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Influence of Ac-Signal Amplitude on the Dielectric Properties of Al-Tiw-Ptsi/N-Si Schottky Diodes

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ABSTRACT

Influence of ac-signal amplitude on the dielectric properties of Al-TiW-PtSi/n-Si Schottky diode has been investigated at the room temperature and bias voltage in the range of -2V÷4V, when the amplitude of test signal (500 kHz) changed from 5mV to 1V. By the using impedance method have been obtained real (ε') and imaginary (ε′) parts of dielectric constants and electric modul (M′ and M") , loss tangent (tanδ), ac electrical conductivity (σ_{ac}), the series resistance (R_s), On all dependences on voltage and amplitude of ac-signal , there is a jump in the value of the parameter in the range of voltage values 1-2V and 200mV It can be concluded that, at certain values, the amplitude of the ac-signal can significantly affect the interfacial polarization even at high frequencies.

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Introduction

One of the tasks of the development of science and technology is the creation of new devices that meet certain requirements: low financial costs, small geometric dimensions, multifunctionality. When choosing the object of study Al-TiW-PtSi/n-Si Schottky diode, the advantages of Schottky barrier diodes (SBD) in comparison with p-n junctions were taken into account: simple technology, a wide choice of contacting materials, high performance, possibility of dense placement.

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. At the same time, the main development trend is based on the multifunctional use of devices. Multifunctionality is based on the sensitivity of the device and the ability to control it when the operating factors change in a narrow range [4]. Schottky diodes on the basis silicide-silicium contact attract wide attention of researchers. Metal silicides are characterized by high metallic conductivity and high temperature stability. In contacts with silicides, the interface is displaced deep into the semiconductor, which eliminates the influence of the environment and minimizes the density of surface electronic states. From this point of view, in a number of innovative studies, a special place is occupied by the study and application of multifunctional devices based on a metal-semiconductor contact with a Schottky barrier, the interface of which is protected by the influence of the environment [4,5]. 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. 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]. On the other hands reducing the size of devices puts forward the problem of the appearance of fluctuations in parameters. PtSi is of interest for infrared applications due to its high work function [4-6]. 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 occur, which can affect the electrical and dielectric properties of this structure [7,8].

The purpose of our research connected by the several reasons. Firstly, the diodes studied have a small geometric area (~10-6 cm2). 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 TiW alloy) was placed in the contact structure. Second, based on admittance measurements in the temperature range from 79 to 360 K, was revealed the existence of self-assembled spots similar to quantum wells, which were formed as a result of the process formation of PtSi on the semiconductor and the presence of hexagonal voids Si(111) [9]. Third, the surface states 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, electric field strength and frequency, etc.) is of considerable interest for modern technology [14]. In our previous works the method of admittance spectroscopy (20mv pik to pik) was used to study the dependence of dielectric characteristics of PtSi/nSi and Pd2Si/n-Si diodes on frequencies, temperature and illumination intensity [10-13]. The obtained results revealed that the highest values of dielectric losses ε″ and tanδ corresponds to a frequency of 500 kHz and a temperature of 300 K. However, at the same time, there is no information in the scientific literature about the effect of the ac-signal amplitude on the dielectric characteristics of PtSi/n-Si diodes and power dissipated in a dielectric.

Knowledge of the electrical characteristics of silicide–silicon contact is important for understanding the formation of Schottky barriers, surface states. A detailed study of these contact structures, the possibility of using deviations of electro-physical parameters due to nano-sized regions will contribute to the creation of new multifunctional devices with small geometric dimensions.

Materials and Methods

Investigated Al-TiW-PtSi/n-Si (SBD) were fabricated with the using the methods planar technology and photolithography. These methods are traditionally used for small geometrical sizes diodes. As a semiconductor wafer was chosen a single crystal of n-type silicon (P doped) with diameter of 3 inches, a resistivity of 0,7 Ω•cm and a thickness of 3,5 µm.

