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Research Progress of MXene/graphene Composites in the Application of Electronic Information Field

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Abstract:
The rapid development of electronic information technology has resulted in an increased demand for high-performance electronic materials. Research has focused on MXene/graphene composites due to their exceptional electrical conductivity, mechanical strength, and thermal stability. This paper presents a comprehensive review of the latest research progress in the field of electronic information, with a particular focus on MXene/graphene composites. It provides a detailed analysis of the applications of MXene/graphene composites in key technological areas, including energy storage and conversion, electronic devices, and optoelectronic devices. Additionally, it identifies the current technological challenges and explores potential future developments in this field. It is anticipated that by optimizing the preparation process of the composites and exploring new application areas, MXene/graphene composites will achieve breakthroughs in the fields of flexible electronics, smart sensors, and high-efficiency energy storage. These advancements are anticipated to catalyze a transformative impact on the electronics and information sector, marking a significant leap forward in technological evolution.

Keywords: MXene; graphene; composites; electronic information; research progress

1. Introduction

In the global field of electronic information technology, there is an increasing demand for high-performance electronic materials. MXene and graphene have garnered significant attention in the field of electronic materials research owing to their distinctive physical and chemical characteristics, including superior electrical conductivity, robust mechanical properties, and thermal stability [1]. Although MXene and graphene each exhibit significant advantages, they face a series of challenges in practical applications, such as the preparation conditions of MXene that limit its wide application, and the technical challenges of graphene in large-scale production and integration still exist [2]. To address these challeng-

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es, scientists have investigated the creation of MXene/graphene composites, aiming to leverage the combined strengths of both materials to realize substantial improvements in performance via their complementary functionalities [3].

The composites of MXene and graphene exhibit significant potential in the realms of supercapacitor technology, sensing, transparent conductive coatings, and EMI shielding, attributed to their fine-tuned electrical conductivity, bolstered mechanical attributes, and steadfast thermal performance [4]. However, the research and application of such composites still face many challenges, including preparation cost, interfacial compatibility, and effective integration in complex electronic systems [5, 6].

The objective of this paper is to provide a comprehensive review of the recent research progress made in the field of electronic information with regard to MXene/graphene composites. In the initial phase of this research, the focus will be on exploring the suitability of these composite materials for energy storage and conversion applications, emphasizing their capacity to boost both energy density and power density. Subsequently, an analysis will be conducted on their utilization in electronic devices, with a particular focus on their impact on enhancing device performance and stability. Furthermore, an evaluation of the potential use of these materials in optoelectronic devices will be conducted, with a particular focus on their ability to enhance photoelectric conversion efficiency. Following an examination of these applications, this paper will proceed to investigate the current technical challenges associated with material synthesis, performance optimization and scale-up production. Finally, an outlook will be provided on the future development of MXene/graphene composites, including a prediction of their potential impact and market trends in the field of electronic information. Through these analyses, this paper aims to provide researchers and industry engineers with in-depth technical insights and guidance on future research directions.

2. Basic Properties of MXene and Graphene

2.1 Chemical Composition and Physical Properties of MXene

MXene is a two-dimensional transition metal carbide, nitride, or carbon-nitride with the chemical formula Mn+1XnTx, where M represents early transition metal elements such as Sc, Ti, V, etc., X represents C and/or N elements, and Tx represents surface end-groups such as -O, -OH, -F, etc. MXene is typically prepared using a "top-down " method by selectively etching the A layer in the MAX phase. Such methods include fluorine-containing etching and fluorine-free etching, among which HF etching is the earliest reported preparation method for MXene through the reaction of fluoride ions with the aluminum layer [7]. The surface functional groups and layer spacing of MXene are tunable, which provides a tunable figure of merit for electronic device applications. In addition, the sp^2 hybridized honeycomb structure of MXene enhances its thermal conductivity and electron mobility in flexible electronic devices by laser reduction technique.

