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Investigation Of Dielectric Properties For SnO_2-PVA/n-Si Schottky Barrier Diode

Çiğdem BİLKAN[1*]

[1] Tokat Gaziosmanpaşa University, Erbaa Vocational School of Health Services, Department of Medical Services and Techniques, Tokat, Türkiye
Çiğdem BİLKAN ORCID No: 0000-0002-3347-673X

Corresponding author: cigdem.bilkan@gop.edu.tr

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Keywords
Schottky Barrier Diodes, Dielectric properties, Electrical modulus

Abstract: The dielectric properties of SnO2-PVA nanocomposite films were examined graphically using capacitance (C) and conductivity (G/ω) data obtained over a wide frequency and voltage range at room temperature. For SnO_2-PVA/n-Si, some dielectric parameters (dielectric constants (ε', ε'') and electrical modulus (real M' and imaginary M'' parts), loss tangent (tan δ) and ac electrical conductivity (σ_{ac}) frequency and voltage dependence were calculated. As the frequency increased for each applied bias voltage, the ε', ε'' and tan δ values decreased, and it was observed that the changes in these parameters were more effective at low frequencies due to the additional loads on the interface states. While M' increases as the frequency increases due to the short-range mobility of charge carriers and has low values in the low-frequency region. The value of M'' decreases as the frequency increases due to the decrease in polarization and the density of interface states (N_{ss}) effects. While the value of electrical conductivity is almost constant at low frequencies, it increases almost exponentially at high frequencies.

SnO_2-PVA/n-Si Schottky Bariyer Diyotun Dielektrik Özelliklerinin İncelenmesi

Anahtar Kelimeler
Schottky Engel Diyotları, Dielektrik özellikler, Elektrik modülüs

Öz: 300 K°'de SnO_2-PVA nanokompozit filmlerin dielektrik özellikleri, geniş bir frekans ve voltaj aralığında elde edilen kapasitans (C) ve iletkenlik (G/ω) verileri kullanılarak grafiksel olarak incelenmiştir. SnO_2-PVA/n-Si için bazı dielektrik parametrelerinin (dielektrik sabitleri (ε', ε'') ve elektriksel modülüs (M' ve M''), kayıp tanjantı (tan δ) ve ac iletkenliğin hem gerçek hem de sanal kısımları (σ_{ac}), vb.), frekans ve gerilime bağımlılığı hesaplandı. Uygulanan her ön gerilim için frekans arttıkça ε', ε'' ve tan δ değerleri azalmış ve ara yüzey durumlarına gelen ilave yüklerden dolayı bu parametrelerdeki değişikliklerin düşük frekanslarda daha etkili olduğu görülmüştür. M', yük taşıyıcılarının kısa menzilli hareketliliği nedeniyle frekans arttıkça artarken, düşük frekans bölgesinde düşük değerlere sahiptir. Polarizasyon ve Ara yüzey durumların yoğunluğu (N_{ss}) etkilerinin azalması nedeniyle frekans arttıkça M'' değeri azalır. Elektriksel iletkenlik değeri düşük frekansta hemen hemen sabit iken, yüksek frekansta neredeyse katlanarak artmaktadır.

1. INTRODUCTION

Schottky barrier diodes (SBDs) are integrated circuit elements actively used in the electronics industry and technological products and have a very important place in technological developments. Many parameters affect the performance of Schottky barrier diodes, such as: preparation processes of the surfaces, interface states resulting from trap levels created by pollution atoms resulting from production, series resistance of the device, densities of the doped atoms, potential barrier in homogeneities that will occur at the interface of the two structures when contacting the metal and semiconductor, voltage and frequency applied externally to the structure, temperature of the environment where the structure is located, the existence of an polymer interlayer that separates the metal and the interface from each other and passivates the interface states that will occur [1, 2]. ε', ε'', M' and M'', tan δ, and σ_{ac} parameters are also significantly impacted by these structural parameters. Additionally, the locally active polarization mechanisms of the structure are severely affected.

Studies on the molecular orientation behaviour, relaxation, and polarization mechanisms of polymers are currently ongoing, even though the dielectric properties of many polymers used in electronics have been investigated. One of the greatest ways is to look at dielectric loss and dielectric constant scenarios based on frequency. These computations allow for the analysis of a polymeric film's polymer structure and the voicing of opinions regarding its potential application as an interface in electrical devices.

