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RF Magnetron Sputtering of Silicon Carbide and Silicon Nitride Films for Solar Cells

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RF-magnetron nonreactive sputtering method from solid-phase target in argon atmosphere was used for obtaining thin silicon carbide and silicon nitride films, that are used for constructing solar cells based on substrates of single crystal silicon of p-type.

Keywords: Atomic force microscopy, RF- magnetron sputtering, Silicon carbide, Silicon nitride, Thin films, Solar cells

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1. INTRODUCTION

Silicon carbide and silicon nitride are widely used in electronics because of their unique properties. SiC is often used for creating power electronic devices, which performance exceeds silicon-based devices. Memory effect in Si_3N_4 is used in the non-volatile devices (flash memory) [1-3]. In many cases, the widespread use of carbide and silicon nitride in heterostructures of electronic devices is associated with high permittivity of these materials (amorphous Si_3N_4 $\varepsilon = 7.5$ and for 4H-SiC $\varepsilon = 9.6 \div 10.0$ at $T = 300$ K). In the case of creating a solar cell (SC) with the use of films of these materials, they are most commonly used as the upper antireflection layers in heterostructures or as passivation layers silicon surface [7]. The use of SiC has good prospects for creating pin solar cells as a wide band of light absorbing material, which heterostructures based on SiC have already achieved an efficiency SC exceeding 15 % [8,9]. Widely spread application of silicon carbide and silicon nitride in the production of solar cells and electronics in general is connected with the use of effective thin-film technology and new design solutions. Currently the most often used methods for preparation of SiC and Si_3N_4 represent different modifications of the chemical vapor deposition (CVD) method. Using comprehensive and environmentally hazardous methods of producing thin films of these materials hinders their widespread use in solar energy. For example, these technologies for the preparation of the a-SiC thin films, environmentally harmful silane (SiH_4), propane (C_3H_8) and phosphine (PH_3) are used [9, 10]. The aim of this study is to apply environmentally friendly rf- magnetron sputtering method for carbides and nitrides of silicon thin films for solar cell devices.

2. EXPERIMENTAL SECTION

Films of amorphous plus microcrystalline ($a + \mu c$) SiC and Si_3N_4 were obtained by nonreactive magnetron sputering, using solid state target on plant VN-2000. The depositions were carried out on a cold and hot substrates of *p*-Si (100) with a resistivity of 2 Ohm·cm. Before layering the layer of native oxide SiO_2 was extracted from the substrate by etching in HF. Thicknesses of the films were controlled by atomic-force microscopy methods (AFM) according to heigh of steps on the edge of the film. The compositions of deposited films were characterized by Raman Spectroscopy (RS) techniques using co-focal nanometric resolution Omega Scope AIST-NT Raman microscope with Ar^+ laser excitation at 532 nm. The morphology features of the thin layers were studied by tapping-mode AFM (NTEGRA Aura, NT-MDT) in a controlled atmosphere or low vacuum. The amorphous plus microcrystalline nature of the films is confirmed by the results of electron diffraction obtained on SiC and Si_3N_4 specially prepared samples in a JEOL Ltd. JEM 2100 transmission electron microscope.

3. RESULTS AND DISCUSSION

For characterization of SiC nanolayers the Raman Spectroscopy (RS) techniques were used. The Raman spectrum show a dominant band at 982 cm^{-1}, i.e. in the spectral region close to the frequency of the modes characteristic of SiC [11]. The morphology features of SiC thin films were studied by AFM. The average height of the surface features varies when the film thickness 1-2 nm, 3-5 nm and 25-35 nm when the film thickness changes from 2 nm to 6 nm and 56 nm, respectively. The lateral dimensions of those elements are of the order of tens of nanometres. A 2D autocorrelation function was applied to the AFM images. It was found that Sa, average roughness increases along growth the film thickness and equals to 0.2, 0.9 and 7.3 nm for the film thickness 1-2 nm, 3-5 nm and 25-35 nm, respectively. Mixed of cubic symmetry microcrystalline plus amorphous nature of the films is confirmed by the results of electron diffraction obtained on SiC films in a JEOL Ltd. JEM 2100 transmission electron microscope.

