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STUDY OF DIELECTRIC PROPERTIES AND POWER DISSIPATION OF PTSI/N-SI SCHOTTKY DIODES AS A FUNCTION OF ALTERNATING SIGNAL

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ABSTRACT

The dielectric properties and power dissipation of PtSi/n-Si Schottky diodes of small area ($8x10^{-6}$ cm^2) were studied when the bias voltage varied in the range -2V ÷ 4V at room temperature. The amplitude of the alternating signal (V_{ac}) varied from 5 mV to $1x10^3$ mV. Studies based on impedance measurements revealed the dependence of dielectric parameters (ε′, ε″), ac-conductivity (σ_{ac}) and power dissipation (P) only at V_{ac} = 200 mV. The obtained result is explained by the inhomogeneity of polarization and surface states.

1. Introduction

Most elements of modern solid-state electronics are based on contact structures with a Schottky barrier. The many advantages of these structures compared to n-junctions are of interest for the creation of multifunctional devices. Simple technology, a wide selection of materials, and the ability to manufacture densely packed structures are the basis for the fabrication of devices with low material costs and high performance capabilities. High speed due to charge transfer is carried out by the main charge carriers. Small dimensions of contact structure provide high packing density of elements on the crystal [1-3]. The miniaturization of semiconductor structures brings to the fore the task of rapidly improving the technology for obtaining and studying micro- and nanostructures and their rapid introduction into industrial production. The main goal of modern electronics is the development of multifunctional, stable, small-sized devices with low power dissipation.

The multifunctionality of the devices is achieved due to the sensitivity of the device and the ability to control it when operating factors change in a narrow range [4]. Taking into account the relevance of the topic, we investigated PtSi/n-Si Schottky diodes with small geometric dimensions and equipped with a diffusion barrier. Platinum silicide was used as the metal film of the diode. Interest in silicide is due to its high conductivity and temperature stability. Besides, PtSi is of interest for infrared applications due to its high work function [4,6].

Platinum silicide (PtSi) is formed due to chemical reaction between platinum (Pt) and silicon (Si). In such contact structure, the interface between silicide and silicon is formed in the semiconductor, which eliminates the influence of the environment and minimizes the density of surface electronic states [4-6].

An important role in the formation of barriers in contact structures is played by the crystal structure of the metal film and the crystallographic orientation of silicon [4-6]. The presence of silicides ensures the production of barriers with guaranteed adhesion of the metal to silicon and better mating of the lattices of the two materials. On the other hands reducing the size of devices puts forward the problem of the appearance of fluctuations in parameters. During the process of formation of a silicide compound on the surface of silicon, a rearrangement of atoms occurs continuously. As a result of the formation of the interfacial layer inhomogeneities are likely to appear, which can influence on the electrical and dielectric properties of this structure [7,8].

The purpose of studying the influence of an alternating signal on the properties of a PtSi/n-Si Schottky diode is connected by the several reasons. Firstly, the studied diodes have a small geometric area (~10^{-6} cm^2). Second, it is known that aluminum (Al) has a high diffusion coefficient. In order to prevent the penetration of Al through the silicide film, a diffusion barrier (an amorphous $Ti_{10}W_{90}$ alloy) was placed between PtSi and Al.

Third. Previous studies of diodes revealed the presence of self-assembled patches with a high impurity concentration [9]. The surface states of a PtSi/n-Si Schottky diode and their distribution were previously studied by us as functions of temperature and frequency, the dielectric characteristics were studied as functions of frequency [10-13]. We have studied the dielectric characteristics of diodes with the simultaneous application of dc- and ac- voltage. Dielectric losses, which characterize the conversion of a part of electrical energy into thermal energy, are an important electrophysical parameter of contact structures. The magnitude of these losses indicates the features of the polarization mechanism. Dielectric losses usually change to a large extent when various kinds of impurities are introduced into the dielectric and are a sensitive indicator of changes in the structure of the dielectric. The study of dielectric losses and their dependence on structural defects and various factors (temperature, dc- and ac-voltage, and frequency of test signal, etc.) is of considerable interest for modern electronics [14]. Our previous studies were devoted to studying the dependence of the dielectric parameters of PtSi/n-Si and Pd_2Si/n-Si diodes on frequency, temperature and illumination intensity based on admittance spectroscopy (20 mV peak to peak) [10-13].

