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The Investigation of Temperature Dependent Reverse Bias Capacitance-Voltage (C-V) Characteristics of Au/Ppy/N-Si (MPS) Type Schottky Barrier Diodes (Sbds) at 100 Khz and 500 Khz

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ABSTRACT: Au/PPy/n-Si (MPS) type SBDs were fabricated and their electrical characteristics were investigated in the temperature range of 140-340 K at 100 and 500 kHz frequencies by using analyzed the C-V measurements. The C-V plots have inversion, depletion and accumulation regions for each temperature. The value of C increases with increasing temperature almost as exponentially in inversion and depletion regions. The reverse bias C^{-2} vs V plots show a linear behavior in the wide range bias voltage and so the values of doping atoms (N_D), Fermi energy (E_F), diffusion potential (V_d), and barrier height (Φ_B(C-V)) were obtained from intercepts and slopes of these plots for each temperature and frequency. While the E_F increases with increasing temperature, ΦB decreases as linearly. The l values of Φ_B(C-V) range from 0.703 eV at 140 K to 0.161 eV at 340 K for 100 kHz and 0.810 eV at 140 K to 0.391 eV at 340 K for 500 kHz, respectively. The electrical conductivity (σac) increases as exponential with temperature. The activation energy (Ea) values were found as 30.8 meV from the slope Ln(σ_{ac})-q/kT plot. These results implied that electrical characteristics of the SBDs are quite function of temperature at low frequencies and temperatures.

Keywords: Au/PPy/n-Si (MPS); Temperature and frequency dependent reverse bias C-V characteristics; Arrhenius plot and activation energy

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INTRODUCTION

SBDs with and without an interfacial layer are the bases of a large number of electronic devices. The quality and stability of them are depended of many parameters such as surface cleaning, the nature of interfacial layer and BH at M/S interface, devices temperature, density distribution of interface states (N_{ss}), series resistance (R_s) of devices and voltage (Nicollian and Brews, 1982; Sze 1981; Sharma 1984; Rhoderick and Williams, 1988; Bülbül , 2007; Altındal et al, 2005; Alialy et al, 2014; Marıl E et al, 2015; Marıl E et al, 2015; Afandiyeva et al, 2008) Especially, N_{ss} and interfacial layer play an important role on the main electrical parameters. The main advantages of interfacial polymer layer its easy preparation, low cost and compatibility with the conventional oxide layer such as SiO_2, SnO_2. The analysis of the reverse bias (C-V) measurements only at room temperature cannot supply enough information to us on the conduction process and nature of BH formation at M/S interface (Alialy et al, 2015; Marıl et al, 2015; Demircioğlu et al, 2011; Demircioğlu et al, 2011; Altındal et al, 2008) But, when these measurements were performed in the wide temperature, they can be supplied more information to us the conduction process and nature of BH formation at MS interface. On the other hand, the obtained value of BH from the forward bias I-V characteristics is always lower than the reverse bias C-V characteristics due to their nature of measurement methods. It is well known that the apparent barrier height for electrons from metal to semiconductor (Φ_B(C-V)=V_o+kT/q+E_F) is almost as Fermi energy level (E_F) lower than from the metal to semiconductor (V_o+kT/q).

In previous study (Gümüş et al,2015), the electrical and dielectric properties of the MPS type SBDs have been investigated in the temperature range of 140-340 K at 100 and 500 kHz frequencies using C-V and G/ω-V measurements. In the other our study (Gümüş and Altındal 2014), the forward bias I-V characteristics of the MPS type SBDs were investigated in the wide temperature range. We observed that an abnormally increase in the BH (Φ_{Bo}) and decrease in ideality factor (n) with increasing temperature were explained by single Gaussian distribution model of BHs. In order to observe the discrepancies between BHs obtained from the forward I-V measurements and reverse bias C-V measurements method, in this study, the values of V_d, E_F, N_D, and Φ_B(C-V) have been investigated as function of temperature (140-340 K) at 100 and 500 kHz frequencies. In addition, the activation energy value (E_a) was also obtained from the Arrhenius plot.

