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ON-OFF CHARACTERISTICS OF PHOTODETECTORS BASED ON SWCNT-Si HETEROJUNCTION

L. A. Dronina[1], N. G. Kovalchuk[1], V. A. Papou[1], A. V. Patapovich[1], S. L. Prischepa[1,2]

[1]Belarusian State University of Informatics and RadioElectronics, Minsk, Belarus, lizadronina@yandex.by
[2]National Research Nuclear University «MEPhI» Russia, Moscow

Carbon based photodetectors based on SWCNT/Si heterojunction demonstrate high photoelectric performance due to their high carrier mobility and excellent optoelectronic properties. However, almost all SWCNT-based heterostructures to date have been fabricated by depositing pre-formed and purified nanotubes onto the prepared main surface of a photodetector (PD) window. A serious drawback of this method is its lack of manufacturability, which is an obstacle to the development of a viable industrial technology for formation of high responsivity SWCNT-based PD components for photonic integrated circuits.

In this work, we have reported a simple and feasible route for a straightforward and scalable synthesis of high-quality, high-transparent SWCNT thin films deposited directly on a PD window. With an optimal SWCNT transparency of 74% (at 550nm), the SWCNT-based photodetector exhibits excellent photoelectric response from the visible region (450 and 642 nm) with a high responsivity (R_λ) of 1.11 A/W and 1.34 A/W and detectivity (D) of 1.9×10^{11} Jones and 2.3×10^{11}Jones at −3V bias at 450 nm and 642 nm respectively. Besides, the external quantum efficiency (EQE) reaches a value of 306% at 450 nm and the response of the devices is comparable to the commercial photodetectors based on Si technology. Finally, the SWCNT

film-based photodetectors fabricated in this work provide stability under laboratory conditions for at least 1 year. These results provide important insights for the future integration of carbon nanotubes with silicon device technology.

A SWCNT/Si heterojunctions were fabricated as follows. First, prior to the deposition, the surface of the Si active area was cleaned by etching in a hydrofluoric acid and, afterward, SWCNT thin films, containing randomly oriented nanotubes, were directly grown on them, employing the FCCVD method based on the catalytic decomposition of liquid hydrocarbon by pyrolyzing solutions of ethanol-ferrocene [1].

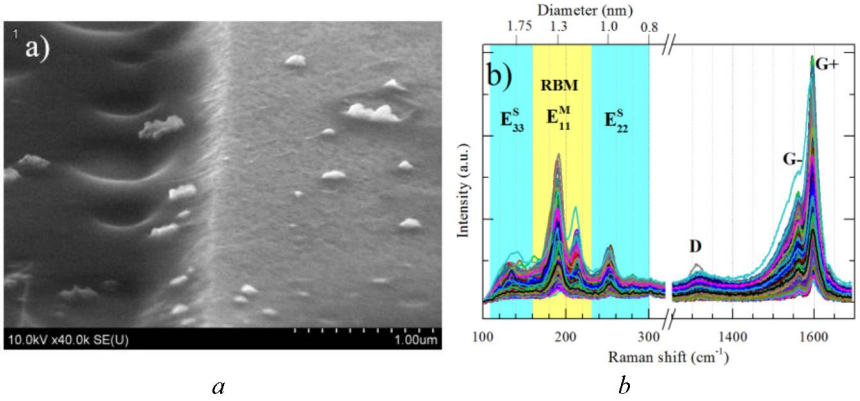
A precursor solution was prepared by dissolving at room temperature proper amount of the ferrocene powder ($Fe(C_5H_5)_2$, 98% purity) in ethanol (C_2H_5OH, 99.8% purity). The ferrocene/ethanol solution was mechanically stirred for 5 minutes and next transferred into a container (syringe) attached to the atomizer. We used a specially designed syringe-based device, driven by an electric motor for controlling the injection rate, which in our case was equal to 0.2 ml/min. After connecting all equipment, Ar (99.99% purity) was fed into the system as gas carrier (it contributed to remove oxygen from the system). Ar flow was constant and equal to 100 sccm during the entire process and was regulated by a gas flow controller. The furnace was heated to the setting 1050 ^{o}C temperature in approx. 30 min time. After the furnace temperature was stable, the atomizer was turned on. The volume of ferrocene/ethanol solution introduced during a given process was 1.5 ml.

