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Research Article

Voltage and Frequency Dependence Dielectric Properties of Au/n-CdTe Schottky Diodes

Hatice KANBUR ÇAVUŞ[1,5*], Murat ÇAVUŞ[2], Caner İLDEŞ[3], Selva BÜYÜKAKKAŞ[4], Recep ŞAHİNGÖZ[5]

[1]Yozgat Bozok University, Institute of Hemp Research, Department of Material and Energy, Yozgat, Türkiye
[2]Yozgat Bozok University, Faculty of Education, Department of Mathematics and Science Education, Yozgat, Türkiye
[3]Yozgat Bozok University, Application and Research Center of Science and Technology (BILTEM), Yozgat, Türkiye
[4]Niğde Ömer Halisdemir University, Faculty of Arts and Sciences, Department of Physics, Niğde, Türkiye
[5]Yozgat Bozok University, Faculty of Arts and Sciences, Department of Physics, Yozgat, Türkiye

Abstract

In this study, voltage and frequency dependent dielectric properties of Au/n-CdTe Schottky diodes grown by thermal evaporation method were investigated. The frequency and voltage dependent of capacitance-voltage ($C-V$) and conductance-voltage ($G/\omega-V$) characteristics were measured in the frequency range of 1 kHz - 500 kHz at room temperature. Dielectric constant (ε'), dielectric loss (ε''), dielectric loss tangent ($\tan\delta$), the ac electrical conductivity (σ_{ac}), and complex impedance (Z^*) were calculated from the $C-V$ and $G/\omega-V$ characteristics and plotted as a function of frequency.

Keywords: Schottky diodes, Dielectric properties, Complex impedance, Electrical conductivity, Capacitance

1. INTRODUCTION

Recently many researchers decided to use CdTe for device applications semiconductor solar cells, radiation detectors and diodes. Also high optical absorption coefficient, direct band gap in the visible light spectrum were made their mind to choose CdTe [1–8]. In literature some preparation methods such as sputtering, spray pyrolysis, metal-organic chemical vapour deposition and thermal evaporation were used for the preparation of thin CdTe films [9–15]. The advantages of the thermal evaporation technique are high deposition rates and lower cost. This process produce a strong vacuum and we can fabricate very high purity thin films. The structural and optical properties of thermally evaporated CdTe thin films have been presented reported recently [16–21].

Therefore, a clear understanding of the physical principles underlying the properties of these interfaces is essential for developing practical devices based on this semiconductor material [22–28]. In this study, the dependencies of dielectric properties of thermally evaporated Au/n-CdTe Schottky diode were investigated.

2. MATERIAL AND METHODS

The CdTe diodes were fabricated on monocrystalline CdTe (111) substrate by thermal evaporation technique in a vacuum about 2×10^{-5} Torr. For the manufacturing process, CdTe wafers were cleaned by using standard cleaning method; and finally quenched in de-ionized water with a resistivity of 18 MΩ. After surface cleaning, high purity gold (Au) metal (99.999%) with a thickness of 1000 Å was thermally evaporated in the vacuum system at a pressure of $\sim10^{-6}$ Torr. Low-resistance ohmic contacts were formed by thermal annealing at 400°C for 5 min in flowing N_2. After ohmic contact, circular dots of 1 mm in diameter and 1100 Å thick Au rectifying contacts were deposited onto CdTe surface. Hall measurements indicated the films to be n-type. The $C-V$ and $G/\omega-V$ characteristics of Au/n-CdTe diode were measured at room temperature by the Keithley 4200 UCF Semiconductor Parameter Analyser.

[1,5] https://orcid.org/0000-0001-8525-0313 [2]https://orcid.org/0000-0002-2341-6485 [3]https://orcid.org/0000-0003-3168-935X

[4]https://orcid.org/0000-0003-2967-1521 [5]https://orcid.org/0000-0002-9525-8068

[*]**Correspondence: hatice.kanbur@bozok.edu.tr**

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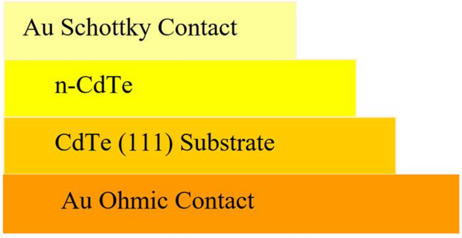

Figure 1. Au/n-type CdTe Schottky diode

3. RESULTS AND DISCUSSION

Figure 2 and Figure 3 show the $C-V$ and $G/\omega-V$ plots of Au/n-CdTe Schottky barrier biode SBD carried out at the frequency range of 1 kHz–500 kHz at room temperature. As can be seen Figure 2 and Figure 3, the low-frequency capacitance and conductance increases with applied voltage while the high-frequency capacitance and conductance remains almost constant. Also reported that in the high frequency, the interface states (N_{ss}) cannot follow the ac signal and consequently do not contribute appreciably to the Au/CdTe Schottky barrier diodes capacitance [22–28].