The obtained results revealed that the highest values of dielectric losses ε'' and $tan\delta$ correspond to a frequency of 500 kHz and a temperature of 300 K. However, currently, the scientific literature does not pay attention to the study of the influence of amplitude of ac-voltage on dielectric parameters, resistance and conductivity and the power dissipation of PtSi/n-Si diodes.

2.Materials and methods

To fabrication the studied PtSi/n-Si diodes with small geometric dimensions (8x$10^{-6}$$sm^2$), the photolithography method was used. Characteristics of the semiconductor substrate are - monocrystalline silicon n-Si (111), a resistivity silicon wafer is 0.7 Ω·cm, diameter about 3 inches, thickness is 3.5 μm. A platinum film with a thickness of about 0.6 μm was obtained on a pre-cleaned surface of single-crystalline silicon wafer. Then the Pt/n-Si plate was annealed at a pressure of 6×10^{-5} Torr at 773 K and in an atmosphere of N_2 and H_2 gases [10-13,15].

The amorphous $Ti_{10}W_{90}$ diffusion barrier was deposited on the silicide film (PtSi) by magnetron sputtering method [15-17]. On a semiconductor matrix, was fabricated 14 diodes, areas of which changed from $1x10^{-6}$ cm^2 to $14x10^{-6}$ cm^2) (Fig.1). Geometric area of investigated diode is $A=8x10^{-6}$ cm^2.

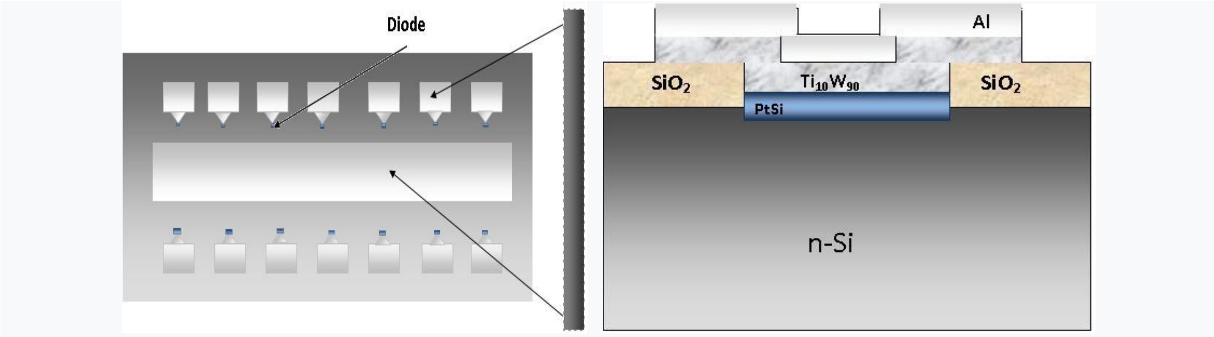

Fig.1. The diode matrix (a) and cross section of PtSi/n-Si Schottky diode (b).

The dependences of the dielectric properties, conductivity, resistance and power dissipation of a PtSi/n-Si Schottky diode on the amplitude of the alternating voltage were obtained as a result of measurements using an HP 4192A low-frequency impedance analyzer and an external pulse generator.

A bias voltage (-2V ÷ +4V) and an alternating signal (500kHz, 5mV÷$1x10^3$mV) were simultaneously applied to the PtSi/n-Si Schottky diode.

3.Results and Discussion

To study the influence of the amplitude of the alternating signal (Vac) on the dielectric parameters of a PtSi/n-Si Schottky diode, measurements of the capacitance (C) and conductance (G) of the diode were carried out when changing direct (V_{dc}) and alternating voltage (V_{ac}).

It is known that complex permittivity can be described as [18-23]

$$\varepsilon^* = \varepsilon' - i\varepsilon'' \qquad (1)$$

where real (ε′) and imaginary parts (ε″) of complex permittivity, i is the imaginary root of -1.