For the fabrication of silicide film at first Pt film with the thickness about 0,6 µm has been obtained by the magnetron-sputtering method at the vacuum about 10^{-4} Torr on the surface of Si wafer. As working gas was used Argon plasma. Silicon wafer preliminary was heated at 523K during 250 s. The silicon n-Si (111) wafer was cleaned in a mix of a peroxide-ammoniac solution and in deionized water with resistivity of 18 MΩ•cm. For fabrication of a homogeneous PtSi film the wafers (Pt/n-Si) were annealed at 6×10^{-5} Torr at 773 K during 10 min and then in a special ampoule at 783 K for 30 min in atmosphere of the gases N_2 and H_2 [10-15].

The amorphous TiW alloy was deposited (Figure 1) between Al and PtSi as diffusion barrier to prevent the penetration of Al to PtSI [15-17]. Fabricated chip contains 14 Al–TiW–PtSi/n-Si structures, areas of which changing from $1x10^{-6}$ cm^2 to $14x10^{-6}$cm^2 (Figure 1). In this paper the results of diode with the area of 8x10-6 cm2 are presented.

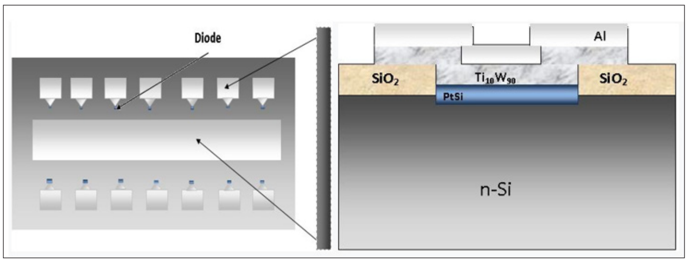

Figure 1: (a) Structure of the Fabricated Chip and (b) Cross Section of Al-TiW-PtSi/n-Si (SBD)

Measurements of the C-V and G/ω-V characteristics of the Al-TiW-PtSi/n-Si Schottky barrier diode (SBD) were carried out at room temperature and sinusoidal test signal (500 kHz) using an HP 4192A LF impedance analyzer. The signal amplitude of which varied from 5 mV to 1V was applied to the sample from an external pulse generator.

Results and Discussion

The aim of these investigation is obtaining the influence of amplitude of ac-signal on dielectric loss and power dissipated in Al-TiW-PtSi/n-Si Schottky barrier diode. By the using impedance analyzer HP 4192A LF (impedance spectroscopy method) have been obtained C and G/ω characteristics at room temperature and sinusoidal test signal (500 kHz). From an external pulse generator to the sample was applied test signal amplitude (V_{ac}) of which changed in the range 5mV- $1x10^3$mV. At the same time, a bias voltage from -2V to 4V was applied to a diode with a geometric area A=$8x10^{-6}$ cm^2.

With the purpose of the separate the bulk and the surface phenomena and to determine the bulk dc-conductivity of the studied Al-TiW-PtSi/n-Si Schottky barrier diode the formalism of the complex permittivity was applied [18-23]. It is known, that the complex permittivity can be described as

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

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/ω-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 capacitance, G is conductance of investigated device, is the angular frequency ($\omega=2\pi f$) of the applied electric field. The real part of the complex permittivity (ε′), at different value of (V_{ac}) was calculated using the measured capacitance value from the expression

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

where C_0 is the capacitance of an empty capacitor, d_i is the thickness of the dielectric gap, A is the rectifier contact area of the structure (A= $8x10^{-6}$ cm^{-2}) and ε_0 is the permittivity of free space charge (ε_0 = 8.85 • 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=ε'ε_0A/d_i). The imaginary part of the complex permittivity, ε″ at the various amplitudes (V_{ac}) was calculated using the measured conductance values by the following relation

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

The loss tangent (tanδ) can be calculate by the following equation

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

The ac-electrical conductivity (σ_{ac}) for Al-TiW-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]

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

Another quantity often used to analyze the dynamics of charge carriers is 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

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

The real component M′ and the imaginary component M″ are calculated from ε′ and ε″. It should be noted that the power dissipated in the dielectric depends on the amplitude of the alternating signal (V_{ac}) and determined by dielectric losses [14, 26-31]. According to the theory of active power of dielectric losses for device with parallel equivalent circuit (Schottky diodes) described as

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

As can be seen from (9) power of dielectric losses dependent on the square of the effective value V_{ac} , tanδ, the frequency of ac signal and the capacitance of the structure.

