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The effect of frequency and illumination intensity on the main electrical characteristics of Al-TiW-Pd_2Si/n-Si structures at room temperature

H. USLU*, Y. ŞAFAK, İ. TAŞÇIOĞLU, Ş. ALTINDAL
Physics Department, Gazi University, 06500 Ankara, Turkey

The effect of frequency and illumination intensity on the main electrical parameters such as ideality factor (n), zero bias barrier height (Φ_{Bo}), depletion layer width (W_D), doping concentration (N_D) and interface state densities (N_{ss}) of Al-TiW-Pd_2Si/n-Si structures have been investigated by using current-voltage (I-V) and admittance spectroscopy (C-V and G/w-V) techniques at room temperature. In addition, the dielectric constant (ε') and dielectric loss (ε''), loss tangent (tanδ) and ac electrical conductivity (σ_{ac}) have been investigated using C-V and G/w-V measurements at various frequencies and illumination intensities. Experimental results show that both the value of capacitance (C) and conductance (G/w) increase with increasing illumination intensity and decreasing frequency. On the other hand the value of R_s decreases with increasing illumination densities. Also, the ε', ε'', tanδ and σ_{ac} values were found strongly frequency, bias voltage and illumination intensity. The results can be concluded to imply that the interfacial polarization can more easily occur at low frequencies and high illumination intensities consequently contributing to the deviation of electrical and dielectric properties of Al-TiW-Pd_2Si/n-Si structures.

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1. Introduction

In general, platinum silicide (PtSi) contacts suffer from a number of processing difficulties associated with the Pt due to its high melting temperature. Therefore, palladium silicide (Pd_2Si) and Al-TiW-Pd_2Si offer a useful alternative to Al and PtSi as a rectifier contact material. Thus, palladium silicide films are commonly used in the fabrication of metal-semiconductor (MS) and metal-insulator-semiconductor (MIS) type Schottky barrier diodes (SBDs) on silicon devices [1-9]. Because of the importance of metal silicide in integrate circuit technology Pd_2Si films on Si have received a lot of attention in the past. The first studies on Pd_2Si films were made by Kircher [1], who investigated the metallurgical properties and electrical characteristics of Pd_2Si contacts on n-Si. Wittmer et al. [6] and Shepela [7] performed the measurement of resistivity of Pd_2Si film grown on Si substrate. However, the illumination effect on main these parameters of metal-Pd_2Si/Si structures at various frequencies have been not investigated in detail yet. Both electrical and dielectric properties of the SBDs especially depend on the native or deposited interfacial insulator layer, the N_{ss} and barrier formation at M/S interface. Palladium silicide (Pd_2Si) offers a useful alternative to Al-PtSi as a contact material.

In this study, the frequency and applied bias voltage dependent dielectric parameters such as dielectric constant (ε') and dielectric loss (ε''), loss tangent (tanδ) and ac electrical conductivity (σ_{ac}) of Al-TiW-Pd_2Si/n-Si structures have been investigated by using C-V and G/w-V measurements at various frequencies and illumination intensities at room temperature.

2. Experimental procedure

The Al-TiW-Pd_2Si structures were fabricated on 2 inch diameter n-type (P doped) single crystal silicon wafer with (111) surface orientation, 0.07 Ω-cm resistivity, 3.5 μm thickness and the area of 8 x 10^{-6} m^2. After the cleaning process, high purity Al with a thickness of about 2000 Å were thermally evaporated onto whole back side of Si wafer at a pressure about 10^{-6} Torr in high vacuum system. The ohmic contacts were formed by annealing them for a few minutes at 723 K. Al was also deposited onto TiW-Pd_2Si/n-Si structure by he same method until the thickness of Al film on $Ti_{10}W_{90}$-Pd_2Si-nSi layer was about 1 μm. The Al-TiW-Pd_2Si/n-Si structures and details of the fabricated procedures were given in our previous study [4]. *I-V* and conductance measurements were performed by use of a Keithley 2400 I-V source-meter and an HP4192A LF impedance analyzer, respectively.