MATERIAL AND METHODS

In the present study, the MPS type SBDs were fabricated on the n-Si (P-doped) wafer with (100) orientation, 280 μm thickness, 1-Ω·cm resistivity. The more detail information on the structure and the fabrication process for the MPS type SBDs can be found in our previous report (Gümüş and Altındal 2014). After the fabrication of processes, SBDs were mounted on a copper holder by silver-dag and electrical contacts were made by using thin silver-coated Cu-wires. The temperature dependent C-V data were performed in wide temperature (140-340 K) in Janis VPF-475 cryostat with Lake-Shore 321 temperature controller at 10^{-3} Torr for 100 kHz and 500 kHz with help of HP 4192A LF impedance analyzer. All measurements were performed by the help of a microcomputer through an IEEE-488 AC/DC converter card.

RESULTS AND DISCUSSION

The C-V measurements of the MPS type SBD were performed in wide temperature range (140 K-340 K) by applying a small ac signal of 50 mV amplitude from the external pulse generator in wide range of voltage and represented in Fig.1 (a) and (b) for 100 kHz and 500 kHz, respectively.

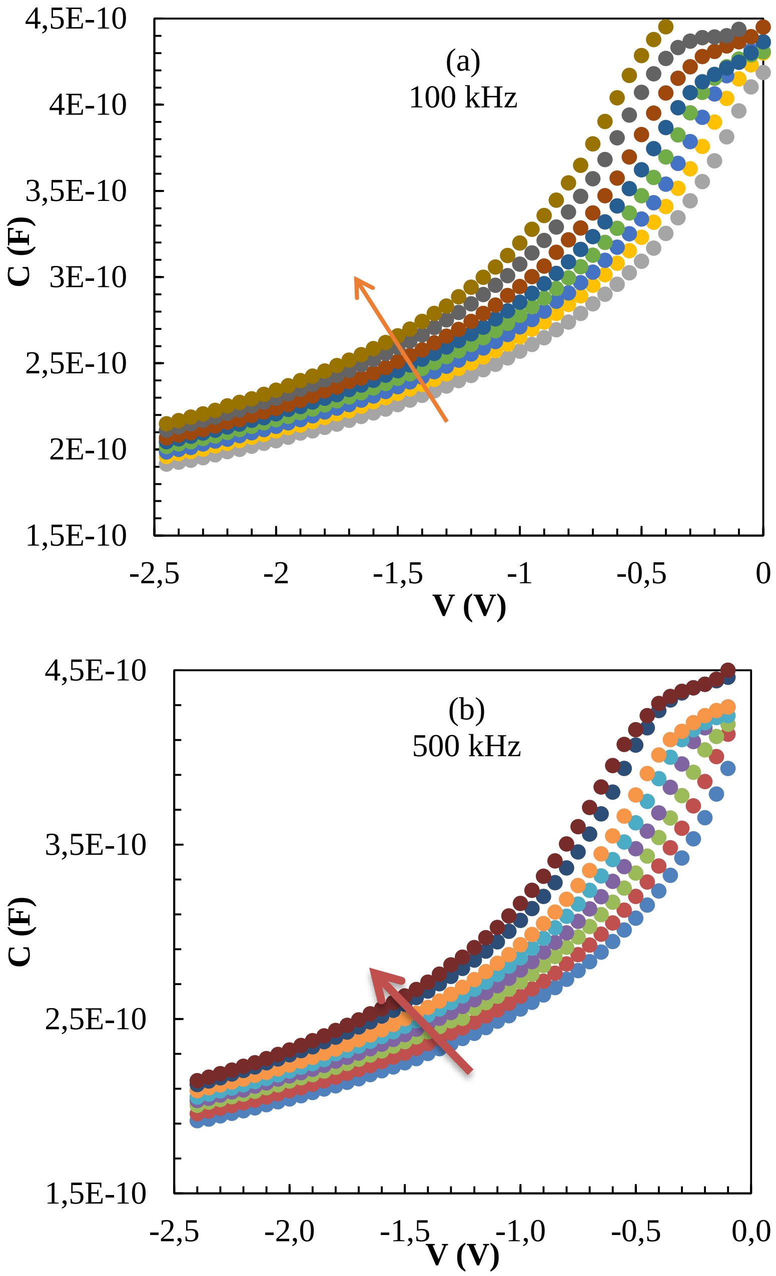

Figure 1: The C-V plots of the MPS type SBD, a) 100 kHz, b) 500 kHz for various temperatures.

