p-Si/n-SiC NANOLAYER PHOTOVOLTAIC CELL

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ABSTRACT: Thin films of amorphous SiC were prepared by non-reactive magnetron sputtering in an Ar atmosphere. A previously synthesized SiC was used as a solid-state target. Deposition was carried out on a cold substrate of p-Si (100) with a resistivity of 2 Ohm·cm. The Raman spectrum shows a dominant band at 982 cm^{-1}, i.e. in the spectral region characteristic for SiC. The film thickness determined from atomic force microscopy measurements was about 8-40 nm, the height of the structural units of the film was 1-2 nm, while the linear dimensions were of the order of tens of nanometers. The amorphous nature of SiC grown on the Si substrate is confirmed by the presence of the diffraction rings which indicate the absence of the dominant orientation of the prepared films. A heterostructure consisting of a p-type Si (100) and a layer of amorphous n-type SiC was fabricated and studied. The investigation of its electrical and photoelectric properties shows that the entire space charge region is located in Si. This is in addition confirmed by the spectral dependence of the p-Si/n-SiC photo sensitivity. The barrier height at the p-Si/n-SiC interface estimated from dark I-V characteristics is of the order of 0.9-1.0 eV. Load I-V characteristics of p-Si/n-SiC-amorphous-nanolayer solar cells demonstrate under standard AM1.5 illumination conditions a conversion efficiency of 7.22%.
Keywords: SiC, Si, nanolayer, heterostructure, solar cell.

1 INTRODUCTION

Despite the development of new generations of solar cells (SCs) based on new principles and technologies, silicon remains the basic material for the production of photovoltaic (PV) devices. However, broader terrestrial application of Si-based PV cells is still limited, since the cost of electricity generated by these devices is still too high. Therefore, there is a wide search for new opportunities to reduce this cost by the use of new materials and structures for the production of silicon devices. In particular, good perspectives have SCs based on SiC heterostructures, which have achieved already an efficiency exceeding 15% [1-4]. These devices are designed to operate at an increased level of radiation and high temperature. The constraint is the cost of SiC, meeting the requirements of the electronics industry, which averages at least $ 100 per 1 sq. Inch. [5]. The difficulties in the application of SiC in electronics are characterized also by the SiC polymorphism. The number of crystalline modifications of silicon carbide is more than 200. Crystalline layered superstructure SiC is built from elementary layers of three types. The periodicity of elementary layers varies from tens of angstroms to tens of nanometers. Silicon carbide is a semiconductor; the n-type conductivity of SiC is usually caused by doping with nitrogen or phosphorus, while the p-type conductivity is determined by aluminum, boron, gallium or beryllium impurities [6]. The problem of increased consumption of SiC can be solved by the use of amorphous and nano crystalline SiC. The aim of this work was to create a photovoltaic solar cell structure based on amorphous silicon carbide nanolayer.

2 PREPARATION OF SiC NANOLAYERS

Thin films of amorphous SiC were prepared by the method of high-frequency non-reactive magnetron sputtering in an Ar atmosphere using an Ukrrospribor VN-2000 setup. A previously synthesized silicon carbide was used as a solid-state target. Deposition was carried out on a cold substrate of p-Si (100) with a resistivity of 2 Ohm·cm. The layer of silicon oxide was removed from Si substrate by chemical etching in HF before the SiC film deposition. n-SiC nanolayers with the thickness up to 40 nm have been deposited on p-Si substrates.

3 CHARACTERIZATION OF SiC NANOLAYERS

The composition of deposited layers was characterized by Raman Spectroscopy (RS) techniques using co-focal nanometric resolution Omega Scope AIST-NT Raman microscope excited with an 532 nm Ar^+ laser. The Raman spectrum of the obtained layers is presented in Fig. 1.

