Biosensing Characteristics of Polyaniline-Coated Nitrogen-doped Titanium Dioxide Nanostructures

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Abstract
In this work, polyaniline-coated nitrogen doped titanium dioxide nanostructures were used for the fabrication of biosensing device. The performance of the fabricated device was assessed by the most common and important parameters; selectivity, sensitivity, response time and stability.

Keywords: Titanium dioxide; Polyaniline; Biosensors; Operation assessment
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1. Introduction

Biosensing refers to the use of biological elements to detect and measure the presence of specific chemicals, pathogens, or environmental changes, often in real-time [1]. These sensors typically consist of a biological recognition element (e.g., enzymes, antibodies, or nucleic acids) coupled with a transducer that converts the biological interaction into a measurable signal [2,3]. Biosensors have wide applications in medical diagnostics, environmental monitoring, and food safety. For instance, glucose sensors for diabetes management and pathogen detection in water quality are common examples [4]. Advances in nanotechnology and microelectronics have led to more sensitive, portable, and cost-effective biosensing technologies, driving innovation in personalized healthcare [5,6].

The most common materials used for biosensing devices include metals, semiconductors, polymers, and carbon-based materials [7]. Gold and platinum are widely used due to their biocompatibility and ability to facilitate efficient electron transfer, especially in electrochemical biosensors [8,9]. Silicon is often employed for its integration potential in microelectronics and high surface area [10,11]. Graphene and carbon nanotubes offer exceptional electrical conductivity, surface area, and biocompatibility, making them ideal for enhancing sensitivity in biosensors [12,13]. Polymers like polyaniline and polyimide are used for flexible and cost-effective biosensors [14]. Nanomaterials such as nanoparticles and nanowires further improve detection sensitivity and enable miniaturization of devices [15,16].

Nitrogen-doped titanium dioxide (TiO_2) nanostructures are used in photocatalysis for environmental cleanup, such as degradation of organic pollutants and water purification [17-20]. They also enhance solar energy conversion in dye-sensitized solar cells and improve the efficiency of hydrogen production via water splitting [21,22]. Additionally, they are employed in self-cleaning surfaces and antimicrobial coatings [23,24].

In this work, polyaniline-coated nitrogen doped titanium dioxide nanostructures were used for the fabrication of biosensing device. The performance of the fabricated device was assessed by the most common and important parameters; selectivity, sensitivity, response time and stability.

2. Experimental Part

The fabrication of nitrogen-doped titanium dioxide (N-TiO_2) nanostructures using the pulsed-laser deposition (PLD) method involves a process where a high-power laser is used to vaporize a titanium target in the presence of nitrogen or nitrogen-containing gases [25]. In this technique, a pulsed laser is directed at a titanium target in a vacuum chamber, causing the material to ablate and form a plasma plume. As the plume cools, it condenses on a substrate, forming a thin film. By introducing nitrogen during deposition, nitrogen atoms are incorporated into the TiO_2 lattice, creating N-TiO_2 nanostructures.

PLD offers precise control over film thickness, stoichiometry, and doping concentration, making it ideal for fabricating high-quality N-TiO_2 nanostructures [26]. The resulting films possess enhanced photocatalytic properties, improved electronic characteristics, and increased surface area, thanks to the controlled nanostructuring. The doping of nitrogen into TiO_2 modifies its electronic structure, allowing it to absorb visible light more effectively and improving its photocatalytic activity under light exposure [27].

For biosensing devices, N-TiO_2 nanostructures can be employed as active sensing elements due to their high surface area and catalytic properties. In biosensors, these nanostructures can be functionalized with biomolecules such as enzymes, antibodies, or DNA sequences. The high surface reactivity of N-TiO_2 enhances the binding of biomolecules and improves the sensitivity of the device. When the target analyte interacts with the biosensor, changes in the electronic or optical properties of the N-TiO_2 can be detected, making it useful for detecting a wide range of biological and chemical substances in environmental and medical applications (Fig. 1).

A basic biosensor includes a bioreceptor layer, which is typically functionalized with a biological recognition element like an enzyme, antibody, or DNA strand, which specifically binds to the target analyte. It also includes a transducer that converts the biological recognition event into a measurable signal. This could be an electrochemical sensor (detecting current/voltage change), optical sensor (detecting light changes), or a piezoelectric sensor (measuring mass change). A signal processing unit is another important component of a basic biosensor to module processes the raw data from the transducer, amplifies the signal, and converts it into a readable format, typically shown on a display. The final output, such as a graphical readout or digital data, is displayed for the user to interpret the results.