Were perfomed AFM studies and a comparative analysis of thin films Si3N4 grown by rf-magnetron sputtering on a cold ($T_S = 40$ ºC) and hot ($T_S = 800$ ºC) substrate. The results of these studies are shown in Figure 3. As a result of analysis the AFM images, it was established that the increment of the relative magnitude of the surface area (S_{dr}) increased from 0,8 % for $Ts = 40$ ºC, up to – 8,9 % for $Ts = 800$ ºC.

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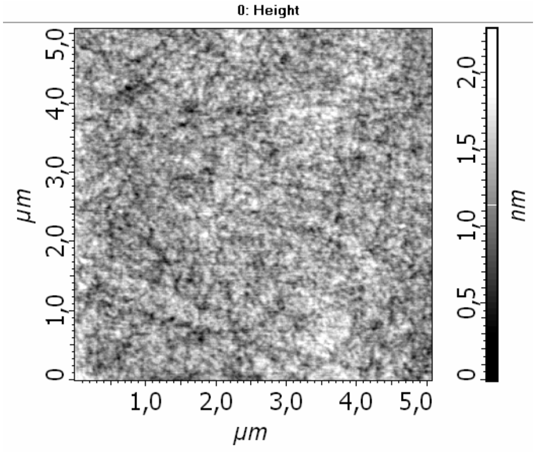
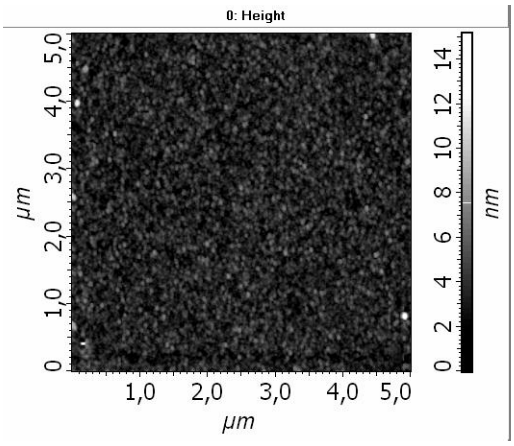


a



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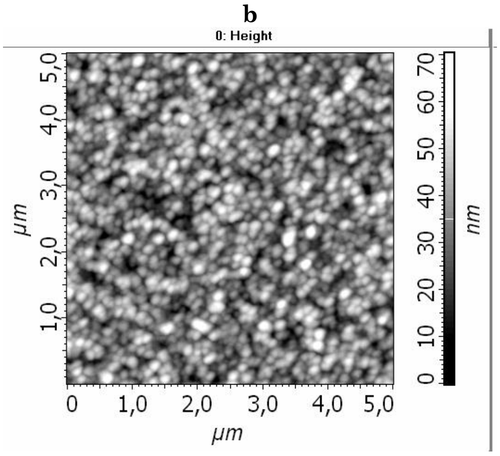
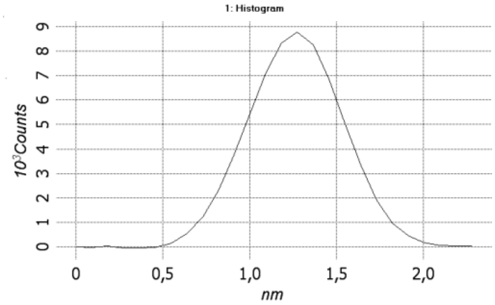


c

Fig.1. – AFM images of free surfaces SiC with grey scale for film thicknesses (a) $d = 8$ nm, (b) $d = 20$ nm, (c) $d = 56$ nm

The compositions of Si_3N_4 films were characterized by RS techniques. The position of the maximum in the spectrum of Raman scattering corresponds to the compound Si_3N_4, and the shape of the spectrum is characteristic of the nano crystalline state.