2.2 Chemical Composition and Physical Properties of Graphene

Graphene is a monolayer two-dimensional material composed of carbon atoms arranged in a hexagonal lattice, with each atom hybridized in the sp^2 configuration. It has excellent mechanical properties and superb electrical and thermal conductivity. The fabrication of graphene can be achieved through various methods, including mechanical exfoliation, chemical vapor deposition (CVD), and the reduction-oxidation (redox) technique. Within the array of techniques for graphene synthesis, mechanical exfoliation stands as the pioneering approach. This method involves the separation of graphene layers from pristine graphite through the application of adhesive tape, a process that led to the initial isolation of graphene. Furthermore, Chemical Vapor Deposition (CVD) has emerged as a prominent technique for the fabrication of large-scale graphene films. The CVD method is highly favored due to its potential to facilitate the industrial-scale production of graphene, thus holding significant promise for the advancement of graphene technology. The sp^2 hybridized honeycomb structure of graphene gives it a carrier mobility of about 15,000 $cm^2/(V\text{-}s)$ at room temperature, which far exceeds that of silicon and other known materials [8]. In the realm of materials science, graphene is recognized for its superior thermal conductivity. Specifically, a pristine, defect-free monolayer graphene is characterized by an exceptional thermal conductivity coefficient, which can reach a maximum value of 5300 watts per meter-kelvin.

3. Preparation and Characterization of MXene/graphene Composites

3.1 Preparation Methods

Preparation methods for MXene/graphene composites include bottom-up and top-down synthesis methods. Bottom-up methods such as chemical vapor deposition (CVD) growth can grow high-quality MXene and graphene under controlled conditions. Liquid phase exfoliation is an effective preparation method to obtain MXene and graphene by exfoliating layered materials in a liquid. The in situ synthesis method provides a new way to innovate composite materials, which can be formed directly during the material growth process. Interfacial engineering is another important preparation method to optimize the properties of composites by controlling the material interfaces [9].

3.2 Preparation Methods

Variations in synthesis approaches substantially influence the structural and property profiles of MXene/graphene composite materials. For example, CVD-grown graphene has high crystallinity and excellent electrical conductivity, while MXene prepared by liquid phase exfoliation has better layer spacing and surface functional groups. These attributes endow the composites with superior electrical conductivity, enhanced mechanical characteristics, and improved thermal stability. By optimizing the preparation process, the properties of the composites can be further enhanced to meet the demand for high-performance materials in the field of electronic information [10].

4. Applications in the Field of Electronic Information

4.1 Energy Storage and Transformation

The application of MXene/graphene composites is receiving a lot of attention in the field of energy storage and conversion. The refinements in electrical conductivity, the strengthening of mechanical attributes, and the augmentation of thermal stability in these composites bestow MXene/graphene composites with marked benefits, particularly in elevating energy density and stabilizing cycling performance. MXene/graphene composites are optimal for supercapacitors due to their high surface area and electrical conductivity. For example, porous MXene films prepared by gas-assisted foaming method not only exhibit excellent capacitance performance, but also outstanding multiplicity performance [11]. Furthermore, the alignment of energy storage potential ranges and the synchronization of charge storage dynamics between graphene-based and MXene-based anodes have been realized through strategic structural adjustments and surface modifications. These enhancements have, in turn, led to significant improvements in the energy density and power density of asymmetric supercapacitors [12].

In the field of battery technology, the application of MXene/graphene composites also shows great potential. The adjustable surface functional groups and interlayer spacing of MXene offer a customizable performance profile, including exceptional thermal conductivity and electron mobility, which are vital for advancements in battery technology [13]. Especially in zinc ion battery technology, the application of MXene can significantly enhance the cycle stability and energy density of the battery.

4.2 Electronic Devices

The application of MXene/graphene composites in electronic devices also shows great potential. The development of graphene-based integrated circuits provides a new direction for RF performance enhancement, while the high electrical conductivity and mechanical strength of MXene offer the possibility of performance enhancement for sensors and transistors.

In the field of sensors, the high sensitivity and fast response properties of MXene/graphene composites make them important for sensor applications. For example, MXene composites with biomass nanomaterials can enhance the performance of sensors by increasing their flexibility and providing more ion transport channels.

In the field of transistors, the high electron mobility and thermal stability of MXene/graphene composites give them potential applications in high-performance electronic devices [14]. By optimizing the preparation process of the composites, their performance in electronic devices can be further enhanced.

4.3 Optoelectronic Devices

The utilization of MXene/graphene composite materials is broadening within the field of optoelectronics. The excellent optical properties of graphene and the high conductivity of MXene make these composites show unique advantages in photodetectors and light emitting diodes (OLEDs).

