and ε'' (b) of ZnSe/p-Si diode

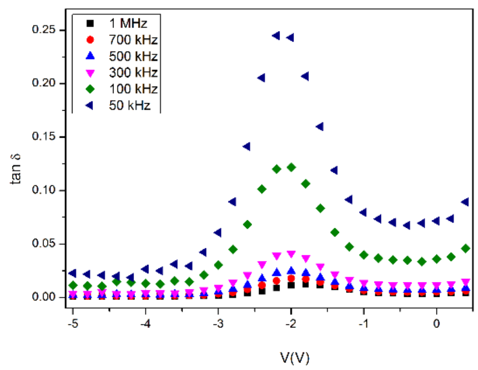

Figure 2. Frequency dependent room-temperature $tan\delta$ of ZnSe/p-Si diode

The ac electrical conductivity (σ_{ac}) of the dielectric material can be expressed as [18, 30],

$$\sigma_{ac} = \omega C_m \, tan\delta(d_i/A) = \omega\varepsilon_0\varepsilon'' \qquad (3)$$

and the observed conductivity behavior of the ZnSe/p-Si diode is presented in Fig.3 at different voltage and frequency values. The magnitude of the σ_{ac} peaks (Fig.3) increase with increasing frequency and their positions shift toward the positive bias voltages. The observed behavior in σ_{ac} values can be accompanied by an increase of the eddy current and it is also related to the increase of $tan\delta$ [21, 29]. This behavior can also be attributed to a gradual decrease in the series resistance with increasing frequency [6, 21, 23, 31].

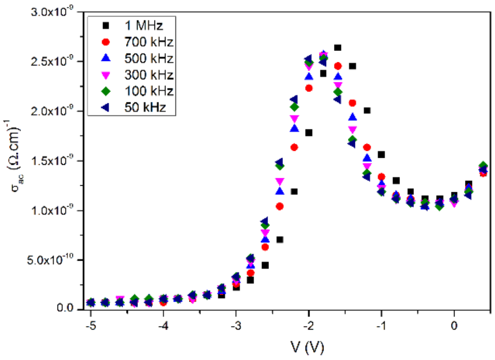

Figure 3. Frequency dependent room-temperature σ_{ac} of ZnSe/p-Si diode

The complex impedance Z^* and complex dielectric modulus M^* can be used to analyze the relaxation properties of ZnSe/p-Si diode [21, 23]. In fact, these analysis of ε^* within the Z^* formalism is commonly used to separate the bulk and the surface phenomena and to determine the bulk dc conductivity of the material [32]. Additionally, M^* can be used to monitor the electrical properties of the material and is a useful technique to investigate the influences of frequency on the relaxation processes [33]. As a simply geometric inverse of the admittance, Z^* can be written as $Z^* = 1/i\,\omega C_0\varepsilon^*$, and then as an inverse of ε^*, M^* can be defined as,

$$M^* = i\omega C_0 Z^* \qquad (4)$$

where real and imaginary part of M^* are interrelated with ε^* as $M' = \varepsilon'/(\varepsilon'^2 + \varepsilon''^2)$ and $M'' = \varepsilon''/(\varepsilon'^2 + \varepsilon''^2)$, respectively [23, 28].

As shown in Fig.4, M' increases with increase in frequency and decrease in voltage, and an inverse behavior with frequency is observed in M''. With changing frequency, the decrease in the height and the shift in the position of the peaks can be evaluated with the conductivity relaxation process in the junction and the effect of the interface state density [29, 34].

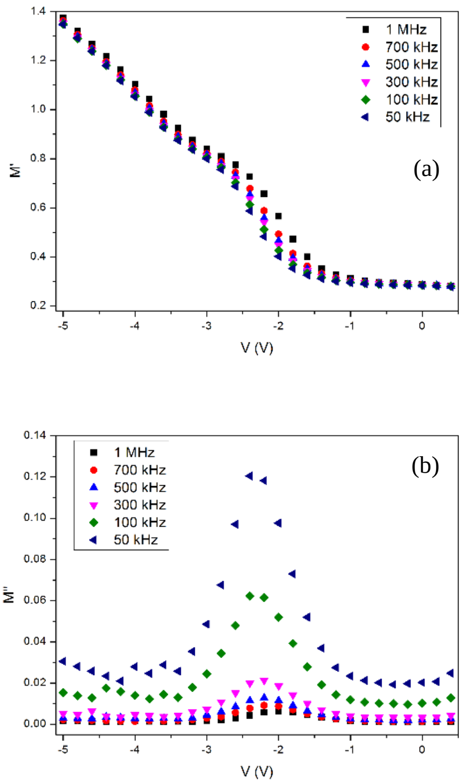

Figure 4. Frequency dependent room-temperature M' (a) and M'' (b) of ZnSe/p-Si diode

