Metal–Organic Framework Materials for High‐Capacity and Thermal‐Regulating Lithium‐Ion Battery Anodes

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Abstract. Metal–organic framework (MOF)‐based anodes offer a unique combination of high surface area, tunable porosity, and uniformly distributed active sites. This enables rapid lithium‐ion diffusion and robust accommodation of volumetric changes during cycling. Among these materials, zeolite‐type imidazolate frameworks (ZIFs) distinguish themselves through their zeolite‐like topology, ultra‐porosity, and exceptional thermal and chemical stability, providing a rigid yet open scaffold for reversible lithium storage. Likewise, MIL‐type frameworks leverage flexible metal–carboxylate linkages to form stable solid‐electrolyte interface layers, yielding high Coulombic efficiency and prolonged cycle life. However, the practical implementation of pristine MOF anodes is hampered by inherently low electronic conductivity, framework degradation via repeated ligand coordination, and cost‐intensive, multi‐step synthesis protocols. To address these challenges, recent strategies include thermal carbonization to generate metal‐oxide/carbon composites, hybridization with conductive networks such as graphene or carbon nanotubes to create core–shell or three‐dimensional architectures, and heteroatom doping to introduce additional redox‐active centers. Concurrently, simplified, room‐temperature or microwave‐assisted one‐pot syntheses using inexpensive precursors promise to enhance scalability and reduce environmental impact. By surmounting conductivity, stability, and manufacturability issues, MOF‐derived anodes hold significant promise for next‐generation lithium‐ion batteries, offering improvements in energy density, rate capability, and thermal safety critical for electric vehicles and grid‐scale energy storage.

Keywords: Metal–Organic Framework; Lithium‐Ion Battery; Anodes; review.

1. Introduction

As global attention to environmental pollution and sustainability has increased, the global energy mix has transitioned to low-carbon. To reduce air pollution caused by transportation, governments have started to call for low-carbon mobility and support the development of electric vehicles through funding and policies, which has led to an increasing demand for EVs [1]. EVs are popular due to their zero emissions and high energy conversion rates, but electric vehicles still face problems such as bulky size and weight. These problems are due to the low energy density of the batteries equipped with the current EVs. In order to achieve a sufficient range, it is necessary to expand the battery volume, which directly leads to the EVs being unable to solve the volume problem. Moreover, ensuring energy density, safety, and economy is essential to searching for new alternative materials. Lithium batteries are probably used most in EVs. Still, this kind of battery, the ternary lithium battery, has a high energy density that significantly improves the whole vehicle range. Still, high energy density often means higher heat release, which requires the design to be equipped with a highly efficient thermal management system to protect the safety of the battery in the high-speed charging and discharging process. Therefore, traditional graphite anode materials are gradually showing their limitations in terms of structural stability, cycle life, and environmental friendliness in order to meet the future demands of high-performance batteries, such as higher energy density, better safety, and lower cost. Therefore, finding ways to expand the energy density of EVs while emphasizing safety and economy has been a hot research topic.

As the technology of lithium-ion batteries continues to advance, the need for anode materials in battery systems has expanded beyond high specific capacity to include extended cycle life, thermal stability, and strong overall performance in high-rate discharge. Though its theoretical specific capacity is at the top limit and lithium dendrites, which are needle-like structures that can form on the surface of the lithium anode during rapid charging and discharging, are prone to growing, traditional graphite offers specific benefits in terms of electrical conductivity and structural stability, which presents safety hazards. Researchers have focused on novel materials with distinct pore structures and modifiable chemical compositions to address these issues; metal-organic frameworks (MOFs) have garnered significant interest among these materials because of their superior structural manipulation and chemical variety [2]. Currently, research into developing new materials focuses on achieving a balance between high energy density and high cycling reliability by improving the electrode structure, optimizing the synthesis process, and regulating the electrode-electrolyte interface reaction [3].

