WEP Warwick Evans Publishing

Transactions on Materials, Biotechnology and Life Sciences
ISSN: 2960-1932, eISSN: 2960-2319 | Volume 7
MISBP 2024

Preparation and Application of MOF-Based Electrochemical Sensors for Biomedical Detection

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Abstract. In the field of biomedicine, sensor technology has become an ideal tool for health monitoring and medical services. Electrochemical methods are the most promising candidate technology for the detection due to their simplicity, high sensitivity and specificity. Electrochemical sensors ingeniously combine electrochemical technology with sensor technology. This kind of sensors can achieve efficient and accurate detection. The combination of health monitoring and big data technology poses new requirements for sensors. Achieving high precision, specific identification, and real-time monitoring have become the research directions of electrochemical sensors. Many new functional materials are used to modify electrodes to achieve these functions. Metal-organic frameworks (MOFs) have attracted a lot of attention in the last 20 years because of their special structure which gives them a great range of applications. This porous material helps the electrode capture target molecules, thereby achieving improved sensitivity. In recent years, there are an increasing amount of researches on MOF-based electrochemical sensors. Therefore, this work focuses on the discussion of electrochemical sensors and MOFs. In addition, electrochemical sensors based on MOFs for biomedical detection have also been summarized. This work will promote the application of sensor technology in health monitoring and biomedicine.

Keywords: Sensors; MOFs; Biomedicine; Detection; Electrodes.

1. Introduction

Nowadays, technology is advancing rapidly, with the appear of more new equipment for production and testing. In this case, there is an increasing demand for testing methods. Sensors are important devices for detecting the conditions and properties of substances. There are various types of sensors, such as temperature sensors, gas sensors, and biosensors [1-3]. These devices are used in different areas.

Especially in the realm of biomedicine, chemical sensors such as gas sensors and electrochemical sensors are very important. They make a significant contribution to the detection of biomedicine. The sensors that are most useful for detecting characteristics such as the nature of substances are electrochemical sensors. Moreover, the electrochemical sensors which are based on metal-organic frameworks (MOFs) are a good choice for biomedical detection.

In this article, electrochemical sensors based on MOFs are introduced and their characteristics will be presented in various aspects. Therefore, electrochemistry is briefly introduced, followed by the background of electrochemical sensors, including their structures, advantages and disadvantages. After understanding electrochemical sensors, the article will move on to the preparation of electrochemical sensors. Among the materials which are used to prepare electrochemical sensors, MOFs material is worthy of being explored. Because of the special structure, MOFs can improve the accuracy and sensitivity of electrochemical sensors [4-6]. Therefore, the properties and structure of MOFs will be investigated. Besides, the electrochemical sensors based on MOFs will be used in biomedical and it will be compared with other sensors to highlight the advantages.

2. Electrochemical Sensors and MOFs

2.1. Electrochemical Sensors

Electrochemistry means the transfer of charge from an electrode to another phase. The chemical change takes place at the electrode and the charge proceeds through most of the phases of the sample, carrying out the chemical reaction afterwards as a basis for the sensing process.

An electrochemical sensor is a sensor that is produced by an electrochemical reaction. The first electrochemical sensors appeared in the 1950s for monitoring gases such as oxygen. After continuous updating and optimization in the 1980s, electrochemical sensors were used for the detection of a number of toxic gases and demonstrated good accuracy. It is a new branch in the field of sensor technology which combines biological and electronic detection techniques. The electrochemical sensor is a type of sensor that has emerged based on electrochemical principles. It consists of hydrophobic membranes, electrodes, electrolytes, filters and other important components. It receives and detects the nature and concentration of the object by testing an electrical signal generated by an electrochemical reaction.

As to the gas electrochemical sensor, the measured gas reacted firstly. The gas passes through tiny capillary-type openings. It interacted with the sensing electrode through a hydrophobic barrier layer for catalysis. Finally, after passing through the electrodes, a current which is proportional to the gas concentration will flow to the positive and negative electrodes. This current will determine the gas concentration to detect the state of the object. Electrochemical sensors are used in a wide range of applications, they can be used to measure humidity, chemicals, pollutant gases and biological DNA [1]. It can detect the state of the detected object in real time. Therefore, electrochemical sensors are very valuable for research.

However, electrochemical sensors still have some shortcomings. Firstly, it is very sensitive to temperature. It usually exhibits higher sensor readings at temperatures higher than 25 degrees. Secondly, it is easy to receive interference from other gases when measuring the gas concentration. In practice, the interference from other gases may be high, which may lead to incorrect data or false alarms. The third issue is longevity, which is about one to three years for electrochemical sensors. However, in practice, the lifetime may be reduced for a number of reasons such as temperature and pressure. The other gases mentioned above can also reduce the life of an electrochemical sensor to a certain extent, which is often unavoidable. There will also be a long-term shift in the data, which is expected to decline by about 2 per cent per month. So the priority for electrochemical sensors is to make them more stable and to reduce external influences on them.

2.2. Preparation of Electrochemical Sensors

Preparation of electrochemical sensors is the most fundamental process before performing electrochemical measurements. The preparation process is mainly divided into several parts.

The first step is to determine the composition of the electrode. The core of the electrochemical sensor is the electrode, so it is the most important part of the four steps. Different materials have different impacts on the electrochemical sensor, choosing the right material to form the electrode can enhance the sensitivity and accuracy of sensors.