In the field of photodetectors, the high sensitivity and fast response properties of MXene/graphene composites make them important for applications in photodetectors. By optimizing the photoelectric properties of the materials, the detection efficiency and speed of photodetectors can be improved.

In the field of OLEDs, the application of graphene can improve the luminescence efficiency and stability of the devices. The introduction of MXene can further enhance the performance of OLEDs, especially in improving the performance of photodetectors [15].

4.4 Electromagnetic Shielding

MXene/graphene composites show great potential for application in the field of electromagnetic shielding due to their unique two-dimensional structure and excellent elec-

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trical conductivity. These materials can effectively absorb and reflect electromagnetic waves, thus reducing the negative impact of electromagnetic interference on electronic devices. Studies have shown that by adjusting the layer spacing and surface functional groups of MXene/graphene composites, their electromagnetic shielding effectiveness can be optimized to achieve more efficient electromagnetic wave absorption and shielding [16].

4.5 Flexible Electronics and Wearable Devices

The flexibility and high conductivity of MXene/graphene composites make them promising for a wide range of applications in flexible electronics. These composites can be used to fabricate wearable devices such as flexible displays, health monitoring sensors and smart textiles. For example, MXene/graphene-based flexible sensors have attracted attention for their high sensitivity and wide detection range, capable of detecting weak signals such as human movement, pulse and sound waves. In addition, the applications of these composites in flexible batteries and supercapacitors are expanding, providing stable and bendable energy storage solutions for wearable devices [17].

4.6 Quantum Dots and Photocatalysts

MXene/graphene composites also show great potential in the stabilization of quantum dots and the preparation of photocatalysts. The surface functional groups of MXene can form stable bonds with quantum dots, which improves the stability and photoluminescence properties of quantum dots. The applications of this composite in photocatalysis, such as photocatalytic decomposition of water for hydrogen production and degradation of organic pollutants, show excellent photocatalytic activity and stability [18]. In addition, the high electron mobility and thermal stability of MXene/graphene composites give them potential for applications in photodetectors and light-emitting diodes (OLEDs) [19].

4.7 Biocompatibility of Nanocomposites

Biocompatibility studies of MXene/graphene composites are key to their application in biomedical fields. These composites can interact with biomolecules and cells without inducing significant toxic reactions, which opens up the possibility of their application in drug delivery, biosensing and tissue engineering. It has been shown that MXene/graphene composites are biocompatible and can promote cell attachment and growth, while exhibiting a promotional effect on cell activity [20]. These properties make MXene/graphene composites promising for a wide range of applications in biomedical fields, especially in tissue engineering and regenerative medicine.

5. Conclusion

As two-dimensional materials with unique electronic and mechanical properties, MXene and graphene are increasingly emphasized for the potential application of their composites in the field of electronic information. This paper reviews the fundamental properties of MXene and graphene, the preparation methods of the composites, and the diverse applications in the field of electronic information, including energy storage and conversion, electronic devices, optoelectronic devices, and electromagnetic wave absorbing materials. In particular, it is pointed out that the tunability of surface functional groups and layer spacing of MXene and the sp^2 hybridized honeycomb structure of graphene provide tunable figure of merit and excellent thermal conductivity and electron mobility for electronic device applications.

Although MXene/graphene composites show great application prospects, they still face many technical challenges in practical applications. For example, the stability, interfacial compatibility, and feasibility of large-scale production of the composites need to be addressed. Future research should focus on optimizing the preparation process of the composites and improving their properties, as well as exploring new application areas to meet the growing industrial technological demands.

There is an increasing demand for high-performance materials in the electronic information industry, and further research and development of MXene/graphene composites will have a profound impact on the technological progress of the industry. Meanwhile, considering the environmental impact and sustainable use of resources, researchers should also pay attention to the environmental friendliness and recyclability of the materials in order to realize the green manufacturing and application of the materials.

In the future, MXene/graphene composites are expected to realize breakthroughs in flexible electronics, smart sensors, and efficient energy storage. With advances in materials science, nanotechnology and manufacturing technology, the potential applications of these composites will continue to expand, revolutionizing the field of electronics and information.

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