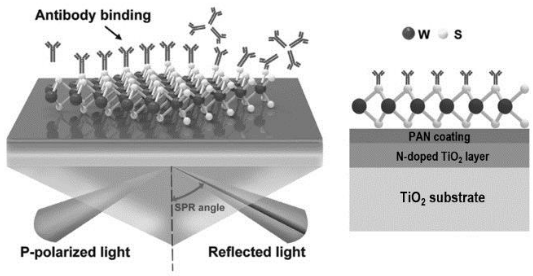

Fig. (1) Schematic diagram of PAN-coated nanostructured N-doped TiO_2 device for surface plasmon resonance biosensor

3. Results and Discussion

Characterizing and assessing a biosensing device involves evaluating several key performance metrics to ensure its functionality, sensitivity, and reliability. The primary methods used for this are sensitivity that refers to the device's ability to detect low concentrations of the target analyte.

The selectivity of a biosensor is its ability to distinguish the target analyte from other substances present in the sample. This is assessed by testing the biosensor with various interfering compounds and comparing the response to the target analyte (Fig. 2).

The sensitivity of the biosensing device can be assessed by measuring the minimum detectable signal, typically defined as the limit of detection (LOD). The LOD is determined by testing the device with a known low concentration of the target and observing the signal response (Fig. 3).

Response time of the biosensing device measures how quickly the biosensor detects the target analyte and reaches a stable signal. A fast response time is critical for real-time applications, such as medical diagnostics. This can be evaluated by introducing the analyte and recording the time taken for the sensor to show a significant change in its output (Fig. 4).

Stability refers to the biosensor's ability to maintain consistent performance over time (Fig. 5). Reproducibility is the ability to provide similar results across multiple tests or devices. Both of these are assessed through repeated testing under similar conditions, over an extended period.

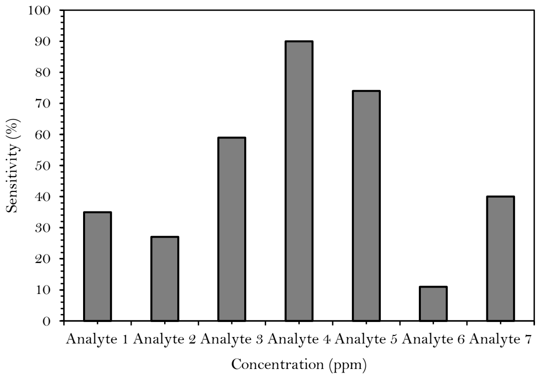

Fig. (2) Sensitivity of the fabricated biosensing device for different analytes tested in this work

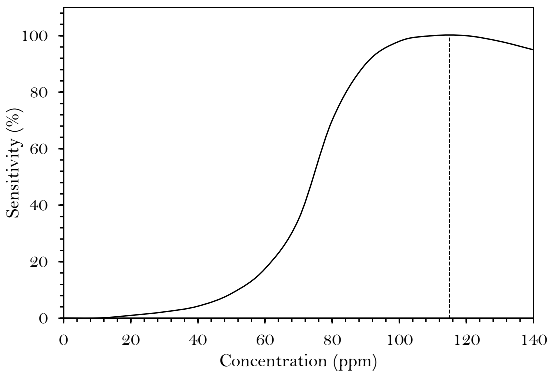

Fig. (3) Sensitivity of the fabricated biosensing device as a function of concentration

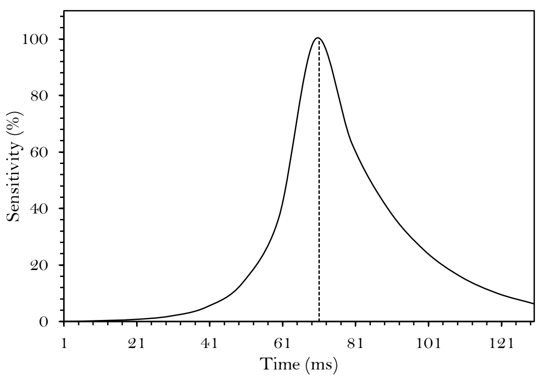

Fig. (4) Sensitivity of the fabricated biosensing device as a function of exposure time

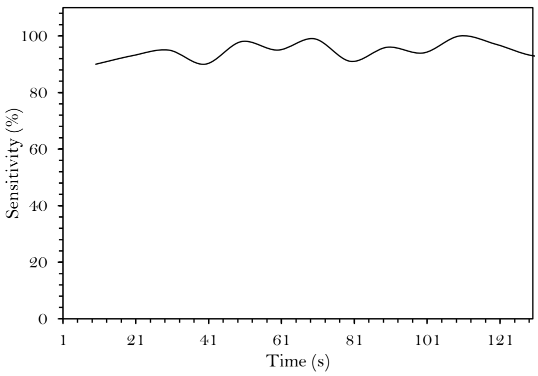

Fig. (5) Sensitivity of the fabricated biosensing device as a function of operation time at constant concentration

4. Conclusions

In concluding remarks, the PAN-coated N-doped TiO_2 nanostructures can be successfully employed as a biosensing device with good performance parameters. These nanostructures can be produced with high structural purity to the level ensuring that a good control can be achieved in sensing parameters, mainly, selectivity, sensitivity, rise time, and stability.

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