Preparation of SiC/SiNWs/graphene heterojunction on 4H-SiC(0001)

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Si nanowires (NWs) can be used as the visible and near-infrared absorption layer in SiC/SiNWs/graphene heterostructure to solve the problem that SiC optoelectronic devices cannot be operated by visible and near-infrared lights. In this paper, Si NWs are prepared on 4H-SiC substrate by using the Au-catalyzed chemical vapor deposition. The SiNWs on 4H-SiC have the polycrystalline structure with a preferred growth orientation of <111>. The SiC/SiNWs/graphene heterostructure exhibits good photoelectric performance, with a VIS-NIR illumination of 0.1W/cm^2, the photocurrent and the open-circuit voltage are J_{ph}=4.27nA and V_{OC}=0.035V, respectively.

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1. Introduction

Silicon carbide (SiC) has attracted considerable attention due to their excellent material properties such as wide bandgap and high thermal conductivity. However, the wide bandgap also causes a serious problem which is not sensitive to visible (VIS) and near-infrared (NIR) light [1-2]. Graphene has excellent electrical conductivity and light transmittance, which makes it have an application prospect in transparent electrodes. Moreover, graphene has broad spectral absorption characteristics from ultraviolet to infrared region.

In recent years, because of the unique mechanical flexibility and excellent light trapping capability, Si nanowires (NWs) become a hot topic in the high performance flexible photodetector. Luo et al prepared Au particle to form the graphene/SiNWs Schottky junction and fabricated a high performance NIR photodetector with local surface plasmon effect, which proves the application feasibility of the SiNWs/graphene heterojunction in optoelectronics [3-7].

In this paper, the SiC/SiNWs/graphene heterojunctions are prepared on 4H-SiC successfully. The relationship between the size and growth time of the SiNWs is investigated. J-V properties of the SiC/SiNWs/graphene heterojunctions under dark and VIS-NIR illumination are measured.

2. Experimental

An n-type doped (doping concentration of ~10^{17}cm^{-3}) 4H-SiC(0001) wafer was purchased from CREE. The SiNWs are prepared on 4H-SiC substrate at 500°C by using chemical vapor deposition (CVD). Gas source and carrier gas used in this work are silane and hydrogen (electronic grade high purity). Au layer of 2 nm is used as a catalyst, which is deposited on the substrate by electron beam evaporation. The graphene was spin-coated with polymethylmethacrylate, removed from the Cu foils rinsed by DI water and then transferred onto the SiNWs [7-8]. The schematics of the SiC/SiNWs/graphene heterostructure are shown in Fig. 1.

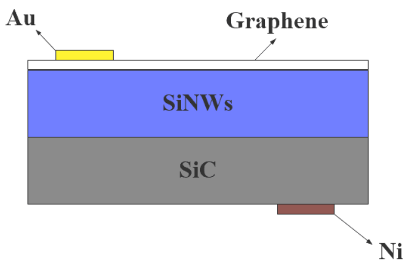

Fig. 1. Schematic cross-section of the SiC/SiNWs/graphene heterostructure

SEM (Oxford Quanta-450), XRD (Rigaku Dmax-Rapid) and Raman spectroscopy (RENISHAW inVia, 514 nm laser) were employed to characterize SiC/SiNWs/graphene heterostructures.

3. Results and discussions

The length and the growth quality of the SiNWs on 4H-SiC are characterized by the planar view SEM, as shown in Fig. 2. The length of SiNWs is severely infected by growth time (Fig. 2a-d). The diameters and lengths of SiNWs with different growth time are summarized in Table 1. When the growth time increases from 1 min to 40 min, the length of the SiNWs increases from 7.67 μm to 82.55 μm, and the diameter increases from 67.45 nm to 153.8 nm. As the growth time increases, the diameter exceeds 0.1 μm. According to the report, the trapping effect is not obvious after the nanowire exceeds 0.1 μm. Fig. 2(f) shows the high magnified image of SiNWs on 4H-SiC. For the single nanowire, the diameter is relatively uniform, no tapering appearance is observed. It indicates that the growth conditions of the SiNWs on 4H-SiC (such as growth temperature, growth pressure, etc.) are relatively suitable.