As shown in Fig.1, these plots have three bias regions which are corresponding to the accumulation, depletion and inversion like a MOS type capacitor. The value of C increases systemically with increasing temperature for two frequencies. The C^{-2}-V plots of the MPS type SBD were represented in Fig. 2a and b for 100 kHz and 500 kHz, respectively, and they have a good linear range in wide bias voltages. As can be seen in C^{-2} versus V plots have a good linear behavior in wide range of applied bias voltage. Such linear behavior them are indicated that the surface states and the inversion layer charges cannot follow the ac signal for enough high frequency (f≥100 kHz) and hence do not contribute appreciably to the diode capacitance. For MIS or MPS type structures, the value of the depletion layer capacitance varies with the applied bias voltage as expressed by the following relation:

$$C^{-2} = \left(\frac{2}{q\varepsilon_s\varepsilon_o N_D A^2}\right)(V_D - kT/q - V) \quad \text{(1a)}$$

Here; N_D is the concentration of doping donor atoms (P), V_D is the diffusion potential, respectively. The voltage or x-axis intercept of the C^{-2}-V plot gives directly the value of V_o and it is related to diffusion potential ($V_D = V_o + kT/q$). The values of V_o and N_D from the intercept and slope (=2/($q\varepsilon_s\varepsilon_o N_D A^2$)) of C^{-2}-V plot for each temperature for 100 and 500 kHz. Thus, the value of Φ_{Bo}(C-V) was found as function of temperature by using following relation:

$$\Phi_B(C-V) = (V_0 + \frac{kT}{q}) + \frac{kT}{q} Ln(\frac{Nc}{ND})_F = V_D + E_F \quad (2)$$

It can be seen from Table 1, the value of barrier height Φ_B(C-V) decreases with increasing temperature in contrast to the barrier height extracted from I-V measurements. This discrepancy can be explained by the nature of measurement method which is corresponding to different applied bias voltage and also the apparent BH for electrons from metal to semiconductor is higher than at about E_F from the semiconductor to metal. As shown in Table 1, while the value of $\square_B$(C-V) range from 0.703 eV at 140 K to 0.161 eV at 340 K for 100 kHz and range from 0.810 eV at 140 K to 0.391 eV at 340 K for 500 kHz, respectively. It is clear that the value of BH decreases almost linearly with temperature for two frequencies and can be expressed as:

$$\Phi_B(T) = \Phi_B(0\ K) - \alpha T \quad (3)$$

As can be seen in Fig. 3, the value of Φ_B(C-V) has a negative temperature coefficient ($\alpha = \Delta\Phi_B/\Delta T \approx -2.65 \times 10^{-3}$ eV/K) of the BH like the forbidden bandgap of the Si semiconductor ($= -4.73 \times 10^{-4}$ eV/K).

In other words, as can be seen in Table 1, the value of BH at absolute temperature (Φ_B(0 K)) and the negative temperature coefficient ($\alpha = \Delta\Phi_B/\Delta T$) of the BH are experimentally found as 1.10 eV and -2.65x10^{-3} eV/K at 100 kHz, 1.14 eV and -2.08x10^{-3} eV/K at 500 kHz, respectively. The value of BH at zero-temperature obtained from the reverse bias C^{-2}-V plot is very close to the 1.078 eV obtained from the forward bias I-V data by using modified Richardson plot in previous study (Gümüş and Altındal, 2014). It is clear that the value of BH obtained from reverse bias C^{-2}-V plot is higher than obtained from the forward bias I-V data as at about E_F energy level. As can be seen in previous study (Gümüş and Altındal, 2014), the other important result is that the BH obtained from the forward bias I-V data decreases with the decreasing temperature which is in-agreement with the reported negative temperature coefficient of the BH in ideal case and forbidden bandgap of semiconductor.

