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# Preparation and Application Analysis of MXene

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## Abstract

**As an emerging two-dimensional transition metal carbide and/or nitride in recent years, MXene has become a research hotspot in many fields such as energy storage, catalysis, and adsorption with its unique two-dimensional layered structure, large specific surface area, excellent electrical conductivity, mechanical stability and magnetic properties. In this paper, the preparation method of two-dimensional material MXenes is briefly described, and its application progress in various fields in recent years is reviewed and summarized. Finally, the existing problems at this stage and the future research direction and development prospects are analyzed.**

## Keywords

**Mxene; 2D Materials; Application.**

## 1. Introduction

As a kind of crystal material with high aspect ratio and atomic thickness, two-dimensional (2D) materials have excellent electrical and mechanical optical properties, and have been widely studied and applied in various fields [1]. Two-dimensional transition metal carbon and/or nitride (MXene), a new two-dimensional material first discovered by researchers at Drexel University in 2011, has attracted widespread attention from academia [2]. MXene is a graphene-like [3] two-dimensional transition metal material [4,5], with high specific surface area [6], excellent conductivity [7] and abundant end-group functional groups [8], MXene has great potential in the field of energy storage such as supercapacitors, secondary batteries, and sensors. MXenes is excellent due to its large specific surface area Conductivity and hydrophilicity and abundant surface groups (favorable for modification, surface modification, deposition, etc.). It has high application value and broad development prospects in many fields such as environment, information, energy and biology. This article summarizes the preparation method of MXenes,the application in various fields, and its current problems and future development are analyzed and prospected.

## 2. The Brief Description of MXene Material

The general formula of MXene is Mn+1XnTx, where M represents the early transition metal, X represents carbon or nitrogen, usually n=1~3, T represents the surface terminal (the main functional groups are -OH, -O and -F), x represents the number of surface functional groups, and the elements, surface terminals and interlayer cations present in the MAX phase and MXene are shown in Fig 1 [9].

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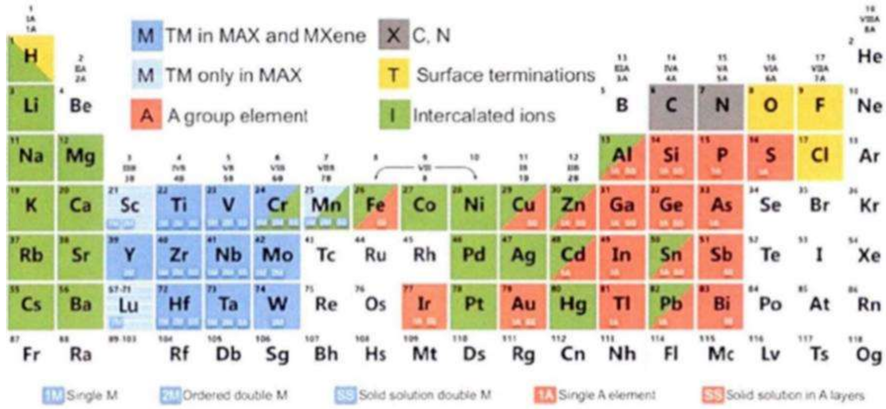


**Fig. 1** lements, surface terminations, and interlaminar cations in the MAX phase and MXene [9]

The surface of MXene has functional groups such as -F, -OH, and =O, so that the surface of MXene is negatively charged, MXene has a hexagonal dense packing structure, transition metal (M) atoms are tightly packed and arranged, element X atoms are located in octahedral positions, and their adjacent layers are connected by van der Waals forces, resulting in the prepared MXene presenting an accordion structure [10], as shown in Fig 2.

