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Amorphous Silicon Carbide Nanowires for Optical Sensor Device

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In this study, amorphous silicon carbide nanowires (NWASC) on Si substrates were fabricated by depositing hydrogenated amorphous SiC thin films on silicon nanowire by RF magnetron sputtering, with different thicknesses. The scanning electron microscopy showed the formation of nanostructured NWASC and strong photoluminescence intensity was noticed. Due to the large surface area and the high stability, the SiC nanowires were used as the Schottky diode optical sensor device (Au/NWASC/Si/Al). The results presented in this work show the impact of the thickness and the surface structuring on the optoelectronic properties of amorphous SiC thin films. Finally, a high photocurrent and high relative spectral response value of Au/NWASC/Si/Al were observed for the thinner amorphous SiC layer.

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PACS/topics: SiC nanowire, Schottky diode, optical sensor, photocurrent, spectral response

1. Introduction

Silicon carbide (SiC) is an important semiconductor which can be operated at high powers, high temperatures, and high frequencies. Micrometer-sized whiskers of SiC have been widely used to strengthen ceramic composites which had brought dramatic revolution in mechanical and optoelectronic industries [1]. Furthermore, nanostructures of SiC [2] are of great interest because of their broad range of potential applications as field electron emitter, light emitter, and other reinforcing uses [3–8]. Considering these advantages of SiC, it is worthwhile to fabricate efficient and stable photoelectrodes with favorable structures of SiC. Actually, such investigations have already been in progress. Bulk and film of the SiC have been employed as photocatalyst for water splitting [9–12]. It is known that the nanostructuration would greatly enlarge the specific surface areas of the SiC photocatalyst, and thus increase the reactive sites for photocatalysis. As a result, the efficiency of water splitting would be improved [13]. Results by Zhou et al. indicates that the SiC nanowires own a high photodegradation rate for acetaldehyde [14]. In particular, hydrogen amorphous silicon carbide (a-SiC:H) films have attracted much interest for their potential applications in many kinds of optoelectronic devices [15, 16]. By controlling the carbon content in a-$Si_{0.72}C_{0.28}$:H films, the optical band gap could be readily adjusted between 1.8 and 3.2 eV, which makes them suitable candidates for application in full-color light emitting diodes (LED). In our previous work, we have studied the microstructures and optical properties of NWASC films prepared by two steps. In the first one, the formation of silicon nanowire on silicone type p is done by metal-assisted chemical etching [17]. In the second one, hydrogenated amorphous SiC thin films are deposited on silicon nanowire by pulverization RF magnetron sputtering, with different thickness. The elaborated NWASC films are used to investigate devices for energy conversion.

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2. Experimental

The formation of nanowire amorphous silicon carbide (NWASC) are prepared by two steps. First, elaborated silicon nanowires are done by metal-assisted chemical etching. Second, deposition of hydrogenated amorphous silicon carbide thin films on silicon nanowire, is done by RF magnetron sputtering of p-type 6H-SiC polycrystalline, with different thickness. Moreover, we have studied the morphology and optical properties of NASC with of SiC thin films with differences thickness, using scanning electron microscopy (SEM), UV spectroscopy, and photoluminescence (PL). After formation of the ohmic contact as aluminum, the samples were placed into a deposition chamber in order to evaporate a thin layer of gold (Au, with 99.9% purity) on the NWASC to form the Schottky contact (Au/NWASC/p-Si/Al) to investigate devices for energy conversion.

3. Results and discussion

3.1. Macrostructure of NWASC

The morphologies and structures of the Si and SiC nanowire arrays were further characterized by SEM, and the results are shown in Figs. 1 and 2. It can be observed from Fig. 1 that the diameter and length of the Si nanowires are about 80 nm and 3 μm, respectively. Figure 2d demonstrates that the length of the NWASC are similar to those of the Si nanowires and the diameter increases with thickness of SiC layer, shown in Fig. 2a–d.

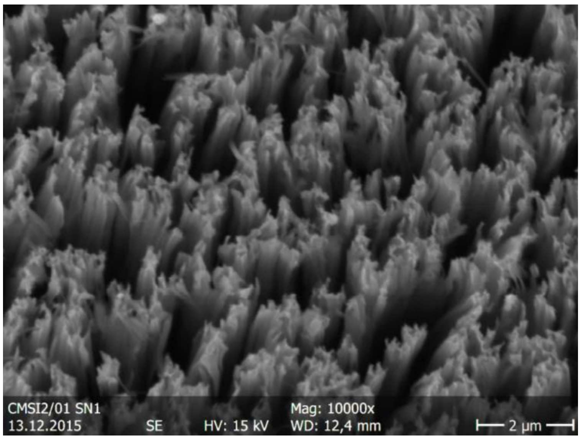

Fig. 1. SEM micrographs of silicon nanowire.

