International Journal of Science Academic Research
Vol. 05, Issue 06, pp.7694-7697, June, 2024
Available online at http://www.scienceijsar.com

ISSN: 2582-6425

Research Article

SOFT AND SELF-REPAIRABLE BIOSENSOR PLATFORM FOR WEARABLE HEALTH-CARE MONITORING

***Soomin Ju**

Seoul Academy, South Korea

Received 19th April 2024; **Accepted** 14th May 2024; **Published online** 28th June 2024

Abstract

Recently, soft bioelectronics have introduced innovative functionalities across various device applications. The use of conventional rigid metal/semiconductor materials in wearable biosensor applications often leads to limited biocompatibility, mechanical mismatch, and chronic tissue damage in biotic/abiotic interfaces. In term of these requirements, alternative materials that offer softness, flexibility, and self-healing capabilities to improve the performance and wearing-comfort on skin. The emergence of soft and self-healing biosensor platforms marks a significant advancement in wearable healthcare monitoring. These platforms integrate novel materials offering flexibility, resilience, and autonomous repair capabilities, thereby addressing key challenges in long-term health monitoring. This paper presents an overview of the development and applications of such biosensor platforms, highlighting their potential to revolutionize healthcare monitoring. The integration of soft and self-healing materials enables comfortable and reliable monitoring, facilitating continuous data collection without compromising user comfort or sensor functionality. This review paper encapsulates the essence of the innovative biosensor platform, emphasizing its transformative potential in wearable healthcare monitoring.

Keywords:

INTRODUCTION

The convergence of healthcare and technology has sparked a paradigm shift in how we perceive and manage personal well-being. In this era of personalized medicine, the demand for continuous health monitoring solutions has escalated, driven by the desire for proactive health management, early disease detection, and improved quality of life. Wearable biosensor platforms have emerged as transformative technology, promising to revolutionize healthcare delivery by providing real-time physiological data in non-invasive and convenient ways. However, traditional wearable biosensors often encounter limitations related to comfort, durability, and long-term wear ability, hindering their widespread adoption and effectiveness (1-3). In response to these challenges, researchers across interdisciplinary fields have been actively pursuing innovative strategies to develop soft and self-healing biosensor platforms. These platforms represent a paradigm shift in wearable sensor technology, offering enhanced comfort, flexibility, and resilience compared to their rigid counterparts (4,5). By mimicking the mechanical properties of biological tissues, soft biosensor platforms conform to the body's contours, minimizing discomfort and enabling prolonged wear. Furthermore, the integration of self-healing mechanisms endows these platforms with the ability to autonomously repair damage, extending their lifespan and improving reliability. The development of soft and self-healing biosensor platforms is based on diverse disciplines, including materials science, engineering, and biomedical research. Fundamental to their design is the selection and engineering of functional materials with tailored mechanical, electrical, and biocompatible properties. Soft elastomers, hydrogels, and conductive polymers serve as the building blocks for these platforms, enabling the fabrication of stretchable, flexible, and biocompatible sensor arrays. Moreover, advances in nanotechnology have enabled the integration of nanomaterials, such as carbon nanotubes, graphene, and nanoparticles, to enhance sensor sensitivity and selectivity. This review article aims to provide a comprehensive overview of recent technical direction of soft and self-healing biosensor platforms for wearable health-care monitoring. We will explore the underlying principles guiding their design, fabrication techniques, and functional capabilities. Furthermore, we will review about new capability of biosensor, which shows softness and self-healing properties. To further discussion about self-healing phenomenon, we will discuss about a few kinds of self-healing mechanism widely used in material science and chemistry research. This review will delve into the integration of soft and self-healing biosensor platforms with emerging technologies, such as wireless communication, data analytics. These integrations enable real-time monitoring, data interpretation, and personalized intervention strategies, facilitating timely healthcare interventions and improving patient outcomes. Additionally, we will examine the challenges and future directions in the field, including but not limited to improving biocompatibility, enhancing sensor performance, and addressing regulatory considerations, to accelerate the translation of these innovations into clinical practice. We hope to inspire further research and innovation in this rapidly evolving field, ultimately contributing to the development of personalized and proactive healthcare solutions.

