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Dependencies of photoelectric properties of SiC/Si structures grown by the method of atoms substitution on synthesis time

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Abstract. This paper is dedicated to an exploration of the photoelectric properties of Si–SiC structures grown by the substitution method on silicon substrates of (001) orientation. For the samples with the synthesis times of 40, 60, 90, 120 and 900 s, magnitudes of the saturation currents are determined and the coefficients of efficiency are calculated. The obtained dependencies of the photoelectric characteristics on the synthesis time are explained using the theory of formation of dilatation dipoles during the synthesis by the method of atoms substitution.

1. Introduction

Interest in the study of the photoelectric properties of SiC films on Si at the present time is steadily increasing [1], although these studies are at the initial stage. This is due to the fact that it is possible to obtain photosensitive structures operating at elevated temperatures and in conditions of high radiation. However the production of such photosensitive structures is currently hindered by a lack of high-quality epitaxial layers of SiC on Si. This is due to a large difference between the lattice parameters of Si and SiC, primarily. In the works [2–6] authors have developed a new method for the synthesis of nanoscale SiC films on Si. This method is based on the discovery of a new mechanism of relaxation of elastic stress during growth of epitaxial films by pre-embedding the ensemble of nanoobjects – dilatation dipoles in the lattice of the substrate. Dilatation dipole is a stable complex consisting of the attractive centers of dilatation of the carbon atoms in the interstitial positions of silicon atoms and silicon vacancies. In [7] photoelectric properties of heterostructures − substrate Si nanoscale film of silicon carbide (Si/SiC), grown by the method of substitution atoms were investigated. In this article we studied the structure of Si/SiC synthesized on *n*-Si (001) of KEF-4.5 type and structures grown on *p*-Si (111) substrates of KDB-10 type. The authors have shown that the most effective structure of heterojunctions of Si/SiC is formed on the substrates of *n*-type conductivity type KEF-4.5 (001) orientation.

The aim of this work is to study the dependency of photoelectric characteristics of SiC films on Si grown by the method of substitution atoms on the time of synthesis.

2. Materials and methods

In this work the photoelectric properties of the heterostructures Si/SiC are investigated. These heterostructures were grown by the method of substitution of silicon atoms on the carbon atoms inside

the silicon substrate [2–6]. The films were synthesized on *n*-Si (001) substrates of KEF-4.5 type in atmosphere of carbon monoxide (CO) and silicon tetrahydride (SiH_4) at a temperature 1250 °C and at a pressure 0.5–0.7 Torr. Measurements of the photoelectric characteristics was carried out on five samples of Si/SiC grown at different synthesis times of, namely at 40, 60, 90, 120 and 900 s. To measure the photo-properties, we deposited round semitransparent nickel (Ni) contacts onto surface of the SiC films with a radius of 1 mm by magnetron sputtering through masks under heating to 200 °C. The transparency of the contacts, monitored relative to a glass reference sample, was found to be 30 %. The contact to Si was formed from conducting silver paste, which also served as a contact to the substrate holder. Thus, the closure of the contacts formed a closed electrical circuit (figure 1).

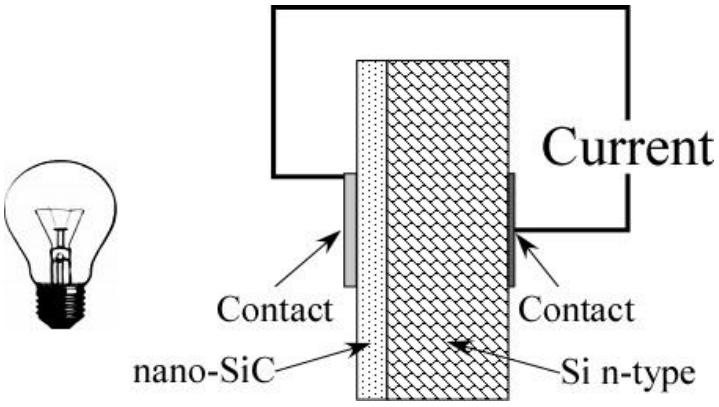

Figure 1. The circuit of the electronic circuit through the diode structure Si/SiC.