With the implementation of a dc or ac electric field, the charges stored in the trap energy levels can be released and this can create an additional charge effect on the device [3, 4-7]. Especially, at low frequencies, for these surface states, charges can follow the ac signal. Moreover, there is less time to orient interfacial dipoles in the direction of the ac electric field [7]. This paper aims the examination of electrical and dielectric parameters of Ag/SnO_2-PVA/n-Si SBDs with SnO_2-doped PVA polymer interface layer under varying frequency and voltage at 298 K.

2. MATERIAL AND METHOD

2.1. Measurements

The fabricated structure was obtained with the use of an n-type (P-doped) single crystals silicon wafer with 300 mm thickness and 3" diameter. Wafers were cleaned in solutions of $3H_2SO_4$:$1H_2O_2$, 20% HF, and de-ionized water. Rectifying and ohmic contacts were deposited using Ag metal, and the back contact was annealed at 700 °C to gain the ohmic feature. SnO_2-PVA nanocomposite film with a thickness of 10 nm was deposited on a substrate with magnetron sputtering using a hot compacting $Bi_4Ti_3O_{12}$ powder of a stoichiometric composition as a target material.

The C-V and G/ω-V analyses of the Ag/SnO_2-PVA/n-Si nanocomposite structures were held at room temperature. The analyses were made between (-7) V and (+3) V and in the frequency range of 70 kHz-3 MHz using an HP 4192A LF impedance analyser (In Figure 1)

3. RESULTS

In this paper, the SnO_2-PVA nanostructure was fabricated, and the electrical and dielectric parameters of the structure were analysed. How electrical and dielectric properties change, especially with frequency changes (increase or decrease), has been examined graphically. The real (ε', M', tan δ, σ_{ac}) and imaginary (ε", M") parts of dielectric parameters were also obtained. The obtained values were examined graphically.

Four different types of polarization mechanisms are active in dielectric materials. These can be listed as follows; oriental/dipolar and interfacial polarization, atomic, electronic, or ionic [8]. Oriental/dipolar and interfacial polarizations have a large effect on dielectric properties because the dielectric constant remains almost constant at high frequencies. Interfacial polarization is very active due to the N_{ss} effect when $f \leq 10^3$ Hz. In the frequency range of 10^3-10^6 Hz, dipolar and interfacial polarization are more active because impurities and surface charges are active in this region. Atomic or ionic polarization occurs in high frequencies such as 10^{10}-10^{13} Hz. At very high frequencies such as about 10^{15} Hz, electronic polarization is especially active.

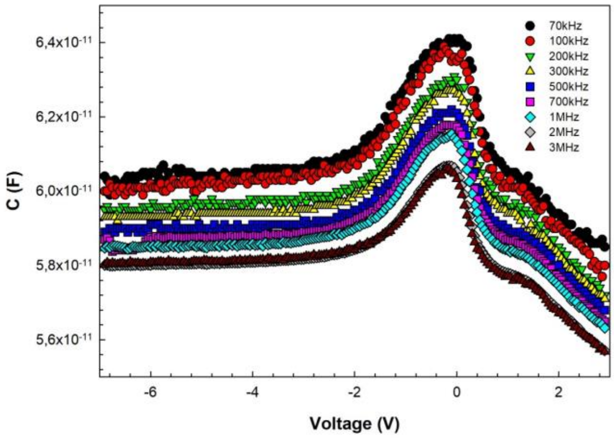

Figure 1 (a). The variation of the C-V characteristics between (-7 V)-(+3 V) of the Ag/SnO_2-PVA /n-Si SBDs.

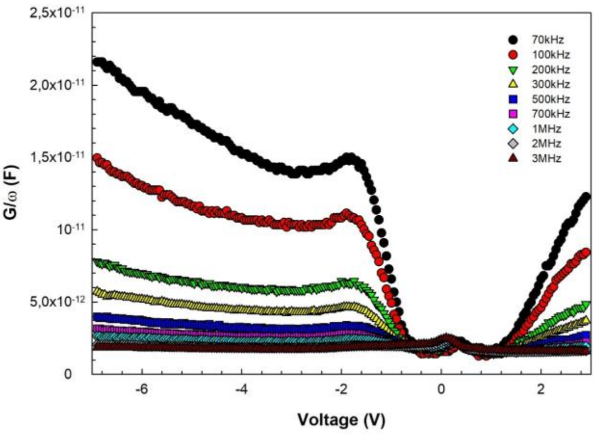

Figure 1 (b). The variation of the G/ω-V characteristics between (-7 V)-(+3 V) of the Ag/SnO_2-PVA /n-Si SBDs.