Wearable biosensor

The emergence of wearable biosensors represents a transformative development in healthcare and personal monitoring. These devices are designed to be worn comfortably on the body, providing continuous, real-time monitoring of various physiological parameters and biomarkers. A wearable biosensor typically integrates biorecognition elements, such as enzymes or antibodies, with miniaturized transducers, such as electrodes or optical sensors,

---

Corresponding Author:** ***Soomin Ju
Seoul Academy, South Korea.

all within a compact and often flexible form factor (6) (Figure 1). This combination enables the detection of biomolecules like glucose, lactate, or specific proteins directly from bodily fluids like sweat, tears, or interstitial fluid. Recently sweat-based biosensors have been demonstrated in previous researches. Sweat-based biosensors leverage the unique composition of sweat to monitor various biomarkers, offering a non-invasive and continuous monitoring solution for health and fitness applications. These biosensors typically utilize biochemical composition in sweat, containing electrolytes, metabolites, and specific biomarkers indicative of physiological state. The principle involves collecting sweat from the skin surface, either through wearable patches or microfluidic channels, and analyzing it for target analytes using specific recognition elements like enzymes or antibodies. The interaction between the recognition element and the target biomarker produces a measurable signal, which is then transduced and processed to provide real-time information about the wearer's health status. Sweat-based biosensors have shown promise in monitoring hydration levels (7), electrolyte balance, glucose levels (8), and even stress hormones, opening up possibilities for personalized health monitoring and disease management. Their non-invasive nature and potential for continuous monitoring make them particularly valuable for applications in sports performance, healthcare, and wellness tracking.

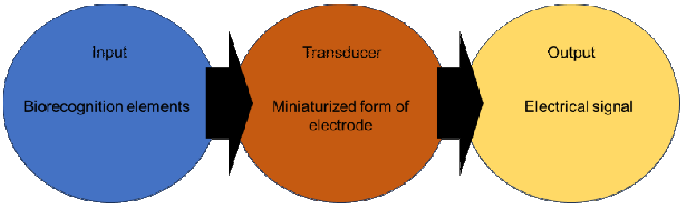

Figure 1. Basic components of wearable biosensor

To access the health status in daily lives, system requires sweat secretion method for continuous input to sensors. Reverse iontophoresis is a method involving the application of a slight electrical current to the skin, facilitating the extraction of molecules, including ions and small molecules, from the body. In the realm of sweat-based biosensors, reverse iontophoresis serves as a means to gather sweat from the skin's surface for subsequent analysis (9, 10).In this process, a gentle electrical current is delivered to the skin via an electrode. This current sets up an electrochemical gradient, propelling charged molecules, such as components of sweat, through the skin barrier and into a collection reservoir. By adjusting electrical parameters like current strength and duration, one can regulate the pace and volume of sweat extraction. Once harvested, the sweat sample undergoes analysis using biosensing techniques to identify and measure various biomarkers present in sweat, such as electrolytes, metabolites, and hormones. Wearable biosensors offer several advantages over traditional diagnostic methods, including non-invasive or minimally invasive monitoring, continuous data collection, and the ability to track health metrics in real-world settings. They hold immense potential for applications ranging from personal health and wellness monitoring to clinical diagnostics and disease management. Additionally, the advent of wearable biosensors has linked to innovations in data analytics, connectivity, and integration with smart phones or other mobile devices, enabling users to access and interpret their health information conveniently. As the technology continues to advance, wearable biosensors are poised to play a significant role in empowering individuals to take proactive control of their health and enabling healthcare professionals to deliver more personalized and timely interventions.

