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Self-Healing Materials: An Innovative and Sustainable approach to Biosensor Fabrication †

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Abstract: Biosensor technology is a fast-growing area in biomedicine as the demand for rapid analysis is increasing nowadays. A significant problem that biosensors face is the degradability and failure of biosensor materials, mainly due to temperature, pH, or the state of applied stress. Innovative material design and synthesis methods are required to close the reusability gap for these devices. Moreover, new materials are needed to ensure a better and cheaper diagnosis, especially in countries where diagnostic equipment is not readily available. Self-healing materials, a novel class of smart materials, can repair themselves without external stimuli when damage occurs to the structure. Deformations can be self-healed, giving rise to multiple applications, including flexible electronics and biosensors. This mini review summarizes the self-healing mechanisms, the properties and applications of self-healing materials in biosensors. Furthermore, emphasis is given to the sustainability and environmental aspects of these materials.

Keywords: biosensors; self-healing; biomedicine; materials science; smart materials

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1. Introduction

A vast advance in materials science has been seen in the last few years due to research efforts in the area of smart materials. Self-healing materials are defined as materials that can repair themselves after an external stimulus alters the structure of the material [1]. Self-healing properties have been observed in many kinds of materials and, especially soft materials. The underlying mechanisms of self healing processes have been studied in both organic and organic-inorganic hybrid polymeric materials. Due to their mechanical properties and cost, soft materials find use as the primary materials in bioelectronics [2]. Biosensors are analytical devices used for the detection of analytes produced by chemical and biological reactions. The main working principle of biosensors is that they generate a signal when they detect an analyte. The parts of a typical biosensor are the bioreceptors, the transducer, the electronics, and the display [3]. The materials used for the production of biosensors need to be stable under changes in pH, temperature, or applied stress. Along with stability, biosensors need to have selectivity, reproducibility, sensitivity, and linearity. Microcracks and defects can influence the conductivity of biosensors, and also self healing mechanism can play a vital role in the use of the device [4]. Thus, the materials used in these devices also need to meet the aforementioned specific criteria. Another aspect that needs to be mentioned is the cost of the materials. As self-healing materials can repair themselves, the stability of biosensor materials can increase the lifespan of the biosensor and thus extend its use. This is a crucial parameter, as biosensors need to be easily available for use in developing countries where there is no available diagnostic equipment. Moreover, reusability and repair of materials can lead to a reduction of the biosensor cost and thus increasing their sustainability [5].

2. Self-Healing Mechanisms

Self-healing materials can be categorized according to the mechanism of the self-healing process. They can either be self-healed externally with the help of a healing agent or internally without any other healing material [6]. The first mechanism is referred as extrinsic self-healing while the later as intrinsic self-healing. Extrinsic self-healing relies in the encapsulation of structures such as microcapsules or fibers in the primary material. As microcapsules break the healing agent releases resulting in the self-healing process. These healing agents can be a polymer initiator or a monomer, and even a catalyst. In the case of intrinsic mechanism, strategies such as cycloaddition, acylhydrazone bonds, hydrophobic interactions, hydrogen bonding, π-π stacking, Diels-Alder reaction, metal ligand and ionic interactions take place [7–13]. Such chemical reactions can recover the defects and repair the material from deformations.

3. Self-Healing Applications in Biosensors

Various self-healing materials have been reported in the literature as parts of biosensor devices. Yoon et al., reported the use of a citric acid-based supramolecular polymer with carbon fibers embedded in the polymer mix for a K^+/Na^+ biosensor [14]. Another application of a self-healing protein hydrogel with bovine serum albumin was used for the detection of glutathione in a sensing system. This hydrogel, exhibited remarkable self-healing recovery 10 min after cutting [15]. Chitosan based self-healing hydrogels have also been used for biosensing applications [16]. Moreover, Shen et al., reported the use of self-healing carboxylmethyl chitosan for glucose detection [17]. Other self-healing biosensors incorporated a nanocellulose self-repaired nanocomposite in a polyvinyl alcohol matrix [18]. Won et al., utilized carbon dots in a self-healing hydrogel for label-free cancer detection [19]. Finally, self-healable silk fibroin was used for the fabrication of multifunctional biocompatible biosensors [20].

4. Conclusions

Mimicking nature's self-healing properties, self-healing materials, a novel and innovative class of materials, can autonomously repair themselves. Depending on the presence of a healing agent, the mechanisms behind the process are divided into extrinsic and intrinsic. Being a sustainable and cost-effective choice, these materials can find applications in numerous areas of technology, especially in biosensors where constant and reliable monitoring is needed. Finally, more research in self-healing polymers and hydrogels can make these smart materials an environmentally and biocompatible choice for the bioelectronics of the future.

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