When a dc or ac electric field is applied, stored charges at N_{ss} and trap levels may be released and create additional load on the device. For low frequencies, at the interface states, charges can follow the ac signal, and therefore the interface dipoles can orient themselves in the direction of the ac electric field in a shorter time. As a result, these charges create additional capacitance and additional conductance (C_{ex} and G_{ex}/ω) in the measured value. With this, in the accumulation and depletion zones, investigated all parameters of the structure are high. The values of ε' and ε" were obtained from the Equations 1 and 2. The results were given in Figure 2 and 3, respectively:

$$\varepsilon' = \frac{C}{C_o} = \frac{Cd_i}{\varepsilon_o A} \quad (1)$$

$$\varepsilon'' = \frac{G}{\omega C_o} = \frac{Gd_i}{\varepsilon_o \omega A} \quad (2)$$

In the equations, A is the area of the diode (rectifier contact), ε_o=8.85x10^{-12} F/m is the permeability of the free space charge and Co= ε_o A/d$_i$ is the capacitance at the lowest frequency, di is the thickness of the intermediate polymer interface layer, ε' and ε'' components express the energies stored and lost in each cycle of the applied external electric field.

Tan δ called loss tangent value was also found by using the ε' and ε'' as in Equation 3, and the results are given in Figure 4 [8]:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} = \frac{G}{\omega C} \quad (3)$$

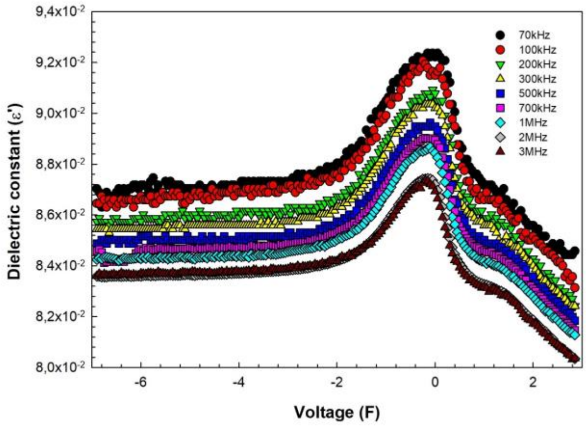

Figure 2 (a). Frequency-dependent the variation of the dielectric constant (ε') of the Ag/SnO_2-PVA /n-Si/Ag SBDs at room temperature.

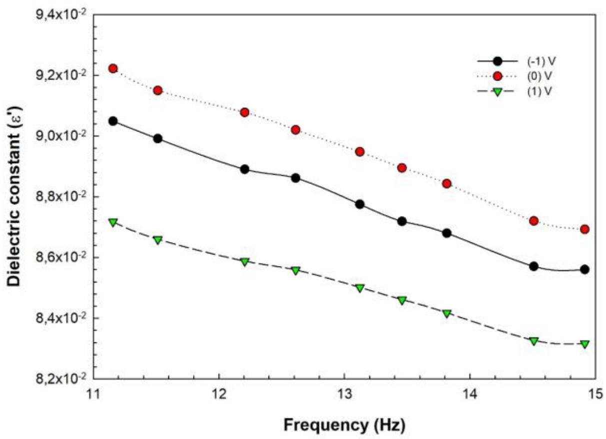

Figure 2 (b). Voltage-dependent the variation of the dielectric constant (ε') of the Ag/SnO_2-PVA /n-Si/Ag SBDs at room temperature.

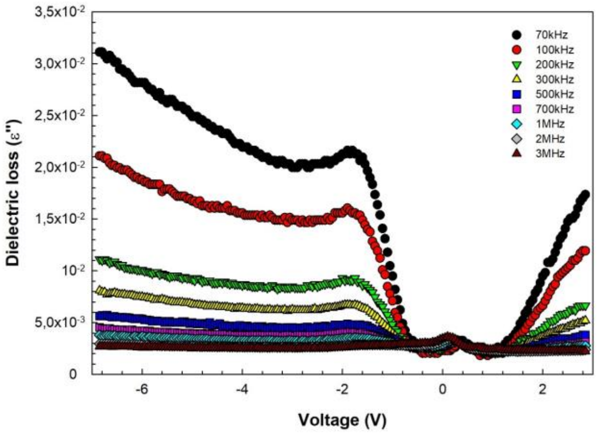

Figure 3 (a). Frequency-dependent the variation of the dielectric loss (ε'') of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