At admittance Y^* measurements $C - V$ and $G/\omega - V$, the following relation holds

$$\varepsilon^* = \frac{Y^*}{j\omega C_0} = \frac{C}{C_0} - i\frac{G}{\omega C_{oi}} \qquad (2)$$

where C is measured capacitance, G is measured conductance of investigated diode, C_0 is the capacitance of an empty capacitor, ω is the angular frequency ($\omega = 2\pi f$) of the applied electric field.

With the aim of investigation the real (ε') and imaginary (ε″) parts of complex permittivity (ε^*) of PtSi/n-Si(111) Scottky barrier diode have been calculated at different value of alternating voltage (V_{ac}) on the basis of measured C-V and G-V characteristics

$$\varepsilon' = \frac{C}{C_0} = \frac{Cd_i}{\varepsilon_0 A} \quad (3)$$

where d_i is the thickness of the dielectric gap, A = $8x10^{-6}$ cm^{-2} is the rectifier contact area of PtSi/n-Si Schottky barrier diode, ε_0 is the permittivity of free space charge (ε_0 = $8.85 \cdot 10^{-14}$ F/cm).

In the generalized model of the metal–semiconductor contact must be taken into account the presence of thin dielectric gap between contacting materials. In this respect, in the strong accumulation region, the maximal capacitance of the structure corresponds to the dielectric layer capacitance ($C_{ac}=C_i=\varepsilon'\varepsilon_0 A/d_i$).

By the using measured conductance of PtSi/n-Si Schottky barrier diode at the various amplitudes (V_{ac}) of ac-signal was calculated the imaginary part of the complex permittivity ε″

$$\varepsilon'' = \frac{Gd_i}{\varepsilon_0 \omega A} \qquad (4)$$

The loss tangent (tanδ) for PtSi/n-Si Schottky barrier diode can be expressed as

$$tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (5)$$

The ac-electrical conductivity (σ_{ac}) for PtSI/n-Si Schottky diodes was calculated by the following equation.

$$\sigma_{ac} = \omega C tan\delta \left({}^{d}/_{A} \right) = \varepsilon'' \omega \varepsilon_0 \qquad (6)$$

Comparing the real and imaginary part of the impedance, the series resistance is given by [24]

$$R_s = \frac{G}{G^2 + (\omega C)^2} \qquad (7)$$

Besides, to analyze the dynamics of charge carriers in PtSi/n-Si have been used the complex electric modulus, which is inversely proportional to the complex permittivity [25].

The main advantage of this method is that it suppresses the contribution from electrode polarization, which dominates the permittivity formalism. The real component M' and the imaginary component M'' are calculated from ε′ and ε''.

$$M^* = \frac{1}{\varepsilon^*} = M' + jM'' = \frac{\varepsilon'}{\varepsilon'^2 + \varepsilon''^2} + j\frac{\varepsilon''}{\varepsilon'^2 + \varepsilon''^2} \qquad (8)$$

It should be noted that the results of research into power dissipation due to dielectric losses are important in the fabrication of new devices.

The power dissipated in the dielectric depends on the amplitude of the alternating signal (V_{ac}) , determine by dielectric losses [14,26-31] and described for device with parallel equivalent circuit (Schottky diodes) as

$$P = V_{ac}^2 \omega C tan\delta \qquad (9)$$

In Fig. 2, 3 and 4 show the change in the real (ε'), imaginary (ε'') parts of the dielectric constant and loss tangent (tan δ) of a PtSi/n-Si diode with a Schottky barrier depending on the bias voltage and the amplitude of the alternating signal (V_{ac}).

As shown in Fig. 2a, Fig. 3a and Fig. 4a, the main parameters characterizing the dielectric properties ε', ε'' and tanδ depend on the bias voltage only in the range of 0-2.0 V at room temperature (T = 300K). At high values of the applied voltage, the values of ε', ε'' reach almost constant values. The studied parameters do not depend on the amplitude of the alternating signal, varying from 5 mV to $1x10^3$ mV at a frequency of 500 kHz, with the exception of V_{ac} = 200 mV (Fig. 2b, Fig. 3b and Fig. 4b). It should be noted that when the amplitude of the alternating signal V_{ac} = 200 mV the characteristics differ sharply from others. However, the nature of the dependence remains. Thus, it indicates that at V_{ac} = 200 mV the polarization in PtSi/n-Si Schottky barrier diodes sharply increases.