6. CONCLUSION (SONUÇ)

In this work, frequency dependent electrical and dielectric properties were investigated by carrying out and $C-V$ and $G/\omega-V$ measurements and the results were discussed as a continuation of the published works on I-V measurements. Thus, the presence of the interface states and their distribution characteristics were analyzed to explain the possible frequency dispersion of the capacitance and conductance. Depending the capacitance and conductance characteristics, the values of ε' and ε'' were calculated in the approximation of the presence of interfacial oxide layer and the particular distribution of interface states, and they were found in decreasing behavior with increase in frequency. ε' was seem to be frequency independent in the negative voltage region whereas characteristic peak profile for each measured frequency was observed in ε'' plot. In addition, related to the frequency dependence of these values, the characteristics of $tan\delta$ showed a peak at each frequency. The variation of σ_{ac} was explained by increase in the eddy current and it is also related to the increase of $tan\delta$. In addition, considering electric modulus formalism, the relaxation properties of ZnSe/p-Si diode were determined.

REFERENCES (KAYNAKLAR)

[1] Wasa, K., Hayakawa, S., "RF-Sputtered n-p Heterojunction Diodes of ZnSe-Si and ZnSe-GaAs", ***Jpn. J. Appl. Phys.*** 12: 408-414 (1973).

[2] Darwish, S., Riad, A.S., Soliman, H.S., "Electrical conductivity and the effect of temperature on photoconduction of n-ZnSe/p-Si rectifying heterojunction cells", ***Semicond. Sci. Technol.*** 11: 96-102 (1996).

[3] Jiansheng, J., Zhang, W., Bello, I., Lee, C.S., Lee, S.T., "One-dimensional II–VI nanostructures: Synthesis, properties and optoelectronic applications", ***Nano Today*** 5: 313-336 (2010).

[4] Venkatachalam, S., Mangalaraj, D., Narayandass, Sa.K., Velumani, S., Schabes-Retchkiman, P., Ascencio, J.A., "Structural studies on vacuum evaporated ZnSe/p-Si Schottky diodes", ***Mater. Chem. Phys.*** 103: 305-311 (2007).

[5] Zhang, X., Zhang, X., Wang, L., Wu, Y., Wang, Y., Gao, P., Han, Y., Jie, J., "ZnSe nanowire/Si p–n heterojunctions: device construction and optoelectronic applications", ***Nanotechnology*** 24: 395201 (2013).

[6] Gullu, H.H., Bayrakli, O., Yildiz, D.E., Parlak, M., "Study on the electrical properties of ZnSe/si heterojunction diode", ***J. Mater. Sci.: Mater. Electron.*** 28: 17809-17815 (2017).

[7] Chattorpadhyay, P., Raychaudhuri, B., "Frequency dependence of forward capacitance-voltage characteristics of Schottky barrier diodes", ***Solid-State Electron.*** 36: 605-610 (1993).

[8] Gokcen, M., Altuntas, H., "On the profile of temperature dependent electrical and dielectric properties of Au/SiO_2/n-GaAs (MOS) structures at various frequencies", ***Physica B*** 404: 4221-4224 (2009).

[9] Tataroglu, A., Yucedag, I., Altindal, S., "Dielectric properties and ac electrical conductivity studies of MIS type Schottky diodes at high temperatures", ***Microelectron. Eng.*** 85: 1518-1523 (2008).

[10] Akkal, B., Benamara, Z., Gruzza, B., Bideux, L., "Characterization of interface states at Au/InSb/InP(100) Schottky barrier diodes as a function of frequency", ***Vacuum*** 57: 219-228 (2002).

[11] Sze, S.M., "***Physics of Semiconductor Devices***", Wiley, New York, 1981.

[12] Murat, P., "The contribution of broad interface state bands to the capacitance of metal/semiconductor diodes", ***Solid-State Commun.*** 59: 67-70 (1986).

[13] Murthy, B.S., Rao, P.R.S., "Frequency dependence of junction capacitance", ***IETE J. Res.*** 17: 273-276 (1970).

[14] Haddara, H.S., El-Sayed, M., "Conductance technique in MOSFETs: Study of interface trap properties in the depletion and weak inversion regimes", ***Solid-State Electron.*** 31: 1289-1298 (1998).

