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Metal-Organic Frameworks: Performance, Fabrication, and Applications in Biosensors

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Abstract. Biosensors serve as key detection tools in many fields, such as clinical diagnosis, environmental monitoring and food safety. Although breakthroughs have been achieved in the field of sensor technology, related issues such as sensitivity, specificity and stability remain unresolved. Recent academic research has highlighted the significant prospects of metal-organic frameworks (MOFs) as potential solutions to these problems. The MOFs, which are composed of organic ligands and metal ions, have high surface area, adjustable pore size and excellent chemical versatility. By optimizing these characteristics, the sensitivity and selectivity of biosensors are improved, thereby improving their performance. This study analyzes the extensive research on MOF-based biosensors. This paper emphasizes their synthesis methods, functionalization strategies, and applications. Specifically, the application here is mainly in the detection of biomarkers of cancer and cardiovascular diseases. The role of MOFs-based biosensors in cell and tissue imaging is discussed as well. The goal of this research paper is to explain the latest research results and define potential areas of exploration for subsequent scientific research works. This work would contribute to improve MOF-based biosensing technology.

Keywords: Metal-Organic Frameworks (MOFs); Biosensors; Cancer Biomarkers; Cardiovascular Markers; Imaging Techniques.

1. Introduction

Research development in the area of biosensors plays a key function in clinical prognosis, environmental tracking and meal protection law. A selection of biosensors along with electrochemical, optical, and piezoelectric sensors were developed. It is carried out for the detection and quantification of specific substances. However, the demanding situations such as confined sensitivity, specificity, and stability frequently hinder overall performance improvement [1]. Newly developed substances and technology aimed toward improving the overall performance of biosensors have grown to be the point of interest of modern-day studies interest to meet the challenges encountered [2].

Metal-organic frameworks (MOFs) are increasingly becoming an innovative material inside the subject of biosensors. Metal ions or clusters, which are shaped by way of the coordination of natural ligands, construct a porous and multifunctional MOF framework [3]. The excessive surface region, adjustable pore size, and diverse chemical functions of MOFs lead to the desired materials for optimizing biosensor overall performance [4, 5]. Studies attention has been focused on MOF-based biosensors, which have attracted a good deal of interest due to their capacity to conquer current limitations and enhance detection abilities [6, 7].

This work specializes in the function and contribution of MOFs in promoting the development of biosensor technology. This research involves the introduction of MOFs and their technological refinement. It also examines the practicality and capability of those substances in detecting most cancers-associated biomarkers, coronary heart disorder markers, as well as imaging media. It aims to provide a complete evaluation of the development of MOF and outline future study directions for enhancing biosensor overall performance [8-10].

2. MOF-Based Materials

2.1. MOF Materials

MOFs are substances organized with the aid of combining metallic ions or clusters with natural ligands. They are characterized by means of the formation of rather porous crystalline structures. Those substances have a series of favorable properties.

Firstly, it has the property of high surface region. MOFs exhibit high surface place characteristics of more than 3000m²/g. The full-size surface of those materials comes from their porous shape, which presents numerous energetic websites for interaction with target analytes. By way of increasing their surface location, the overall performance of biosensors is advanced. It is executed by increasing the available binding sites for analytes, thereby enhancing sensitivity and detection limits.

Also, adjustable pore sizes is one of the most important properties it has. During the preparation processes of MOFs, the pore sizes may be adjusted by carefully selecting particular steel ions and organic connectors. MOFs can acquire selective intermolecular interactions for particular molecules because of their adjustable shapes. Researchers have designed MOFs with precise pore sizes to provide biosensors that can identify analytes in complicated matrix with high selectivity.

MOFs exhibit chemical versatility. The versatile chemical properties of MOFs enable them to mix exceptional useful metallic ions and ligands. This feature allows MOF materials to be designed for precise uses with the aid of adjusting their structures and properties, including hydrophobicity and charge. Therefore, MOFs materials can be designed as structures suitable for various environments according to requirements.

The specific recognition performance of MOFs make them perform well within the utility subject of biosensors because they can interact exactly with target analytes, which is important for reaching accurate and reliable measurements [1].

2.2. Functionalization Methods for MOFs

The purpose of useful modification of MOFs is to enhance their performance in precise occasions. There are numerous key techniques to gain this goal.

The ligand exchange is considered as a good way for MOFs to achieve functionalization. In MOFs, the procedure of replacing the authentic organic ligand with a brand new ligand with certain capabilities is known as ligand trade. Through this step, MOFs may be given extra chemical reactivity, or their interaction with particular goal analytes may be improved. The introduction of useful chemical groups including amino, carboxyl or thiol organizations can decorate the interaction between MOFs and unique organic molecules. Consequently, their performance within the subject of biosensing is drastically improved [2].

Subsequently, MOFs can also be modified by metal substitution. In the framework of MOFs, the metal ions can be alternatived. After substitution, the electronic properties and catalytic capabilities of MOFs are converted, thereby optimizing their model to detection biological objects precisely. According to previous reports, adopting this strategy in zinc based MOF sensors results in more sensitive detection of target substances [3].