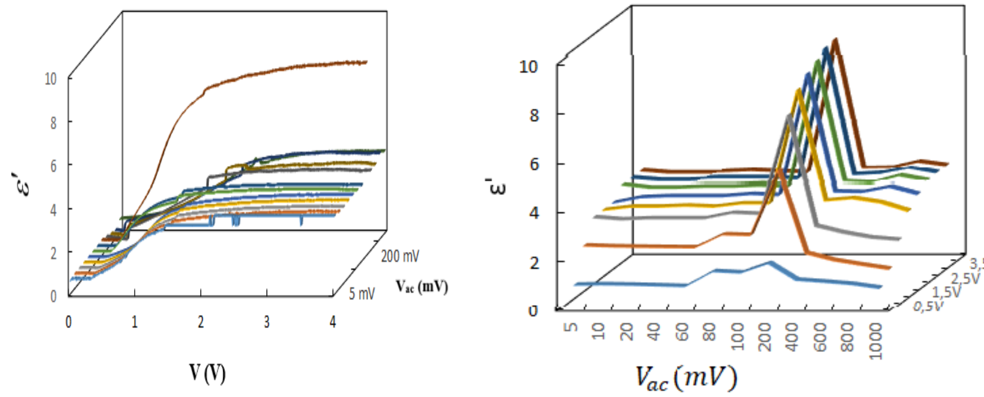

Fig. 2. The dependence of the dielectric constant of PtSi/n-Si Schottky barrier diode: a) on dc-voltage ($\varepsilon' - V$) for various amplitudes of V_{ac} and b) on amplitude of ac-voltage ($\varepsilon' - V_{ac}$) for various applied bias voltage

A sharp increase in ε' indicates an increase in the intensity of polarization, that is, the accumulation of charge at the boundary of regions with different conductivities. The obtained result corresponds to the Maxwell-Wagner theory.

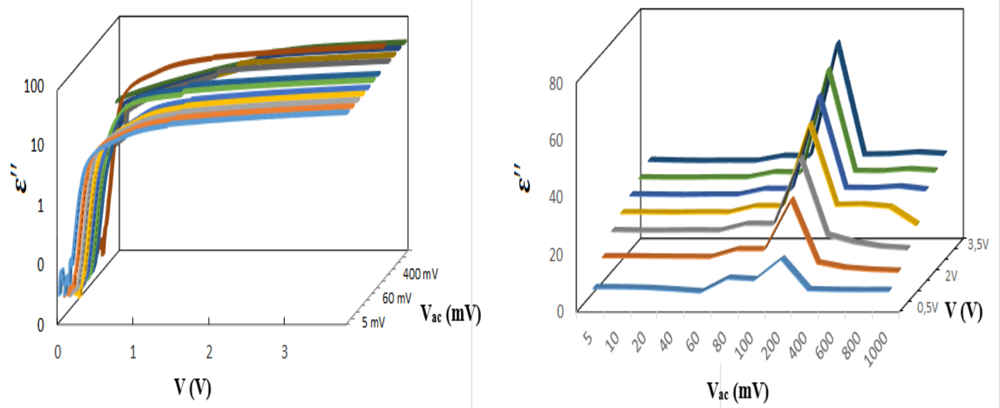

Fig.3. The dependence of the dielectric loss of PtSi/n-Si Schottky barrier diode at room temperature: a) on bias volage ($\varepsilon'' - V$) for various amplitudes of V_{ac} and b) on amplitude of ac-signal (ε''-V_{ac}) for various applied dc- voltage

As can be seen in these figures, the peak values on ε'' – V_{ac} (Fig. 3b) and $tan\delta$ -V_{ac} (Fig. 4b) observed at V_{ac} =200 mV, increase with increasing dc-voltage, the positions of the peaks do not shift.