Design of geometry for mechanical softness and stretch ability

Technological breakthroughs in nanostructured materials have revolutionized the field of bio-integrated electronics, offering unprecedented flexibility for device integration. However, while nanostructured materials enable vertical bending, achieving multidirectional bending and stretchability is crucial for seamless integration with soft, curved, and dynamically moving organs.This section explores various techniques utilized to impart stretchability to bio-integrated electronics, including buckling structures, pop-up structures, serpentine design, and fractal design (Figure 2).

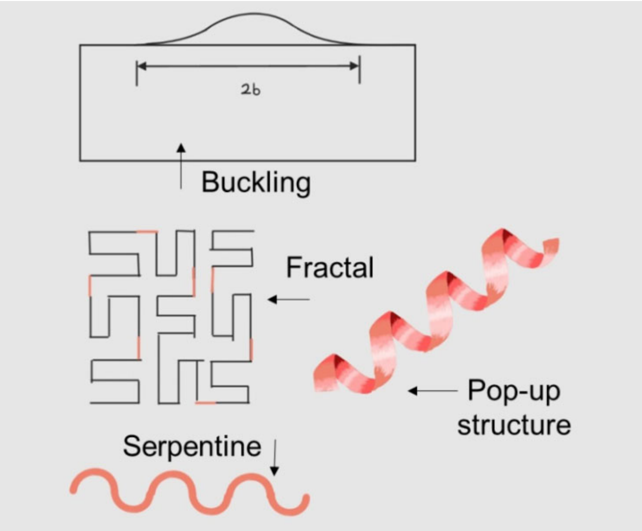

Figure 2. Technical design for imparting softness and stretchability

These kinds of design are widely used for imparting softness and stretchability to conventional materials. One of typical design is ultrathin, which have been used in stretchable electronics for various applications, however, it is challenging to achieve deformability even if it can enhance the softness. Although ultrathin devices exhibit limited stretchability, incorporating a wavy structure through buckling can enhance their flexibility. By bonding the ultrathin device to a pre-strained elastomeric substrate and then releasing the pre-strain, a buckled structure is formed. Control over wavelength, amplitude, and buckling type allows customization based on device and substrate characteristics. However, mechanical fractures may occur under high strain, impacting device performance. To mitigate strain-induced variations, a controlled delamination technique separates the metal interconnection from the substrate, forming an arch-shaped pop-up structure while the active device region remains on the substrate. This pop-up structure enables various deformations without compromising device functionality.Further advancements include complex pop-up structures achieved by manipulating bonding areas and utilizing alternative designs.The robust bonding between materials could be formed by using interfacial bonding layer or surface treatments. Nevertheless, excessive external strain beyond the pre-strain threshold can lead to mechanical fracture, emphasizing the importance of pre-strain value in determining stretchability limitations. In contrast, an elastic device with a serpentine design can stretch beyond the pre-strain value, offering enhanced stretchability. Incorporating serpentine design into the island-bridge structure enables high stretchability, ensuring resilience to mechanical stress beyond the pre-strain threshold. The integration of stretchable nanostructured materials into bio-integrated electronics holds immense promise for advancing medical diagnostics and therapeutics. Continued research into innovative design techniques and material compositions is essential to overcome existing limitations and unlock the full potential of stretchable bio-integrated electronics.

Material strategies for soft, self-repairable biosensor

Flexible and stretchable bioelectronic devices are expected to provide new opportunities in diverse medical and healthcare applications. These soft bioelectronic devices can be applied to soft curved organs including brain, heart, and skin, making high-quality biotic/abiotic interfaces between devices and tissues due to their mechanical softness. As material properties of such devices are similar with those of human tissues and organs, their sensing and therapeutic performance as well as long-term biocompatibility in vivo will be improvedover those of conventional bulky and rigid devices. Specifically, these soft electronic devices can be conformally integrated with the human body, which minimize the impedance and maximize the signal-to-noise ratio, and thus, they can capture various biosignals from target sites and convert them into electrical signals efficiently with high accuracy.

