DOI 10.5162/EUROSENSORS2025/TP34

Ultra-Stable Few-Layer Black Phosphorus UV Detector Encapsulated in Nitrocellulose

Michał Suplewski [1], Małgorzata Szczerska [1], Paweł Jakóbczyk [1]*
[1] Department of Metrology and Optoelectronics, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology, Gabriela Narutowicza 11/12, 80-233 Gdansk, Poland,
* corresponding author, pawel.jakobczyk@pg.edu.pl (Paweł Jakóbczyk), Phone: +48 58 347 19 76

Summary:
We present a novel UV photodetector based on few-layer black phosphorus (FLBP) encapsulated in nitrocellulose, which enhances material stability while preserving intrinsic electronic properties. The detector operates in the solar-blind UV region (205-285 nm), exhibiting a clear resonance shift in response to UV light. With no need for external optical filters, this flexible device can be integrated into wearable and portable sensor platforms. The nitrocellulose coating significantly mitigates environmental degradation, marking a step forward in phosphorene-based optoelectronics.

Keywords: black phosphorus, UV photodetector, nitrocellulose, solar-blind, environmental stability

Introduction

Phosphorene, a two-dimensional allotrope of black phosphorus, possesses exceptional optoelectronic properties, including a tunable bandgap and high carrier mobility, making it a promising material for photodetection applications. However, its practical implementation has been severely limited by its rapid degradation under ambient conditions [1–3].

We present a novel UV photodetector composed of a few layers of black phosphorus encapsulated in nitrocellulose, a protective matrix that enhances stability while preserving the intrinsic electronic properties of the material. Our device exhibits a distinctive resonance shift in response to UV light (205-285 nm), driven by the interplay between the anisotropic band structure of the phosphor and the strain-modulated encapsulation environment. Notably, this detector operates in the solar blind region without the need for additional optical filters, and its flexible structure enables seamless integration into wearable and portable sensor platforms. The nitrocellulose coating significantly mitigates environmental degradation, exceeding previous stability benchmarks for black phosphorus-based devices.

Our research represents a significant step towards the commercialisation of phosphorene-based optoelectronics, paving the way for highly stable UV photodetectors with applications in environmental monitoring, biomedical diagnostics and industrial safety.

FLBP/nitrocellulose photodetector fabrication

FLBP was synthesized via liquid-phase exfoliation of commercially available black phosphorus crystals (Smart Elements). In this process, 38 mg of pre-ground BP crystals were dispersed in 8 mL of argon-purged 95% ethanol (Sigma-Aldrich), resulting in a concentration of 4.75 mg/mL. The mixture was then subjected to controlled ultrasonication using a Bandelin Sonopuls HD2200 probe system operating at a frequency of 20 kHz and a power setting of 40 W, with a pulsed 0.5-second ON/OFF cycle. To minimize degradation, the reaction vessel was kept at a temperature of 0–3°C using an ice bath, while continuous argon gas purging (Air Liquide) was maintained throughout the 4-hour exfoliation process. The fabrication procedure for FLBP suspension followed established protocols from the literature [4]. The FLBP/nitrocellulose photodetector was fabricated by first creating a thin FLBP layer through drop-casting 5 µL of FLBP suspension onto interdigital electrodes, repeating the process five times to ensure adequate coverage. All steps of the FLBP film fabrication were carried out in a glove box under an argon atmosphere to prevent degradation. After each deposition, the sample was left to dry at room temperature for 30 minutes inside the glove box. Once the final FLBP layer was completed, a protective nitrocellulose coating was applied by drop-casting from an ethanol solution. The resulting FLBP/nitrocellulose (FLBP/NC) composite film was first dried under argon at room temperature for 24 hours, followed by an additional drying step under reduced pressure for 2 hours.

Mesurement system

We connected to the sample via two gold probe needles using a FormFactor Cascade MPS150 probe station. Resistance measurements were performed using a KEITHLEY 2450 SourceMeter. To ensure measurement stability and minimize electromagnetic interference, all tests were conducted inside a grounded Faraday cage (FormFactor Cascade ShieldEnclosure), mounted on a vibration-isolated FormFactor Cascade table. A distinct change in resistance is observed upon activation of the 1.2 mW LED source, confirming the functionality of the detector in the deep-UV region.