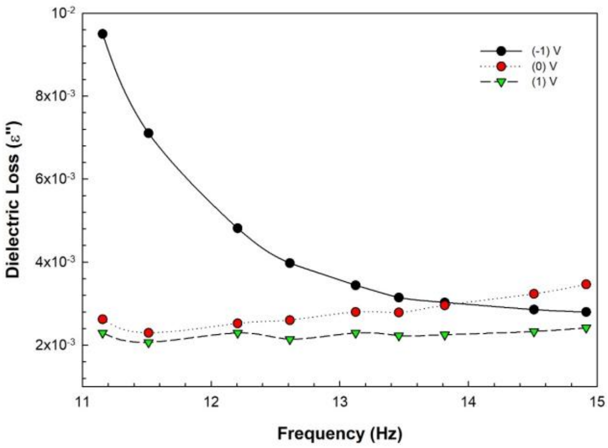

Figure 3 (b). Voltage-dependent the variation of the dielectric loss (ε'') of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

The fact that the parameters ε' and ε'' decrease as the frequency increases can be explained by the Debye relaxation model for the effect of dipole and interface/surface polarizations and interfacial states. For every applied bias voltage, the main dielectric parameter values ε', ε'', and tan δ have been found to decrease with increasing frequency. However, these changes are more pronounced in the depletion region, particularly at low frequencies, because of the extra carrier charges in the

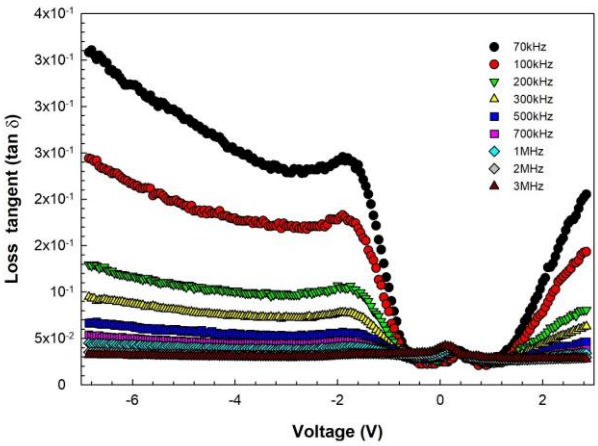

Figure 4 (a). Frequency-dependent the variation of the tan δ of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

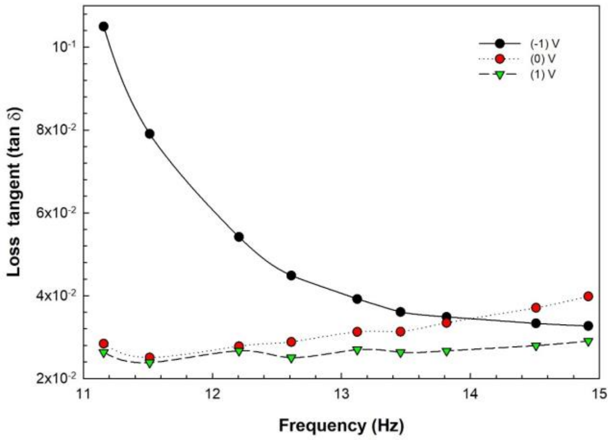

Figure 4 (b). Voltage-dependent the variation of the tan δ of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

surface states or traps, their relaxation times, and the polarization effect.

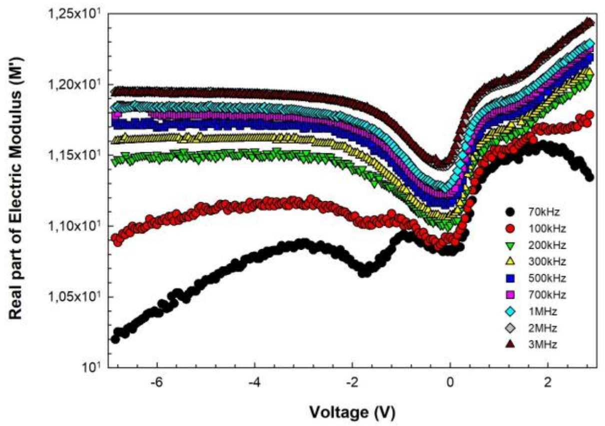

Figure 5 (a). Frequency-dependent the variation of the M' of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

