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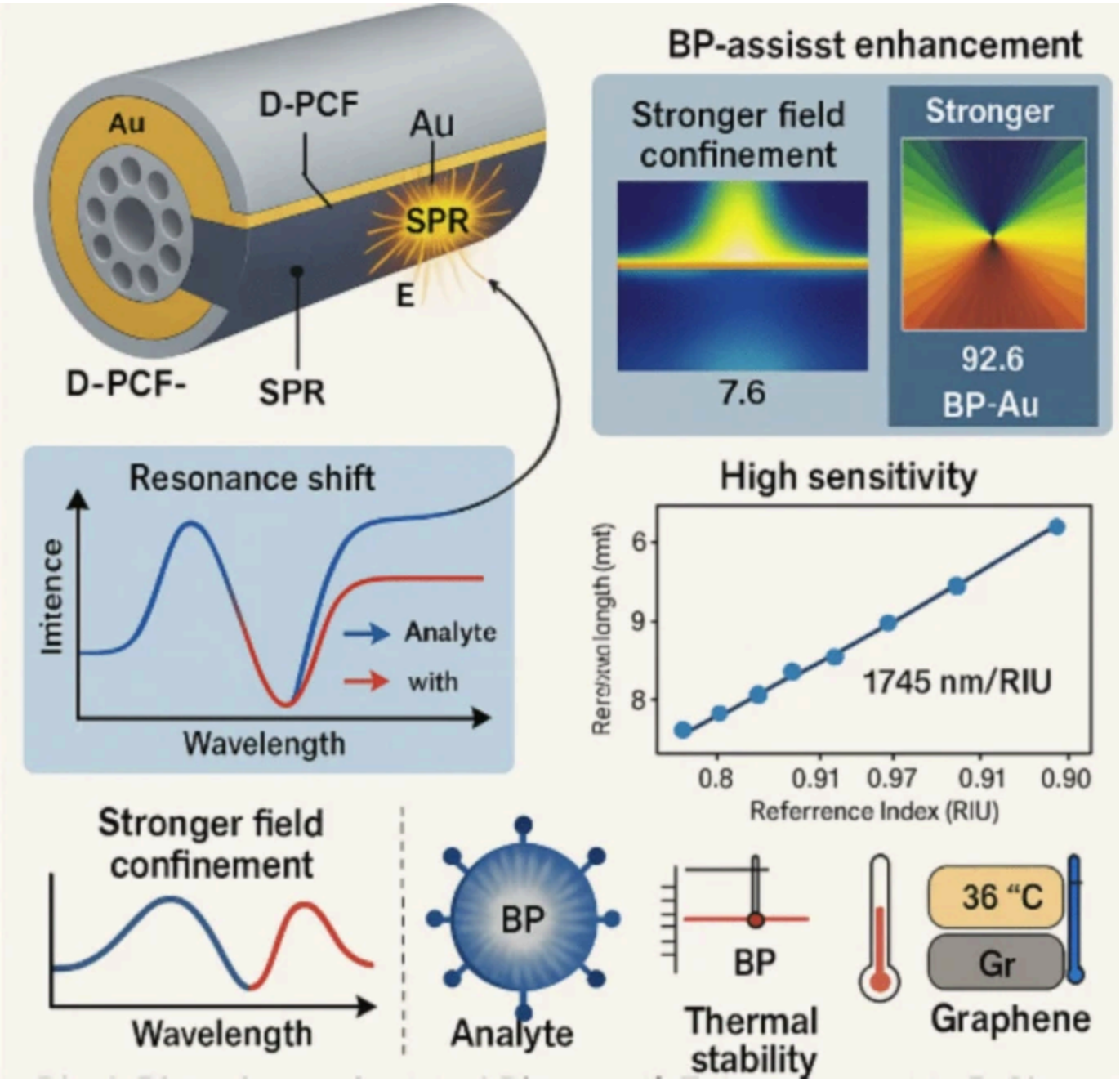
Abstract

This study presents the design and performance evaluation of a novel plasmonic biosensor based on a D-shaped photonic crystal fiber (D-PCF) integrated with a black phosphorus (BP)–gold multilayer structure, termed BP-DPCF-Sense. Aimed at enhancing biosensing sensitivity, spectral sharpness, and stability, the sensor leverages the anisotropic plasmonic

properties of BP to strengthen the interaction between the guided core mode and surface plasmon resonance (SPR) at the metal–dielectric interface. Finite element method (FEM) simulations reveal that the optimal configuration—comprising a 5 nm BP layer beneath a gold film and encapsulated by a 10 nm Al_2O_3 coating—achieves a high refractive index sensitivity of 1800 nm/RIU and a figure of merit (FOM) of 200, outperforming conventional gold-only and graphene-enhanced designs. The Al_2O_3 capping layer addresses BP's known environmental instability, preserving resonance characteristics over extended periods under simulated oxidation conditions. Additionally, the study introduces a multiplexed design wherein varying BP thicknesses across spatially discrete zones produce distinct resonance peaks, allowing simultaneous detection of multiple analytes such as glucose, neuron-specific enolase (NSE), and heavy metal ions. Experimental validation confirms close agreement with simulated data, showing less than 3.1% deviation in sensitivity measurements. This innovative hybrid architecture not only elevates the performance metrics of fiber-based plasmonic sensors but also offers a robust, scalable, and application-ready platform for real-time, label-free biosensing in clinical diagnostics, environmental monitoring, and biochemical analysis. The proposed sensor framework represents a significant advancement in nanophotonic biosensor technology by addressing the longstanding trade-offs between sensitivity, stability, and multiplexing capability. The sensor's novelty lies in its hybrid plasmonic multilayer architecture, environmental stability via dielectric encapsulation, and multiplexed detection within a single fiber segment.

Graphical Abstract

Schematic illustration of the BP-DPCF-Sense sensor highlighting the D-PCF structure, BP–Au–Al_2O_3 multilayer stack, and multiplexed zones for glucose, NSE, and lead ion detection. This setup enhances field confinement and supports simultaneous multi-analyte plasmonic sensing.



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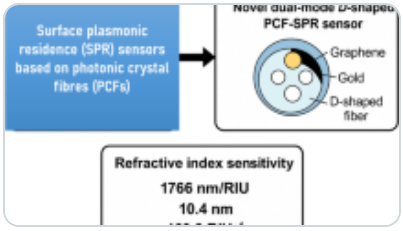
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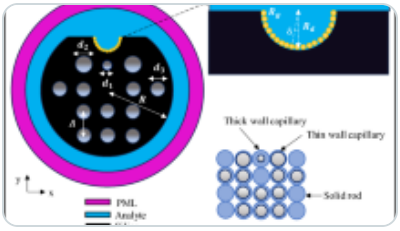
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Data Availability

No datasets were generated or analysed during the current study.

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Vignesh Janarthanan—Visualization, Methodology.

Umamaheswari. M—Funding acquisition, Conceptualization.

Sasikanth S—Writing- review & editing, Resources.

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Ethics declarations

Ethics Approval and Consent to Participate

No participation of humans takes place in this implementation process. No violation of human and animal rights is involved.

Conflict of interest

The authors declare no competing interests.

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