Results

The performance of the developed UV photodetector based on few-layer black phosphorus (FLBP) encapsulated in nitrocellulose was verified through resistance measurements under deep-UV illumination. As shown in Fig. 1, the device demonstrates a clear change in resistance upon exposure to a 265 nm LED source at 1.2 mW power for 1620 s.

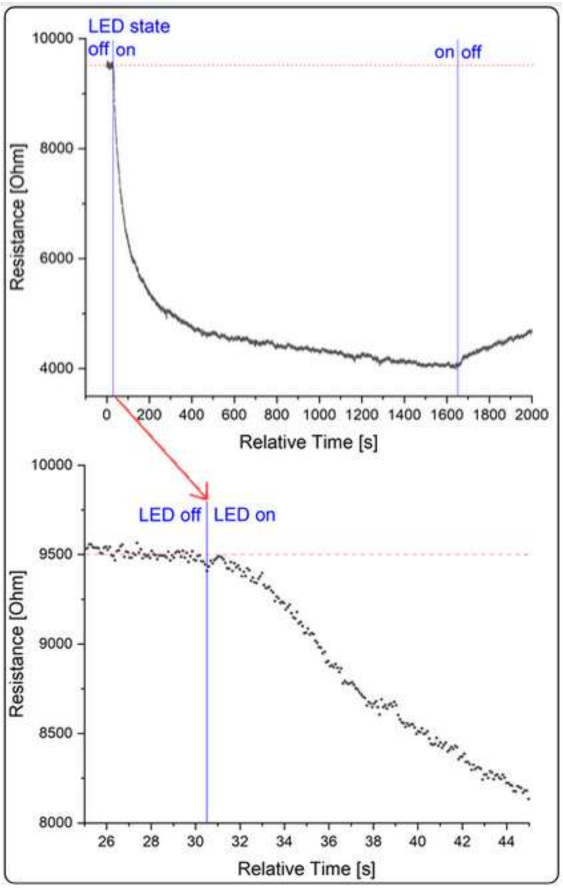

Fig. 1. Time-dependent resistance of the FLBP sample measured with and without illumination with a 265 nm LED diode. Changes in resistance are observed after switching on the 1.2 [mW] LED.

On a flat FLBP/NC surface kept in the dark at room temperature, the average surface resistance is approximately 9 kΩ. When the 265 nm LED source is switched on, the FLBP/NC material absorbs the incoming photons, causing electrons to be excited from the valence band to the conduction band, thereby generating electron-hole pairs. This process increases the number of charge carriers, resulting in a decrease in the material's resistance. As a result, the average surface resistance rapidly drops to 4.1 kΩ. When the light is switched off, the electron-hole pairs recombine, and the average surface resistance begins to increase again (Fig. 1).

This measurable and reversible change in resistance confirms the detector's sensitivity to UV light and demonstrates its solar-blind UV performance without the need for external filtering. Moreover, the observed reversibility indicates that the nitrocellulose encapsulation effectively preserves the functional properties of FLBP during prolonged exposure to ambient conditions.

References

[1] D. Roy, P. Pal, T. Pal, and R.-A. Doong, "Advancement in phosphorene: Synthesis, properties, and applications," Applied Materials Today 35, 101944 (2023).

[2] W. Li, Z. Wang, F. Zhao, M. Li, X. Gao, Y. Zhao, J. Wang, J. Zhou, Y. Hu, Q. Xiao, X. Cui, M. J. Eslamibidgoli, Michael. H. Eikerling, R. Li, F. Brandys, R. Divigalpitiya, T.-K. Sham, and X. Sun, "Phosphorene Degradation: Visualization and Quantification of Nanoscale Phase Evolution by Scanning Transmission X-ray Microscopy," Chem. Mater. 32, 1272–1280 (2020).

[3] L. Peng, N. Abbasi, Y. Xiao, and Z. Xie, "Black Phosphorus: Degradation Mechanism, Passivation Method, and Application for In Situ Tissue Regeneration," Adv Materials Inter. 7, 2001538 (2020).

[4] M. Szczerska, M. Kosowska, J. Gierowski, M. Cieślik, M. Sawczak, P. Jakóbczyk, „Investigation of the Few-Layer Black Phosphorus Degradation by the Photonic Measurements", Adv. Materials Inter. 10, 2202289 (2023)

Acknowledgements

This study was supported as a project funded by the Ministry of Science and Higher Education of the Republic of Poland under agreement no. MNiSW/2024/DPI/433.