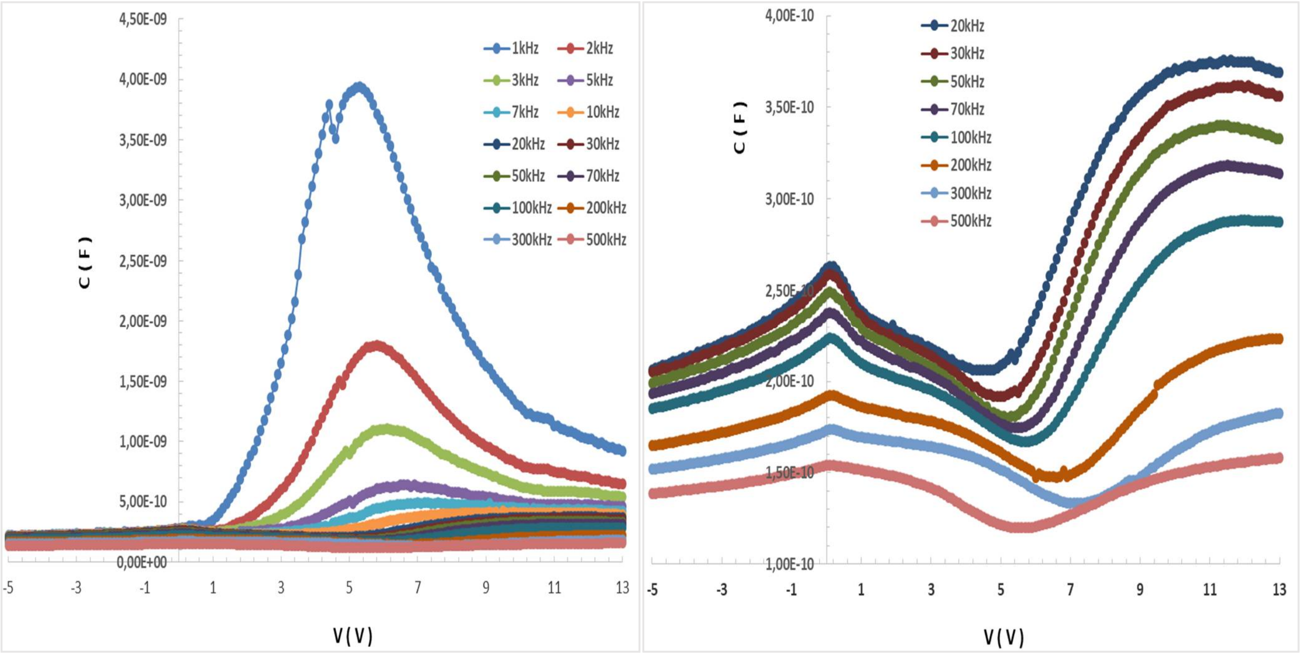

Figure 2. The C versus V graphs of the structures for each frequency

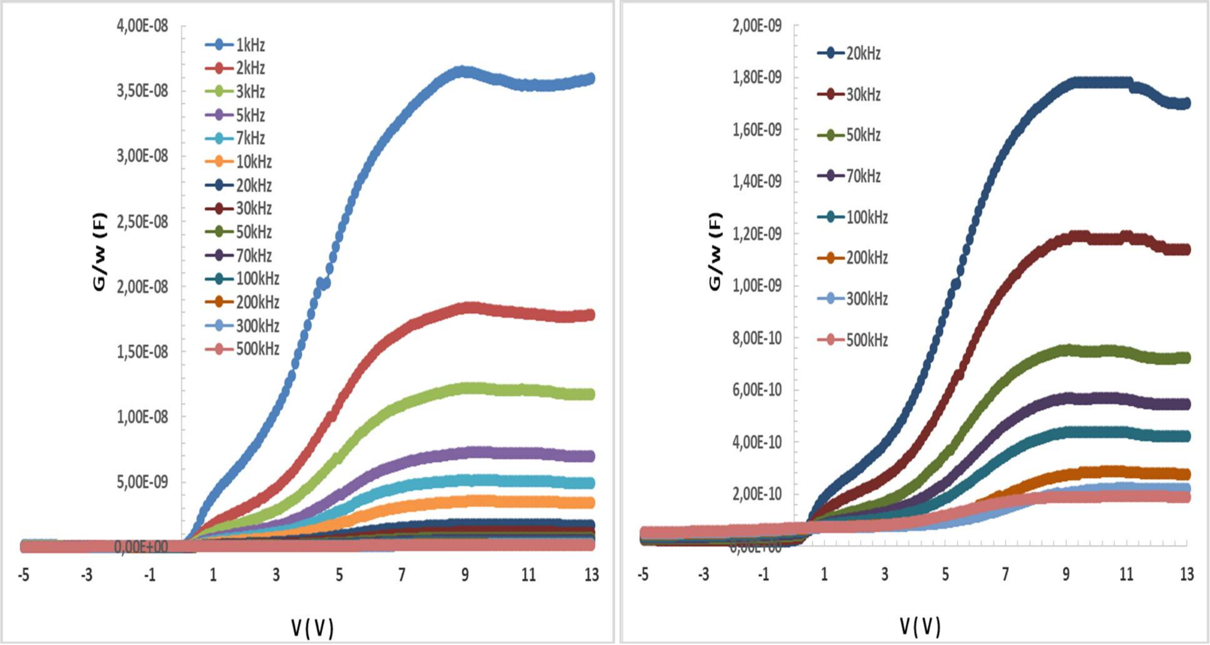

Figure 3. The G/ω versus V graphs of the structures for each frequency

Series resistance (R_s) is one of the important parameter for Schottky diodes. The real value of resistance R_i at sufficiently high frequencies (f = 500 kHz or f > 500 kHz) corresponds to the real value of R_s for Schottky diodes and can be subtracted from the measured C and G values in the strong accumulation region as follows [22, 23],