All these data presentation methods are equivalent, as they are the result of one experiment, but they carry complementary information. Figure 2, Figure 3 and Figure 4 show the ε′-V, ε''-V and tanδ-V dependence of the Al-TiW-PtSi/n-Si Schottky barrier diode when amplitude of ac-signal (V_{ac}) changed from 5mV to $1x10^3$mV at frequency 500kHz and room temperature (T=300K), respectively.

As can be seen from figure 2 the values of ε' increase with increasing voltage, then reaches a constant value. It should be noted that the ε'-V dependence characterized by a sharp increase in ε' at the amplitude of the alternating signal V_{ac}=200 mV. At the same time, the nature of the dependence remains. A sharp peak at 200mV can be attributed to the increasing of polarization in Al–TiW–PtSi/n-Si SBD.

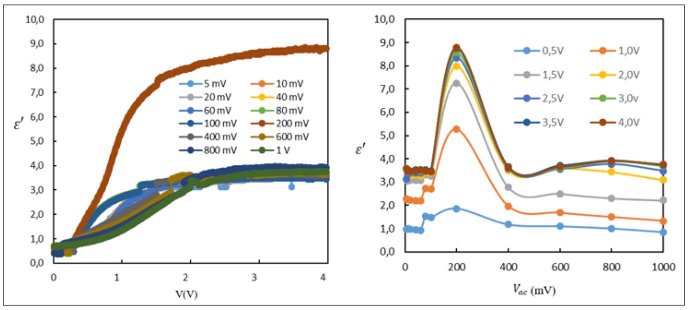

Figure 2: The Variations of the Dielectric Constant of Al–TiW–PtSi/n-Si SBD at Room Temperature: a) ε′-V for Various Amplitudes of V_{ac} and b) ε′-V_{ac} for Various Applied Voltage

It is known that the real part of the dielectric constant ε' is determined by the polarization intensity. According to the Maxwell–Wagner theory, the change in ε' is due to interfacial polarization. This means that charge accumulates at the boundary of less conductive regions. Figure 3 and 4 show the dependence of the imaginary part of dielectric constant (ε'') and the loss tangent (tanδ) of the Al–TiW–PtSi/n-Si Schottky barrier diode on the voltage and amplitude of ac-signal (V_{ac}).

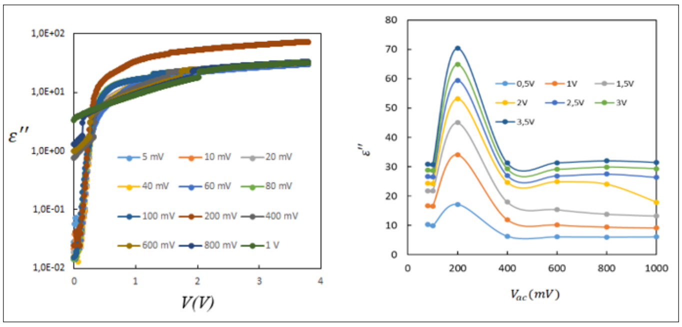

Figure 3: The variations of the dielectric loss of Al–TiW–PtSi/n-Si SBD at room temperature: a) ε″-V for various amplitudes of V_{ac} and b) ε″-V_{ac} for various applied voltage

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

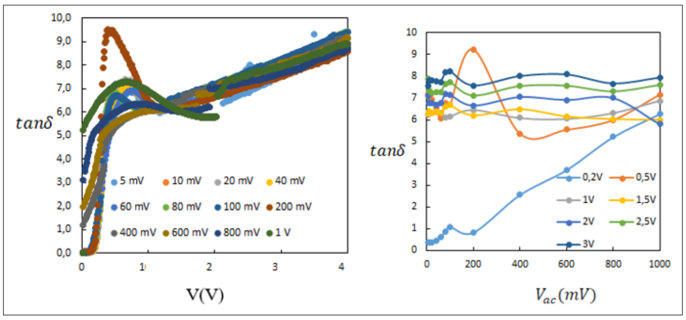

Figure 4: The variations of tangent loss of Al–TiW–PtSi/n-Si SBD at room temperature: a) tanδ-V for various amplitudes of V_{ac} and b) tanδ -V_{ac} for various applied voltage

The tanδ –V characteristics have a peak only at V_{ac}=200mV. It is well known that the peak behavior of the ε″ and tanδ depend on a number of parameters such as doping concentration, interface state density, series resistance of diode and etc. In addition, the capacitance and conductance are extremely sensitive to the interface properties and series resistance. This occurs because of the surface states that respond differently to test ac-signal.

