Time response study of SWCNT/Si based photodetectors

L. A. Dronina[a], N. G. Kovalchuk[a], A. L. Danilyuk[a], A. V. Danilchyk[b], E. V. Lutsenko[b], S. L. Prishepa[a]

[a] *Belarusian State University of Informatics and Radioelectronics, 220013 Minsk, Belarus*
[b] *Stepanov Institute of Physics of NAS Belarus, 220072 Minsk, Belarus*
E-mail: lizadronina@yandex.by

Introduction. The extraordinary properties of single-walled carbon nanotubes (SWCNTs), such as mechanical strength and flexibility, air stability, heat and electrical conductivity, optical transparency and compatibility with silicon and other conventional materials, have attracted a lot of research producing countless theoretical and experimental investigations and a large number of potential applications. In particular, these properties make SWCNTs the perfect candidate to realize a new generation of transistors, diodes, chemical-biological sensors, photodetectors, solar cells and integrated circuits.

Moreover, thanks to its fascinating features SWCNTs coupled with their compatibility with low-temperature processes is nowadays emerging as a perspective material for future integrated optoelectronics [1]. For example, versatile-functionality optoelectronic integrated circuits fabricated using SWCNTs via a CMOS-compatible low-temperature doping-free technique, allows for higher communication speeds between layers compared to traditional optical fiber communications [2].

A key component of optoelectronic integrated circuits that performs photoelectric conversion, the photodetector, is located at the end of the chain that converts the light signal into in electrical one, and the characteristics of the entire chip ultimately rely on its performance under extreme conditions. Importantly, reliable photodetector performance at fast signals detection is expected to help maintain high operational parameters for the photonic integrated circuit. One of the most effective nanostructures for these applications is considered to be the Schottky barrier, formed between a metal and a semiconductor. For these reasons, heterojunctions between SWCNT films and silicon have attracted significant attention over the past decade. Such devices combine the high visible light absorption of silicon, its widespread availability and low cost with the advantage of the high optical transparency and high electronic charge mobility of SWCNT for fast response time.

Following this insight, in this work, we continue the research cycle started in works [3,4], now focusing on the potential of the SWCNT/Si based photodetectors for fast signals detection.

1 Experimental. To form the Schottky barrier, 30 nm thick SWCNT films were deposited directly onto a pre-cleaned phosphorus-doped (N_D = 10^{16} cm^3) Si (n-type) using floating catalyst chemical vapor deposition [3]. The effective area of the photodetector window was S_{eff} = 0.061 cm^2 [4]. The single-walled nature of the nanotubes and the prevalence of their metallic conductivity were confirmed by Raman and IR spectroscopies. More details about the sample's fabrication and characterization can be found elsewhere [3, 4].

To investigate the potential of our devices in fast signals detection, a diode-pumped regenerative amplifier for femtosecond laser pulses based on a Yb:KGW crystal was used.

2 Results and discussion. Time response characteristics of SWCNT/n-Si photodetector have been estimated by using the room temperature measurments under 520 nm (Fig.1a, 2a) and 260 nm (Fig.1b, 2b) femtosecond laser illumination with different power (P_{in}) ranging from 2mW to 15mW. The time response (τ_r), defined as the time difference between the 90% and 10% of the full-scale signal, is shown in the inset for different wavelengths at P_{in} ~ 2mW. From these figures emerges the ability of the device to detect a fast multicolour signal, responding with times not exceeding 50ns. Interestingly, experimental data revealed that time response follows an increasing trend with light pulse energy.

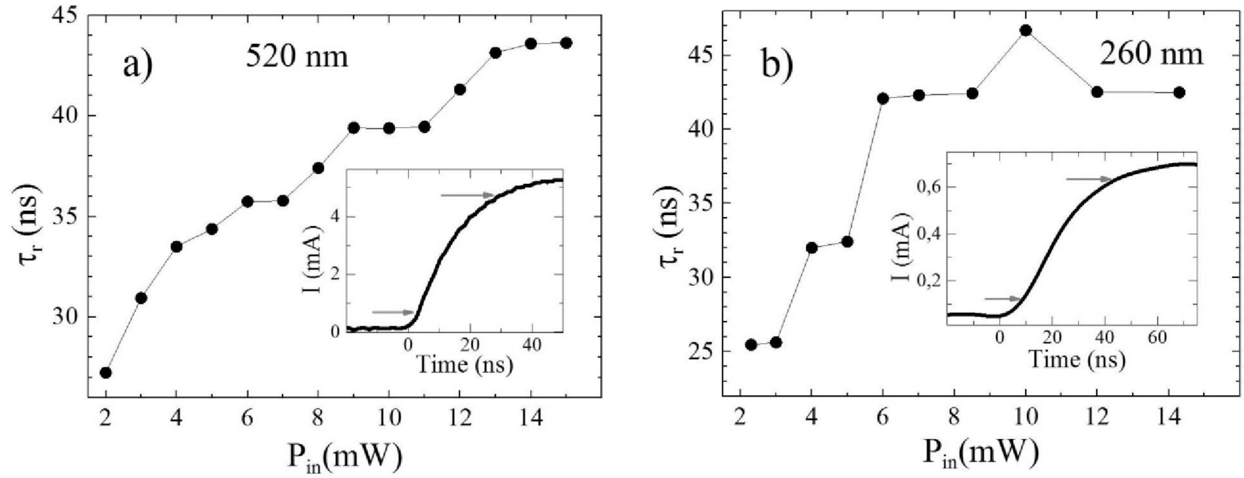

Fig. 1. Response time of the SWCNT based photodetector to a 200-fs pulsed laser as a function of different power measured at 520 nm (a) and 260 nm (b).
Insets: Typical response time (τ_r) to a single 200 fs laser pulse for P_{in} ~ 2mW and wavelengths of 520 nm (a) and 260 nm (b). The arrows indicate the 10% and the 90% of the pulse height used as a criterion for the rise time estimation

Conclusion. It was shown that the SWCNT based photodetectors are able to detect a light signal under 520 nm and 260 nm femtosecond laser illumination, with rise times of a few tens of nanoseconds, indicating the potential of the SWCNT/n-Si heterojunction in high-speed devices. In summary, our research is necessary for a deeper understanding of the fundamental operating principles of SWCNT/Si based photodetectors.

Acknowledgments. The authors acknowledge partial financial support from the Belarusian Republic Foundation for Fundamental Research, Grant F25ME-016.

References.

1. A review on monolithic 3D integration: From bulk semiconductors to low-dimensional materials/ Z. Hu [et al.] //Nano Res. – 2025. – Vol. 18, №. 3. – P. 94907225.
2. Carbon nanotube-based three-dimensional monolithic optoelectronic integrated system/ Y. Liu [et al.] //Nature Communications. – 2017. – Vol. 8, №. 1. – P. 15649.
3. Properties of single-walled carbon nanotube film/Si heterojunctions fabricated in situ/ L. A. Dronina [et al.] //Applied Nanoscience. – 2025. – Vol. 15, №. 1. – P. 2.
4. Temperature-dependent parameters of spatially inhomogeneous heterojunctions single-walled carbon nanotubes/Si/ L. A. Dronina [et al.]//Journal of Physics D: Applied Physics. – 2025. – Vol. 58, №. 19. – P. 195301.