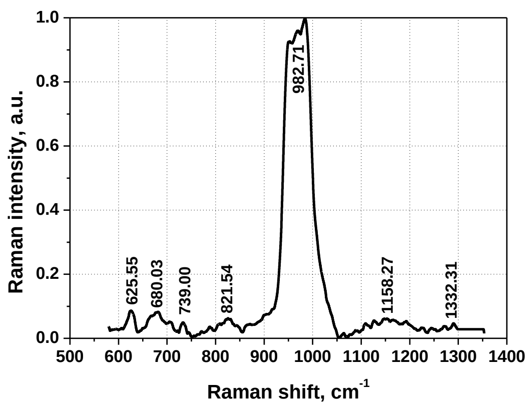

Figure 1: Raman spectrum of SiC nanolayers prepared by high-frequency non-reactive magnetron sputtering in Ar.

The spectra show a dominant band at 982 cm^{-1}, i.e. in the spectral region close to the frequency of the modes characteristic of SiC [7].

The control of the SiC film thickness and the study of the surface morphology were performed by tapping mode atomic force microscopy (AFM) using an NT-MDT Integra Aura setup in a controlled atmosphere or low vacuum. Fig. 2 provides the estimation of the layer thickness from the step height at the edge of the SiC film.

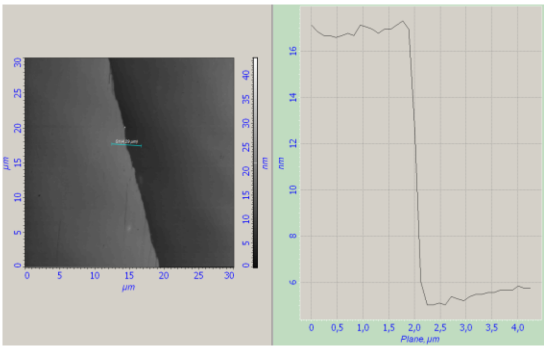

Figure 2: Left panel: AFM image of a SiC thin film on Si (100). Right panel: SiC layer profile at the film edge (right).

Figure 3 demonstrates the evolution of the surface morphology of the SiC films as a function of thickness.

(a)

(b)

(c)

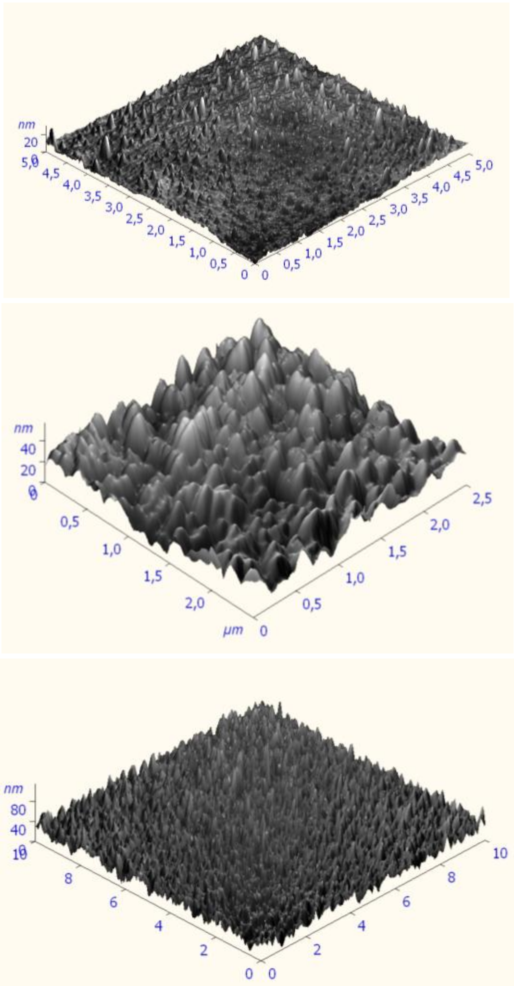

Figure 3: Surface morphology of SiC thin films of different thicknesses measured by AFM.