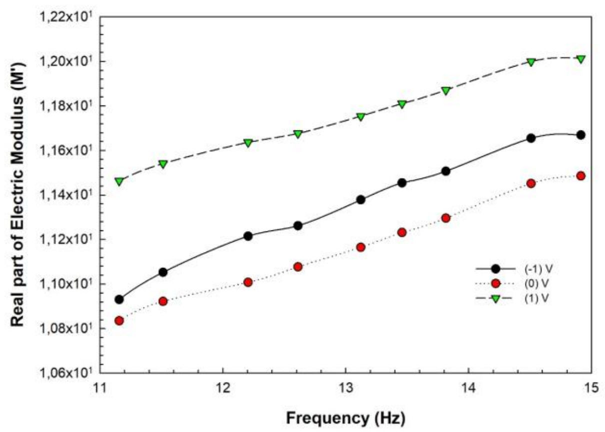

Figure 5 (b). Voltage-dependent the variation of the M' of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

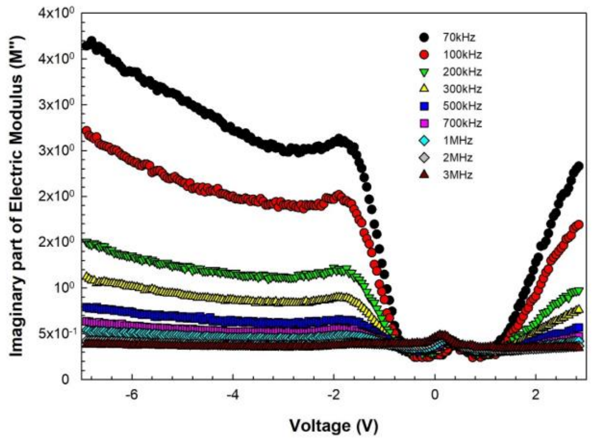

Figure 6 (a). Frequency-dependent the variation of the M" of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

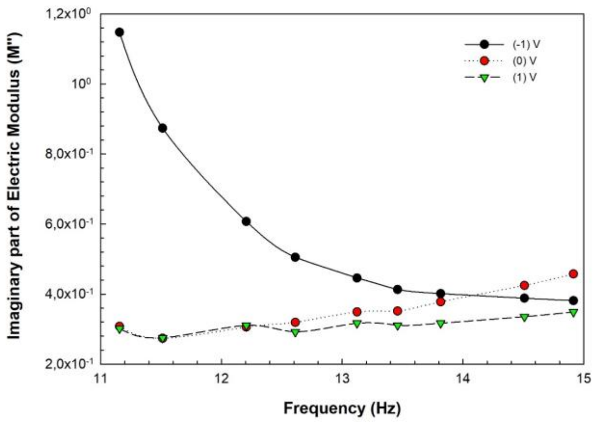

Figure 6 (b). Voltage-dependent the variation of the M" of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

Real and imaginary electric modulus M* formulas have been discussed by various authors in dielectric analysis studies of electronic materials [8]. M* expressions obtained using complex permeability (ε*=1/M*) data are shown in equations 4a and 4b.

$$M^* = M' + iM'' = \frac{\varepsilon'}{\varepsilon'^2 + \varepsilon''^2} + i\frac{\varepsilon''}{\varepsilon'^2 + \varepsilon''^2} \qquad (4)$$

Using the ε', ε'', and Equation 4, M' and M" were derived and are shown in Figures 5 and 6, respectively. As we can see in Figure 5, M' values are low in the low-frequency zone but increase with frequency because of the charge carriers' short-range mobility. M" values, in contrast to M' values, fall as frequency increases. This is because as frequency rises, polarization and N_{ss} effects diminish.

Dielectric relaxation is responsible for the rise in electrical modulus and dielectric properties in depletion and accumulation zones. All these characteristics decrease with increasing polarization because increasing polarization causes an increase in the number of carriers, which is proportional to the applied bias voltage [8].

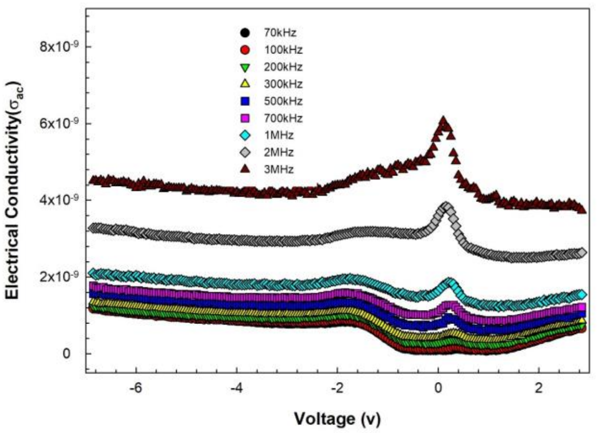

Figure 7 (a). Frequency-dependent the variation of the σ_{ac} of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