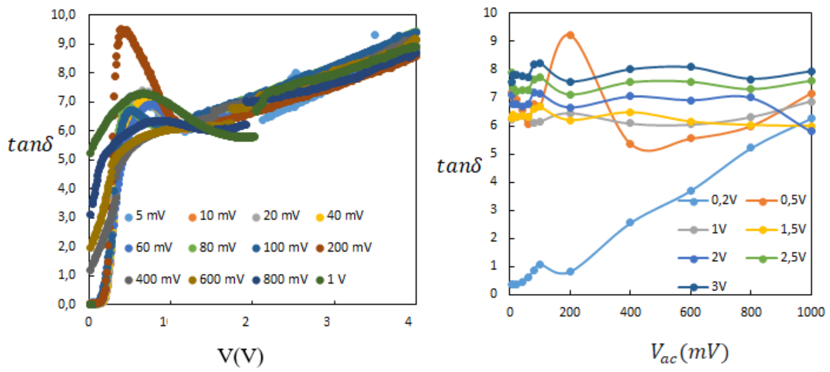

Fig 4. The dependence of tangent loss of PtSi/n-Si Schottky barrier diode at room temperature on: bias voltage a) ($tan\delta - V$) for various amplitudes of V_{ac} and b) on amplitude of alternating signal ($tan\delta$ -V_{ac}) for various applied voltage

The $tan\delta - V$ characteristics have a peak only at V_{ac}=200mV.

The nature of the dependences ε'' and $tan\delta$ on bias voltage and amplitude of alternating voltage, the appearance of the peak and its position depends on polarization, conductivity, surface states, homogeneity of the medium, energy losses, degree of doping, etc. Besides, the capacitance and conductance of diode are extremely sensitive to the interface properties and series resistance. In this case, the contribution of surface states recharging at given frequencies of the alternating signal is of great importance.

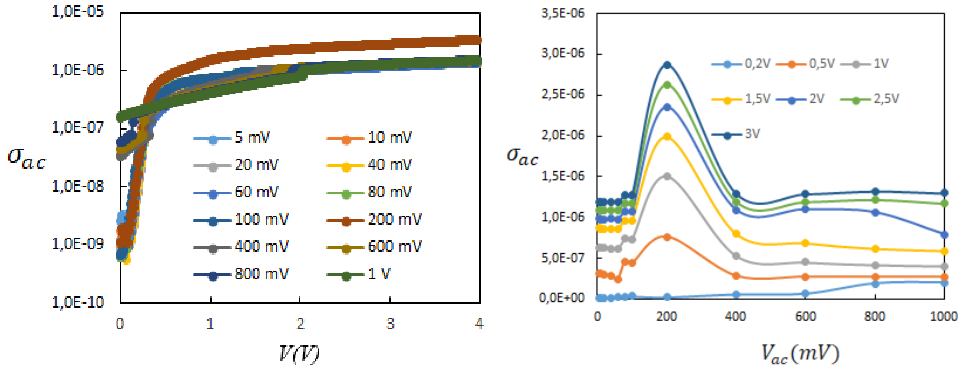

Fig 5. The variations of ac-electrical conductivity (σ_{ac}ac) of PtSi/n-Si Schottky barrier diode at room temperature: a) on dc-voltage ($tan\delta - V$) for various amplitudes of V_{ac} and b) ac-voltage ($tan\delta$ -V_{ac}) for various applied voltage

The behavior of ac-electrical conductivity (σ_{ac}) of the PtSi/n-Si Schottky barrier diode at different voltage and V_{ac} is presented in Fig. 5. It is noticed that the electrical conductivity generally increases with increasing voltage. However, at low and high value of amplitude (V_{ac}) σ_{ac} practically independent on $V_{ac}$with the exception of 200mV.

In the present paper according to a method by Nicollian and Brews [24], the real series resistance of PtSi-nSi Schottky barrier diode was calculated from the $C - V$ and $G - V$ characteristics in strong accumulation region.

The dependence of R_s of investigated diode (PtSi/n-Si) on bias voltage and amplitude of alternating signal (V_{ac}) show in fig.6.

