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Review

Metal-organic frameworks for direct electrochemical applications

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ABSTRACT

Metal-organic frameworks are a class of functional porous materials. In recent years, metal-organic frameworks have become a hot research topic in the field of electrochemistry because of their controllable morphology, abundant pores, high specific surface area and versatility. Herein, we summarize the latest developments of metal-organic frameworks and metal-organic framework composites as electrode materials or catalysts for electrochemical applications such as batteries, supercapacitors, electrocatalysts and electrochemical sensors. The morphological and electrochemical properties of these promising metal-organic framework materials for their future development are discussed. Finally, based on the reported literature, we propose the future direction of metal-organic frameworks and metal-organic framework composites in the field of electrochemistry.

Contents

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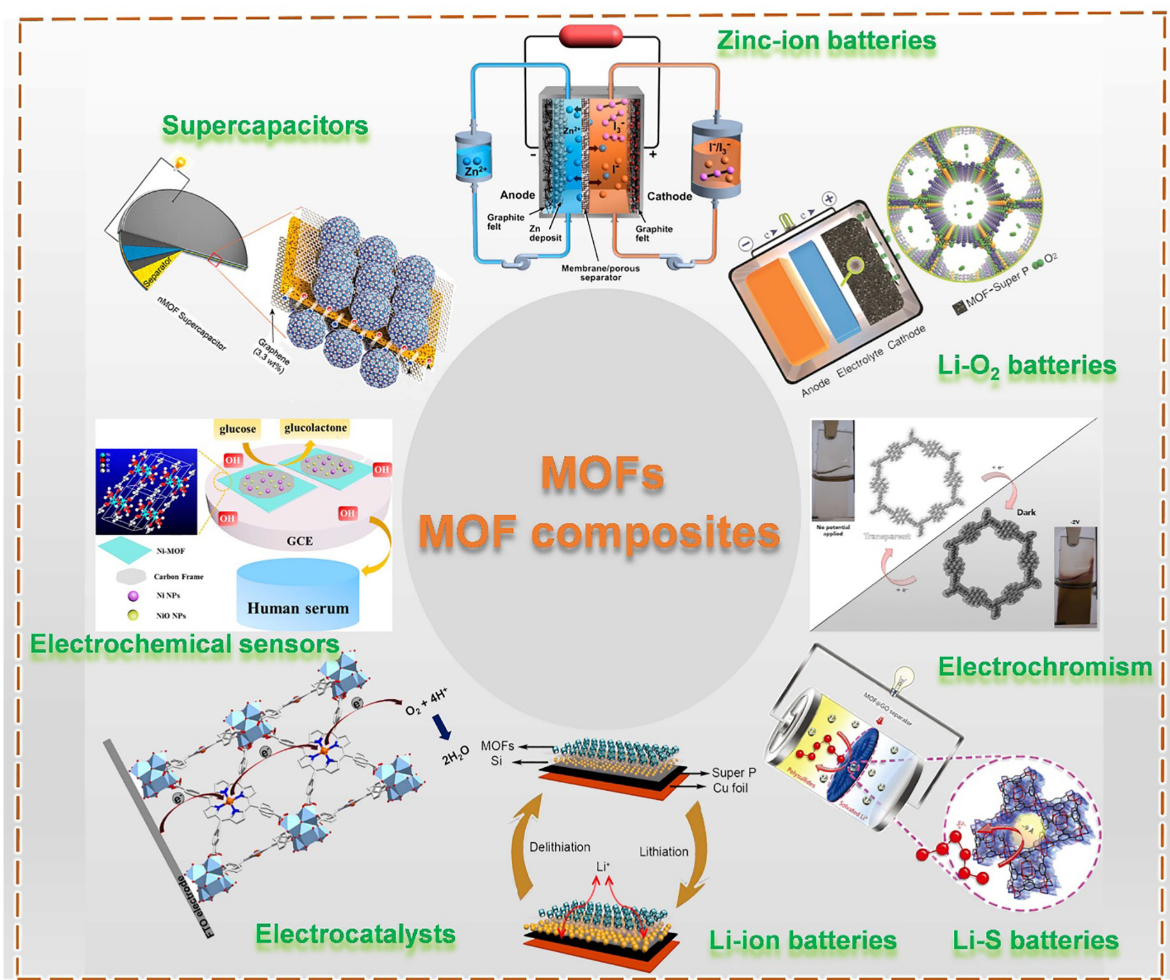
1. Introduction

Metal-organic frameworks (MOFs) are a new class of porous crystalline materials constructed by the coordination of metal ions/clusters and organic bridging ligands in a three-dimensional (3D) space [1,2]. MOFs have aroused widespread concern in the past few years and have now become one of the most rapidly developing areas of research. To date, more than 20,000 MOFs with different compositions, crystal structures and morphologies have been reported [3,4]. Because of their tailorable structure and functionality, high porosity and large internal surface area, MOFs have great potential in a variety of applications, such as gas storage [5–7], separation [8,9], catalysis [10–12], sensors [13,14], biomedicine [15,16], and so forth.

The applications of MOFs in electrochemistry have been reported by many researchers over the past few years because the specific surface area of MOFs usually ranges from 1000 to 10,000 $m^2\ g^{-1}$, which is higher than the surface area of most conventional porous materials. The pore size can be adjusted by altering the length of the organic ligand, for a maximum pore size of 9.8 nm [17,18]. For instance, in summaries of previous studies, some researchers have outlined the different synthetic methods of MOFs and have used MOFs as precursors to synthesize nanomaterials with various morphologies, such as nanoparticles, nanosheets, nanorods, nanospheres, etc [19–26]. Additionally, many researchers have summarized the latest research on the applications of nanostructured MOFs and MOF-derived materials in batteries and supercapacitors [27–32]. Although the design and application of MOFs have made great progress, but until recently, the potential of electrocatalysts have attracted the attention of researchers. They mainly study MOF-based materials as catalysts in important energy conversion electrochemical reactions including oxygen reduction (ORR), oxygen evolution reaction (OER) and hydrogen evolution reaction (HER) as well as MOF-based materials in lithium-air batteries and carbon dioxide reduction for new progress in electrochemical applications [33–35]. Among different MOFs applications, MOF-based electrochemical sensors are a hopeful application. In recent years, some researchers have discussed the application of MOFs and their derivatives in sensors [14,36].

In this review, we provide an overview and comment on the recent progress of MOFs in batteries (lithium-ion batteries (LIBs), lithium-sulfur (Li-S) batteries, lithium-oxygen (Li-O_2) batteries, sodium-ion batteries (SIBs), etc.), supercapacitors, electrocatalysts, electrochemical sensors, and so on. A schematic diagram is shown in Scheme 1. Similarly, a few earlier reviews reported the applications of MOFs or their derivatives. For example, Morozan et al. [37] reviewed the applications of MOFs and MOF-derived materials in the field of electrochemistry. Moreover, Wang and co-workers also applied MOFs to energy storage (batteries, supercapacitors) [38,39]. In recent years, Xu's group has focused on the development of MOFs and their derivatives for clean energy applications, including batteries, supercapacitor, catalysis, and so on [1,35,40–44]. In addition, some researchers have reported



Scheme 1. The schematic diagram of MOFs and MOF composites for electrochemical application.