Metal-organic framework (MOF) materials are created when metal ions or clusters self-assemble with organic ligands through ligand bonding. They have a special porous structure that is excellent at ion diffusion, interfacial reactions, and structural stability, and offers many active sites for improved ion storage. MOF synthesis processes are typically conducted in milder climates than graphite materials, can use renewable raw materials, have a more minor environmental impact, and employ more environmentally friendly production and disposal methods, which can simultaneously balance cost-effectiveness and green manufacturing. Cao et al. employed a one-step solvothermal method to synthesize hexagonal Ni-MOF composites with conductive carbon, achieving a high specific capacitance of 977.04 F g^{-1} at 0.5 A g^{-1} and retaining 92.34% capacity after 5000 cycles, demonstrating MOFs' advantages in high capacity and excellent cycling stability as battery anodes [4]. Wang et al. prepared mesoporous-rich nitrogen-doped carbon@graphene nanosheets, exhibiting high specific capacity and excellent long cycle life compared to the melamine-unmodified anode [5]. These composites combine the high surface area of MOFs with the exceptional conductivity of graphene, providing abundant electrochemically active sites and rapid electron/ion transport pathways, thereby significantly enhancing lithium-ion battery performance. Ye et al. pyrolyzed a metal-organic framework to produce 0.5 nm microporous carbon. As a sodium-ion battery anode, it delivers significantly higher capacity and better cycling reversibility, greatly reducing first-cycle irreversible capacity loss and enhancing Na^+ storage reversibility [6].

This paper discussed the implementation of various metal-organic framework composites in the thermal management system of new energy vehicle batteries. It comprehensively analyzed the advantages and shortcomings of different material systems and synthesis processes by systematically comparing thermal conductivity, phase transition temperature, engineering feasibility, and other performance indicators. This paper was divided into five parts: 1. The introduction explained the comprehensive advantages of metal-organic framework (MOF) materials in battery anode application by adjustable porous structure, high specific capacity, and cycling stability, as well as a green and low-carbon synthesis process, 2. Case descriptions were divided into the definition of Zeolitic Imidazolate Framework (ZIF), the definition of MOF, and the definition of Materials of Institut Lavoisier (MIL), which introduce the synthesis methods, structural characteristics, and the application of the three typical MOF materials in the anode of the battery, respectively. Problem analysis would be carried out to compare the pore structure, conductivity, cycle stability, and thermal management performance of various materials, and analyze the main bottlenecks. 4. Suggestions would be made based on the previous analysis to propose improvement ideas, and a visual comparison of the advantages and disadvantages of different materials and synthesis processes would be made through the form of tables. 5. Conclusion summarized the results of the research, and concluded that the comprehensive advantages of MOF materials in terms of improving the energy density, cycle life, and safety of batteries, as well as the outlook. 6. The research results were summarized, and the advantages of MOF materials in improving energy density, cycle life, and safety of batteries are summarized, and the future development direction was anticipated.

2. Case description

2.1. Metal-organic frameworks

Metal-organic frameworks (MOFs) are a class of porous polymers consisting of metal clusters coordinated with organic ligands to form one-, two-, or three-dimensional structures. The main syntheses of MOFs include high-throughput solvothermal synthesis, chemical vapor deposition synthesis, and pseudomorphic replication. These materials are structurally well-defined, diversified, and designable, have a large specific surface area and porous structure, and are biocompatible. MOF is widely used in gas storage and separation, water capture, pollutant adsorption, fluorescence sensing, catalysis, and supercapacitors. It shows great potential in environmental purification and energy conversion. Meanwhile, it has important application prospects in pharmaceutical and biotechnology, such as drug delivery and bioimaging. In catalysis, MOFs have been widely used in organic multiphase catalysis, photocatalysis, electrocatalysis, and advanced oxidation due to their crystalline porosity, flexible modifiability, and large specific surface area. The oxidation and reduction reactions catalyzed by MOFs are mainly catalyzed by unsaturated metal sites, functional catalysis of organic ligands, and catalytically active guest molecules encapsulation.

2.2. Zeolitic Imidazolate Framework

ZIF (Zeolitic Imidazolate Framework) is a subclass of MOFs, a tetrahedral framework formed by the self-assembly of transition metal ions with imidazole or its derivatives via ligand bonding, and is isomorphic to the zeolite topology. ZIFs are mainly prepared using solvothermal or hydrothermal techniques. This material has a homogeneous microporous structure and high specific surface area, characterized by high stability, high porosity, and organic functionality. Due to its substantial porosity, resistance to thermal changes, and chemical stability, ZIF exhibits excellent selectivity in gas adsorption, storage, and separation and has also been widely used in catalytic and sensing applications, providing a new multifunctional material option for energy, environmental, and other application scenarios.