$$R_s = \frac{G_m}{G_m^2 + wC_m^2} \tag{1}$$

where C_m and G_m are the measured capacitance and conductance values in the strong accumulation region. The voltage and frequency dependence of the resistance was obtained from the measurements of $C-V-f$ and $G/\omega-V-f$ curves by using Eq. 1. It is clearly seen in Figure 4 that R_s is strongly dependent on voltage and frequency.

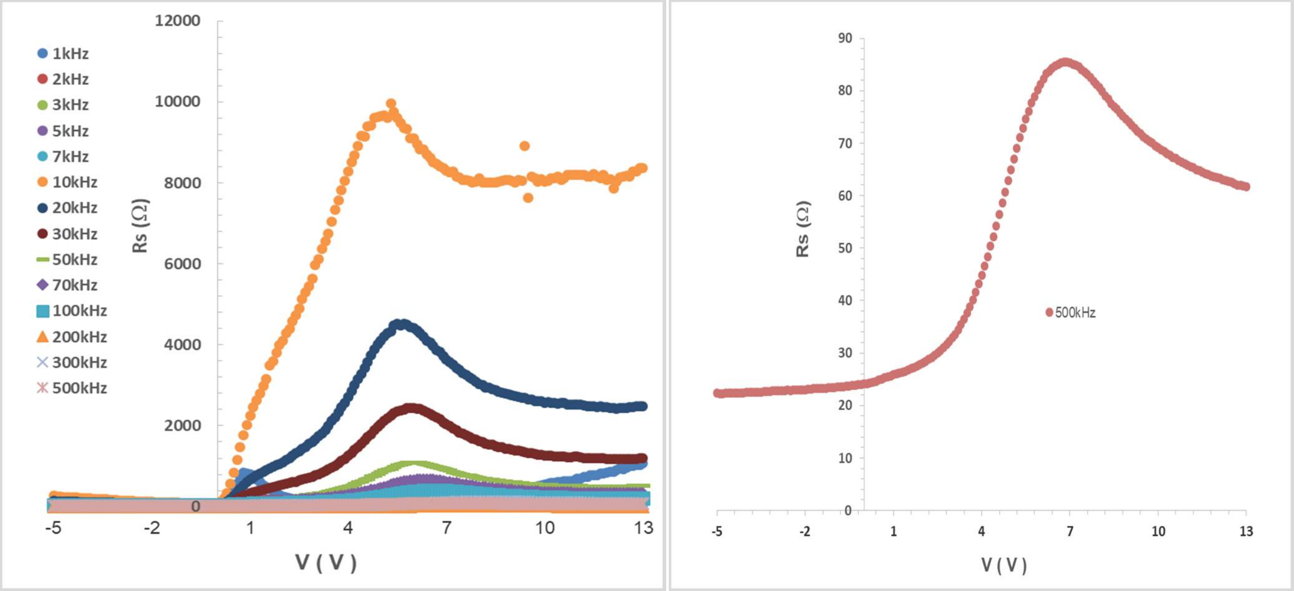

Figure 4. The R_s versus V graphs of the structure for distinct frequency

The frequency distribution of N_{ss} can be derived from Hill Coleman method by using the following equation [23]:

$$N_{ss} = \left(\frac{2}{qA}\right)\frac{(G_m/\omega)_{max}}{((G_m/\omega)_{max}/C_{ox})^2 + (1 - C_m/C_{ox})^2} \tag{2}$$

where, A is the area of the diode, ω is the angular frequency, C_m and G_m are the measured capacitance and conductance which correspond to peak values, C_{ox} is the capacitance of insulator layer. From this relation, C_{ox} is obtained as

$$C_{ox} = C_{ma}\left[1 + \left(\frac{G_{ma}}{\omega C_{ma}}\right)^2\right] = \frac{\varepsilon_i \varepsilon_0 A}{d_{ox}} \tag{3}$$

The density distribution profile of N_{ss} for Au/n-CdTe diode was obtained by using Eq. 2 and given in Figure 5. The values of various parameters for the Au/CdTe Schottky barrier diodes determined from $C - V$ and $G/\omega - V$ characteristics in frequency range of 1 kHz–500 kHz are given in Table 1.