3. Results and discussions

3.1. Electrical Characteristics of Al-TiW-Pd_2Si/n-Si

For SBDs with a series resistance Rs, the relation between the applied forward bias voltage (V) and the current (I) can be written as [10,11]:

$$I = I_o \exp\left(\frac{q(V-IR_s)}{nkT}\right)\left[1-\exp\left(\frac{-q(V-IR_s)}{kT}\right)\right] \quad (1)$$

where I_o is the reverse saturation current and it can be described by

$$I_o = AA^*T^2 exp\left(-\frac{q\Phi_{Bo}}{kT}\right) \quad (2)$$

where the quantities IR_s, A, A^* (120A/cm^{2}K^2 for n-type Si) and T are the terms is the voltage drop across R_s, the rectifier contact area, the effective Richardson constant and temperature in Kelvin, respectively.

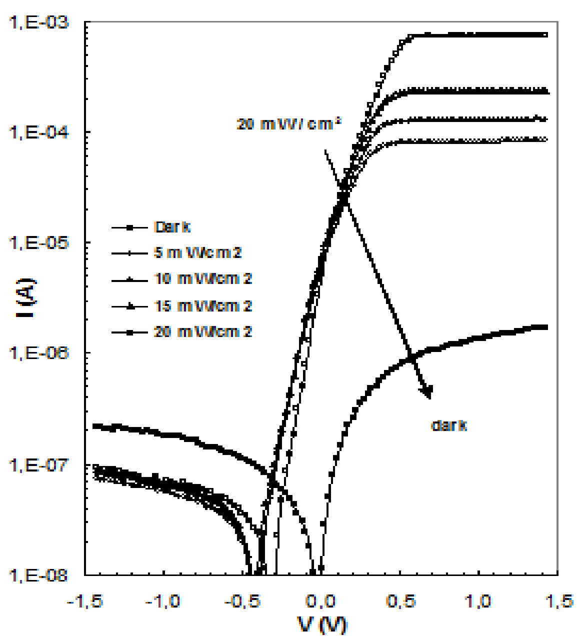

Fig. 1. The semi-logarithmic LnI-V characteristics of Al-TiW-Pd_2Si/n-Si structure in dark and under various illumination levels at room temperature.

Fig. 1. shows the Ln *I-V* characteristics of the Al-TiW-Pd_2Si/n-Si structure. The increase in the forward can be attributed to production of electron-hole pairs under illumination. The I_o, Φ_{Bo} and n values were obtained according to thermionic emission (TE) [10,11] were found to be a strong function of illumination level and are given in Table 1.

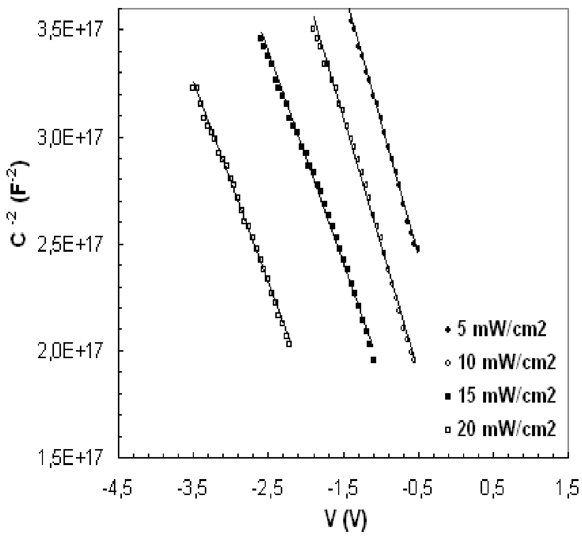

Fig. 2. The C^{-2}-V plots of Al-TiW-Pd_2Si/n-Si structure under various illumination levels at room temperature.