As can be seen from the Fig. 3(a,b,c), the film thicknesses vary from 8 nm up to 40 nm, the height of the structural units of the film is of 1-2 nm, and the linear dimensions are of the order of tens of nanometers.

The amorphous nature of the film is confirmed by the results of electron diffraction obtained on a SiC film in a JEOL Ltd. JEM 2100 transmission electron microscope. As seen in Fig. 4(a), the presence of diffraction rings indicates the absence of the dominant orientation of the amorphous SiC film grown on a Si (100) substrate. From Fig. 4(b) the structure of amorphous islets in SiC film is clearly visible.

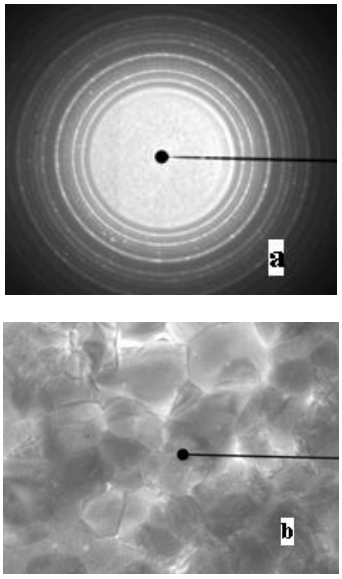

Figure 4: (a) Diffraction pattern and (b) TEM image of a SiC thin film.

These results correlate well with the results obtained by atomic force microscopy and confirm the fine structure of the film.

4 p-Si/n-SiC-NANOLAYER PHOTOVOLTAIC CELL: PREPARATION AND CHARACTERIZATION

We have prepared a heterojunction photovoltaic cell consisting of a substrate of p-type Si covered by a layer of amorphous n-type SiC. The Si substrate was specially treated with chemical etchants before the SiC layer deposition. The best results have been achieved with SiC layers with the thickness of 10 nm. Onto silicon carbide thin film an Ag/Cu grid has been deposited as top electrode. A continuous Ag:Cu layer has been deposited as back electrode. The cross-section schematic of the solar cell device is shown in Fig. 5.

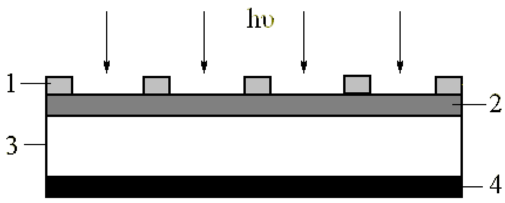

Figure 5: Cross-section schematic of the p-Si/n-SiC solar cell: 1-front grid (Ag); 2- n-SiC amorphous layer; 3- single-crystal p-Si substrate; 4- back contact (Cu).

The dark I-V characteristic of the elaborated p-Si/n-SiC solar cell is shown in Fig. 6.

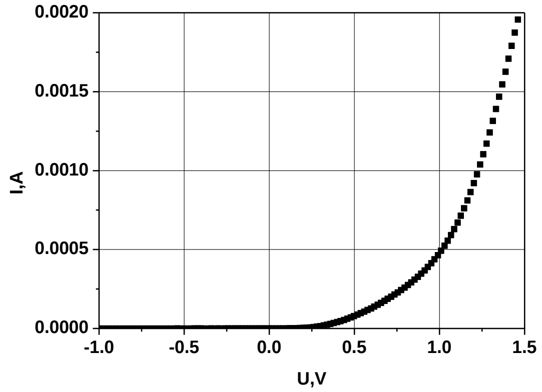

Figure 6: Dark current-voltage characteristic of a p-Si/n-SiC solar cell.

The barrier height at the Si/SiC interface estimated from dark I-V measurements performed at different temperatures is of the order of 0.9 – 1.0 eV. These values are much higher than the half of Si forbidden gap. As a consequence, the physical *p-n* junction is formed in the Si substrate near the Si/SiC interface; the entire space charge region, where the light absorption takes place and charge carriers are generated and separated, is located in Si. This fact is in addition confirmed by the spectral dependence of the Si/SiC photo sensitivity in Fig. 7 which entirely corresponds to the respective characteristic of Si solar cells.