To study the photocharacteristics of heterostructures Si/SiC special electro-optic installation was constructed. The installation includes an OSRAM XBO 150W/4 xenon lamp emitting light in the spectral range 185–3500 nm, a quartz lens with a diameter of 50 mm and a focal distance of 100 mm, an iris diaphragm, V7-21A voltmeter and voltage source. With the help of this installation a light spot with a diameter of 2 mm was focused on the semitransparent contact formed on the surface of the SiC film. The intensity of the light was set by the iris diaphragm and controlled by a photodiode placed near the sample. The current–voltage (I–V) and load I–V characteristics of the samples were measured by a voltmeter and voltage source. Load I–V were determined at power of the light 100 mW/cm^2. All the electrical and optical characteristics were measured at room temperature T = 293 K. More details on this electro-optic installation and the studies on it are described in [7].

3. Results and discussion

The graph (figure 2(a)) shows I–V characteristics of heterojunctions SiC/Si grown by the method of atoms substitution with the times of synthesis 60, 90 and 900 s. It follows from the figure 2(a) that I–V characteristics of the investigated structures are of the same nature as of the diode. Note that I–V characteristics of the other samples had a similar appearance. The biggest difference of the forward and reverse currents was observed for the sample that was synthesized in 60 s. The initial regions of the forward I–V characteristics at low voltages are described by the dependence (1) with factor of not ideality n = 4:

$$j = j_s \exp\left(qV/nkT\right), \tag{1}$$

here, j is the current; j_s is the saturation current; q is the elementary charge; V is the voltage; k is the Boltzmann constant and T is the temperature. Figure 2(b) shows the dependence of the voltage-saturation current passing through an area of 1 cm^2 on the time of synthesis of SiC films on substrates Si. From this dependence it follows that the maximum of the voltage-saturation current was observed for structures that have been synthesized in 60–90 s. Hence, most efficient in terms of photovoltaic conversion structure is formed approximately 1 min.

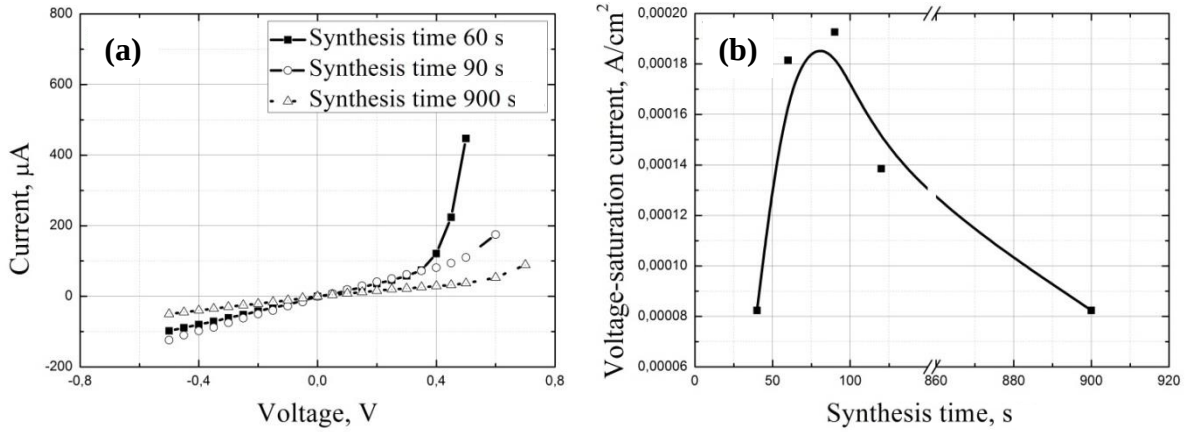

Figure 2. I–V characteristics of the heterostructures Si/SiC **(a)**; dependence of the saturation current on the time of synthesis of heterostructures Si/SiC **(b)**.