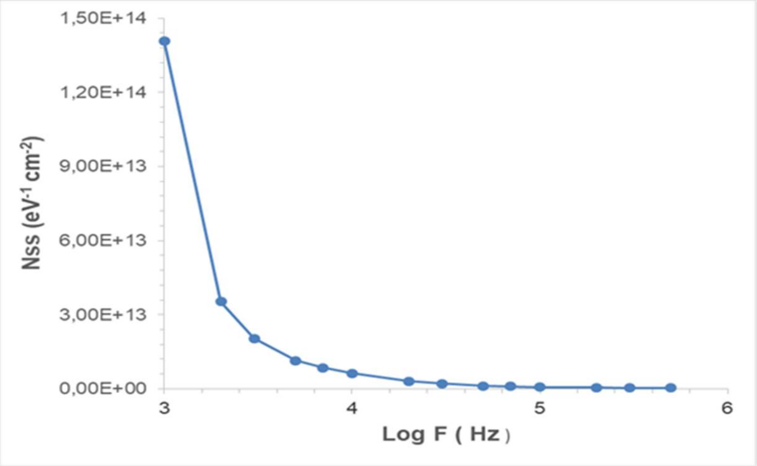

Figure 5. The N_{ss} versus log F graph for the structure

Table 1. The calculated electronic parameters in the wide ranged 1 kHz–500 kHz

F (Hz)	V_{max} (V)	C_{max} (F)	G_{max}/ω	N_{ss} (eV^{-1}cm^{-2})
1000	5,4	3,92x10^{-9}	2,70x10^{-8}	1,41x10^{14}
2000	5,8	1,80x10^{-9}	1,40x10^{-8}	3,53x10^{13}
3000	6,2	1,10x10^{-9}	9,80x10^{-9}	2,04x10^{13}
5000	6,7	6,40x10^{-10}	6,20x10^{-9}	1,15x10^{13}
7000	7,3	4,91x10^{-10}	4,80x10^{-9}	8,57x10^{12}
10000	9,2	4,12x10^{-10}	3,60x10^{-9}	6,30x10^{12}
20000	11,4	3,76x10^{-10}	1,76x10^{-9}	3,06x10^{12}
30000	11,5	3,62x10^{-10}	1,20x10^{-9}	2,08x10^{12}
50000	11,5	3,40x10^{-10}	7,30x10^{-10}	1,26x10^{12}
70000	11,7	3,18x10^{-10}	5,50x10^{-10}	9,42x10^{11}
100000	12,0	2,88x10^{-10}	4,20x10^{-10}	7,14x10^{11}
200000	13,0	2,24x10^{-10}	2,80x10^{-10}	4,69x10^{11}
300000	13,5	1,84x10^{-10}	2,20x10^{-10}	3,65x10^{11}

The dielectric behaviour of the structure has been studied over a wide range of frequency (1 kHz–500 kHz). The complex permittivity (ε^*) formalism has been used to obtain significant data about the chemical and physical behaviour of the electrical and dielectric properties. The complex permittivity can be defined in the following complex form [23].

$$\varepsilon^{*} = \varepsilon' - j\varepsilon'' \tag{4}$$

The real part of the complex permittivity, the dielectric constant (ε'), at the various frequencies is calculated using the measured capacitance values at the strong accumulation region from the relation [22,23],

$$\varepsilon' = \frac{C}{C_{\mathrm{o}}} \tag{5}$$

where C_o is capacitance of an empty capacitor. $C_o = \varepsilon_o(A/d)$; where A is the rectifier contact area in cm^{-2}, d is the interfacial insulator layer thickness and ε_o is the permittivity of free space charge ($\varepsilon_o = 8.85 \times 10^{-14}\ F/cm$). In the strong accumulation region, the maximal capacitance of Schottky diode corresponds to the insulator capacitance (C_{ox}) ($C_{ac} = C_{ox} = \varepsilon'\varepsilon_o A/d$). The imaginary part of the complex permittivity, the dielectric loss (ε''), at the various frequencies is calculated using the measured conductance values from the relation:

$$\varepsilon'' = \frac{G}{\omega C_{\mathrm{o}}} \tag{6}$$

The loss tangent (tan δ) can be expressed as follows:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \tag{7}$$

The ac electrical conductivity (σ_{ac}) of the dielectric material is given by the following equation:

$$\sigma_{ac} = \omega C \tan\delta\ (d/A) = \varepsilon''\omega\varepsilon_{\mathrm{o}} \tag{8}$$

Analysis of the complex permittivity (ε^{*}) data within the Z^{*} formalism ($Z^{*} = 1/Y^{*} = 1/i\omega C_{\mathrm{o}}\varepsilon^{*}$) is commonly used to separate the bulk and the surface phenomena and to determine the bulk dc conductivity of the material [22,23]. The complex impedance or the complex permittivity ($\varepsilon^{*} = 1/M^{*}$) data were transformed into the M* formalism using the following relation:

$$\mathrm{M}^{*} = j\omega C_{\mathrm{o}} Z^{*} \tag{9}$$

or

$$\mathrm{M}^{*} = \frac{1}{\varepsilon^{*}} = M' + jM'' = \frac{\varepsilon'}{\varepsilon'^{2} + \varepsilon''^{2}} + j\frac{\varepsilon''}{\varepsilon'^{2} + \varepsilon''^{2}} \tag{10}$$