2.3. 2.3 Materials of Institut Lavoisier

MILs (Materials of Institut Lavoisier) are a prominent sub-family of metal-organic frameworks (MOFs): they consist of porous metal carboxylates built from trivalent metal cations (e.g., Cr^{3+}, Fe^{3+}, Al^{3+}) and multidentate carboxylic acid ligands, which assemble into highly ordered frameworks with large, permanent pores. Like other MOFs, MILs combine an exceptionally high specific surface area with tunable pore size and open metal sites, giving rise to a pronounced “breathing” behavior and outstanding structural stability. Thanks to these features, MIL-type MOFs have been extensively applied to gas storage and separation, catalytic conversion, drug delivery, and environmental remediation. Moreover, in photocatalysis, their open metal centers and accessible pores facilitate efficient separation and transport of photogenerated charge carriers, enabling rapid degradation of organic pollutants and effective energy-conversion processes.

3. Analysis & Challenge

3.1. Metal-organic frameworks as LIBs Anodes

In general, most of the MOF materials were prepared using solvothermal methods. For example, Si@MOF-c, a composite electrode material with MOF-derived carbon as the matrix and nanosilicon coated inside, was prepared as follows: multilayer electrodes were assembled by casting a thin carbon nanotube (Super P) and sodium alginate cushion layer, followed by a silicon layer (80 wt% Si, 10 wt% binder, 10 wt% Super P) in micropatterned slits. These were then capped with a layer of MOF-74 or MOF-199 (90 wt%) with PVDF binder (10 wt%). Upon pyrolysis (800 °C, 3 h), the MOF layer carbonized to form a conductive matrix embedding 0.5–1.0 g nanoscale Si particles within MOF-

derived carbon. The final slurry (80 wt% active Si@MOF-c, 10% binder, 10% Super P) was cast into electrodes (~2.2 mg·cm^{-2} loading) and paired with lithium metal for half-cell tests [7]. The prepared electrode and synthesis process were shown in Fig.1:

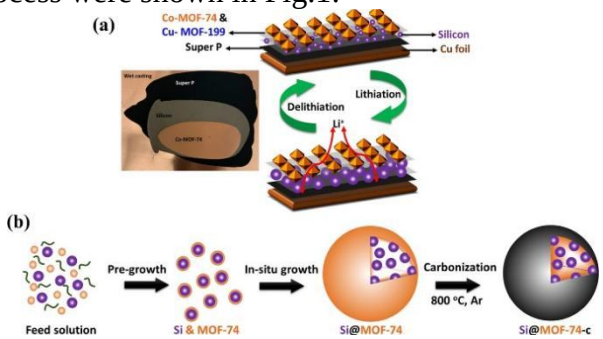

Fig. 1 Schematic illustration of synthesis of (a) multilayer Sandwich and (b) carbonized composite matrix "encapsulation" configurations [7].

As shown in Fig. 2. The Si@MOF-c composites exhibit exceptional energy density and cycling stability. The 0.5Si@MOF-c electrode (~2.2 mg cm^{-2} loading) delivers an initial reversible capacity of ~1,000 mAh g^{-1} and retains 60% (~600 mAh g^{-1}) after 100 cycles at C/10, outperforming a 20Si-10CMC baseline (40% retention). The 1.0Si@MOF-c variant achieves ~1,900 mAh g^{-1} initially and still holds 1,200 mAh g^{-1} after 20 cycles—quadruple the 300 mAh g^{-1} in prior Zn-based Si@MOF-c. Rate tests show 0.5Si@MOF-c maintains ~800 mAh g^{-1} when returned to C/10 after 2 C. High loading, sustained capacity, and superior Coulombic efficiency underscore Si@MOF-c's advantage in boosting battery energy density [7]. MOF exhibit exceptional thermal stability and tunable decomposition behavior, making them highly effective as flame retardants by promoting char formation, suppressing heat release, and enhancing fire resistance in polymeric matrices [8].

