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SEAWIZARD-Multiplex AI-Enabled Graphene Based Lab-On-Chip Sensing Platform for Heavy Metal Ions Monitoring on Marine Water

Authors : M. Moreno, M. Alique, D. Otero, C. Delgado, P. Lacharmoise, L. Gracia, L. Pires, A. Moya

Abstract : Marine environments are increasingly threatened by heavy metal contamination, including mercury (Hg), lead (Pb), and cadmium (Cd), posing significant risks to ecosystems and human health. Traditional monitoring techniques often fail to provide the spatial and temporal resolution needed for real-time detection of these contaminants, especially in remote or harsh environments. SEAWIZARD addresses these challenges by leveraging the flexibility, adaptability, and cost-effectiveness of printed electronics, with the integration of microfluidics to develop a compact, portable, and reusable sensor platform designed specifically for real-time monitoring of heavy metal ions in seawater. The SEAWIZARD sensor is a multiparametric Lab-on-Chip (LoC) device, a miniaturized system that integrates several laboratory functions into a single chip, drastically reducing sample volumes and improving adaptability. This platform integrates three screen-printed graphene electrodes for the simultaneous detection of Hg, Cd and Pb via square wave voltammetry. These electrodes share the reference and the counter electrodes to improve space efficiency. Additionally, it integrates printed pH and temperature sensors to correct environmental interferences that may impact the accuracy of metal detection. The pH sensor is based on a carbon electrode with iridium oxide electrodeposited while the temperature sensor is graphene based. A protective dielectric layer is printed on top of the sensor to safeguard it in harsh marine conditions. The use of flexible polyethylene terephthalate (PET) as the substrate enables the sensor to conform to various surfaces and operate in challenging environments. One of the key innovations of SEAWIZARD is its integrated microfluidic layer, fabricated from cyclic olefin copolymer (COC). This microfluidic component allows a controlled flow of seawater over the sensing area, allowing for significant improved detection limits compared to direct water sampling. The system's dual-channel design separates the detection of heavy metals from the measurement of pH and temperature, ensuring that each parameter is measured under optimal conditions. In addition, the temperature sensor is finely tuned with a serpentine-shaped microfluidic channel to ensure precise thermal measurements. SEAWIZARD also incorporates custom electronics that allow for wireless data transmission via Bluetooth, facilitating rapid data collection and user interface integration. Embedded artificial intelligence further enhances the platform by providing an automated alarm system, capable of detecting predefined metal concentration thresholds and issuing warnings when limits are exceeded. This predictive feature enables early warnings of potential environmental disasters, such as industrial spills or toxic levels of heavy metal pollutants, making SEAWIZARD not just a detection tool, but a comprehensive monitoring and early intervention system. In conclusion, SEAWIZARD represents a significant advancement in printed electronics applied to environmental sensing. By combining flexible, low-cost materials with advanced microfluidics, custom electronics, and AI-driven intelligence, SEAWIZARD offers a highly adaptable and scalable solution for real-time, high-resolution monitoring of heavy metals in marine environments. Its compact and portable design makes it an accessible, user-friendly tool with the potential to transform water quality monitoring practices and provide critical data to protect marine ecosystems from contamination-related risks.

Keywords : Lab-On-Chip, Printed Electronics, Real-Time Monitoring, Microfluidics, Heavy Metal Contamination
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