[15] Nicollian, E.H., Goetzberger, A., "MOS conductance technique for measuring surface state parameters", ***Appl. Phys. Lett.*** 7: 216-219 (1965).

[16] Bulbul, M. M., Zeyrek, S., "Frequency dependent capacitance and conductance–voltage characteristics of Al/Si_3N_4/p-Si(100) MIS diodes", ***Microelectron. Eng.*** 83: 2522-2526 (2006)

[17] Tataroglu, A., Altindal, S., "Study on the frequency dependence of electrical and dielectric characteristics of Au/SnO_2/n-Si (MIS) structures", ***Microelectron. Eng.*** 85: 1866-1871 (2008)

[18] Symth, C.P. "***Dielectric Behavior and Structure***", McGraw-Hill, New York, 1955.

[19] Kar, S., Narasimhan, R.L., "Characteristics of the Si-SiO_2 interface states in thin (70-230 Å) oxide structures", ***J. Appl. Phys.*** 61: 5353-5359 (1987).

[20] Daniel, V.V., "***Dielectric Relaxation***", Academic, London, 1967.

[21] Yildiz, D.E., Dokme, I., "Frequency and gate voltage effects on the dielectric properties and electrical conductivity of Al/SiO_2/p-Si metal-insulator-semiconductor Schottky diodes", ***J. Appl. Phys.*** 110: 014507 (2011).

[22] Chelkowski, A., "***Dielectric Physics***", Elseiver, Amsterdam, 1980.

[23] Tataroglu, A., Altindal, S., Bulbul, M.M., "Temperature and frequency dependent electrical and dielectric properties of Al/SiO_2/p-Si (MOS) structure", ***Microelectron. Eng.*** 81: 140-149 (2005).

[24] Kaya, A., Vural, O., Tecimer, H., Demirezen, S., Altindal, S., "Frequency and voltage dependence of dielectric properties and electric modulus in Au/PVC + TCNQ/p-Si structure at room temperature", ***Curr. Appl. Phys.*** 14: 322-330 (2014).

[25] Tataroglu, A., "Dielectric Permittivity, AC Conductivity and Electric Modulus Properties of Metal/Ferroelectric/Semiconductor (MFS) Structures", ***GU J. Sci.*** 26: 501-508 (2013)

[26] Ataseven, T., Tataroglu, A., "Temperature-dependent dielectric properties of Au/Si_3N_4/n-Si (metal-insulator-semiconductor) structures", ***Chin. Phys. B*** 22: 117310-1-6 (2013)

[27] Strzalkowski, I., Joshi, S., Crowell, C. R., "Dielectric constant and its temperature dependence for GaAs, CdTe, and ZnSe", Appl. Phys. Lett. 28: 350-352 (1976)

[28] Altindal, S., Asar, Y. S., Kaya, A., Sonmez, Z., "Investigation of interface states in Al/SiO2/p-Si (MIS) structures with 50 and 826 angstrom SiO2 interfacial layer using admittance spectroscopy method", ***J. Optoelectron. Adv. Mater.*** 14: 998–1004 (2012)

[29] Bilkan, C., Asisian-Kalandaragh, Y., Altindal, S., Shokrani-Havigh, R., "Frequency and voltage dependence dielectric properties, ac electrical conductivity and electric modulus profiles in Al/Co_3O_4-PVA/p-Si structure", ***Physica B*** 500: 154-160 (2016)

[30] Popescu, M. Bunget, I., "***Physics of Solid Dielectrics***", Elseiver, Amsterdam, 1984.

[31] Riad, A.S., Korayem, M.T., Abdel-Malik, T.G., "AC conductivity and dielectric measurements of metal-free phthalocyanine thin films dispersed in polycarbonate", ***Physica B*** 270:140-147 (1999).

[32] Macedo, P.B., Moynihan, C.T., Bose, R., "Role of ionic diffusion in polarization in vitreous ionic conductors", ***Phys. Chem. Glasses*** 13:171-179 (1972).

[33] Hoque, Md.M., Dutta, A., Kumar, S., Sinha, T.P., "Dielectric Relaxation and Conductivity of $Ba(Mg_{1/3}Ta_{2/3})O_3$ and $Ba(Zn_{1/3}Ta_{2/3})O_3$", ***J. Mater. Sci. Technol.*** 30: 311-320 (2014).

[34] Baraz, N., Yucedag, I., Asisian-Kalandaragh, Y., Altindal, S., "Determining electrical and dielectric parameters of dependence as function of frequencies in Al/ZnS-PVA/p-Si (MPS) structures", ***J. Mater. Sci.: Mater. Electron.*** 28: 1315-1351 (2017)