Thirdly, chemical grafting is another key technique. Chemical change is done at the surface of MOFs to covalently bond specific useful molecules. In this way, their performance can be enhanced. With the help of this technology, molecules with specific identification, which include antibodies, enzymes, or nucleic acids, may be correctly introduced into the surface of MOFs. It is reported that MOFs exhibit good electrochemiluminescence when grafted with Ruthenium (II) complex. Using these modified MOFs for biosensors can achieve ultra sensitive performance [4].

Besides, post-synthetic modification (PSM) is also well acknowledged for the modification of MOFs. After the initial synthesis procedure, chemical modification of MOFs is carried out on MOFs, which maintains the original basic skeleton structure of MOFs. According to different bonding methods, PSM can be divided into two types which are covalent based PSM and coordination based PSM. This will be carried out through the use of technologies together with metal ion exchange or linker change. PSM can regulate its properties to enhance the overall performance of MOFs and make them more suitable for specific biosensing applications [5].

By these strategies, MOFs with specific properties can be generated, thereby improving their application effects in various biosensing fields.

3. Applications of MOF-Based Biosensors

3.1. Detection of Cancer Biomarkers

MOF-based biosensors have been confirmed of promising use in the detection of most cancer biomarkers. Right here are a number of the principles makes use of.

Prostate-precise antigen (PSA) is one of the essential biomarkers in the detection of prostate cancer. It is reported that biosensors based on MOFs were creatively designed to improve the sensitivity and accuracy of detecting antigens which are specific to the prostate. The new sensor performs better than the conventional detection methods thanks to the use of MOFs which can immobilize PSA antibodies. An early diagnosis can be conducted via the excessive-density reputation sites presented by using MOFs. It is reported that MOFs endow the biosensor with the performance of capture PSA [6].

Carcinoembryonic antigen (CEA) is a tumor marker that is linked to the presence of numerous malignant tumors. In the colorectal tumor prognosis and monitor process, detecting CEA can help monitor the progression of the disease. CEA usually increases with the occurrence of cancer. According to reports, the biosensor for detecting carcinoembryonic antigen showed high detection sensitivity after modification with MOFs, resulting in improved capture efficiency for CEA. The use of MOF based biosensors can achieve high sensitivity, rapid response, and low-cost detection of CEA [7].

Biosensors based on MOFs have super promise for the detection of most cancer biomarkers, which could lead to advanced diagnoses.

3.2. Detection of Cardiovascular Disease Markers

Biosensors constructed from MOFs have demonstrated exceptional efficacy in tracking biomarkers linked to cardiovascular disease. The following are some notable applications.

Firstly, the detection of cardiac troponin I (cTnI) is crucial in the diagnosis of myocardial infarction because it is a particular biomarker for this condition. Highly sensitive detection of cTnI has been achieved by the development of MOF-based biosensors. An early and specific diagnosis of coronary heart contamination is made viable by way of the precise detection of cTnI. With these upgraded sensors, the cardiovascular device may be monitored and handled more efficaciously [8]. Secondly, strategies for detecting B-type natriuretic peptide biomarker (BNP) play a vital role in the assessment of cardiac failure. The utility of biosensors based on MOFs is reported to enhance the efficiency of BNP detection. The mixing of positive recognition elements allowed for this to be achieved. When diagnosing and monitoring coronary heart failure, using MOF-based biosensors which can detect BNP are accurate and effective [9]. Besides, biosensors based on MOFs have the potential to improve patient care by facilitating speedy and precise analysis of cardiovascular illnesses.

3.3. Cell and Tissue Imaging

MOFs are used for imaging of cells and tissues due to their particular optical property and imaging talents.

Fluorescence imaging is one of the important applications of MOFs for biomedical imaging. Excessive-decision imaging era may be performed through functionalized MOFs. This technology uses fluorescent dyes or probes to conduct in-depth research on cells and tissues. MOFs with large surface areas can adsorb many fluorescent molecules, thereby achieving high-decision imaging technology. This MOF-based biosensor offers help for the tracking of biomarkers [10, 11].

MOFs can also be used in magnetic resonance imaging (MRI) and computed tomography (CT) imaging. MOFs combined with quantum dot materials exhibit strong fluorescence properties and are often used for imaging. By using metal ions with unique magnetic or X-ray absorption characteristics, MOFs can improve the comparison and clarity of photographs. This complements the accuracy of organic tissue imaging analysis and visualization, thereby facilitating more accurate diagnostic tactics [10].

Within the subject of imaging application, the utility of MOFs has found its multifaceted features. It greatly improves the efficiency of diagnostic and scientific research via imparting refined and enhanced pix of biological samples.

4. Conclusion

MOFs offer superb advantages when they are utilized in biosensor applications. MOFs have the characteristics of simple preparation and good biocompatibility. MOFs, due to their good sensitivity, selectivity, and stability, are applied in the detection of biomarkers associated with most cancers and cardiovascular ailments. In addition, MOFs can also be combined with materials with fluorescent properties for biomedical imaging. This highlights their giant contribution to clinical analysis and medical research. In the realm of MOF synthesis and functionalization, uninterrupted advancement is essential for overcoming novel analytical barriers and broadening the potential application realm of MOF-based biosensors.

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