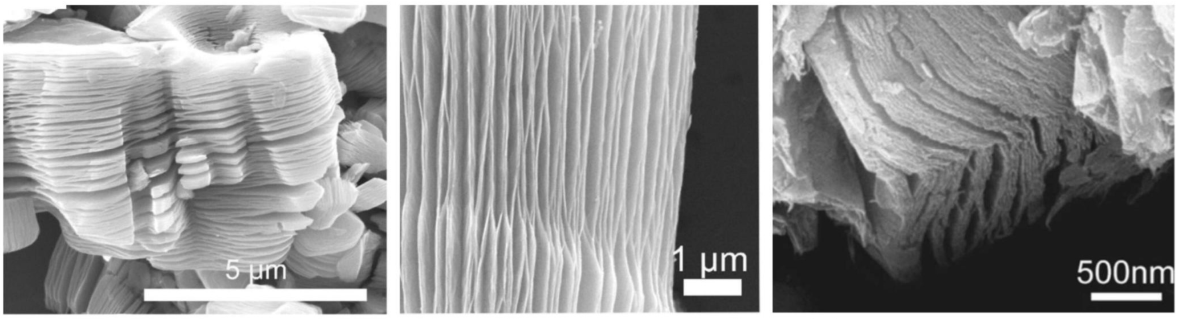


**Fig. 2** SEM diagram of Mxene [10]

## 3. Preparation of MXene

Generally, multilayer MXene is obtained by etching MAX, and physical methods such as interpolation of multilayer MXene and ultrasound can be removed to obtain a single or less-layer MXene. MXene can be prepared in a variety of ways, and the surface of MXene carries different functional groups due to the different etching agents used in different etching processes. Therefore, the surface properties of MXene are highly dependent on the preparation method chosen.

### 3.1. HF Etching Method

MXenes materials are typically obtained by etching the MAX phase with HF solutions. As one of the most widely used methods for preparing multilayer MXene, taking Ti3AlC2 as an example, the reaction process is shown below [11]:

$$Ti_3AlC_2(MAX)+3HF=AlF_3+3/2H_2+Ti_3C_2 \quad (1)$$

$$Ti_3C_2+2H_2O=Ti_3C_2(OH)_2+H_2 \quad (2)$$

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$$Ti_3C_2+2HF=Ti_3C_2F_2+H_2 \tag{3}$$

Multilayer MXene is formed by formula (1), and the two reactions of formula (2) and formula (3) occur in parallel, and after etching the Al layer, the Ti layer has a high surface energy, which will adsorb $OH^-$, $F^-$, etc. in solution. Until now, HF etching is still one of the commonly used methods for preparing MXene. High concentration of HF is highly toxic and corrosive, and the risk of the experimental process is high, which not only has certain harm to the health of the experimenter, but also causes pollution to the environment. In addition, MXene surfaces obtained in this way usually exist. In more $F^-$ containing functional groups, the conductivity of MXene is reduced [12].

### 3.2. Modified Acid Etching Method

Due to the hazards of HF itself, researchers have improved the original HF etching method, in which HF is generated in situ by the reaction of fluoride salts ($NH_4HF_2$, LiF, NaF, KF, and $FeF_3$) and HCl, often referred to as "in situ HF etching"[13,14].Using the in-situ HF etching method, by adjusting the etch dosage, reaction time and other factors, not only can the MXene yield be improved, but also the structure of MXene can be changed, improving the overall performance of MXene. In addition, cations are introduced during the modified acid etching process to play an intercalation role, weaken the interaction between the layers of MXene, and facilitate the peeling of the multilayer MXene during ultrasound. However, this method still has problems such as low production efficiency and difficult to deal with a large amount of acid waste liquid.

### 3.3. Molten Fluorine Salt Etching Method

MXenes nitride has more stable chemistry and higher conductivity efficiency than MXenes carbide, but the dissociation of nitrogen MAX requires more energy, and $Ti_nN_{n-1}$ tends to be more easily dissolved during HF etching, making it difficult to produce. Urbankowski et al. [15] selectively removed the Al atom intercalation of $Ti_4AlN_3$ by molten fluorine salt etching, and then obtained a few layers of $Ti_4N_3T_x$ nanosheets by washing and centrifugation, but the purity of the obtained product was low and the crystallinity was poor. The key to molten salt etching is atmosphere protection and temperature, if the temperature is too high or the atmosphere protection is insufficient, the structure of the product may be cubic phase. In addition, the main drawback of the molten salt etching method is that the fluoride in the molten salt product is difficult to completely remove, and the crystallinity of the prepared MXenes material is poor.