The variations of dielectric constant, dielectric loss, tan δ and ac conductivity with frequency for the CdTe thin films in the frequency range of 1 kHz–500 kHz are shown in Figure (6-9) respectively. The dielectric constant is found to decrease with the increase in frequency. The thin films of CdTe exhibited the similar behavior in the case of dielectric loss. In general, four possible mechanisms may be contributed to be low-frequency dielectric behavior of MIS Schottky diodes: interface states, ac conductivity, dipole-orientation and charge carriers [7,17,22,23,29]. Figure 9 displays the variation of ac conductivity with frequency. The ac conductivity of CdTe thin films is found to increase with the frequency.

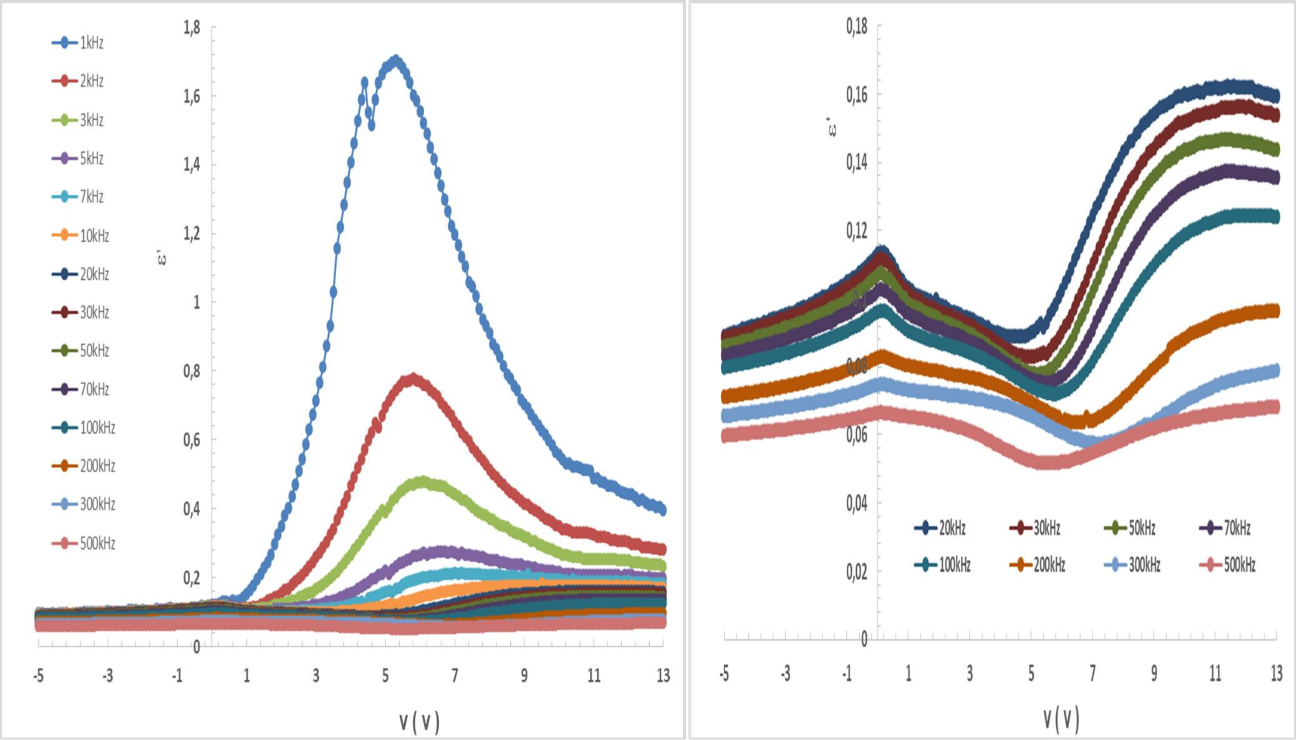

Figure 6. Variations of the dielectric constant of Au/n-CdTe Schottky Diode

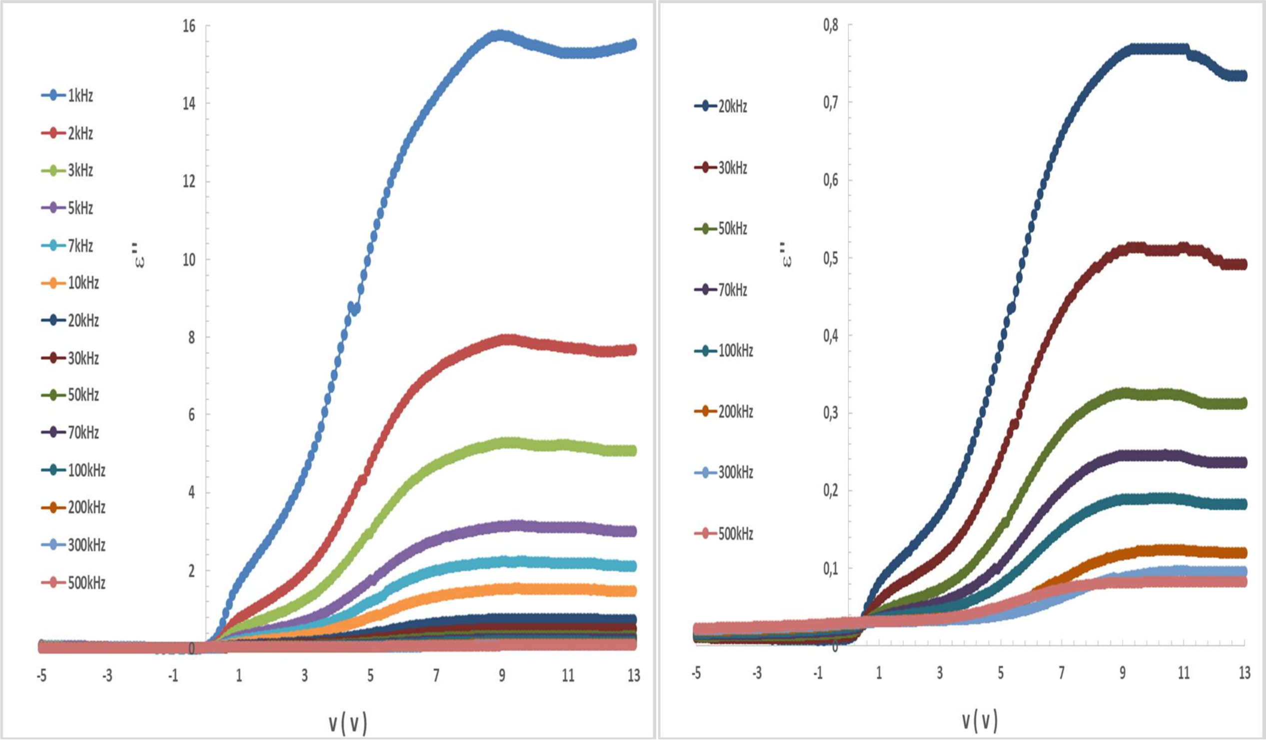

Figure 7. Variations of the dielectric loss of Au/n-CdTe Schottky Diode

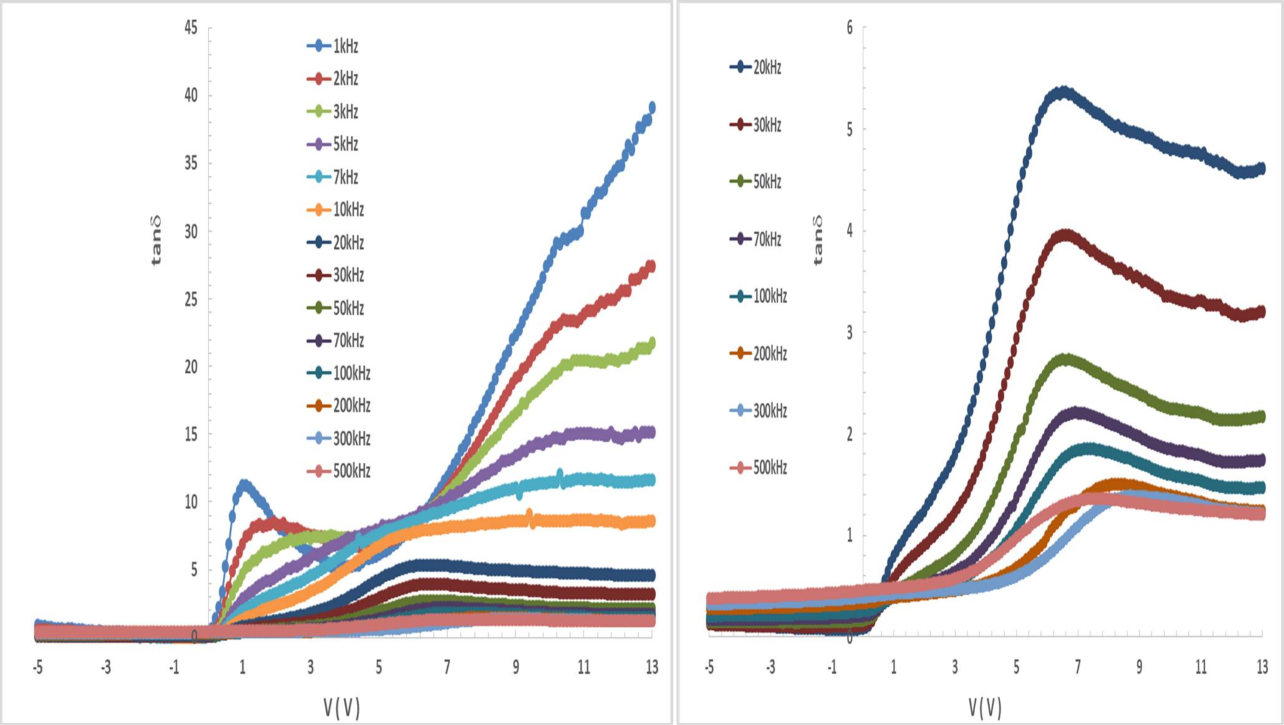