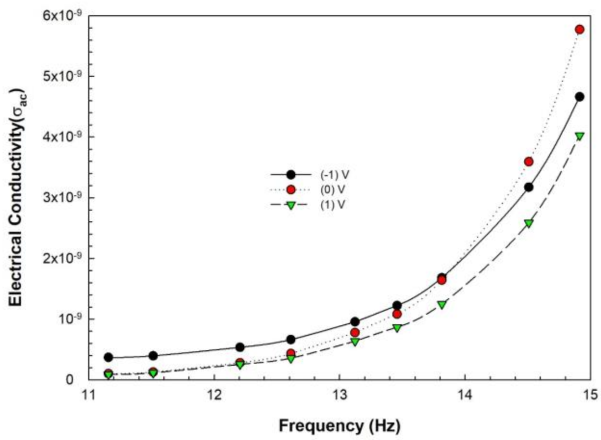

Figure 7 (b). Voltage-dependent the variation of the σ_{ac} of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

In order to determine the dielectric properties of the interfacial layer, the strong accumulation region is considered. In particular, in this region, the actual values of the ε" and σ_{ac} parameters are investigated [8]. The following formulas were used to determine the diode structure's frequency- and voltage-dependent ac electrical conductivity (σ_{ac}) at room temperature. The outcomes are displayed in Figure 7:

$$\sigma_{ac} = \omega C \tan\delta(\frac{d_i}{A}) = \varepsilon^{''} 2\pi f \varepsilon_o = b\omega^s, \quad (1 > s > 0) \qquad (5)$$

In here,   is angular frequency of the applied ac voltage, b and s are constants. Figure 7 shows σ_{ac}-V plot of the Ag/SnO_2-PVA /n-Si SBDs. While the value of s is almost constant at low frequencies, increases almost as exponentially and shows a peak at high frequencies which correspond to σ_{dc} and σ_{ac}, respectively.

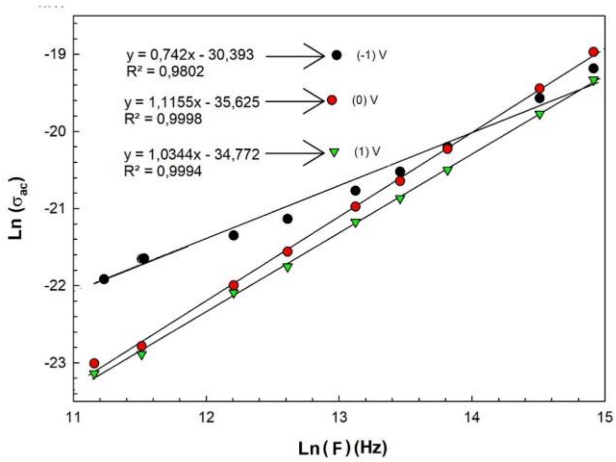

Figure 8. The Ln (σ_{ac})-Ln (F) of the Ag/SnO_2-PVA /n-Si SBDs at room temperature.

It is well known, that the hoping of carrier charges from one state to another state located between (SnO2-PVA) and n-Si in the forbidden band gap of the semiconductor leads to an increase in frequency-dependent ac electrical conductivity as seen in Eq. (5). To the value of s, double logarithmic ln(σ_{ac}) vs ln (f) plot was drawn for various applied bias voltage and given in Figure 8. As seen in Figure 8, the ln(σ_{ac}) vs ln (f) graph shows good linear behavior for each voltage, and its slopes (s) are found to be 0.74, 1.12, 1.03 for (-0.1V), 0V and 1V, respectively [8].

4. DISCUSSION AND CONCLUSION

In this study, SnO_2-PVA nanostructures were prepared and the electrical and dielectric properties of this structure were examined. How electrical and dielectric properties change, especially with frequency changes (increase or decrease), has been examined graphically. For interpretations, real and imaginary parts of the dielectric parameters (ε', ε", M', M", tan δ, and σ_{ac}, etc.) were obtained. These obtained values were examined graphically.

All obtained results confirmed that N_{ss} is an important parameter in electrical and dielectric characterization processes and must be taken into consideration. It has been shown that the diode performance improves in the presence of the SnO_2-PVA nanocomposite interface layer and that the SnO_2-PVA layer can be a good alternative as a dielectric material in MPS-based devices.

Acknowledgement

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