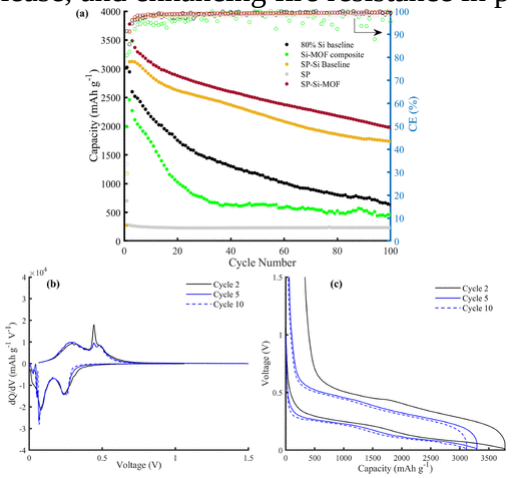

Fig. 2 :(a) Active material discharge capacity for sandwich configuration electrodes with a thick Si loading. MOF-74 used for all electrodes. dQ/dV plot and potential profile for (b, c) the SP-Si-MOF sandwich [7].

Metal–organic frameworks (MOFs) offer exceptional porosity and tunable pore structures for hosting lithium ions, yet their implementation in electrodes and separators faces critical hurdles. First, MOFs' intrinsically low electrical conductivity and limited chemical robustness under repeated lithiation/delithiation cycles restrict achievable capacity and long-term stability. Second, MOF-derived carbon composites often suffer from poor graphitization at moderate pyrolysis temperatures, resulting in high charge-transfer resistance and degraded rate performance. Third, while MOF coatings can elevate separator shrinkage temperatures, achieving uniform, defect-free coatings with strong interfacial adhesion remains challenging, complicating roll-to-roll manufacturing and raising production costs [9]. Furthermore, many MOFs exhibit moisture sensitivity, leading to pore collapse in humid conditions and undermining thermal stability and ion transport. Finally, the high cost of metal centers, organic linkers, and complex synthesis routes hinders large-scale commercialization.

Overcoming these challenges requires rational design of conductive MOF composites, optimized pyrolysis protocols, and scalable, robust coating strategies.

3.2. Zeolitic Imidazolate Framework as LIBs Anodes

There are many ways to prepare ZIF materials, and the following experiments used room temperature solution co-precipitation to prepare ZIF-8 analogues (FZIF10 and CF_3ZIF10) and pristine ZIF-8. Fluorinated ZIF-8 analogues (FZIF10 and CF_3ZIF10) and pristine ZIF-8 were prepared by dissolving 2-methylimidazole (MeImz) and either fluorinated imidazole (10 mol% FImz or CF_3Imz) or MeImz alone, along with $Zn(NO_3)_2 \cdot 6H_2O$ in a 1:1 MeOH/H_2O mixture (3 mL). The solution was stirred at 350 rpm for 5 min at room temperature, then left undisturbed for 24 h to grow nanoparticles. Crystals were collected by centrifugation, washed three times with methanol, dried at 80 °C overnight, and activated at 120 °C for 6 h. A 10× scale-up preserved product quality. Characterization encompassed SEM, laboratory, and synchrotron PXRD (with Rietveld refinement), $^1H/^{19}F$ NMR after acid digestion to confirm linker incorporation, DLS for size distribution, and N_2/H_2O physisorption for porosity. Water intrusion/extrusion tests were performed over five cycles in a porosimeter (up to 50 MPa), with post-cycle PXRD to assess structural stability [10].

