

Surface Chemistry-Enhanced Wearable Biosensors: A Novel Approach for Non-Invasive Continuous Health Monitoring

Zhuo Chen

School of Chemical Engineering, University of New South Wales, Sydney NSW, Australia

ABSTRACT

With the rise of health concerns in recent years, wearable biosensors have gained widespread attention as an important technology for health monitoring. It can monitor human physiological indicators such as blood glucose and lactate. This type of monitoring does not require complex operations or frequent sampling and is non-invasive and capable of real-time monitoring. Chemically modified electrochemical biosensors have further improved the sensitivity and selectivity of monitoring and have the potential for a wider range of applications. In this paper, we will explore the application of surface chemically enhanced wearable sensors for non-invasive health monitoring and their future directions.

KEYWORDS

Wearable Biosensors; Health Monitoring; Non-invasive; Real-time Monitoring; Chemical Modification.

1. INTRODUCTION

Surface chemical enhancement technology enables sensors to exhibit higher sensitivity and selectivity in the detection of biomarkers by modifying their surface materials or introducing functional chemical groups. Such technologies are widely used in the development of electrochemical sensors and provide important support for research on wearable devices. This paper will focus on a few common techniques used for chemical enhancement of wearable sensor surfaces. For example, nanomaterial modification techniques. Nanomaterials are widely used in electrochemical sensors due to their large specific surface area and excellent electrical conductivity, and by modifying the nanomaterials technology, the sensors are able to detect metabolite levels in body fluids more effectively. These materials are able to significantly improve the signal response of the sensor by interacting with target biomolecules (e.g., glucose, lactate), thus enabling highly sensitive detection of biomarkers at low concentrations.

SAMs technology has equally important applications in biosensors. Self-assembled monolayer technology refers to the formation of highly ordered structures by spontaneous arrangement of molecules. The structure which enables precise modulation of the active sites on the surface of the sensor proved its selectivity for specific biomarkers. The application of this method is very important in the development of wearable sensors. By introducing self-assembled carboxyl or amino groups on the electrode surface, for example, the sensor's ability to capture biomolecules such as glucose or lactic acid can be enhanced.

2. NON-INVASIVE HEALTH MONITORING APPLICATIONS OF WEARABLE ELECTROCHEMICAL SENSORS

The key advantage of wearable electrochemical sensors is their non-invasive and real-time monitoring capabilities, enabling biomarker detection through body fluids (e.g., sweat, tears, etc.). [1] These features are not only easy to use compared to traditional blood tests, but also allows for monitoring of health over a long period of time during exercise or daily activities. Sweat, glucose, and lactic acid can be used as measured substances. Especially sweat is rich with electrolytes and metabolites such as sodium, potassium, and chloride ions as well. For example, Na⁺ in sweat can reflect whether an electrolyte disorder or dehydration is occurring in the body. Abnormally elevated chloride ion concentrations also can be used to screen for cystic fibrosis. Lactate levels can indicate muscle fatigue or respiratory failure. Glucose level changes can be used for diabetes management. [4] Heavy Metal Concentration Assessment Provides Early Warning to Subjects. Sweat testing can therefore be used to assess the health of the body. However, because sweat is easily lost through evaporation, has low richness of biomarkers, and is easily polluted and degraded, the development of fast, accurate, in-situ, and real-time sweat collection equipment turns out to be a key necessity to ensure some crucial features (high accuracy, precision, stability, and repeatability) of wearable sweat sensor equipment. Sweat sensors have been widely used in disease management as well. For example, diabetic patients can continuously measure their blood glucose levels with such sensors, and athletes can monitor lactic acid levels in sweat to understand their fitness status and adjust their training intensity. [2] Blood glucose management is one of the key application areas for wearable sensors. While traditional blood glucose testing methods often require frequent blood collection, non-invasive glucose detection can be achieved by wearable electrochemical sensors through sweat or tissue fluids. And maybe next generation can do multimodal and multiplexed measurement. In recent years, with the application of surface chemical enhancement technology, the sensitivity of the sensor has been significantly improved, providing diabetic patients with a high-resolution meaner of health management. Lactic acid is an important marker produced by muscle metabolism during exercise.[3] Real-time monitoring of lactate levels in sweat through wearable sensors can help athletes analyse their training regimen and avoid the damage caused by overtraining. In addition, changes in lactate levels are also closely related to the health of the respiratory and circulatory systems, making it suitable for a variety of health monitoring scenarios.