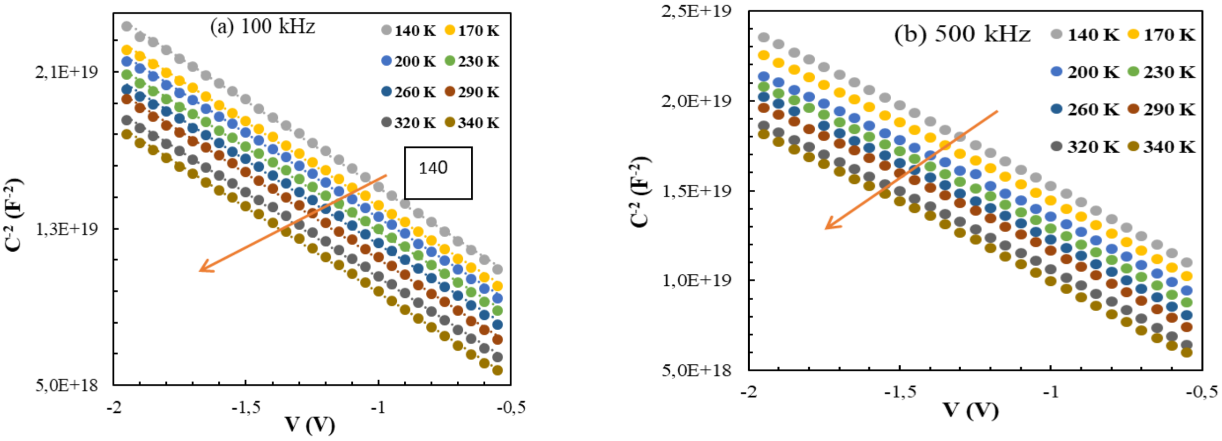

Figure 2. The C^{-2}-V plots of the MPS type SBD a) 100 kHz, b) 500 kHz for various temperatures.

Table 1. The obtained some main electrical parameters from the C^{-2}-V plot of the MPS type SBD at 100 kHz and 500 kHz for various temperatures.

	100 kHz				**500 kHz**			
T (K)	**Vo (V)**	**N_D x10^{16}(cm^{-3})**	**E_F (eV)**	**Φ_{Bo}(C-V) (eV)**	**Vo (V)**	**N_D x10^{16} (cm^{-3})**	**E_F (eV)**	**Φ_{Bo}(C-V) (eV)**
140	0.703	2.192	0.012	0.703	0.729	2.207	0.071	0.812
170	0.632	2.243	0.011	0.635	0.670	2.259	0.090	0.775
200	0.564	2.246	0.009	0.573	0.618	2.340	0.110	0.745
230	0.497	2.261	0.006	0.511	0.551	2.312	0.131	0.701
260	0.417	2.259	0.003	0.437	0.440	2.135	0.154	0.616
290	0.309	2.222	0.002	0.336	0.365	2.279	0.174	0.564
320	0.215	2.246	0.006	0.248	0.243	2.276	0.196	0.466
340	0.123	2.240	0.009	0.162	0.150	2.233	0.212	0.391

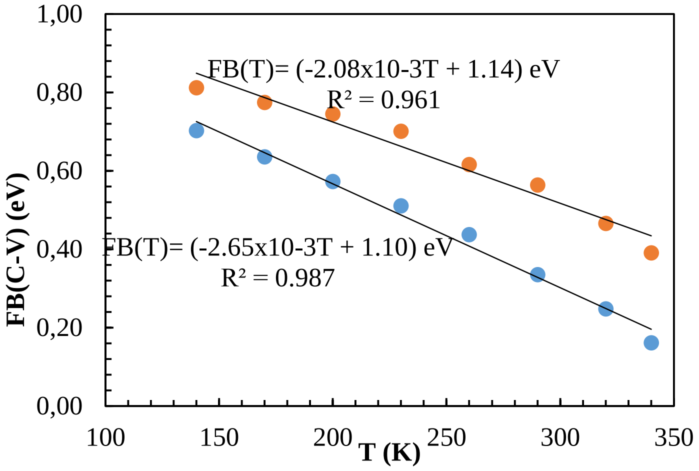

Figure 3: The Φ_B (C-V)-T plots of the MPS type SBD at 100 kHz (o) and 500 kHz (o).