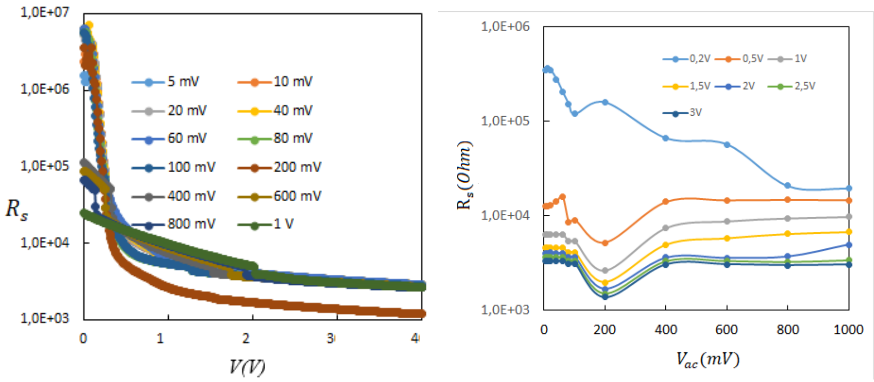

Fig 6. The dependence of the real series resistance R_s of PtSi/n-Si Schottky barrier diode at room temperature (500kHz): a) on dc-voltage ($R_s - V$) for various amplitudes (V_{ac}) and b) on ac-voltage (R_s -V_{ac}) for various applied dc-voltage

By the using real (ε') and imaginary (ε'') parts of complex permittivity have been calculated the dependence of real (M') and the imaginary (M'') parts of electric modulus for PtSi/n-Si Schottky barrier diode on bias voltage and amplitude of alternating signal (Fig.7 and Fig.8)

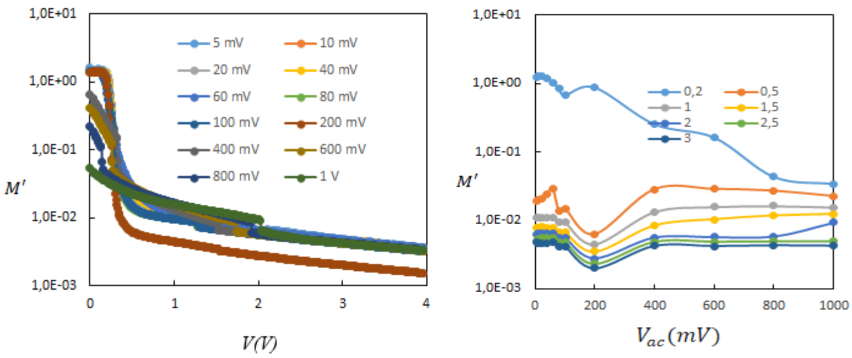

Fig. 7. The dependence of the real part electric modulus (M') of PtSi/n-Si Schottky barrier diode at room temperature on bias voltage: a) $M' - V$ for various amplitudes of V_{ac} and amplitude of alternating signal; b) M' -V_{ac} for various applied voltage

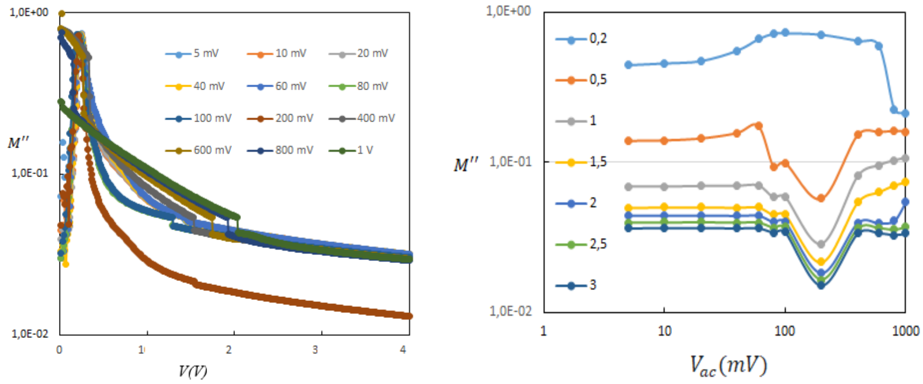

Fig.8. The dependence of the imaginary part of electric modulus (M'') of PtSi/n-Si Schottky barrier diode at room temperature on bias voltage: a) $M'' - V$ for various amplitudes of V_{ac} and amplitude of alternating signal; b) M'' -V_{ac} for various applied voltage

It can be seen from figures 2-8 that all characteristics have features precisely at V=200 mV.