Using a simple room-temperature, one-pot mixed-linker method with water/methanol, ZIF-8 and its fluorinated analogues (FZIF10, CF_3ZIF10) were synthesized as uniform rhombic dodecahedral nanoparticles (~90–220 nm) with high yields (> 80 %). Fluorination increases hydrophobicity and intrusion pressure (up to 28.4 MPa), while controlled linker incorporation preserves crystallinity, microporosity (BET > 1300 $m^2\ g^{-1}$), and reversibility (dissipation < 25 %). PV-isotherms reveal high intrusion volumes (0.27–0.37 $cm^3\ g^{-1}$) with narrow hysteresis, functioning as nearly-ideal molecular springs. The synthesis result was shown in Fig. 3. Both fluorinated ZIFs sustain five consecutive H_2O intrusion/extrusion cycles without structural degradation, as confirmed by PXRD. This combination of high pressure tolerance, reversible energy storage, and cycling stability underscores ZIF materials' potential to enhance energy density in battery and mechanical energy storage systems [10]. Using structurally compatible straight-chain cosolvents in ZIF-8 synthesis produces single-phase, defect-free nanocrystals that exhibit minimal guest/moisture loss and maintain exceptional structural integrity up to 800 °C, delivering markedly enhanced thermal stability [11].

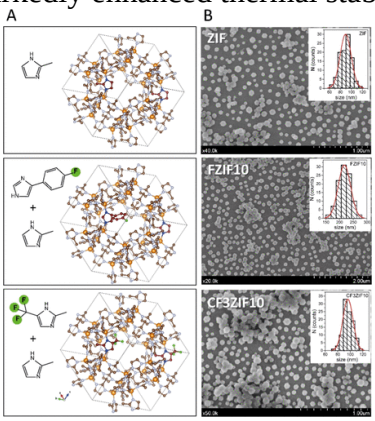

Fig. 3 (A) Illustration of the 3D structures of the different ZIFs evaluated. (B) Representative SEM micrographs of the as-prepared ZIF, FZIF10, and CF3ZIF10 particles. Inset: Histograms of the particle size distribution (idealized as spherical particles) [10]

Despite their high surface area, tunable porosity, and thermal stability, ZIFs face challenges as lithium battery anode materials. Their intrinsic electrical conductivity is extremely low, necessitating conductive additives that increase fabrication complexity and cost. While high porosity enhances ion diffusion, it lowers tap and volumetric energy densities. During cycling, framework collapse and pore blockage occur, especially under high-rate and deep discharge, leading to rapid capacity decay. The large surface area accelerates electrolyte decomposition and thick SEI formation, resulting in low initial coulombic efficiency. Furthermore, ZIF synthesis often relies on organic solvents and high-temperature treatments, hindering scalability and costs. Variability in performance arises from

differences in ligand and metal-node batches. Finally, typical battery operating temperatures are far below ZIFs' thermal stability range, limiting thermal protection benefits. To commercialize ZIF anodes, breakthroughs in conductivity, density, cycling stability, and cost-effective processing are essential.

3.3. Materials of Institute as LIB

A typic MIL for anode application, MIL-101(Cr), is synthesized via a hydrothermal route: an aqueous solution of a chromium salt (e.g., $Cr(NO_3)_3 \cdot 9H_2O$) and terephthalic acid (1,4-benzenedicarboxylic acid) is acidified—with HF or HCl—then sealed in an autoclave and heated to 200–220 °C for 8–12 h. During this process, cr^{3+} clusters coordinate with the dicarboxylate ligands to form green, octahedral crystals. After cooling, the solid product is recovered by filtration or centrifugation, washed repeatedly with water and DMF to remove unreacted linker and by-products, and then solvent-exchanged (e.g., with ethanol) to displace guests from the pores. Finally, the material is activated under vacuum at 120–150 °C, yielding a high-surface-area, thermally stable MIL-101 framework optimized for gas adsorption applications [12]. The Configuration process for MIL-101(Cr) was shown in Fig.4

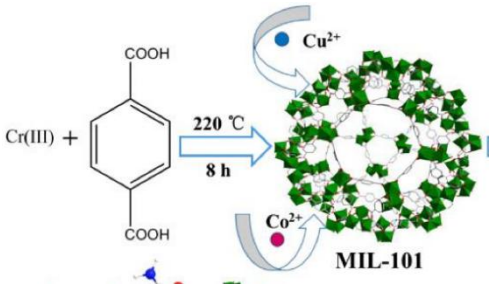

Fig. 4: Configuration process for MIL-101 materials [13]