Figure 8. Variations of the tangent loss of Au/n-CdTe Schottky Diode

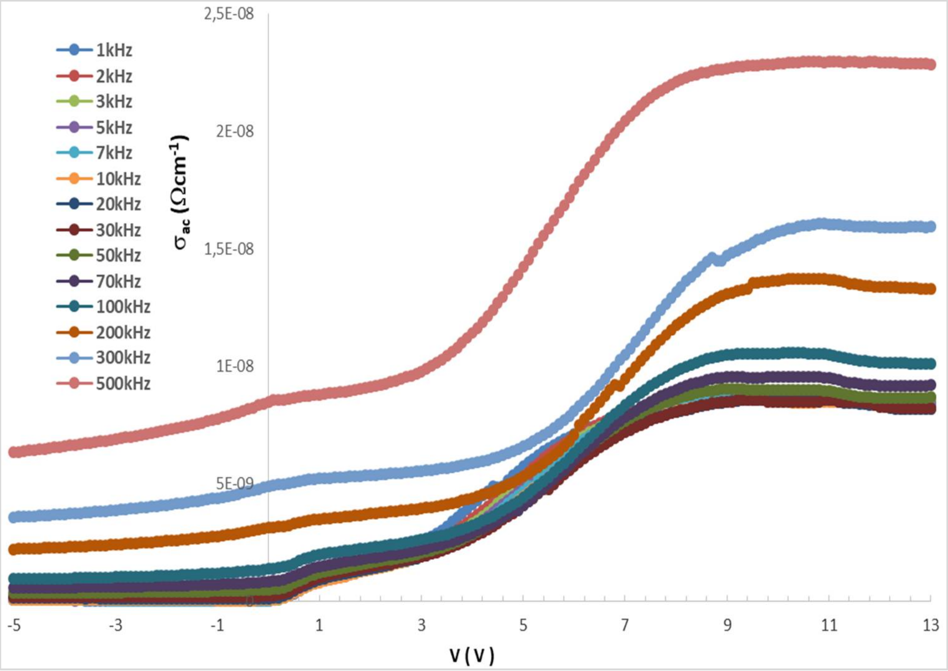

Figure 9. Variations of the ac conductivity of Au/n-CdTe Schottky Diode

The complex impedance plane analysis is based on the plot of the real part of Z' against the imaginary part of Z'' over a wide range of frequencies, 1 kHz–500 kHz in the present study. As can be seen from Figure 10 and Figure 11, Z' and Z'' increase as the frequency is decreased [22,23].

