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SEMICONDUCTORS FOR BIOSENSING APPLICATIONS

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ABSTRACT

Semiconductors are important materials in the current technology where they are implemented to electronic devices as attenuators but they can play also a role as sensors. In the current review, semiconductors are presented as a platform for the construction of biosensors and biosensor like devices serving as detectors in the analytical chemistry. Biosensors using ion sensitive field effect transistors, light addressable potentiometric sensors and analytical devices based on quantum dots are presented here. **Survey** of the current literature is provided and discussion about each analytical method is given here. Future trends in the biosensors based on semiconductors are also outlined.

Introduction

Over the past few decades, biosensors have transitioned from laboratory curiosities to indispensable tools in diagnostics, food quality control, and environmental monitoring. At the heart of this shift lies the integration of semiconductor materials, which enable these sensors to be more compact, responsive, and suitable for real-time applications.

Traditionally, biosensors relied on biochemical reactions that produced signals difficult to process electronically. Semiconductors have bridged that gap. Their ability to convert biological events—such as the binding of an antibody to an antigen—into electrical signals makes them highly useful. The simplicity of their integration into circuits also opens the door to portable and even wearable diagnostic tools.

This paper explores the role that semiconductors play in biosensing, focusing on both the materials and the mechanisms involved. It also reflects on the current state of research and where this exciting technology might be headed in the coming years.

Literature Review

Researchers have long studied how semiconductor properties can be tuned to respond to biological molecules.

For instance, in 2006, Patolsky and colleagues showcased silicon nanowires that could detect DNA strands with extreme precision, even at femtomolar concentrations. Around the same time, graphene—a single-atom-thick layer of carbon—was recognized by Novoselov et al. (2004) for its outstanding conductivity and flexibility. This material has since shown promise in sensing glucose, proteins, and even cancer biomarkers.

Quantum dots have also gained traction in biosensing. These nanoscale semiconductor crystals emit light at specific wavelengths when stimulated, and Saha et al. (2012) reviewed their growing use as fluorescent tags in biological assays.

Recent literature points to growing interest in combining semiconductor nanostructures with microfluidics and digital signal processing to create complete lab-on-chip systems. However, major concerns remain, including sensor selectivity, long-term stability, and the risk of biofouling (where sensor surfaces get clogged by unwanted biological material).

Methodology

This paper uses a qualitative, review-based approach rather than laboratory experimentation. Sources include peer-reviewed scientific journals, technology reports, and academic databases such as ScienceDirect and IEEE Xplore.

Key areas of focus during this study were:

- The types of semiconductor materials being used (e.g., silicon, zinc oxide, graphene, gallium nitride).
- The sensor configurations—especially field-effect transistor (FET)-based biosensors and optical sensors.
- Practical applications across medicine, agriculture, and environmental science.
- Technological challenges and reported performance data (sensitivity, detection limit, response time).

This methodology enables a comprehensive understanding of current trends and gaps in the use of semiconductors for biosensing.

Discussion

4.1 Semiconductor-Based Biosensor Designs

Several approaches exist for converting biological interactions into measurable signals using semiconductors:

- FET-based sensors detect changes in conductivity as charged molecules interact with the sensor's surface.
- Optical sensors, especially those using quantum dots or photonic semiconductors, detect light changes in response to molecular binding.
- Electrochemical sensors involve current or potential shifts as a result of redox reactions at the sensor interface.

4.2 Popular Materials

- Silicon nanowires are prized for their high surface area, making them particularly sensitive.
- Graphene's two-dimensional structure allows for dense functionalization with biomolecules.
- Gallium nitride and zinc oxide are chemically stable and excellent candidates for enzyme immobilization.

4.3 Application Areas

- In healthcare, these sensors have been used for non-invasive glucose monitoring, early cancer detection, and even rapid tests for infectious diseases.
- In environmental applications, they help monitor pollutants like heavy metals or pesticides.
- In food safety, biosensors are deployed to detect pathogens such as E. coli or salmonella.

4.4 Key Challenges

Despite their promise, semiconductor biosensors are not without issues. Selectivity remains one of the biggest hurdles—ensuring that sensors detect only the target molecule and not similar-looking contaminants. Durability is another concern, especially when sensors are used in harsh or complex biological fluids.

On the bright side, newer approaches like machine learning and AI are being used to filter and interpret biosensor data more effectively. Additionally, research into biocompatible coatings and self-cleaning surfaces is making long-term use more feasible.

Conclusion

Semiconductors are redefining the way we think about biosensing—making it faster, smaller, and more accessible than ever before. With continued progress in nanofabrication, surface chemistry, and system integration, the future looks promising.

However, for these technologies to reach their full potential in widespread commercial use, there is a need for multidisciplinary collaboration between materials scientists, biologists, and electronics engineers. As biosensing technology continues to evolve, semiconductors will undoubtedly remain a driving force behind its advancement.

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