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Original research article

Preparation of multi-walled carbon nanotubes/n-Si heterojunction photodetector by arc discharge technique

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ABSTRACT

In this paper, heterojunction photodetector based on drop casting of colloidal multi-walled carbon nanotubes prepared by arc discharge technique on single crystalline silicon was demonstrated. The structural and optical of multiwalled carbon nanotubes MWCNTs was investigated by x-ray diffraction XRD, scanning electron microscopy SEM, Fourier transformation infrared spectroscopy FT-IR, and UV–vis spectroscopy. The dark current-voltage I–V characteristics revealed that MWCNTs/Si heterojunction showed a good rectification characteristics and the ideality factor was found to be around 3.1. The photocurrent to dark current ratio was 1.16×10^3 at 8 V bias applied bias and light intensity of 100 mW/cm^2. The photodetector exhibited good linearity characteristics. The photodetector responsivity was estimated as 0.32 A/W at 800 nm at 9 V reverse bias. The open circuit voltage V_{oc} and short circuit current density J_{sc} of the device were measured.The photodetector has rise time of 30 ns in absence of the external field.

1. Introduction

Carbon nanotubes (CNTs) have received great attention as a new branch of nanomaterials due to their superior physical, chemical, and electronic properties such as long free mean path, useful band gap and high carrier mobility [1,2]. CNTs have been used widely in many fields for applications as batteries [3], hydrogen storage [4], gas sensors [5] carbon nanotubes field effect transistor [6], infrared detectors, solar cells [7] and catalytic application [8]. Many methods were adopted to synthesis CNTs such as arc discharge, laser ablation, chemical vapor deposition, and spray pyrolysis [9–12]. Fabrication and characterization of hybrid photovoltaic multiwalled MWCNTs/n-type Si heterojunction was reported by many authors [13,14]. Ashkan et al. [15] fabricated high photocurrent to dark current ratio single- walled CNTs/Si Schottky contact (MSM structure) using vacuum filtration technique. Solution-processed photodetectors devices propose low cost, large device surface area, physical flexibility and convenient materials integration compared to epitaxially grown, lattice-matched and crystalline semiconductor devices [16,17]. Here, we report on preparation and characteristics study of colloidal multi-walled carbon nanotubes/silicon heterojunction photodetector by arc discharge and drop casting techniques.

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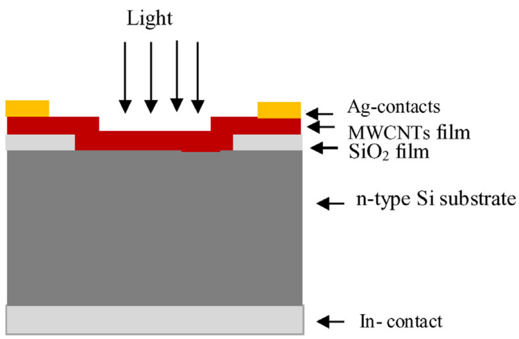

Fig. 1. Cross-sectional view diagram of MWCNTs/ n-Si heterojunction photodetector.

2. Experiment

2.1. Synthesis of MWCNTs

Synthesis of MWCNTS was carried out with aid of homemade arc discharge system. The system consists of DC power supply to generate the arc plasma. Pure graphite movable anode cathode rods were used as electrodes. These electrodes were aligned horizontally in stainless steel chamber (250 mm diameter and 400 mm high). The anode electrode drilled with hole with diameter of 5 mm and 6 cm in depth and this hole was filled with mixture of graphite powder and iron as catalyst. Initially the chamber was pumped to the pressure less than 10^{-1} torr and then filled by argon gas of 99.995% purity. The anode was attached to a linear drive system controlled by computer software, which keeps the predetermined gap distance according to the desired arc voltage after the discharge is initiated via contact ignition. All experiments were done with arc current of about 50 A, discharge voltage of 20 V and the argon pressure of 500 torr inside the chamber. The arc plasma was initiated by contacting two electrodes, and the gaps between the electrodes were carefully controlled to be 1 mm to maintain stable discharge for 5 min. Two types of products were obtained, carbon nanotubes deposit at anode electrode end, and fine particles at deposited on the vessel bottom and internal surface. After that, these products were collected and kept on sample dishes for analysis later.

2.2. Purification of MWCNTs

One gram of MWCNTs produced was heated at 350 °C for 30 min to remove the amorphous carbon. After heat treatment, half gram of MWCNTs was dispersed into a flask containing of 20 ml of 70% sodium hypochlorite solution. The solution was then shaken in an ultrasonic bath for 20 min and was heated at 85 °C in a water bath for 3 h to remove metal catalysts. After cooling, the CNTs were washed with deionised water until the pH of the solution reached approximately 7. Finally, the solution was filtered by centrifugal filtration and dried at 200 °C and purified CNTs were obtained.

2.3. Characterization techniques

The Structural, morphological and optical properties of MWCNTs were investigated by means of (CuKα) XRD-6000, Shimadzu x-ray diffractometer, Fourier transformation infrared spectroscopy FTIR, Inspect S50/FEI company scanning electron microscopy SEM and UIR – 210AShimadzu UV–vis spectrophotometer.

2.4. Preparation of MWCNTs/n-Si heterojunction photodiode

0.8 mg carbon nanotubes, 30 ml ethanol (99.99%) and 0.016 mg of citric acid were mixed carefully in beaker with continuous stirring for 24 h. The (111)-oriented silicon substrates used in this study were n-type and having electrical resistivity of 1–3 Ω cm, thermal oxide layer of 200 nm thick has been grown on silicon with aid of wet rapid thermal oxidation technique using high power halogen lamps at 1000 °C for 45 s. Active area indow of 64 mm^2 area was made by using HF as etchant acid. Drop casting technique was used to deposit MWCNTs layer silicon substrate. After drop casting, the samples were heated at 90 °C under nitrogen to enhance the MWCNTs adhesion on the silicon substrate. To study the characteristics of photodetector, ohmic contacts have been made by deposition of silver and indium electrodes on MWCNTs and silicon substrate, respectively through special mask using thermal resistive technique. Fig. 1 illustrates the schematic diagram of MWCNTs/n-Si heterojunction photodetector structure.

The dark and illuminated I–V characteristics of photodetectors were investigated; the photocurrent was estimated under white light at different intensities. The spectral responsivity of the photodetectors was measured in the range of 350–900 nm by using a monochromator. To calibrate the monochromator, Sanwa silicon power meter was used for this purpose. The rise