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Physical and Informational Security in the Age of the Wearable Device

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Description

One of the special feature characteristics for enzymatic biosensors and bioelectrodes is their “biocompatibility”, that is, ability to operate under physiological conditions. An example can be cholesterol oxidase-covered anode where analyte, that is, cholesterol, was oxidized and hydrogen peroxide produced. The latter was reduced on a coupled mediator-containing cathode. Examples of biocompatible device applications are in vivo determination of dopamine using tyrosinase- based electrochemical biosensor and self-powered biosensors for brainactivity monitoring or contact lens with integrated micro-sized bioanode and biocathode allowing electricity harvesting from tears. The idea is to develop bioanode and biocathode efficient and stable enough to be implantable in the blood stream where, upon consuming of glucose and oxygen, electricity will be generated to power implanted biomedical devices (pacemakers, biosensors, ear implants). Another option and research field is electricity harvesting from sweat or tears by less- or noninvasive biofuel cells, employing “wearable” electronics powering for example integrated (bio) sensors or small electronic devices. Ultimately, an integration of biofuel cells and biosensors has led to a development of self-powered biosensors. These devices can function as “conventional” biofuel cells, but their power output is dependent on the concentration of the “biofuel”/analyte.

Bioelectrocatalysts

Upon the capture, they are capable of cathodic bioelectrocatalysis and readable power output, in the analyse concentration-dependent manner is generated. Further modifications of abovementioned methods were also investigated and reported elsewhere. Devices where one of bioelectrocatalysts is inhibited by the analyte (e.g., laccase inhibition by arsenite/arsenate or cyanide) have been also described. The inhibition decreases the power generated by biofuel cell in a concentration-dependent manner allowing for determination of inhibiting species concentration. Affinity self- powered biosensors have been also fabricated. For example, biofuel cell with a sandwich assay-based biocathode modified with primary antibodies selectively capturing the analyte Nε(carboxymethyl) lysine. Nanoparticles modified with bilirubin oxidase (a cathodic biocatalyst) and secondary antibody is in the next step selectively captured on an electrode surface. All biofuel cell-based biosensors have one feature in common there is no need for maximization of power output since for the detection under the given conditions as low currents or potentials are required as in a case of biosensors.

This demand is typical also for other enzymatic devices biologic circuits, or smart biosensors with ability to perform simple Boolean logic tasks.The use of wearable devices is currently receiving a great deal of attention from the scientific community, society, and industry. Wearable devices are based on the use of wireless strategies for real time and non-invasive monitoring in many applications, with special relevance in health and fitness personalized monitoring. There are many types of wearable devices, including smart watches, wristbands, hearing aids, electronic/optical tattoos, head-mounted displays, subcutaneous sensors, electronic footwear, and electronic textiles. In this context, new trends in wearable devices lead to self-powered sensors that use energy harvesting approaches to obtain clean energy from bio fluids without impacting the environment. Thus, approaches such as enzymatic Biofuel Cells (BFCs) are extremely suitable to power this technology because they are able to produce energy by using molecules such as the glucose or lactate present in sweat, blood, or interstitial fluid.

This fact is especially important in the case of wearable and implantable devices because they should allow for mechanical deformations and be in continuous contact with the user. Hence, it is essential to use non-toxic and biocompatible materials to minimize the risk of epithelisation or allergic reactions. In most wearable and implantable devices, such as biosensors and BFCs, enzymes are included as an active redox catalyst; therefore, biocompatibility of the bio electrode materials is again an essential requirement, not only for their human usage, but also to maintain enzyme stability. In this sense, either for sensors, BFC development, or wearable electronics, specific requirements regarding body adaptation and biocompatibility of the materials is greatly needed for the efficient applicability of this technology so that it can be used by humans in a continuous way without losing their conductive and catalytic properties. Traditionally, non-miniaturized electronics was the most common approach to develop bioelectrodes for biosensors and BFC. However, they present low resistance to deformation and, therefore, flexible materials come into play in the new trends for wearable development due to their superior mechanical properties. To achieve the targeted mechanical stability, flexible electrodes require the introduction of features such as stretchability in order to endure mechanical strain during regular use, or biocompatible features in order to enable their use in human tissues.

Conductive Polymers

PPY is another common conductive polymer used in the development of bioelectrodes. It presents a good ability for composite formation and it is biocompatible, but it is fragile, and the synthesis procedure often involves toxic reagents. Conductive polymers such as polyaniline, polypyrrole, polythiophene , and polyethylenedioxide thiophene have been widely used for bioelectrode development due to their biocompatibility and conductivity and the presence of tunable functionalities. However, their application in biodevices is limited for different reasons. In the case of PANI, it is one of the most common conductive polymers used in biosensors. Conductivity can reach 100 S/cm when doped and presents good selectivity, sensitivity, and biocompatibility; however, the polymer is not active at neutral pH, which hinders its application for bioelectrodes development. PT has good optical properties, and conductivity can reach 10 S/cm if doped. PT is biocompatible if co-polymerized but presents a low mechanical integrity, which prevents its application in biosensing or for energy harvesting purposes.

Finally, PEDOT is one of the most promising conductive polymers for bioelectrode development because it is biocompatible and presents good solubility properties if doped with PSS in order to avoid swelling and collapse in aqueous solutions. When doped with PSS, conductivity can reach up to 200 S/cm. But PEDOT synthesis usually involves the use of toxic reagents and complex procedures that are difficult to implement out of the lab scale.