The N_D, W_D, Φ_B and N_{ss} values were obtained from the reverse bias C^{-2}- V plots (Fig. 2) as following equations [10] and was also given in Table 1.

$$\Phi_B(C-V) = V_0 + \frac{kT}{q} + E_F \quad (3)$$

where V_0 is the intercept voltage and E_F values were obtained according to,

$$E_F = \frac{kT}{q}\ln\left(\frac{N_C}{N_D}\right) \quad (4)$$

where N_C=4.82x10^{15}T$^{3/2}$(m$_e^*$/m$_0$)$^{3/2}$ is the effective density of states in Si conductance band and m_0=9.1x10^{-31} kg the rest mass of the electron. As shown in Table 1, the values of N_D, W_D and Φ_B were found to be a strong function of illumination intensity. The values of W_D and Φ_B were found to decrease, while the N_D increases with increasing illumination level due to the shrinking of the depletion region width (W_D) and restructure and reordering of interface states under illumination effect. The N_{ss} values were calculated from Eq. 5 [12,13]and are given in Table 1. It is clear that the value of N_{ss} decreases with increasing illumination density

$$c_2 = -\frac{2}{q\varepsilon_s\varepsilon_0 N_D\left[d\left(C^{-2}\right)/dV\right]} \cong N_D/N_D' = \frac{\varepsilon_i}{\varepsilon_i + q\delta N_{ss}} = \frac{1}{n} \quad (5)$$

Table 1. Illumination dependent values of electrical parameters obtained from forward bias I-V, reverse bias C-V and C^{-2}-V characteristics of Al-TiW-Pd_2Si/n-Si structure.

Power (mW/cm^2)	I_{ph} (A)	I_o (A)	n	Φ_{B0}(I-V) (eV)	V_D (V)	N_D (cm^{-3})	E_F (eV)	W_D (cm)	Φ_B (eV)	N_{ss} ($eV^{-1}cm^{-2}$)
0	$2.72x10^{-7}$	$5.40\ x10^{-8}$	5.25	0.701	-	-	-	-	-	-
5	$9.65\ x10^{-8}$	$7.33\ x10^{-6}$	5.46	0.578	1.126	$1.80\ x10^{16}$	0.184	$2.83\ x10^{-5}$	1.278	$2.70x10^{13}$
10	$1.06\ x10^{-7}$	$7.83\ x10^{-6}$	5.05	0.576	0.976	$1.89\ x10^{16}$	0.182	$2.56\ x10^{-5}$	1.127	$2.51\ x10^{13}$
15	$1.19\ x10^{-7}$	$9.07\ x10^{-6}$	4.74	0.573	0.576	$2.24\ x10^{16}$	0.178	$1.79\ x10^{-5}$	0.726	$1.95\ x10^{13}$
20	$1.13\ x10^{-7}$	$9.80\ x10^{-6}$	3.92	0.571	0.326	$2.33\ x10^{16}$	0.177	$1.30\ x10^{-5}$	0.479	$1.83\ x10^{13}$

3.2 Dielectric Properties of Al-TiW-Pd_2Si/n-Si Structure

The real and imaginary part of dielectric constant (ε' and ε''), tanδ and σ_{ac} were obtained from C and G/w characteristics as following equations at various illumination levels and frequency (in dark and 20 mW/cm^2) and are given Fig. 3 and Fig. 4, respectively.