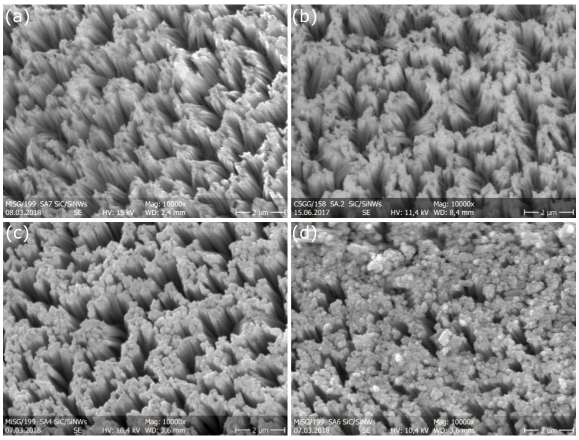

Fig. 2. SEM image of NWASC film grown on p-Si nanowire wafer with different thickness: (a) E_{SiC} = 2 nm, (b) E_{SiC} = 10 nm, (c) E_{SiC} = 40 nm, (d) E_{SiC} = 60 nm.

3.2. Photoluminescence measurements

The luminescence measurements were carried out at room temperature with a Perkin-Elmer LS-50B spectrometer and a xenon lamp (150 W) with an excitation wavelength of 325 nm was used. Figure 3 shows the PL spectra of NWASC which exhibits a high PL intensity in blue compared to the unetched a-SiC sample [18, 19]. Wang et al. found that the PL intensities are enhanced by UV irradiation 325 nm at room temperature and the luminescence center with peak energy 2.20 eV is induced by the UV light for the porous-like SiC samples. They suggested that UV irradiation may induce metastable states as luminescence centers in the sample [20, 21].

3.3. Realization and characterization of AuNASC device

3.3.1. AuNASC device

In order to study the electrical and optical performance of the formed NWASC layers a diode configuration has been realized. Figure 4 shows the top view of Au/NWASC/SNW/p-Si/AlSchottky diode structure.

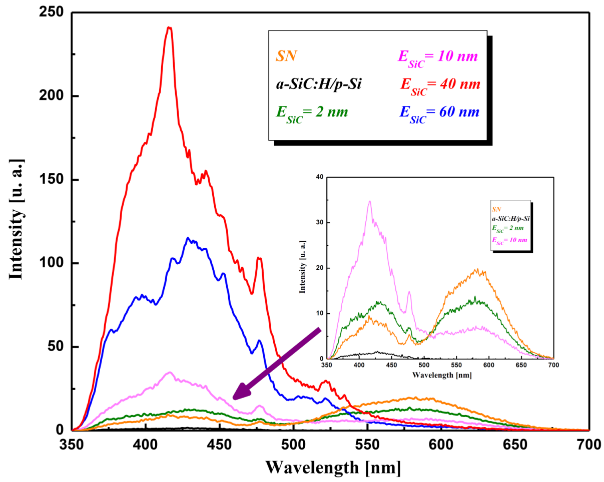

Fig. 3. Photoluminescence spectra of Si nanowire, a-SiC:H/p-Si and NWASC films with different thickness.

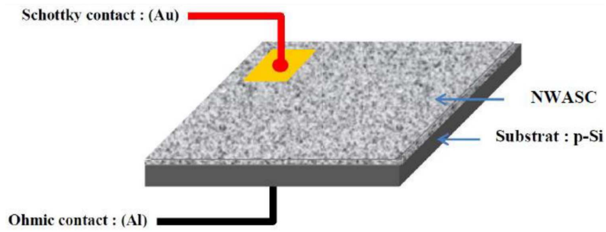

Fig. 4. Top view of Au/NWASC/SNW/p-Si/Al Schottky diode structure.

3.3.2. Device responses

• Characterization I–V of Au/NWASC/SNW/p-Si/Al device

Figure 5 shows the current–voltage characteristic of the Au/NWASC/SNW/p-Si/Al heterojunction measured in the dark and under illumination at room temperature. Typically good rectifying and photoelectric behaviour were observed for the device. The dark leakage current is small, whereas its photocurrent generated under illumination is higher. It is observed that the heterojunction exhibits a rectifying behaviour in the presence of light, too. Under reverse bias conditions photocurrent caused by the NWASC/SNW/p-Si heterojunction, which was irradiated under illumination by white light lamp, was evidently much larger than the dark current.

• Schottky photodiode application of Au/NWASC/SNW/p-Si/Al Schottky photodiodes

The photodiode spectral responsivity was in direct relation with the depletion width (W) and thus with silicon carbide layer resistivity. The spectral response (SR) is given by the formula:

$$\mathrm{SR}\ [\mathrm{A/W}] = \frac{I_{\mathrm{ph}}}{Q}\frac{P_{\mathrm{inc}}}{h\nu}$$

where P_{inc} is the incident power and $h\nu$ is the photon energy.

