Advanced biosensors: Technologies, materials, applications.

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Introduction

Advancements in biosensor fabrication are rapidly transforming health monitoring and diagnostics. This includes a comprehensive overview of recent progress in wearable biosensors, emphasizing innovative materials and manufacturing techniques that enable flexible, stretchable, and conformable devices for continuous health monitoring. The integration of nanomaterials and microfluidics is crucial here, enhancing sensitivity and selectivity to meet the critical need for real-time, non-invasive diagnostics in personalized healthcare[1].

Further exploration into highly sensitive and selective electrochemical biosensors reveals novel fabrication strategies. These often emphasize advanced nanomaterials like graphene and metal-organic frameworks (MOFs). Surface modification techniques and precise structural engineering significantly contribute to improved analytical performance, making these biosensors suitable for diverse applications, from disease diagnostics to environmental monitoring[2].

Another area of significant development involves microfluidic paper-based analytical devices (μPADs) and their integration into biosensing platforms. The simplicity, cost-effectiveness, and portability of paper-based biosensors are key, making them ideal for point-of-care diagnostics, especially in resource-limited settings. Various methods for patterning paper and immobilizing biorecognition elements are employed to achieve functional devices[3].

Advanced manufacturing technologies, specifically 3D printing, are central to creating complex and customizable biosensor architectures. This additive manufacturing approach allows for precise control over device geometry and material composition, resulting in highly efficient and miniaturized biosensors with enhanced analytical capabilities. Applications of 3D printing range from implantable devices to intricate lab-on-a-chip systems[4].

The development of highly sensitive optical biosensors relies heavily on advanced optical materials and structures. Techniques for fabricating plasmonic, photonic crystal, and fiber optic biosensors are explored, leveraging surface plasmon resonance (SPR) and other optical phenomena for label-free, real-time detection of biomolecules. These advancements bring improvements in detection limits and multiplexing capabilities[5].

Field-effect transistor (FET)-based biosensors, particularly those incorporating two-dimensional (2D) materials, represent another key area. The high surface-to-volume ratio and excellent electronic properties of materials like transition metal dichalcogenides (TMDs) are vital, contributing to highly sensitive and rapid detection of various analytes, positioning these as critical for next-generation portable diagnostic devices[6].

Flexible and stretchable biosensors are also seeing significant advancements, tackling critical fabrication challenges and offering solutions for integrating electronic components onto compliant substrates. Materials like liquid metals, conductive polymers, and elastomers are explored for their unique properties, enabling the creation of robust and high-performance wearable devices for continuous monitoring of physiological parameters[7].

An in-depth analysis of micro/nanofabrication techniques for creating advanced biosensors with enhanced performance is also critical. This includes lithography, etching, and thin-film deposition methods. These processes precisely control the nanoscale architecture of sensing interfaces, leading to devices with improved sensitivity, faster response times, and better integration with electronic readout systems[8].

Molecularly imprinted polymer (MIP)-based biosensors are gaining traction due to their high selectivity and robustness, stemming from their unique 'key-lock' recognition mechanism. Various polymerization techniques and integration strategies for MIPs with transducers lead to cost-effective and stable synthetic recognition elements, mimicking natural antibodies for a wide range of analytical targets[9].

Finally, aptamer-based biosensors are another significant area, valued for their high affinity, specificity, and chemical stability, especially when produced synthetically. Different strategies for immobilizing aptamers onto transducer surfaces and integrating them into diverse detection platforms result in highly sensitive and reliable biosensors for clinical diagnosis, food safety, and environmental monitoring[10].

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Conclusion

Recent advancements in biosensor fabrication highlight a diverse array of innovative technologies and materials aimed at improving detection capabilities and expanding applications. Wearable biosensors, for instance, utilize flexible and stretchable materials, alongside nanomaterials and microfluidics, for continuous, non-invasive health monitoring. Electrochemical biosensors leverage advanced nanomaterials like graphene and MOFs, incorporating surface modification and structural engineering for enhanced analytical performance across diagnostics and environmental monitoring. Simple, cost-effective, and portable paper-based analytical devices are emerging for point-of-care diagnostics, emphasizing accessible fabrication methods. Advanced manufacturing techniques, notably 3D printing, enable the creation of complex, customizable biosensor architectures for miniaturized, high-performance systems. Optical biosensors, including plasmonic and fiber optic types, exploit phenomena like surface plasmon resonance for label-free, real-time biomolecule detection with improved limits. Field-effect transistor (FET)-based biosensors, incorporating 2D materials, offer rapid, sensitive detection due to high surface-to-volume ratios. Micro/nanofabrication techniques, such as lithography and etching, provide precise control over nanoscale interfaces, resulting in better sensitivity and integration. Lastly, biomimetic recognition elements like molecularly imprinted polymers (MIPs) and stable synthetic aptamers are being integrated into various platforms, offering high selectivity and stability for clinical, food safety, and environmental applications.

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