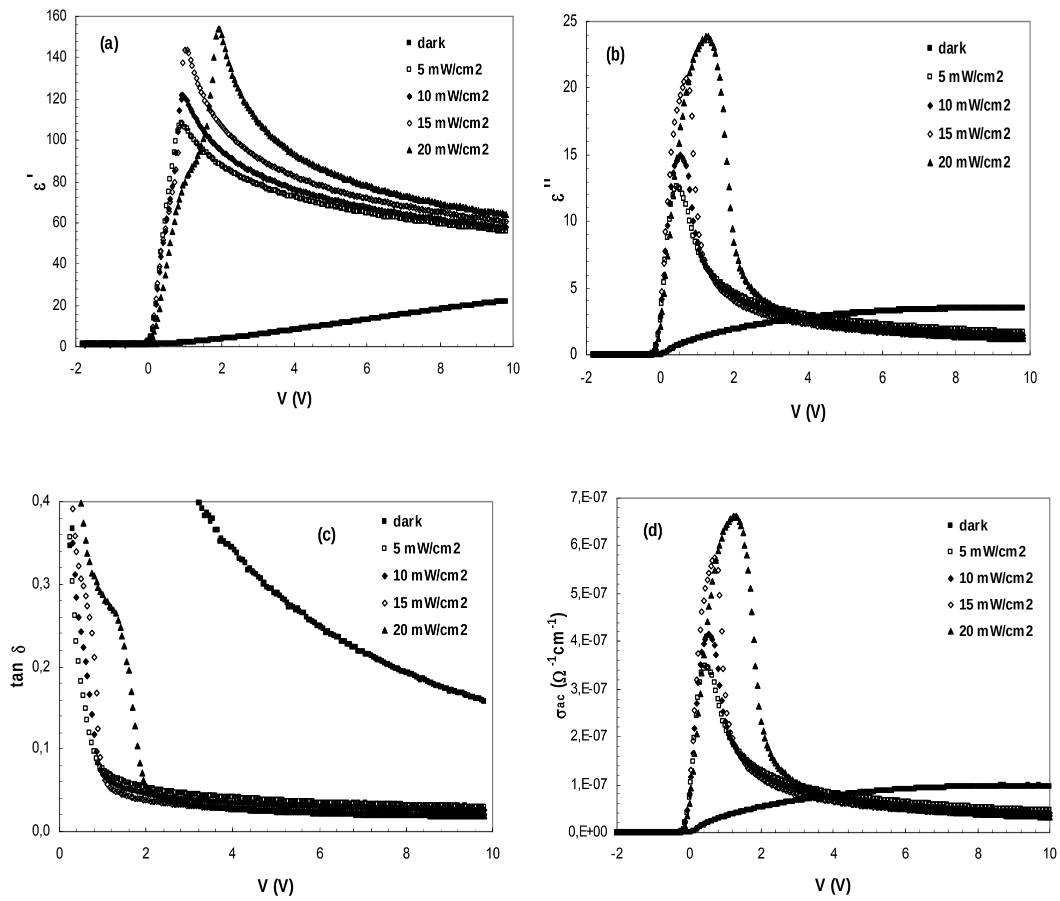

Fig. 3. Voltage dependence of the (a) dielectric constant (ε'), (b) dielectric loss (ε''), (c) loss tangent (tan δ) and (d) ac conductivity (σ_{ac}) in dark and under various illumination levels for Al-TiW-Pd_2Si/n-Si structure.

$$\varepsilon' = \frac{C_m}{C_o},\ \varepsilon'' = \frac{G_m}{\omega C_o},\ \tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (6)$$

and

$$\sigma_{ac} = \omega C \tan\delta (d/A) = \varepsilon'' \omega \varepsilon_o \qquad (7)$$

where $C_o = \varepsilon_0(A/d_{ox})$, d_{ox} is the interfacial insulator layer thickness and ε_o is the permittivity of free space charge (ε_o=8.85 × 10^{-14} F/cm).

As can be seen from Figs. 4 and 5, the ε', ε'' and σ_{ac} were obtained strongly function of illumination levels and frequency. These values increase with increasing illumination levels while decrease with increasing frequency due to space charge polarization caused by impurities or interstitials in the materials. Similar results have been reported in literature [14-17]. Also, it is clear that both the values ε' and ε'' are greater at low frequencies due to the possible interface polarization mechanisms [16-20] since interface states (N_{ss}) cannot follow the ac signal at high frequencies [10-13]. These dispersions in ε' and ε'' with frequency can be attributed to Maxwell-Wagner [18] and space-charge polarization [19].