Several MIL-type MOFs—particularly MIL-53(Fe), MIL-68(Fe), and MIL-101(Fe)—combine robust thermal stability, tunable pore architectures, and abundant Fe^{3+}/Fe^{2+} redox centers to enhance lithium-ion storage. For example, MIL-53(Fe) reversibly inserts about 0.6 Li^+ per Fe at C/40, corresponding to ~75 mAh g^{-1}, and rises to ~93 mAh g^{-1} upon adsorption of 1,4-benzoquinone. Similarly, MIL-101(Fe) accommodates ~0.62 Li^+ per Fe, while MIL-68(Fe) delivers a lower yet appreciable capacity. The well-defined crystalline pores in these frameworks facilitate rapid ion diffusion and preserve structural integrity during cycling, yielding moderate areal and gravimetric capacity improvements. These features establish MIL materials as promising candidates for next-generation, high-density cathodes [12]. What's more, MIL materials such as MIL-53(Fe), MIL-68(Fe), and MIL-101(Fe), synthesized via solvothermal methods and confirmed by thermogravimetric analysis, demonstrate excellent thermal stability while enabling reversible lithium-ion insertion, marking a milestone in MOF-based cathode development [14].

Although MIL-type MOFs boast high porosity and versatile redox chemistry, their deployment as lithium-ion battery anodes is hindered by three interrelated challenges. First, the intrinsic electronic conductivity of MIL frameworks is extremely low, forcing the incorporation of large amounts of conductive additives that dilute the active material and restrict practical areal capacity. Second, repeated lithiation and delithiation induce significant volumetric changes that compromise the fragile MOF architecture, causing pore collapse, rapid capacity fade, and shortened cycle life. Finally, the inherently low tap density of MIL powders limits volumetric energy density, while the complex solvothermal synthesis, extensive solvent-exchange steps, and thermal activation protocols, which typically peak below 400 °C, drive up production costs and impede large-scale manufacturing. Overcoming these hurdles through materials engineering and process optimization is essential to realize MIL-based anodes with high energy density and thermal robustness.

4. Summary

The advantages of metal-organic frameworks (MOFs) include their large interfacial area and tunable pores, which facilitate electrolyte access and provide numerous active sites for lithium ions. Their metal centers and ligands can participate in additional redox reactions, providing more capacity. MOFs can also be used as templates or precursors for composite anodes. However, MOF materials have drawbacks that cannot be ignored. The main problems with MOF are extremely low conductivity and poor cycling stability. Many MOFs may collapse or dissolve in the electrolyte, and their large pore size also reduces bulk energy density and may lower initial Coulombic efficiency. Conductivity and stability can be improved by complexing with conductive additives or carbonizing MOF into porous carbon/metal oxide complexes. Designing conducting ligands or doping mixed valence metals can also enhance electron transport. Nanosizing or introducing flexible structures can shorten the ion diffusion path and provide a buffer for volume changes.

Regarding the advantages of ZIF materials, ZIFs are typically chemically and thermodynamically stable, have a uniform microporous structure, and an extremely high specific surface area. The nitrogen atoms in the ligands can form nitrogen-doped carbon at high temperatures, improving the material conductivity. Such properties allow ZIF-derived materials to provide a uniform distribution of active components, which, upon conversion to nitrogen-doped carbon/metal oxide complexes, tend to achieve high specific capacities. The disadvantages are that ZIF crystals still suffer from poor conductivity and limited lithium transport because of their compact microporous structure. Unmodified ZIF cannot store lithium directly, so most anode applications rely on its derivatives. ZIF may undergo partial decomposition or loss of active material during cycling, resulting in capacity degradation. These drawbacks can be ameliorated by converting ZIF into a conductive nitrogen-doped carbon framework by heat treatment, which “locks” the metal or metal oxide nanoparticles in place. Composites of ZIF with conductive substrates or bimetallic ZIFs can also improve electron transport efficiency. Constructing hierarchical pore or hollow structures in ZIF-derived composites can help change lithium-ion diffusion and buffer volume. Even amorphous (glassy) ZIF phases have shown better cycling stability, and could be explored for future anode designs.