As can be seen in Table 1 and Fig.3, The BH calculated from the C^{-2}-V plots at 100 kHz and 500 kHz decreased linearly with increasing temperature. The values V_o and E_F of the MPS type SBD were also extracted from the reverse bias C^{-2}-V plots at 100 kHz and 500 kHz for each temperature and were drawn in Fig.4 (a) and (b), respectively.

As shown these figures, while the value of E_F quite linearly decreases with increasing temperature, the value of V_o decreases with increasing temperature almost with linearly. The obtained these experimental values of the BH and the change with temperature are good agreement with reported in the literature (Altındal et al, 2008; Özdemir and Altındal 1994). This difference between Φ_B (C-V) and Φ_B (I-V) can be explained by the existence of surface states, barrier inhomogeneity, interfacial organic layer, and the nature pf measurement method (Bengi and Bülbül, 2013; Yakuphanoğlu and Senkal 2007; Chattopadhyay et al, 1998; Güllü et al 2008; Yerişkin et al 2017; Orak and Koçyiğit 2016; Karabulut 2018; Padma et al, 2017; Kınacı 2017; Rajagopal Reddy 2014; Taşcıoğlu, 2010; Pratap Reddy, 2017). The current across the BH and the current is sensitive to barrier distribution at the interface. But, the C is insensitive to potential fluctuations on a length scale of less than the space charge width that the C-V method averages over the whole area. Consequently, the BH obtained from the reverse bias C-V is higher than the forward bias I-V data. A comparative between Φ_B (C-V) and Φ_B (I-V) were carried out by (Demircioğlu et al 2011) for Cr/n-Si/Au-Sb diode were also found similar results.

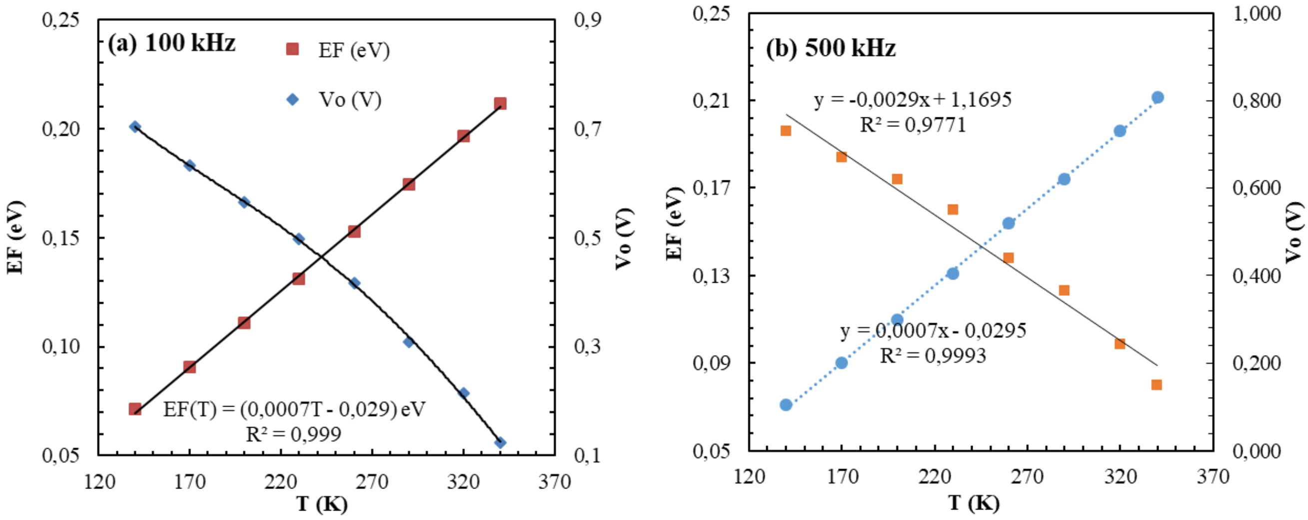

Figure 4. The E_F and V_d vs T plots of the MPS type SBDs at 100 kHz and 500 kHz.