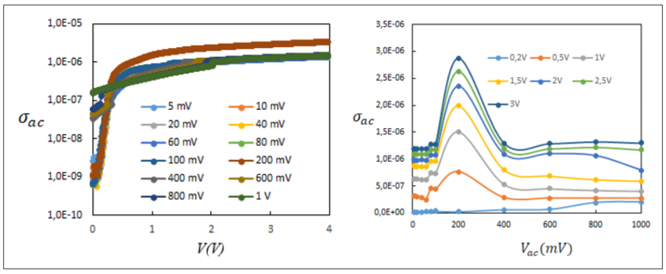

Figure 5: The variations of ac-electrical conductivity (σ_{ac}ac) of Al–TiW–PtSi/n-Si SBD at room temperature: a) tanδ-V for various amplitudes of V_{ac} and b) tanδ -V_{ac} for various applied voltage

The behavior of ac-electrical conductivity (σ_{ac}) of the Al–TiW–PtSi/n-Si SBD at different voltage and V_{ac} is presented in Figure 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, the real series resistance of Al-TiW-PtSi-nSi SBD was calculated from the C and G in strong accumulation region at 500kHz [24]. The dependence of R_s on voltage and V_{ac} show in figure 6.

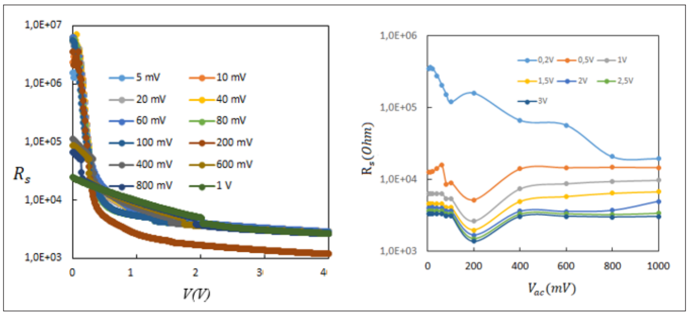

Figure 6: The variations of the real series resistance R_s of Al–TiW–PtSi/n-Si SBD at room temperature: a) R_s-V for various amplitudes of V_{ac} and b) R_s -V_{ac} for various applied voltage The real (M′) and the imaginary (M″) components for Al-TiW-PtSi/n-Si SBD was calculated with the using ε' and ε'' . Figure 7 show the voltage and V_{ac} dependence of the real and imaginary components M′ and M″ of Al-TiW-PtSi/n-Si SBD, respectively

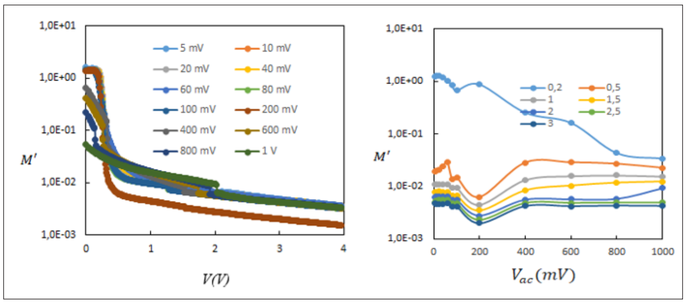

Figure 7: The variations of the real part electric modulus (M′) of Al–TiW–PtSi/n-Si SBD at room temperature: a) M′ -V for various amplitudes of V_{ac} and b) M′ -V_{ac} for various applied voltage