MIL frameworks can hold large amounts of reactive metal ions. They generate porous metal oxide/carbon complexes that exhibit very high lithium capacity and good cycling stability upon thermal treatment. Some MILs are more stable in the chemical environment and provide abundant channels for ion diffusion. However, like other MOFs, pure MIL crystals have low electrical conductivity and are prone to pulverization during cycling. The high metal content reduces the mass-energy density, while the dramatic increase in the volume of metal oxides causes mechanical stress and leads to structural instability. Suggested strategies to improve MIL-based anodes include constructing hierarchical hollow or core-shell structures. For example, carbonizing MIL-101 into hollow Fe_2O_3@C particles can buffer volume changes and shorten ion diffusion paths. In addition, loading conductive elements (e.g., Ni or Co nanoparticles) in MIL frameworks has significantly improved electrical conductivity. It has been found that high reversible capacity and stable cycling of nearly 900 mAh/g can be obtained after loading Ni/NiO nanoparticles on MIL-101. Polymetallic doping or carbon/graphene coating of MIL can also enhance the structural stability. These modifications help to fully utilize the high-capacity potential of MIL materials.

Those advantages and disadvantages are concluded in Table. 1. Future research on MOF-based anode materials will focus on improving conductivity, cycling stability, and scalable production. Hybrid electrodes combining MOF with high-capacity materials, such as silicon, sulfur, or other metal oxides, can utilize the porous nature of MOF to control volume changes and enhance energy density. At the same time, the research will also focus on practical issues: simplifying the synthesis process, reducing costs, enhancing environmental stability, and validating long-term cycling performance to make MOF, ZIF, and MIL-based anodes viable technologies for next-generation batteries.

Table. 1 Comparing of various Metal–Organic Framework Materials in anodes

Type	Advantages	Disadvantages
MOF	-High surface area -tunable pores -redox-active	-Poor conductivity -Instability -low volumetric density
ZIF	-Stable micropores -converts to N-doped carbon -uniform dispersion	-Insulating -limited Li transport -capacity fade
MIL	-Abundant redox -fast ion diffusion	-Low conductivity -low energy density

5. Conclusion

In conclusion, MOF's anodes combine unique structural and electrochemical properties with excellent lithium storage performance. Their ultra-high surface area, precisely tunable pore network, and uniformly distributed active sites facilitate rapid lithium diffusion and accommodate large fluctuations during cycling. Among the MOF family, zeolite-type imidazolate frameworks (ZIFs) stand out for their zeolite-like topology, ultra-porosity, and remarkable thermal and chemical resilience, providing a rigid but open scaffold for reversible lithium storage. Similarly, MIL-type frameworks (e.g., MIL-88, MIL-101) with flexible metal carboxylate backbones can support the formation of stable solid-state electrolyte interphase layers for high Coulombic efficiencies and extended cycle life.

However, several issues must be overcome before widespread use of MOF anodes can be realized. Pristine MOFs typically exhibit poor intrinsic conductivity and must therefore rely on conductive additives or post-synthetic processing. Their delicate ligand bonds are subject to repeated petrochemistry and depetrochemistry, leading to framework degradation, pore collapse, and irreversible capacity loss. In addition, conventional MOF synthesis methods typically require multiple solvent exchanges, high temperatures, and long reaction times, which raises issues of cost, scalability, and environmental impact. Therefore, realizing the full potential of MOF anodes in commercial lithium-ion batteries remains a formidable challenge.

To address these obstacles, current research is seeking several synergistic strategies. Thermal carbonization transform MOF into metal-oxide/carbon composites, thereby significantly improving electronic conductivity and mechanical integrity. Hybridizing MOF with conductive matrices such as graphene or carbon nanotubes can produce layered core-shell or three-dimensional structures that buffer volume changes and accelerate ion/electron transport. Introducing dopants or heteroatoms with redox activity can create new charge storage sites and facilitate electron hopping. At the same time, simplified synthesis through one-pot, room-temperature, or microwave-assisted schemes using inexpensive precursors is expected to reduce fabrication complexity and cost.

In summary, MOF-derived anodes combine the advantages of high porosity, chemical versatility, and emerging electrochemical properties, making them a strong contender for next-generation lithium-ion batteries. By overcoming issues of conductivity, stability, and scalability, these materials can significantly improve energy density, rate capability, and thermal safety- advances will directly benefit electric vehicles and grid-scale energy storage, driving us toward more sustainable energy solutions.

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