It is well known that the effect of surface states (N_{ss}) decreases with frequency and their effects can be neglected low in the enough high frequency limit (f≥1 MHz) (Nicollian and Brews, 1982; Sze 1981). The temperature dependent of electrical conductivity (σ_{ac}) was also found for 500 kHz and increase with increasing as exponential. The activation energy (E_a) value was obtained from the slope of Arrhenius plots (Fig.5) as 30.8 meV. Experimental results were also confirmed that the main electrical parameters of diode are quite function of temperature and frequency and the change in these parameters become more effective especially at low temperatures.

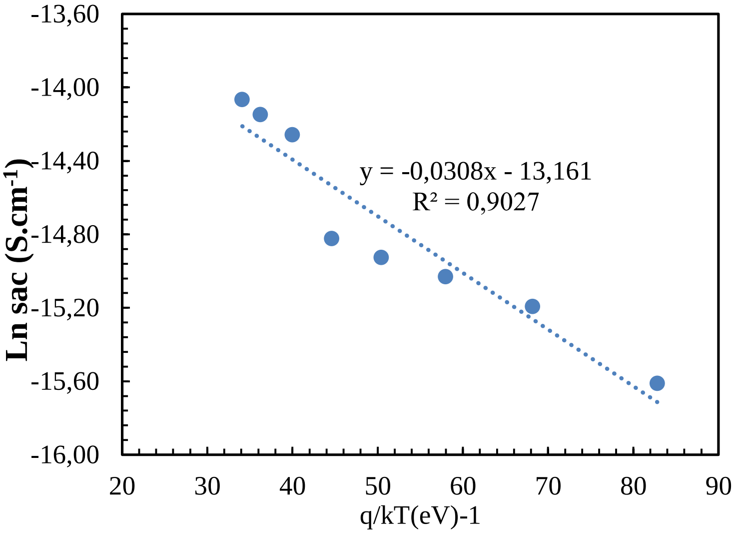

Figure 5. The Ln(σ_{ac}) vs q/kT plot of the MPS type SBD at 500 kHz.

This obtained value of activation energy (E_a=30.8 meV) from ln(s_{ac}) vs q/kT is necessary to escape from traps to other traps or conduction band for electrons. This low value of E_a show that electrons have short rage hopping mechanism rather than wide range of hoping mechanism like from traps to away traps. The observed one linear range of in the Arrhenius plots is also indicated that one type conduction mechanism is dominated in the whole measured temperature.

CONCLUSION

The Au/PPy/n-Si (MPS) type SBDs were grown on the n-Si wafer and their electrical characteristics were investigated in wide temperature (140-340 K) for 100 and 500 kHz C-V measurements. The C-V plots have inversion, depletion and accumulation regions for each temperature and the value of C increase with increasing temperature almost as exponentially. The change in C with temperature becomes more effective in the depletion region. The values of N_A, E_F, V_d and Φ_B(C-V) were extracted the C^{-2} vs V plots for two frequencies. While the value of E_F increases with increasing temperature, Φ_B(C-V) and V_o decrease with increasing temperature almost as linearly. The experimental values of Φ_B(C-V) range from 0.703 eV at 140 K to 0.161 eV at 340 K for 100 kHz and range from 0.810 eV at 140 K to 0.391 eV at 340 K for 500 kHz, respectively. It is expected to the value of BH decreases almost linearly with temperature for two frequencies. The temperature dependent of σ_{ac} was found for two frequencies and increase with increasing as exponential. The values of E_a were also obtained from the slope of Arrhenius plot, Ln(σ_{ac}) vs q/kT, for 500 kHz. Experimental results were confirmed that the electrical characteristics of the prepared MPS type SBDs are quite change with temperature and frequency and this change become more effective especially at low frequencies and temperatures.

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