3. CORE TECHNOLOGIES FOR ELECTROCHEMICAL SENSORS

The development of wearable electrochemical sensors got various of types. There are technologies such as the use of nanomaterials, microfluidics, wireless communication and low-power design. All of them play a huge role in this scope. By introducing nanomaterials (metal nanoparticles, carbon nanotubes, etc.), electrochemical sensors can dramatically improve the accuracy and sensitivity of their measurement. [4] Nanomaterials not only improve the conductivity of the sensor but also increase the reactivity with the target molecule. Studies show that nanomaterial-modified electrochemical biosensors offer high sensitivity and a broad detection range, making them ideal for monitoring complex body fluids.

The wireless data transmission capability of wearable sensors allows them to transmit detection data in real time to mobile devices or the cloud for remote health monitoring. Low-power design is also one of the important research directions for wearable devices. For example, by providing energy to the sensor through a self-powered system (e.g. friction electric nanogenerator), such a technology can further improve the endurance of the sensor.

With the development of wireless communication technology, the combination of wearable sensors and smartphones will also further promote the prevalence of personalized health management.

4. APPLICATION PROSPECTS OF WEARABLE SENSORS

Wearable electrochemical sensors combined with surface chemical modification technology have shown promising applications in several fields. The applications are particularly outstanding in the management of blood glucose in diabetic patients. These sensors are capable of detecting glucose concentration in a non-invasive manner to help patients achieve real-time continuous glucose monitoring. This approach avoids the pain and inconvenience associated with traditional invasive blood collection methods and brings convenience to the lives of patients. In recent years, with the application of surface chemical enhancement technology, the sensitivity and stability of the sensor have been significantly improved. Especially for the detection of glucose at low concentrations raised sharply. Electrochemical sensors have been widely used in clinical diabetes monitoring and are expected to be further extended to home and portable application scenarios in the future.

This electrochemical sensor can be utilized in the field of sports as well. The lactic acid is a key biomarker of physical performance and metabolism during the reaction. Through wearable electrochemical sensors, athletes can be monitored lactate levels in body fluids in real time, so that they can adjust training intensity, strategy and prevent excessive muscle fatigue. In addition, these sensors can simultaneously monitor electrolytes, such as sodium and potassium, to help athletes maintain fluid balance. Studies have shown that electrochemical sensors are able to accurately capture changes in the concentration of these metabolites through surface chemical enhancement technology, providing a highly practical tool for exercise monitoring.

Wearable sensors are essential for diabetes management and athlete fitness monitoring. They also play a key role in managing other chronic diseases. [2] This real-time feedback helps patients and healthcare providers make informed decisions, potentially improving treatment outcomes. Continuous monitoring can also aid in early detection of complications, enhancing overall disease management. With real-time data transmission through wireless technology, these sensors enable physicians to remotely track patients' health and make timely adjustments to treatment plans. This connectivity enhances patient care by facilitating proactive and personalized management of chronic conditions. Literature mentions that such non-invasive, continuous monitoring wearable devices will help improve the accuracy of chronic disease management.

5. CONCLUSION

While wearable electrochemical sensors hold significant promise for health monitoring, several challenges must be addressed to improve their effectiveness and broaden their use. Although surface chemical enhancement has greatly improved sensor sensitivity, enhancing selectivity in complex biological environments remains a key research focus. Future research can make sensors more accurate in detecting specific biomarkers by introducing more functional nanomaterials or multilayer surface modification techniques. Wearable sensors need to be in contact with the skin for a long period of time and work under various environmental conditions, so their long-term stability and durability are especially critical. Cited in the literature! mentions that many current electrochemical sensors suffer from sensitivity degradation after a period of time, mainly due to biological contamination or aging of surface modification materials. Therefore, the development of more durable surface modification materials and self-cleaning mechanisms will be an important direction to enhance the performance of sensors in the future. Currently, most wearable sensors rely on battery power, and continuous monitoring over a long period of time will place higher demands on energy consumption. To address this issue, future research could explore self-powered technologies such as friction electric nanogenerators (TENG) or biofuel cells that utilize chemical energy from human movement or body fluids to power sensors. Self-powered designs could significantly extend sensor battery life, minimizing the need for replacements. At the same time, as wearable sensors have already collected amounts of health data. They efficiently process this information to deliver personalized

health recommendations, which has become a major challenge. Future directions include integrating artificial intelligence (AI) and machine learning (ML) technologies into sensor systems to enable intelligent analysis and real-time feedback of health data. In addition, through 5G communication technology and cloud computing, sensors can be seamlessly connected to telemedicine platforms to provide more personalized and intelligent health management services.

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