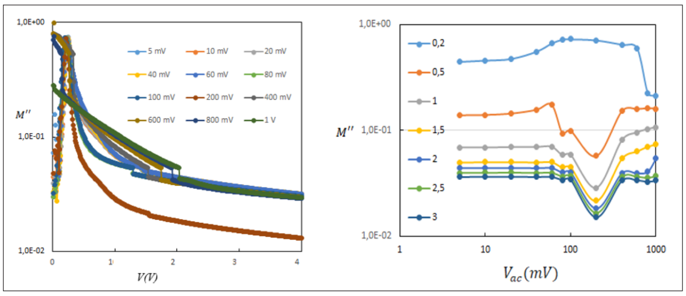

Figure 8: The variations of the imaginary part of electric modulus (M″) of Al–TiW–PtSi/n-Si SBD at room temperature: a) M″-V for various amplitudes of V_{ac} and b) M″ -V_{ac} for various applied voltage

It can be seen from figures 2-8 that all characteristics have features precisely at V=200 mV. For other values of the ac-signal amplitude, the parameters do not depend on the magnitude of the amplitude. In this connection, the dependence of the power dissipated (P) in the dielectric on the amplitude of ac-signal is of interest. The amplitude dependence of the P of Al–TiW–PtSi/n-Si SBD at different voltage are presented in Figure 9.

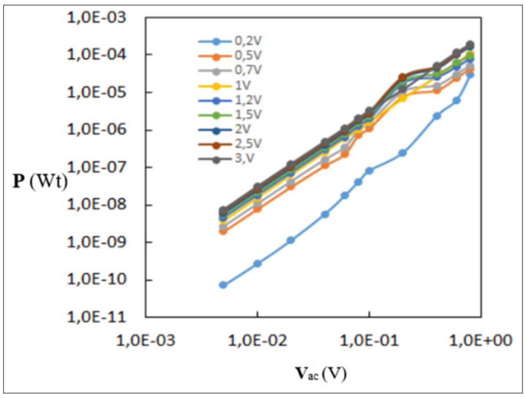

Figure 9: The dependence of the active power of dielectric losses (P) in the Al–TiW–PtSi/n-Si SBD on the amplitude of ac-signal V_{ac}

As can be seen from Figure 9 when the amplitude of the alternating signal (V_{ac}) changes in the range of 5mV-1000mV, the dissipated power in Al–TiW–PtSi/n-Si increases sharply. In addition,, one can notice a small peak at 200 mV.

The obtained dependence (P-V_{ac}) is characteristic of an inhomogeneous structure consisting of regions with different resistivity. This structure is identical to the Maxwell-Wagner two-layer dielectric [32].

It should be noted that in our previous paper, the existence of self-assembled patches with different charge carrier concentrations was discovered [33]. 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 belive in the structure Al–TiW–PtSi/n-Si SBD patches play the role of macrorelaxators. It is known that relaxation phenomena are associated with the recharging of surface states [4,6]. In addition, the energy distribution profile of the density of interfacial states (N_{ss}) obtained by the high-low temperature method for the PtSi/n-Si structure revealed the maximum value of N_{ss} at V=200 mV. That is, the N_{ss} values give a wide peak when E_c - E_{ss} = 0,22 eV. Studies in the article showed the maximum loss tangent at 200 mV [10,33].

In this case, the features in the dependences on V_{ac} for Al–TiW–PtSi/n-Si SBD indicate that the dissipation power at a voltage of 200 mV is associated with the presence of self-assembled patches and the maximum density of surface states.

Conclusion

In the present paper have been investigated dielectric parameters of Al–TiW–PtSi/n-Si SBD for various amplitudes of ac-signal in the range from 5 mV to $1x10^3$ mV at room temperature versus applied voltage from − 2 to 4 V and frequency 500 kHz. Have been obtained that only at V_{ac}=200mV there is a sharp increase in values of the dielectric constant, ac-electrical conductivity and series resistance. The dependence of power dissipation (dielectric losses) revealed a strong dependence on the amplitude of the alternating signal and the presence of a small peak at 200 mV.

Comparison of the results revealed a local heterogeneous structure of contacts according to the Maxwell-Wagner type. The peak at V_ac=200 mV is associated with the maximum value of the surface states density and self-assembled patches.

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