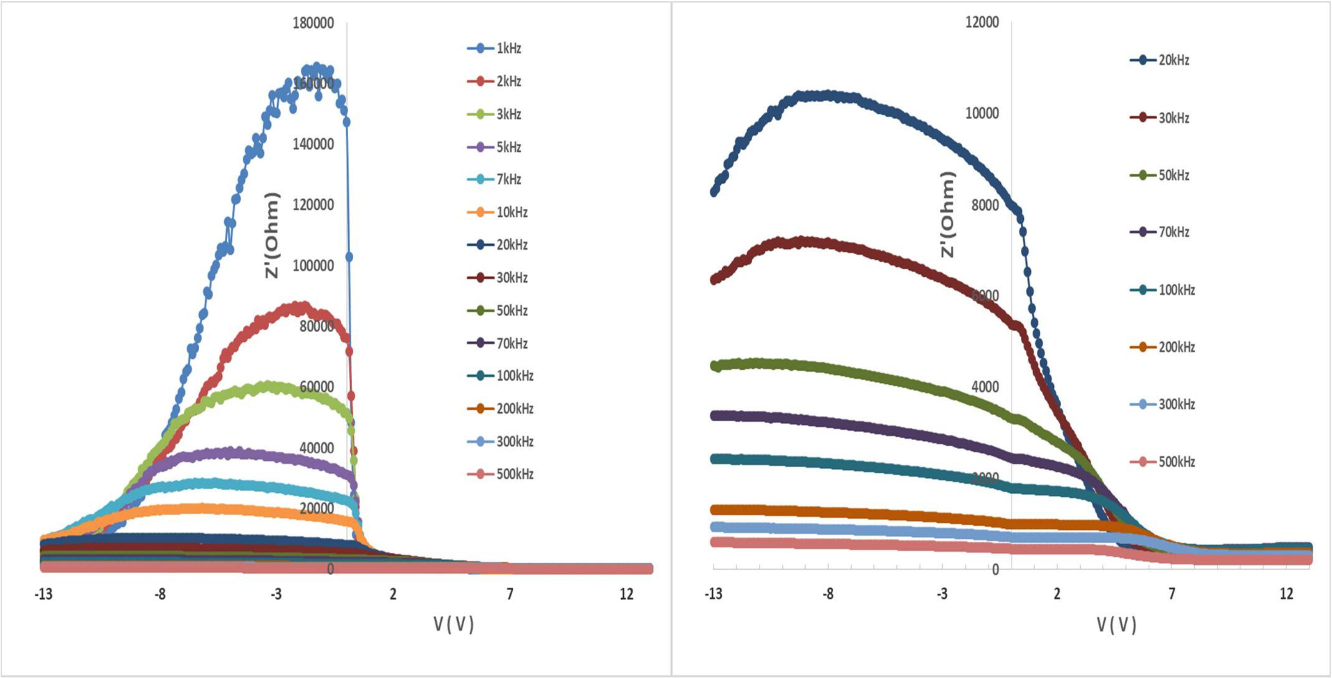

Figure 10. Variations of the real part impedance of Au/n-CdTe Schottky Diode

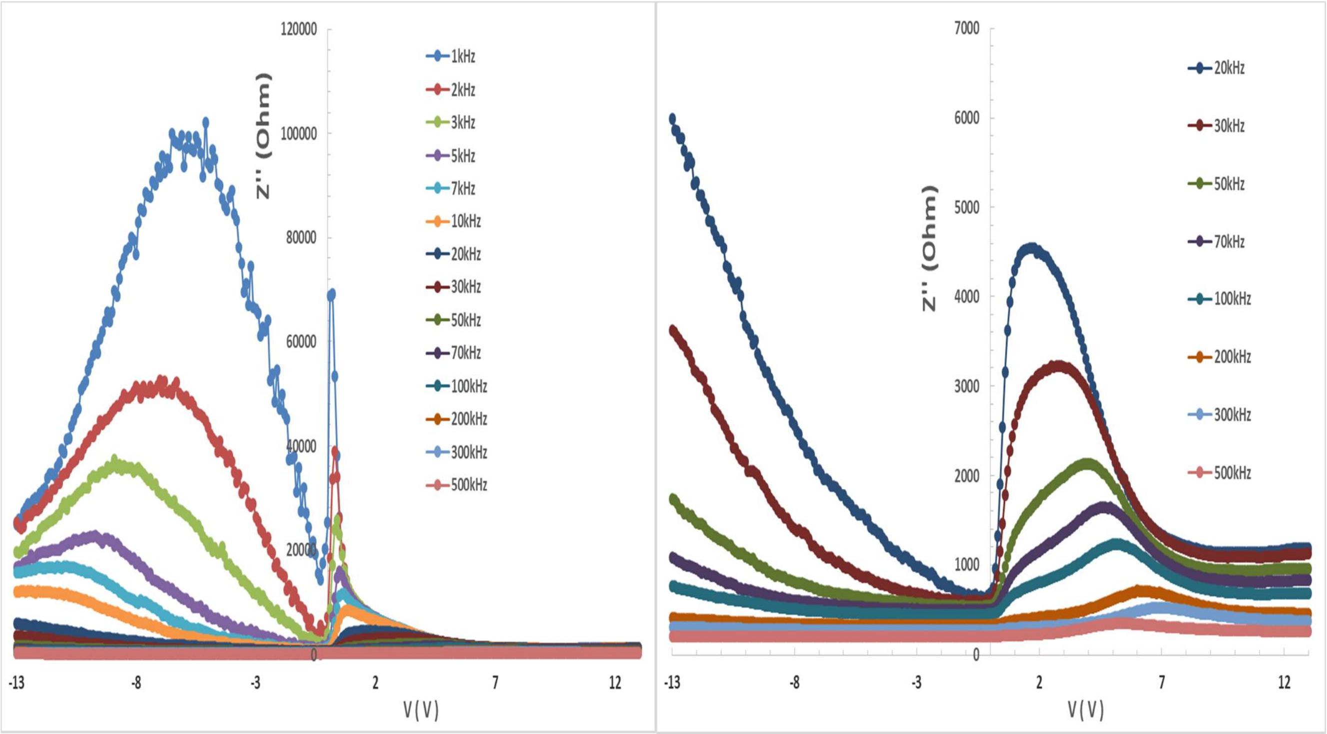

Figure 11. Variations of the imaginary part impedance of Au/n-CdTe Schottky Diode

4. CONCLUSIONS

The frequency dependence of the dielectric properties of Au/n-CdTe Schottky diodes were investigated in the interval 1 kHz–500 kHz using the measured $C-V$ and $G/\omega-V$. It is found that the dielectric constant decreases with the increase in frequency. It exhibited similar behavior in case of dielectric loss. This result shows that there is strong frequency distribution characterizing the frequency dependence for ε' and ε''. The real part of Z' and the imaginary part of Z' of the complex impedance decrease with increasing frequency. Because at high frequencies, the effect of the interface states decreases and the contribution to the impedance decreases. In conclusion, the frequency and voltage dependent dielectric properties confirm that R_s and N_{ss} are important parameters that strongly influence the electrical parameters for Au/n-CdTe Schottky diode.

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AUTHOR'S CONTRIBUTIONS

The authors contributed equally.

CONFLICTS OF INTEREST

There is no conflict of interest.

RESEARCH AND PUBLICATION ETHICS

The author declares that this study complies with Research and Publication Ethics.

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