## 4. Applications of MXene

As a newly researched two-dimensional (2D) compound with multilayer sheet structure, high surface area, excellent metal conductivity, hydrophilicity, excellent ion intercalation behavior and environmental protection characteristics, MXenes has shown great prospects in the development of high-efficiency electrodes, and has great development value and application prospects in the fields of supercapacitors, sensors, electromagnetic interference (EMI) shielding and other fields with its rich chemical properties, excellent electrical conductivity and photothermal conversion performance.

Tahir et al. [16] prepared a novel MXene-coated felt electrode (MXene@CF). In MES, this cathode material has excellent current generation and volatile fatty acid yield. More active sites and sufficient space for microbial growth enhanced mass transfer between microorganisms and substrates, and the concentrations of acetic acid, butyric acid and propionic acid increased by 1.6-fold, 1.1-fold, and 1.7-fold compared to uncoated carbon felts. The results of scanning electron microscopy, electrochemistry and microbial community analysis showed that the MXene coated cathode promoted the formation and enrichment of biofilms. Zhang et al. [17]

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used Ag particles, rGO, and MWCNTs to modify V2CTx to take full advantage of the electrochemical properties of V2CTx. The doping of Ag particles, rGO and MWCNTs can well prevent the collapse and accumulation of V2CTx, increase the layer spacing of V2CTx, expose more active contact sites, and shorten the diffusion path of electrolyte ions, while Ag particles, rGO and MWCNTs transform the original two-dimensional structure into a three-dimensional structure, which can provide a fast transport channel for charge transport and ion diffusion. Liu et al. [18] used two-dimensional Ti3C2 MXene as an anode in MFC to obtain an output voltage of 640 ± 8 mV and a maximum power density of 3.74 W m-2 with an external 1000 Ω resistor, far exceeding the carbon cloth control group. Thanks to the multilayer structure, high surface area and excellent conductivity of Ti3C2MXene, it can provide sufficient nutrients for microbial growth and rapid mass transfer, and provide more active sites for biocatalyzed redox reactions, which promotes direct EET between Ti3C2/CC anodes and microorganisms. Xiang et al. [19] used the electrical properties of MXene to prepare MXene/carbon nanotube/carbon nanoparticle composites by electrostatic assembly method, which had excellent EMI shielding, flexibility, hydrophobicity and photothermal conversion properties, and had broad application prospects in the field of electromagnetic shielding. Zhang et al. prepared collagen fiber/MXene composite aerogel by mixed casting and freeze-drying, and MXene was attached to the surface of collagen fiber as a conductive coating, and the obtained sensor had high sensitivity (61.99 kPa-1) and fast response (0.30 s) [20].

## 5. Conclusion

At present, most of the preparation methods of MXene have low yields and cannot be prepared in large quantities, and the products have a great impact on their properties due to structural defects. Generally, most of the products are multilayer structures, and it is difficult to prepare MXene phase substances with few layers or even single layers. In addition, most of the research at this stage is still at the basic level, MXene surface functional group makes its structure more complex, increases the difficulty of research, due to the lack of a large number of in-depth research, its practical application range is narrow, limiting its development. The functional groups on the surface of MXene are greatly affected by the environment, and when the temperature is high or exposed to humidity, the relative activity of its surface is easily destroyed, and it is oxidized to metal oxides, losing its original properties. Therefore, the focus of future research should focus on the environmental protection of the MXene preparation process and improve the yield of MXene efficient and environmentally friendly preparation method of MXene; Improve the antioxidant properties of MXene and increase the lossless storage time of MXene; In-depth study of the specific role of specific active groups on the surface of MXene to achieve precise control.

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