Product of the reaction, i.e. SWCNTs were blown out of the reactor hot zone by argon, forming a SWCNT film directly on the Si substrates placed in the cold part of the reactor tube. The deposition temperature is one of the key parameters. In particular, the growth rate of the film, the resulting density of nanotubes and their structure depend on it. As a result of numerous tests, we found that SWCNT/Si heterojunctions, optimal for our purposes,

were obtained in the reactor zone, where the temperature did not exceed 200 °C.

After the deposition we sprayed the surface of the SWCNT film with ethanol to improve the adhesion between the film and substrate, at the same time we wiped the edges of the device to avoid unwanted contacts between metal electrodes and the substrate.

The SEM image (Fig. 1, *a*) shows that the film is composed of SWCNTs bundles with smooth surfaces and each SWCNT is interconnected randomly. The single-walled nature of the nanotubes was proven by Raman spectroscopy (Fig. 1, *b*), and the average diameter of observed both semiconducting and metallic SWCNTs was estimated to be ≈ 1.06 nm.



a *b*

Fig. 1. Zoomed-in view SEM image of the electrode (finger) including SWCNT film on Si/ SiO_2 interface (*a*). Raman spectra of SWCNTs on PD substrate detected by 33 nm. Designations S or M are used to denote the electronic transition energies E_{ii}^M for metallic (shaded yellow) and E_{ii}^S for semiconducting (shaded blue) SWCNTs, respectively (*b*)

To further characterize the optoelectronic performance of the SWCNT/Si heterojunction photodetectors, I-V curves were measured both in the dark and under illumination as shown in

Fig. 2. Based on this result, a number of basic metrics of the photodetector were determined [2].

The SWCNT-based photodetector demonstrates good responsivity (R_λ) values of 1.11 and 1.34 *A/W*, competitive detectivity values of 1.9×10^{11} and 2.3×10^{11} Jones, and excellent *EQE* values of 306% and 259% at $V = -3$ V for 450 and 642 nm respectively.

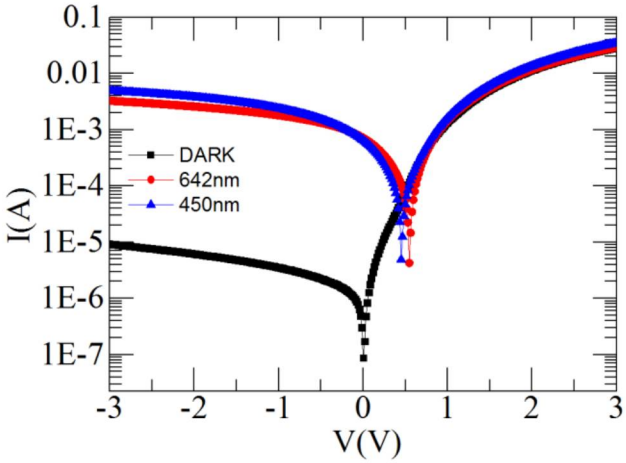
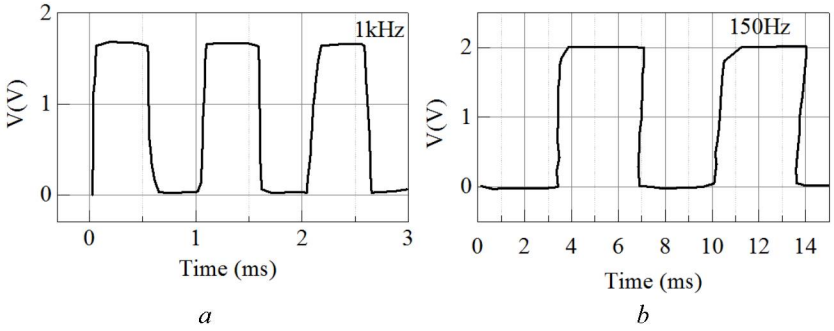


Fig. 2. Current-voltage curves dark and under 642 and 450 nm illumination

The fast response time of charge carriers which is defined as time immediately after absorption to change the photoinduced signal is crucial for most commercial photodetectors. By connecting the SWCNT-based photodetector to an external resistor we measured the dynamic voltage of the resistor with an oscilloscope under 642 nm light illumination with an incident power of 0.32 W/cm^2. The time response characteristics of our photodetector are shown in Fig. 3. It is clear that the sharp switching curve of voltage can be observed when the light is turned on or off. It is also worth noting that the rise time and fall

time were extracted from the dynamic voltage signal waveform and both these values do not exceed 40μs.



a *b*

Fig. 3. Time-dependent measurement under 642 nm illumination with a frequency of 150 Hz and 1 kHz

References

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