The issues in long-term biocompatibility and wearing-comfort of the conventional bioelectronics, which originates from their bulky sizeand rigidity have been major challenges for the widespread application of such closed-loop bio-integrated electronic systems. The mechanical and chemical properties of the conventional rigid electronic materials and devices, such as Young’s modulus, bending stiffness, hydrophilicity, and ion permeability, differ from those of soft human tissue. Especially, modulus, which is essential standard for characterizing the softness of materials, is one of most important parameters to achieve the wearing-comfort by minimizing the modulus mismatch between biological tissue and electronics. Inparticular, major organs such as brain (1−4 kPa) and heart (10−15 kPa) exhibit a large discrepancy in terms of their modulus (i.e., mechanical stiffness) from conventional rigid electronic materials and devices (∼100 GPa). These differences hinder the monolithic conformal integration of the biomedical device with human body, and cause various side-effects, particularly when the bulky rigid devices need to be chronically implanted in or contacted to the target tissue and organ. To overcome current issues in wearable electronics, there have been many progresses based on soft materials, self-healable materials and mechanical designs. Especially, self-repair property, called “self-healing” is one of promising functions, which enables long-term measurements. For example, the bio-implantable sensors inserted in the body could have damage during movements owing to external stress. However, replacement of device is challenging process, as surgical processes including insertion, attachment on correct region of internal body are required, which might burden the subjects. We will review the mechanisms of self-repair process based on aspects of chemistry.

Basic mechanism of self-healing phenomenon

Functional materials have long been indispensable in daily life, initially driven by the need for economical, robust, and enduring substances primarily sourced from nature and processed using rudimentary methods. These early materials primarily served structural purposes without active functionalities. However, evolving demands have steered material development towards tailoring substances to specific applications, culminating in the emergence of "smart" materials. In recent decades, there has been a surge in research focused on self-healing materials, a subset of smart materials engineered to respond predictably to external stimuli. The ability of materials to autonomously repair damage is inspired from biological systems offers immense potential for enhancing safety, durability, and cost-effectiveness across various industries. Efforts in this domain have primarily targeted materials capable of withstanding environmental challenges such as oxidation, radiation, abrasion, and moisture. While traditional repair methods like resin injection and welding have been effective, they often leave weakened areas vulnerable to subsequent damage. Consequently, the pursuit has shifted towards achieving microscopic or even nanoscopic self-repair, leveraging advancements in material chemistry (Figure 3).

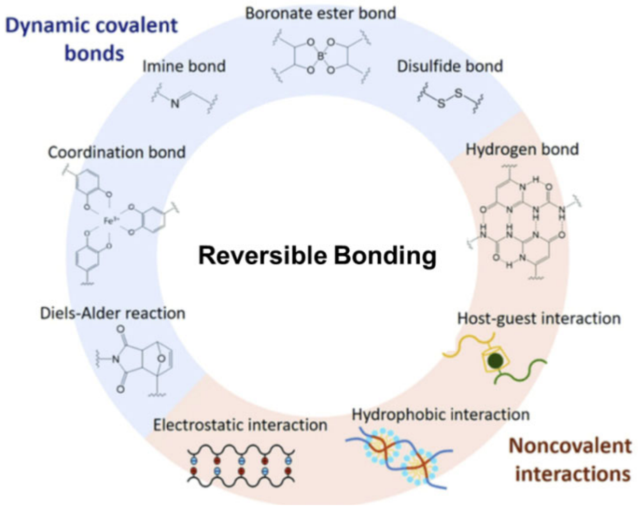

Figure 3. Possible chemical bonds widely used for designing of self-repair materials

