

FET Biosensors: Revolutionizing Diagnostics with Novel Materials

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Introduction

Field-effect transistor (FET)-based biosensors are at the forefront of revolutionizing diagnostic capabilities, offering remarkable sensitivity, swift response times, and label-free detection mechanisms. These advanced biosensing platforms are instrumental in enabling early disease detection and paving the way for personalized medicine through their integration into point-of-care applications. Recent breakthroughs in materials science have significantly enhanced FET biosensor performance, with a notable focus on novel materials that improve signal transduction efficiency and streamline fabrication processes. The adoption of 2D semiconductors such as graphene and molybdenum disulfide (MoS₂) has been pivotal in this regard. Furthermore, the synergy between FET biosensors and microfluidic technologies, coupled with advancements in nanotechnology, is driving their performance to unprecedented levels. These integrated systems are poised to transform healthcare by allowing for rapid and accurate diagnoses closer to the patient. The development of graphene-based FET biosensors has been a significant area of research, owing to graphene's exceptional electronic properties which allow for ultrasensitive and selective detection of a broad spectrum of biomarkers. These include nucleic acids, proteins, and various small molecules, making them versatile tools for diverse diagnostic needs. Researchers are actively exploring surface functionalization strategies to further optimize graphene's sensing capabilities. The utilization of transition metal dichalcogenides (TMDs), like MoS₂, in FET biosensors is another key area of innovation, offering tunable electronic properties and high surface-to-volume ratios that surpass traditional silicon-based FETs for biomolecule detection. The ongoing focus on defect control and stable functionalization is crucial for ensuring the reliability and sensitivity of these emerging biosensing devices. The integration of FET biosensors with microfluidic platforms represents a major stride towards multiplexed detection of disease biomarkers, enabling simultaneous measurement of multiple analytes. This integration facilitates precise sample handling and reagent delivery, thereby enhancing the throughput and efficiency of diagnostic assays. Organic field-effect transistors (OFETs) are emerging as a promising cost-effective and flexible alternative for biosensing applications. Their fabrication using low-cost printing techniques with solution-processable organic semiconductors opens avenues for wearable and disposable biosensing devices, expanding the accessibility of advanced diagnostic tools. Enhancing the sensitivity of FET biosensors is a critical objective, and approaches involving plasmonic nanoparticles are showing great promise. The localized surface plasmon resonance effect amplifies the electrical signal generated by biomolecule binding events, leading to substantially improved detection limits for a variety of analytes. The application of FET biosensors for the detection of infectious diseases is gaining significant traction, particularly for the rapid and sensitive identification of viral RNA and bacterial DNA. These capabilities are vital for prompt

diagnosis, effective outbreak management, and timely clinical interventions. Silicon nanowire FET biosensors have demonstrated remarkable efficacy in detecting specific microRNAs associated with cancer, leveraging the high surface area of nanowires for enhanced capture efficiency and sensitive, selective detection of target molecules. The exploration of multi-gate FET architectures presents an innovative strategy for elevating biosensing performance by improving sensitivity and reducing noise. This advanced design offers better stability and higher on/off ratios, crucial for reliable detection of low-concentration biomarkers in complex biological samples. The development of self-powered FET biosensors addresses the need for autonomous and continuous monitoring systems, particularly for remote or implantable applications. By utilizing triboelectric effects or biofuel cells for power generation, these devices eliminate the requirement for external power sources.

Description

Field-effect transistor (FET)-based biosensors represent a significant advancement in diagnostic technology, characterized by their high sensitivity, rapid response, and label-free detection capabilities. These biosensors are pivotal for point-of-care applications, facilitating early disease detection and the realization of personalized medicine. The integration of novel materials, particularly 2D semiconductors like graphene and MoS₂, along with organic semiconductors, is enhancing signal transduction and simplifying fabrication. The synergistic combination with microfluidics and nanotechnology further elevates their performance, making them indispensable tools for modern diagnostics. Graphene-based FET biosensors have emerged as powerful tools for detecting a wide array of biomarkers, including nucleic acids, proteins, and small molecules, due to graphene's superior electronic properties and the effectiveness of surface functionalization strategies. These sensors offer unparalleled ultrasensitivity and selectivity, although challenges in large-scale production and device integration are being actively addressed to enable widespread practical biomedical applications. The utilization of transition metal dichalcogenides (TMDs), such as MoS₂, in FET biosensors is driven by their tunable electronic characteristics and high surface-to-volume ratios, which provide enhanced performance over traditional silicon-based FETs for biomolecule detection. Research efforts are concentrated on controlling defects and developing stable functionalization techniques to ensure reliable and sensitive biosensing. Microfluidic platforms have been effectively integrated with FET biosensors to achieve multiplexed detection of disease biomarkers. This integration allows for precise control over sample handling and reagent delivery, enabling simultaneous measurement of multiple analytes and paving the way for high-throughput screening and point-of-care diagnostics with minimal sample volumes. Organic field-effect transistors (OFETs) are being developed as a cost-effective

and flexible platform for biosensing. The use of solution-processable organic semiconductors allows for fabrication via low-cost printing techniques, making them suitable for wearable and disposable biosensing devices, as demonstrated by the detection of glucose and lactate with good sensitivity and stability. To further enhance the sensitivity of FET biosensors, research is exploring the use of plasmonic nanoparticles. The localized surface plasmon resonance phenomenon amplifies the electrical signal upon biomolecule binding, leading to significantly improved detection limits for various analytes, thereby pushing the boundaries of ultrasensitive detection. The application of FET biosensors in the detection of infectious diseases is a critical area of development, focusing on the rapid and sensitive identification of viral RNA and bacterial DNA. Advancements in functionalization techniques and device architectures are crucial for improving specificity and reducing assay times, which is vital for outbreak management and timely diagnosis. Silicon nanowire FET biosensors are being developed for ultrasensitive detection of specific microRNAs associated with cancer. The inherent high surface area of nanowires enhances the capture efficiency of target molecules, leading to highly sensitive and selective detection. Strategies for surface modification and signal amplification are continuously being explored to optimize device performance. The investigation into multi-gate FET architectures aims to enhance biosensing performance through improved sensitivity and noise reduction. By precisely controlling multiple gates, these devices can achieve superior on/off ratios and greater stability, which are essential for reliable detection of low-concentration biomarkers, especially in complex biological matrices. The development of self-powered FET biosensors addresses the need for autonomous and continuous monitoring systems, particularly for remote or implantable applications. These devices leverage triboelectric effects or biofuel cells to generate their own power, eliminating the requirement for external power sources and enabling unattended operation. This innovation significantly expands the potential applications of FET biosensors.

Conclusion

Field-effect transistor (FET)-based biosensors are revolutionizing diagnostics with their high sensitivity, rapid response, and label-free detection. Recent advancements involve novel materials like 2D semiconductors (graphene, MoS₂) and organic semiconductors, enhancing signal transduction and simplifying fabrication. Integration with microfluidics and nanotechnology boosts performance for point-of-care applications. Graphene FETs offer ultrasensitive and selective detection of various biomarkers. TMDs like MoS₂ provide tunable electronic properties for improved biomolecule detection. Microfluidic integration enables multiplexed detection. Organic FETs offer a cost-effective and flexible platform for wearable devices. Plasmonic nanoparticles enhance sensitivity. FETs are being applied to detect infectious diseases and cancer biomarkers like microRNAs. Multi-gate architectures improve sensitivity and reduce noise. Self-powered FET biosensors are being developed for autonomous applications.

Acknowledgement

None.

Conflict of Interest

None.

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