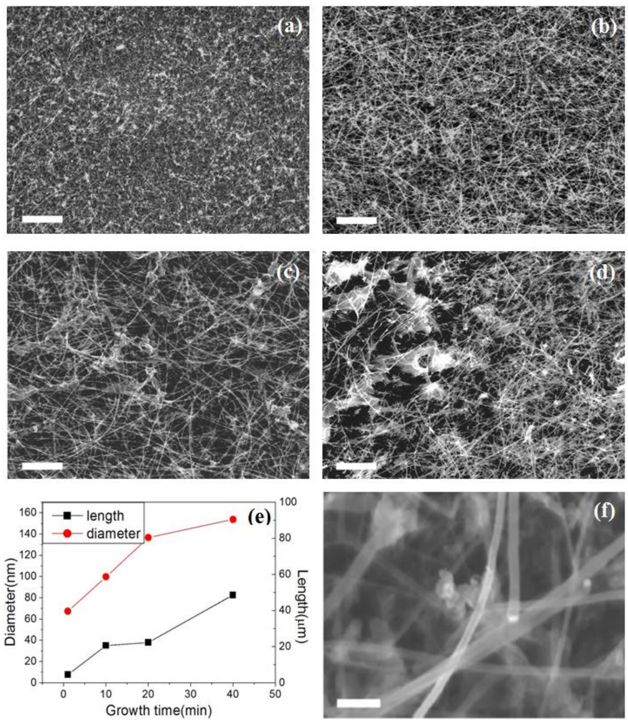

Fig. 2. SEM image of SiC/SiNWs heterostructure with different growth time. (a) 1min, (b) 10min, (c) 20min, (d) 40min. (e) Relationship between length, diameter and growth time of nanowires. (f) High magnification image of the SiNWs. The scale bars in Fig. a-d are 1μm, the scale bars in Fig. f is 250 nm

Table 1. The length and diameter of the SiNWs on 4H-SiC

Time / Size	1min	10min	20min	40min
Length (L_{max})	7.67μm	35.00μm	38.00μm	82.55μm
Diameter (D_{max})	67.45nm	99.75nm	136.7nm	153.8nm

Fig. 3 shows the representative Raman spectra of the SiC/SiNWs heterostructure. There are four typical peaks located at 291.42 cm^{-1}, 518.20 cm^{-1}, 777.24 cm^{-1}, 958.10 cm^{-1}, which belong to 4H-SiC FTA, Si TO, 4H-SiC TO, Si 2TO, respectively. It is well known that the Raman peak of bulk-Si TO mode is located at 520 cm^{-1}, which complies with symmetric Lorentz curve. As the growth time of SiNWs increases, the Si TO mode shifts from 518 cm^{-1} to 496 cm^{-1}, and the full width at half maximum (FWHM) also increases from 1.70 cm^{-1} to 20.01 cm^{-1}, which is due to the small size effect of the SiNWs [9-12]. With the increasing size of the nanowires, The Si TO mode has a red shift and the FWHM is broadened. The limitation of acoustic phonons results in the new vibration modes appearing in the low frequency region of the Raman spectra, and the Raman peak of the optical phonons tend to be significantly asymmetrical [9]. The new vibration modes cause the red shift of the Si TO mode from 518 cm^{-1} to 496 cm^{-1}, as shown in the inset of Fig. 3.

