СЕКЦИЯ 4

НАНОМАТЕРИАЛЫ: ФОРМИРОВАНИЕ И СВОЙСТВА ПРИ ВОЗДЕЙСТВИИ ИЗЛУЧЕНИЙ

SECTION 4

NANOMATERIALS: FORMATION AND PROPERTIES UNDER THE INFLUENCE OF RADIATION

ELECTROPHYSICAL CHARACTERISTICS OF PHOTODETECTOR BASED ON SINGLE WALLED CARBON NANOTUBES/SILICON HETEROJUNCTION

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Device composed of chemical vapor deposited single-walled carbon nanotubes (SWCNTs) on n-type silicon substrates are fabricated and characterized. Important junction figures of merit, such as the barrier height (φ_B ~0.43eV) and ideality factor (η ~3) are extracted from forward bias current-voltage characteristics using a modified version of Cheung's method. The devices exhibit a responsivity of about 1.17 AW^{-1}, detectivity ≈ $8.21 \cdot 10^{11}$ Jones and an external quantum efficiency higher than 200% for 13.2 mW/cm^2 green light irradiation (λ=532nm). These results provide important insights for the future integration of carbon nanotubes with silicon device technology.

Keywords: single wall carbon nanotubes; irradiation; silicon; junction; photodetector.

Introduction

Carbon nanotubes with their nanometric size and compatibility with Si, represent one of the most promising nanomaterials for Si technology integration. Moreover, due to its high conductivity, zero band gap, flexibility, chemical stability, and other extraordinary properties single-walled carbon nanotubes (SWCNTs) offers a very attractive platform for advanced optoelectronic applications [1].

In this work, the room temperature electrophysical characteristics under irradiation of photodetector (PD) consisting of chemical vapor deposited SWCNTs on n-type silicon substrate are studied.

Materials and methods

The PD substrates were specially designed and fabricated by Fondazione Bruno Kessler (Fig. 1). They consist of a gold bottom ohmic contact, above which there is a crystalline (100) n-doped Si region (with a thickness of 104 μm), with an electrical resistivity ρ_{Si}=0.53 Ω cm, due to $N_D=10^{16}$ cm^{-3} doping atoms. On the top surface, two Pt electrodes are deposited on a 300 nm SiO_2 template layer in such a way as to result electrically isolated by the Si substrate. The top contacts are conceived with a multifinger geometry consisting of 50 μm wide platinum combs.

The thin film (transmittance at 550 nm is ~74%), containing randomly oriented single

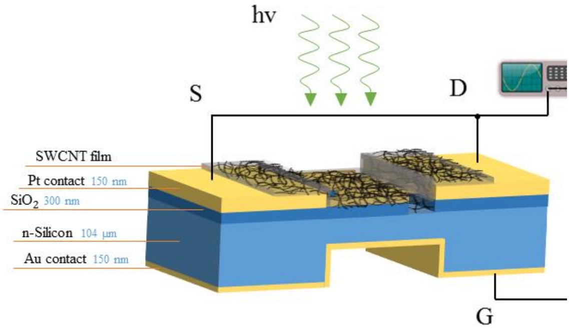

Fig. 1. 3D device schematic in photovoltaic (PV) configuration

wall carbon nanotubes, was grown on PDs substrates from ferrocene/ethanol solution by chemical vapor deposition [2].

Prior to the deposition, an etching with hydrofluoric acid (HF) was performed to remove native oxide on the Si surface.

At the end, we dripped ethanol on the surface of the device to improve adhesion between SWCNTs and silicon.

Raman spectra were obtained at room temperature using a scanning laser confocal micro-Raman spectrometer, Confotec NR 500, by scanning sample areas of 20 × 20 mm^2 with 785 nm, 633nm and 473 nm excitation wavelengths and 100× objective. The accumulation time of the signal for each spectrum was 5 seconds. The laser power was ~1 mW, which allowed us to avoid the effect of sample heating and the corresponding shift in the position and shape of the recorded bands. Lorentz approximation was used to determine the intensity, position, and half-width of the Raman spectra.

All electrical and photoresponse measurements were performed with the sample dark conditions and under light illumination (λ=532nm) using a source-measure unit Keithley 2602A for current-voltage characterization.

Results and discussion

Raman spectra recorded with three excitation wavelengths (Fig. 2) from the studied film have curvature induced G– peaks in G band and radial breathing mode peaks (RBM). The RBM peaks positions correspond to nanotube diameters in the range 0.7-2.5 nm. It should be pointed out that intensity ratio I_D/I_G is quite small, which is the signature of good crystalline quality of the SWCNTs.