The graph (figure 3(a)) shows the load I–V characteristics of heterojunctions SiC/Si grown by the method of atoms substitution with the times of synthesis 60, 90 and 900 s. All the load dependencies of the structures of Si/SiC demonstrate the characteristic diode bend. According to the load curves values of the efficiency η, short-circuit current I_{SC}, open-circuit voltage U_{OC}, fill factor FF and maximum power output P_{max} of test specimen were calculated. The efficiency is determined by the formula (2)

$$\eta = FF \cdot I_{sc} U_{oc} / P, \tag{2}$$

here P – the radiation power incident on the structure Si/SiC. The dependence of the efficiency on the time of synthesis is depicted in figure 3(b). It should be emphasized that all the above values except for the fill factor are correlated with each other.

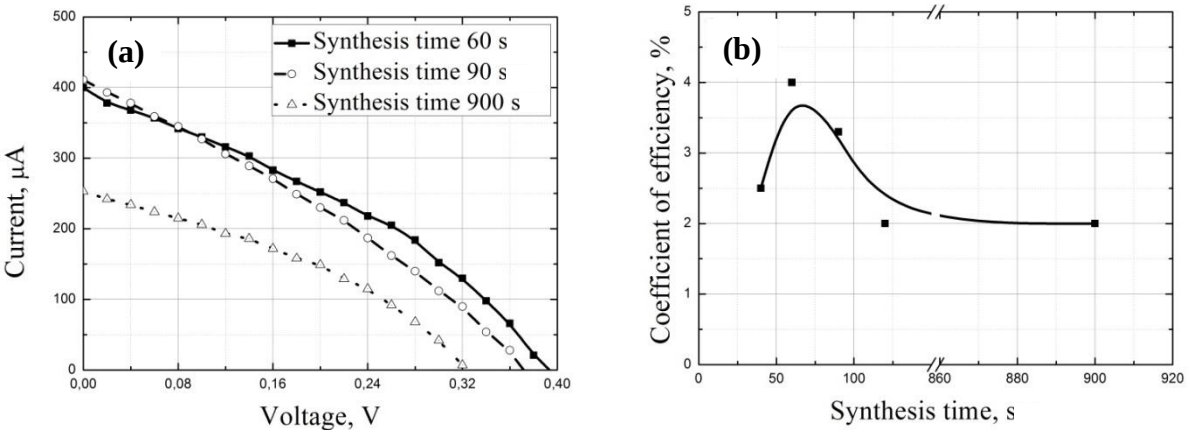

Figure 3. Load I–V characteristics of the heterostructures Si/SiC **(a)**; dependence of the coefficient of efficiency on the time of synthesis of heterostructures Si/SiC **(b)**.

Such dependencies of the photovoltaic characteristics on the time of synthesis are associated with features of the method of synthesis of structures of Si/SiC. According to the concept of the atomic substitution [4–6] at the initial stage of the growth within the matrix of a silicon substrate a part of the silicon atoms are replaced by carbon atoms. As a result, nano-objects, which the authors called dilatation dipoles are being formed. Dilatation dipoles represent the stable complexes of the two centers of dilatation, namely the carbon atom in interstitial position and the vacancy in silicon. It was discovered that the higher the concentration of dilatation dipoles, the higher conversion efficiency of sunlight with heterojunctions of Si/SiC. We established one-to-one correspondence between the time

of synthesis SiC films, the maximum density of the dipoles and the efficiency of conversion of solar light into electrical energy.

4. Conclusions

We investigated photoelectric properties of heterostructures Si(001)/SiC grown by a new method of atoms substitution. The effect of strong dependence of saturation current and maximum efficiency of conversion of solar light heterojunction Si(001)/SiC on the time of synthesis of films and the concentration of dilatation dipoles is discovered. Time interval, which is the most effective for photopleasure structure of heterojunctions of Si/SiC is specified.

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