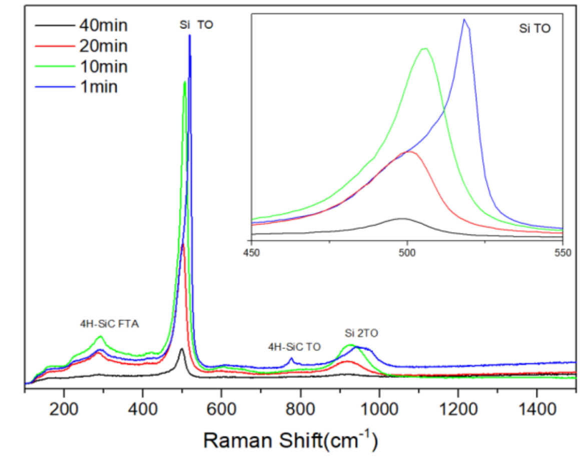

Fig. 3. SiC/SiNWs heterostructure Raman spectrum

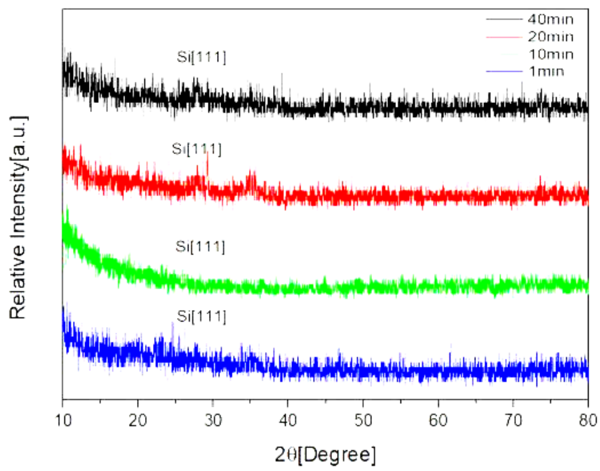

Fig. 4. XRD data of the SiNWs on 4H-SiC with different growth time

The XRD patterns of the SiNWs on 4H-SiC with different growth time were obtained, as shown in Fig. 4. It is shown that the SiNWs with a short growth time have no obvious XRD peak. The Si (111) peak appears when the growth time increases to be 10 min, indicating that the SiNWs with polycrystalline structure is formed, and the preferred orientation is <111>. The Au-Si interface reduces the binding energy in the orientation of Si <111> and makes it easier to form Si nuclei spontaneously. As the growth time increases, the corresponding intensity increases accordingly. In addition, the crystallization quality of SiNWs on 4H-SiC can be improved by high temperature annealing.

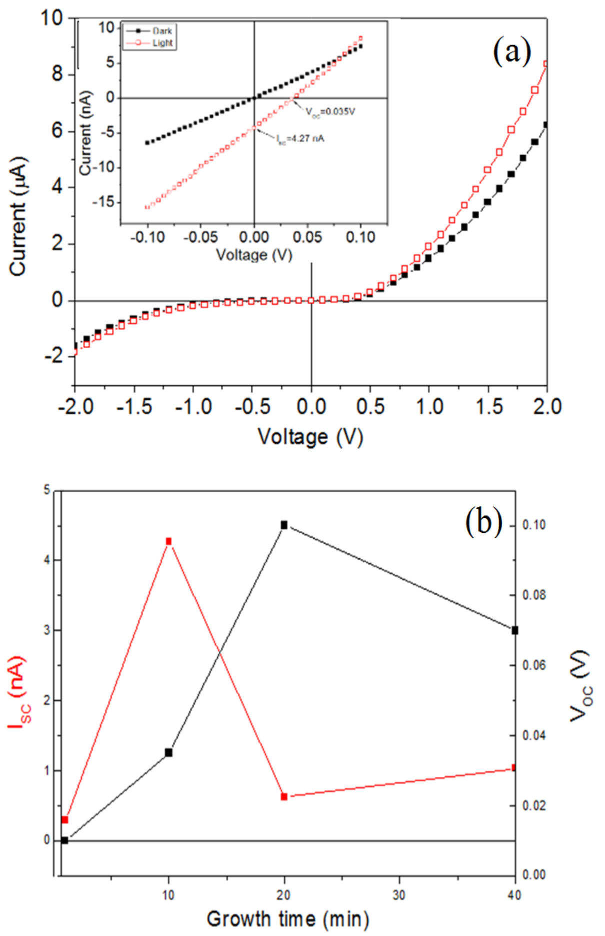

Fig. 5. The electrical and photoelectrical characteristics of the fabricated SiC/SiNWs/graphene heterojunction photodiode (a), I_{SC} and V_{OC} of the SiC/SiNWs/graphene heterojunction photodiode with different growth time (b)

J-V characteristics of the fabricated SiC/SiNWs/graphene heterojunctions with different growth time of the SiNWs are measured at room temperature, as shown in Fig. 5. The black solid and red hollow dotted lines represent the dark and illuminated J-V characteristics, respectively. When the growth time of SiNWs is 10 min, the photodiode indicates obvious rectifying behavior with rectifying ratio up to 10 at ±1V (Fig. 5a). And the turn-on voltage is about 0.36V. The heterojunction exhibits good photoelectric performance, the photocurrent and the open-circuit voltage increase to J_{ph}=4.27nA and V_{OC}=0.035V respectively under VIS-NIR illumination of 0.1W/cm^2. It is found that the J_{ph} has a direct correlation with the growth time of SiNWs. The J_{ph} has a maximum value when the growth time is 10 min. As the growth time increases, the J_{ph} decreases due to the longer carrier transport distance along the axis of SiNWs, the V_{OC} increases correspondingly.

4. Conclusions

In summary, the SiC/SiNWs/graphene heterojunction is prepared on 4H-SiC substrate with different growth time. The SiNWs can be used as the visible and near-infrared absorption layer in SiC/SiNWs/graphene heterostructure to solve the problem that SiC optoelectronic devices cannot be operated by visible and near-infrared lights. Due to the small size effect of the SiNWs, Raman peak of the Si TO mode exhibits red shift and asymmetric broadening at the low frequency with the growth time increase. XRD data show the SiNWs on 4H-SiC have the polycrystalline structure with a preferred growth orientation of <111>. This paper proves the possibility of SiC/SiNWs/graphene heterostructure photodetectors used in VIS-NIR region.

Acknowledgements

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