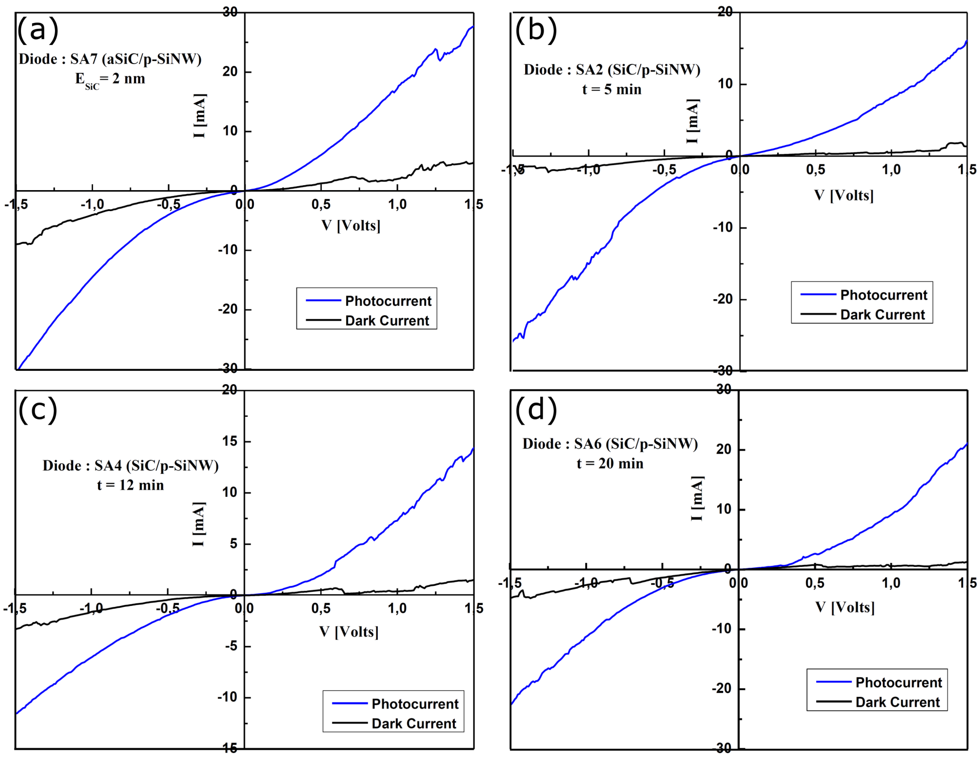

Fig. 5. I–V characteristics curves Au/NWASC/SNW/ p-Si/Al heterojunction in dark and in light (light 38 W white lamp): (a) $E_{\mathrm{SiC}} = 2$ nm, (b) $E_{\mathrm{SiC}} = 10$ nm, (c) $E_{\mathrm{SiC}} = 40$ nm, (d) $E_{\mathrm{SiC}} = 60$ nm.

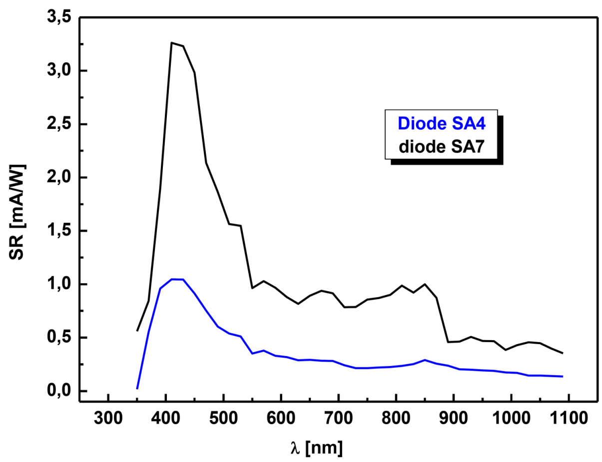

Fig. 6. Spectral response versus wavelength of Au/NWASC/SNW/p-Si/Al heterojunction Schottky diode.

The results presented in this work show the impact of the surface structure on the SR of the Au/NWASC/SNW/p-Si/Al Schottky photodiodes. A relatively high spectral response value of 3.25 mA/W for SiC with thickness of 2 nm and 1 mA/W for thickness of 40 nm, in the blue region [22], reaching a maximum at a wavelength of 420 nm (Fig. 6), was obtained for device based on nanowires a-SiC, namely Au/NWASC/SNW/ p-Si/Al Schottky photodiodes least thick.

4. Conclusion

In this work, we have discussed the formation of NWASC. This obtained structure encouraged us to elaborate devices based on this substrate such as Au/NWASC/SNW/p-Si/Al Schottky diode. The obtained results indicated clearly the impact of the nanowire structure on the optical properties of the fabricated Au/NWASC/SNW/p-Si/Al Schottky diode, where an increase of the photocurrent was noticed. Finally, the Schottky diodes realized with a nanowire thin SiC films (Au/NWASC/SNW/p-Si/Al) showed a good rectifying behaviour which could allow the fabrication of the Schottky diodes for energy conversion.

Acknowledgments

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