Self-healing materials typically operate through extrinsic or intrinsic mechanisms, either triggered by the release of healing agents or the establishment of reversible bonds. While some commercially available materials exhibit self-healing properties through mechanisms like thermal flow, this article primarily focuses on advanced systems capable of multiple healing cycles and tailored for specific applications. Early self-healing systems, predominantly utilized in fiber-reinforced polymers (FRPs), employed techniques such as one-part adhesive-filled fibers and two-part reagent systems. More recent developments have seen the integration of catalyst-containing microcapsules into polymer matrices, enabling autonomous healing through triggered chemical reactions. Despite progress, limitations persist, notably in achieving repeated healing at the same location due to limited distribution of healing agents. Biomimetic approaches, mimicking the capillary networks of biological systems, aim to address this constraint by facilitating more comprehensive healing. The advent of autonomously self-healing materials, featuring dynamically bonded components capable of multiple healing cycles, presents a significant advancement (Figure3). While these materials primarily rely on supramolecular interactions, ongoing research seeks to enhance their mechanical properties for broader industrial applications. Dynamic bonds, both covalent and non-covalent, hold promise for further advancements in self-healing materials. While materials based on these bonds require external stimuli like heat or light for repair, ongoing research endeavors aim to overcome these limitations for robust, versatile self-healing solutions. In summary, the field of self-healing materials continues to evolve, driven by the quest for materials capable of autonomous repair, enhanced durability, and tailored functionalities for diverse applications. Ongoing research promises innovative solutions to address existing challenges, paving the way for a new era of resilient, self-repairing materials.

Conclusion

In conclusion, the emergence of a soft and self-repairable biosensor platform marks a pivotal advancement in wearable healthcare monitoring technology. This innovative platform, characterized by its fusion of flexibility, durability, and self-mending capability, presents a compelling solution for sustained, uninterrupted health monitoring. Its soft, adaptable design ensures optimal comfort during wear, while its innate ability to mend itself bolsters device longevity and reliability. These biosensor platforms hold profound potential in reshaping healthcare paradigms, empowering personalized, real-time monitoring of vital signs, biomarkers, and health parameters. As ongoing research and development propel these soft and self-repairable biosensors forward, they stand poised to catalyze transformative impacts across telemedicine, chronic disease management, and preventive healthcare realms, ultimately fostering enhanced quality of life and well-being on a global scale.

Acknowledgement

I would like to thank JongWook Lee and Sunny Kim for his guidance, encouragement during process of this review paper

REFERENCES

1. Kim J., & A. Campbell. (2018). ‘Talanta’, Elsevier, 163.
2. Neethirajan, S. (2017). ‘Sensing and Bio-sensing Research’, Elsevier, 15.
3. Lee E., & M. Kim, & C.Lee. (2019). ‘Skin-Mountable Biosensors and Therapeutics: A Review’, Elsevier, 299.
4. Wang C., K. Xia, H. Wang, X. Liang, Z. Yin, & Y. Zhang.(2018). ‘Advanced Carbon for Flexible and Wearable Electronics’, Advanced Materials, 1.
5. Li J., W. Wong, & X. Tao. (2020). ‘Recent advances in soft functional materials: preparation, functions and applications’, Royal Society of Chemistry, 1281.
6. Iqbal M., S.g. Gupta & H.S.S. (2012). ‘A Review on Electrochemical Biosensors: Principles and Applications’, Advances in Bioresearch, 158.
7. Yao S., A. Myers, A. Malhotra, F. Lin, A. Bozkurt, J.F. Muth, & Y. Zhu. (2016). ‘A Wearable Hydration Sensor with Conformal Nanowire Electrodes, 1.
8. Kim J., A.S. Campbell, J. Wang. (2017). ‘Wearable non-invasive epidermal glucose sensors: A review’, Talanta, 163.
9. Zheng H., Z. Phu, H. Wu, C. Li, X. Zhang, D. Li. (2022). ‘Biosensors and Bioelectronics’, Elsevier, 1.
10. Potts R.O., J.A. Tamanda, M.J. Tierney. (2002). ‘Glucose monitoring by reverse iontophoresis’, Diabetes/Metabolism Research and Reviews, s49.

****