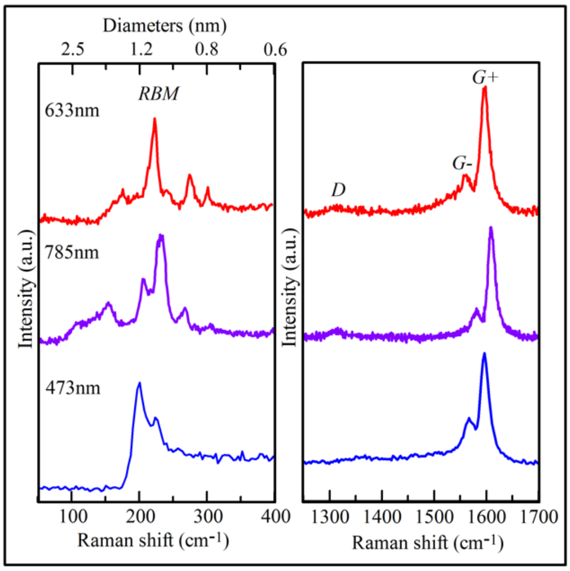

Fig. 2. Raman spectra of the SWCNT grown film on device acquired with 473nm, 633nm and 785 nm excitation wavelengths

Figure 3 shows the room-temperature I–V characteristics of our PD acquired in PV mode in dark conditions (solid line) and under 13.5 mW/cm^2 green light illumination (dashed curve). The forward-biased data were analyzed according to the equation:

$$I = AA^{**}T^2 e^{-\sqrt{\chi}\delta} e^{-\frac{\varphi_B}{kT}} [e^{\frac{q(V-IR_S)}{\eta kT}} - 1]$$

where A is the effective contact area, A** is the reduced effective Richardson constant, T is absolute temperature, φ_B is the barrier height, k is the Boltzmann constant, q is the magnitude of electronic charge, η is the ideality factor, R_s is the series resistance, χ is the mean tunneling barrier height and δ is the interfacial oxide thickness.

The Schottky barrier height (φ_B~0.43eV) and ideality factor (η ~3) extracted from the forward-bias data using a modified version of Cheung's method [3] reveals excellent agreement with the literature data.

The responsivity (R), detectivity (D) and external quantum efficiency (EQE) are important figures of merit to quantify the perfor-

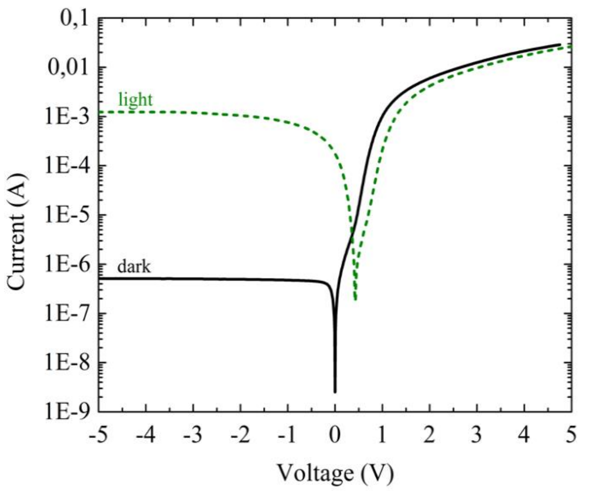

Fig. 3. Device current vs voltage characteristics acquired in Photovoltaic (PV) mode in dark conditions (solid line) and under 13.5 mW/cm^2 green light irradiation (dashed curve)

mances of a PD and to make a comparison among detectors.

The photodetector's ability to generate the photovoltage or photocurrent under irradiation at a certain power density and wavelength is determined by the responsivity and defined as:

$$R_\lambda = \frac{I_{ph} - I_d}{P_{in}}$$

where I_{ph} is photocurrent, I_d is dark current, P_{in} is incident light power density.

Detectivity represents the capability to detect weak light signal, which can be used to compare the performance of different photodetectors with various active materials, geometries, or work mechanism,

$$D = \sqrt{\frac{A}{2qI_d}} R_\lambda$$

The external quantum efficiency, can be experimentally obtained by illuminating the PD with monochromatic light through:

$$EQE = R_\lambda \frac{hc}{q\lambda} \times 100\%$$

where h is the Planck constant, c is the speed of light, λ is the incident light wavelength.

From the experimental data it was obtained that EQE ≈ 272% for the irradiation wavelength of 532nm (P_{in}=13.2 mW/cm^2).

Figure 4 shows the responsivity and detectivity as a function of the optical power of the incident light, P_{in}.

The R, D values are R ≈ 1.17 AW^{-1}, D ≈ 8.21·10^{11} Jones at P_{in} = 13.2 mW/cm^2, which are comparable to values reported for the best SWCNT-based detectors.

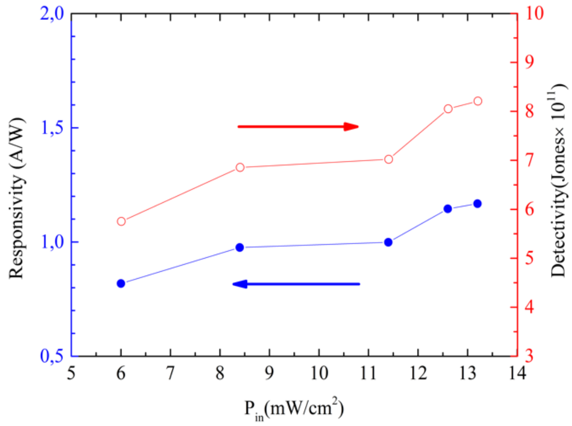

Fig. 4. Responsivity (closed symbols, left axis) and detectivity (open symbols, right axis) as a function of the 532 nm LED light power.

Conclusions

The main figures of merit of the single-walled carbon nanotubes/silicon heterojunction-based photodetectors have been investigated, highlighting the great potential of these devices in optoelectronic applications. The single-walled carbon nanotube film was obtained by devising a very simple, inexpensive, scalable, and fast method that allows to modulate and tune the optical and electrical properties of the device.

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