As is know, ε'' is a measure of energy loss and shows how strongly a material absorbs energy from an external electric field. The loss factor ε'' is affected by both dielectric losses and conductivity. The peak in the ε'' dependence and the sharp minimum on $M'' - V_{ac}$ shows an increase in relaxation losses at V_{ac} = 200 mV.

In connection with the aim of the study the power dissipated (P) in the diode PtSi/n-Si was investigated. The dependence $P - V_{ac}$revealed an increase in power dissipation with increasing amplitude of the alternating signal (5mV÷1x10³ mV). In addition, the dependence clearly shows a weak peak at V_{ac} =200 mV (Fig. 9).

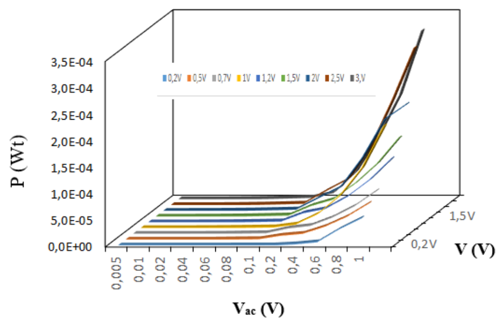

Fig.9. The dependence of the active power dissipated (dielectric losses) (P) in the PtSi/n-Si Schottky barrier diode on the amplitude of ac-signal V_{ac}

The obtained dependence ($P - V_{ac}$) may be due to the heterogeneous structure of depletion layer in PtSi/n-Si Schottky diode. This structure is identical to the Maxwell-Wagner structure of two-layer dielectric [32].

It should be noted that in our previous paper [33], devoted to the study of PtSi/n-Si Schottky barrier diode, the existence of self-assembled patches with different charge carrier concentrations was discovered. The sizes of these spots, similar to quantum wells, were estimated. These patches formed due to hexagonal voids in the crystal structure of Si(111), because the dimensions of these voids allow the penetration of platinum atoms at forming a contact.

We believe that the role of macrorelaxers is played by inhomogeneous sections of the PtSi/n-Si Schottky barrier diode and with the recharging of surface states [4,6]. The density of surfage states (N_{ss}) obtained by the high-low temperature method for the PtSi/n-Si structure revealed the maximum value of N_{ss} about V=200 mV. That is, the N_{ss} values give a wide peak when E_c - E_{ss} = 0,22 eV. Studies in the [33] article showed the maximum loss tangent at 200 mV [10].

So, the features in the dependence parameters on V_{ac} for PtSi/n-Si Schottky barrier diodes revealed that the dissipation power at a voltage of 200 mV is associated with the presence of self-assembled patches in the depletion layer of diode and the maximum density of surface states.

4. Conclusion

The dependence of real (ε') and imaginary (ε″) parts of complex dielectric permittivity and electric modulus (M' , M''), dielectric loss ($tan\delta$), ac-conductivity (σ_{ac}) and series resistance (R_s) on bias voltage (V) and amplitude of alternating signal (V_{ac}) were investigated for PtSi/n-Si Schottky barrier diode. With the increasing of bias voltage from -2V to 4V and amplitude of alternating signal (500kHz) in the range 5mV $\div 1x10^3$mV at room temperature on the all parameters have been observed features only at V_{ac}=200mV. On the dependence of power dissipated on amplitude of alternating voltage revealed the strong dependence and a peak at V_{ac}=200mV also.

The results obtained are in good agreement with previously obtained ones, where the presence of self-organized patches in depletion layer of PtSi/n-Si Schottky barrier diodes with a high doping degree was reported. Inhomogeneous sections of the PtSi/n-Si Schottky barrier diode and the recharging of surface states play a role of macrorelaxers. The value of the alternating signal amplitude ($V_{ac} = 200mV$) causing a sharp change in the parameters corresponds to the maximum value of the density of surface states.

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