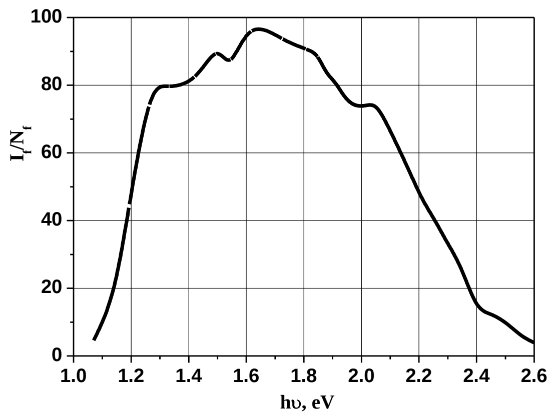

Figure 7: Spectral dependence of the p-Si/n-SiC solar cell photo sensitivity.

The measurements of the load current-voltage characteristics of the as-prepared p-Si/n-SiC solar cells and the determination of their photoelectrical parameters have been carried out under standard AM1.5 conditions (1000 W/m^2, 25°C) with an ST 1000 solar simulator

An I-V load characteristic of a Si/SiC solar cell is presented in Fig. 8. The short-circuit current density is 24.05 mA/cm^2, the open circuit voltage is 0.527 V and the fill factor is 57%.

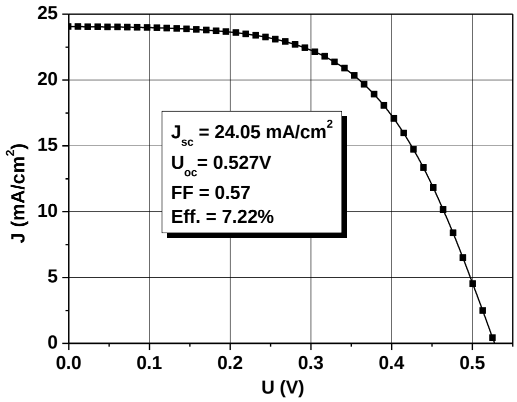

Figure 8: I-V load characteristic of a p-Si/n-SiC solar cell.

The solar energy conversion efficiency of the elaborated structure reaches 7.22%.

5 CONCLUSIONS

- Thin films of amorphous SiC were obtained by non-reactive magnetron sputtering in an Ar atmosphere. A previously synthesized SiC was used as a solid-state target. Deposition was carried out on a cold substrate of p-Si (100) with a resistivity of 2 Ohm·cm.
- The control of the SiC thin film thickness and the study of the surface morphology were performed by the tapping mode atomic force microscopy under a controlled atmosphere or low vacuum. The film thickness was about 8-40 nm, the height of the structural units of the film was 1-2 nm and the linear dimensions were of the order of tens of nanometers.
- The amorphous nature of SiC grown on the Si substrate is confirmed by the presence of the diffraction rings which indicate the absence of the dominant orientation of the obtained films.
- A heterostructure was obtained by magnetron sputtering deposition of a layer of amorphous n-type SiC on the surface of single crystalline p-type Si (100). A respective solar cell was fabricated with an Ag-grid on top of the SiC film. The rear side of the silicon substrate was covered by a continuous layer of Cu.
- The investigation of the electrical and photoelectric properties of the fabricated p-Si/amorphous n-SiC nanolayer solar cells show that the entire space charge region is located in Si, where a physical p-n junction is formed. The barrier height at the Si/SiC interface estimated from temperature dependent dark I-V measurements is of the order of 0.9-1.0 eV.
- The spectral dependence of the Si/SiC photo sensitivity entirely corresponds to the respective characteristic of the Si solar cells. Load I-V characteristics of the elaborated solar cell under standard AM1.5 test conditions demonstrate a conversion efficiency of 7.22%.

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