The second step is the selection of the electrolyte to be used. The electrolyte provides ion exchange of the substance under test to facilitate electrochemical reaction generation during electrochemical sensor measurements. It is important to note that when selecting an electrolyte, attention should be paid to the stability of the electrolyte and whether it will have an effect on the electrodes. If an unsuitable electrolyte is selected, the accuracy of the sensor will be reduced. Sodium nitrate buffer solution is reported to be used as an electrolyte.

The third step is the analysis of the electrochemical reaction, in which the types and products of the electrochemical reaction need to be understood and determined. One of the available methods can be the constant potential method. After understanding the types and products of electrochemical reactions, it is the time to assemble the electrochemical sensors. This is also the final step in the preparation of electrochemical sensors. Once everything is assembled, the preparation of the electrochemical sensor is complete.

2.3. MOFs

MOFs materials have attracted a lot of attention in the last 20 years because of their special structure which gives them a great range of applications. MOFs are metal-organic frameworks which are polymers consisting of polydentate organic ligands and transition metal ions. It can be synthesized by a variety of methods, including hydrothermal method, slow diffusion, conventional heating, slow evaporation, mechanochemical and sonochemical method.

As a low density porous material, it is widely used in chemical industry to store methane and other gases. MOFs are also used in the separation of molecules, catalysis, and drugs carriers. However, the brittle nature of MOFs makes them difficult to be processed and recycled. At the same time, the type and number of functional groups carried by the organic molecular modules during the functionalized construction of MOFs have a very important influence on the diversity and nature of the structure of the target to be measured. Therefore, when MOFs are combined with electrochemical sensors, MOFs can enhance the selectivity and sensitivity of electrochemical sensors. This allows electrochemical sensors to measure the properties and states of objects more efficiently and accurately. So it is very suitable to put electrochemical sensors of MOFs materials into biomedicine.

2.4. Preparation of MOFs materials

MOFs materials are used in various fields because of their structure and function [4]. The preparation of MOFs materials is particularly important. Generally, the preparation of MOFs is determined by the type of metal, organic linker and the type of targeting agent. There are many methods to prepare MOFs materials such as hydrothermal synthesis, and ultrasonic method. However, electrochemical synthesis method is much better than the above methods. It has the advantages of rapid synthesis, good porosity and it can be prepared stably at constant temperature. It is a continuous synthesis of controlled particle morphology under mild reaction conditions and reduced solvent requirements. However, the disadvantages of this method are obvious. It has low yields and is prone to by-products due to external factors. Therefore, a better choice for the preparation of MOFs is the mechanochemical synthesis method, in which metal salts and organic ligands are mechanically milled to react, or mixed, and then MOFs are prepared at specific temperatures. This method not only reduces the environmental pollution caused by solvent volatilization, but also saves costs and allows for the preparation of large quantities of MOFs.

3. MOF-Based Electrochemical Sensors

Electrochemical methods are the most promising candidate technology due to their simplicity, high sensitivity and specificity. At the present time, electrochemical biosensors can be compatible with medical strategies. Meanwhile, they are reasonably priced. This makes electrochemical biosensors helpful in biomedicine, especially those sensors based on MOFs, which are very accurate and efficient in detection and other aspects.

Compared to other sensors, electrochemical sensors have significant advantages, such as they do not require high costs [5]. In addition, they do not require a lot of samples. They can detect and provide data with only a small amount of samples. Trace substances can be detected by using them.

In biomedical research, electrochemical sensors have additional features such as high sensitivity and selectivity when multiple sets of proteins or mobile undiluted samples are punctually destroyed. Moreover, it is possible to analyse the reaction of the detected substances in a reversible way and without the addition of exogenous reagents. It can accurately detect the status of the measured object without calibration and broadcast the display in real time. Electrochemical sensors can also be used for real-time detection of the patients in medical treatment to help doctors treat the patient better. Electrochemical sensors can detect viruses in the body through real-time DNA detection, allowing for effective prevention and treatment. At the same time, due to the working principle of electrochemical sensors, it can complete the detection without harming the patient, effectively preventing the influx of external viruses.

L-cysteine is an important alpha amino acid containing thiol groups, which plays many important roles in the body. It participates in protein synthesis, detoxification, and metabolism. L-cysteine can be found in many proteins in the human body [6, 7]. Hosseini et al. designed an electrochemical sensor based on nanoparticles combine with MOFs. This modified sensor is proved to have good detection performance in complex detection environments.

4. Conclusion

This article described the properties and applications of electrochemical biosensors and MOFs. Their advantages and disadvantages are also discussed. Electrochemical biosensors made of MOFs materials have advantages that many sensors do not have, and are ideally suited for use in biomedicine. The article introduced MOF-based electrochemical sensors in terms of detection situation, accuracy, demand economy and measurement conditions. This sensor bring an outstanding contribution to the biomedical field. Although it is very useful and has many advantages, it still has some disadvantages such as being susceptible to temperature, other gases and atmospheric pressure. All these factors can cause deviation in the results.

In the future, the electrochemical sensor will need to be upgraded in order to obtain accurate data and achieve real-time detection. Even though these situations are difficult, there are also challenges that need to be addressed in order to discover a better electric biosensor for the benefit of the world.

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