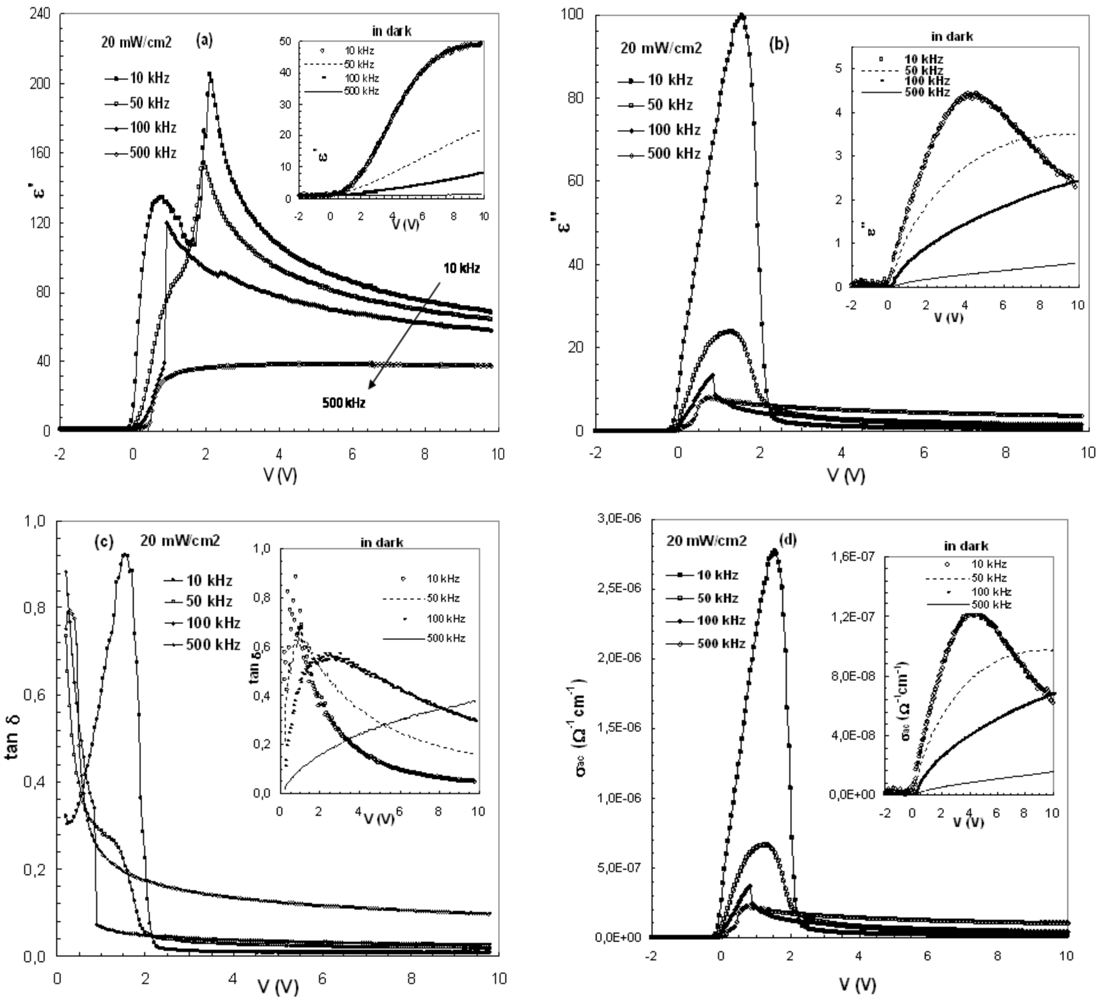

Fig. 4. Voltage dependence of the (a) dielectric constant (ε'), (b) dielectric loss (ε''), (c) loss tangent (tan δ) and (d) ac conductivity (σ_{ac}) at different frequency (10, 50, 100, 500 kHz) for Al-TiW-Pd_2Si/n-Si structure.

4. Conclusions

The electrical, dielectric and ac electrical conductivity *(σ_{ac})* of the Al-TiW-Pd_2Si/n-Si structures have been investigated by using the forward and reverse bias I-V, *C-V* and *G/ω-V* measurements in dark and under illumination at room temperature. Experimental results show that the values of *ε', ε'', tanδ* and σ_{ac} were found to be a strong function of frequency and illumination level. Also, the energy distribution profile of Nss was obtained from the forward bias I-V characteristics by taking into account bias dependence of the effective barrier height (Φe). The values of Nss increase from the midgap towards the top of conductance band and decrease with increasing illumination level. The ε', ε'' and σ_{ac} increase with increasing illumination levels while decrease with increasing frequency due to space charge polarization caused by impurities or interstitials in the materials. The results show that the interfacial polarization can more easily occur at low frequencies and high illumination intensities consequently alter both the electrical and dielectric properties of Al-TiW-Pd_2Si/n-Si structures. Interface polarization reaches a constant value due to the fact that beyond a certain frequency of external field the electron hopping cannot follow the alternative field.

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*Corresponding author: h.uslu@gazi.edu.tr