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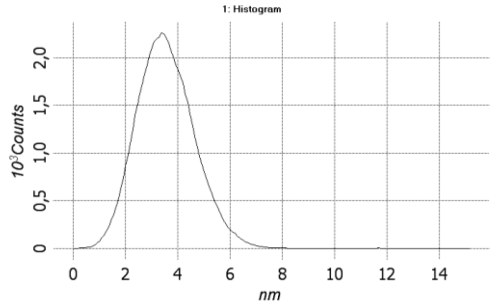

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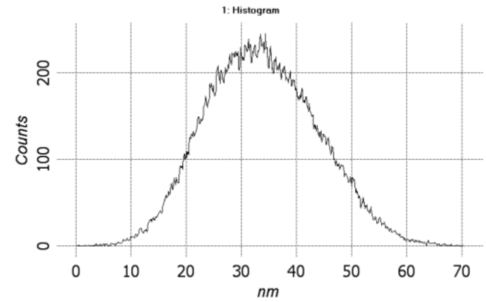

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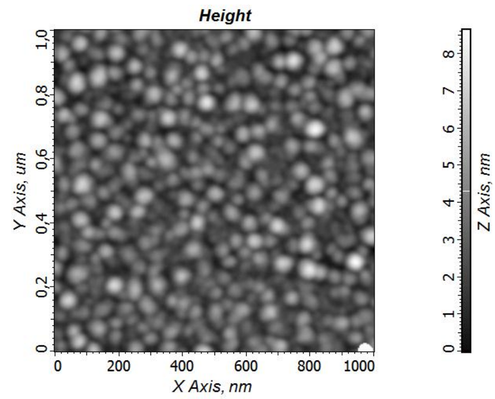
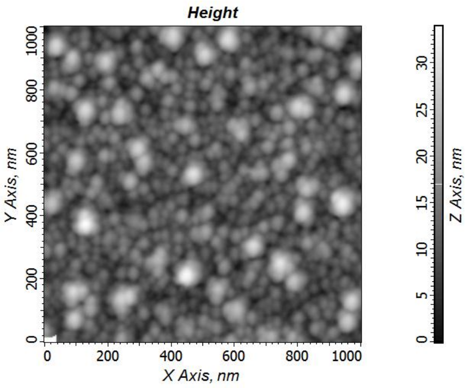
Fig.2. – Histograms for SiC samples of series films thicknesses (a) $d = 8$ nm, (b) $d = 20$ nm, (c) $d = 56$ nm



Peak-to-peak	9.146 nm
Root mean square, RMS	1.311 nm
Roughness average	1.046 nm
Skewness, Ssk	0.789
Kurtosis, Ska	3.463
Sdr, Surface area ratio	0.806 %

a



Peak-to-peak	36.307 nm
Root mean square, RMS	5.136 nm
Roughness average	3.958 nm
Skewness, Ssk	0.955
Kurtosis, Ska	3.947
Sdr, Surface area ratio	8.966 %

b

Fig.3. – AFM images of free surfaces Si_3N_4 films for rf-sputtering substrate temperatures (a) $Ts = 40$ ºC, (b) $Ts = 800$ ºC and results of calculations S-parameters (a surface area) or 3D-parameters, characterizing the structure in three dimensions

Are detected vibrations at frequencies 288, 307 and 347 cm^{-1}, which, correspond to cubic modification of silicon nitride. From electronic diffraction were established that Diffusional regions around the central diffuse reflex are typical for the amorphous material and the presence of ill-defined concentric rings indicating the presence of secondary nanocrystalline phase. Hense, the Si_3N_4 film is in a mixed amorphous and nanocrystalline state ($a + \mu c$) belongs to cubic system, space group Fd-3m.

4. CONCLUSIONS

Thus using our method of nonreactive rf-magnetron sputtering were obtained nanoscale and nanostructured homogeneous films ($a + \mu c$) SiC and Si_3N_4. Were studied their surface morphology, structure and composition. The possibility of increasing more than 10 times the relative surface area Sdr, which is an important indicator for the light-absorbing layers SC.

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