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Application and Development Prospect of MXene Materials in Textile and Garment

Li Dan[1], Guan Fuwang[1,*], Yang Zhuli[1], Qiu Yiping[1,2]

[1]College of Textiles and Apparel, Quanzhou Normal University, Quanzhou, Fujian, 362000, China
[2]College of Textiles, Donghua University, Shanghai, 200051, China
**Corresponding author: guanfuwang6366@126.com*

Abstract: *Mxene, as a new two-dimensional (2D) nanomaterial, has attracted extensive attention in many fields due to its unique high conductivity and high electrochemical surface activity. At present, the research on MXene materials mainly focuses on the fields of composite materials, lubricants, environmental pollution control, energy storage, catalysis, sensors and so on, and there are few applications in the field of textile and garment. However, MXene materials have multi-functional properties and many advantages, and the future application prospect in the field of clothing should not be underestimated. Taking $Ti_3C_2T_x$ MXene as the main research object, this paper summarizes the various characteristics of MXene that may be suitable for clothing materials, and explores its application in wearable devices, electromagnetic shielding, antibacterial and other clothing materials. The prospects and challenges of Mxene in clothing materials are analyzed.*

Keywords: *Mxene; two-dimensional materials; clothing; new materials; application prospect*

1. Introduction

In recent years, transition metal carbon nitride (MXene) has emerged from all two-dimensional materials. MXene not only has super high electrical conductivity similar to metal, but also has excellent mechanical properties. Furthermore, the hydrophilic surface and highly adjustable surface groups of MXene make it easier to form composite materials with other materials. Researchers have been trying to explore more properties of MXene materials. Although a large number of literatures on Mxene have been published, they all summarize the preparation, structure and properties of two-dimensional material Mxene and explore its application in new energy, optics, chemistry, physics, optoelectronic information and other fields. There are few studies on the application of Mxene materials in clothing materials. After consulting relevant literature and network survey, this paper analyzes the current research status of Mxene materials, and analyzes several characteristics that Mxene may be suitable for clothing materials, and discusses the opportunities and challenges of Mxene materials used in clothing materials, in order to provide thinking for subsequent related research.

2. MXene materials introduction

Mxene refers to a family of transition metal carbides, nitrides and carbon nitrides[1]. It was first discovered by Professor Yury Gogotsi and Professor Michel Barsoum of Drexel University in 2011. As a new type of two-dimensional (2D) nanomaterials, the chemical formula is $M_{n+1}X_nT_X$, where (n=1~3), M represents early transition metals (such as Sc, Ti, Zr, Hf, V, Ta, Nb, Cr, Mo, etc.), X represents C or N elements. T_x represents the functional groups (such as -OH, -O, -F, etc.) attached to the surface of MXene produced by chemical etching precursor MAX phase, which produce M_2X, M_3X_2 and M_4X_3 forms of MXene [2-3], respectively. At present, the most studied category of MXene is $Ti_3C_2T_x$. It has a large specific surface area, good metal conductivity of transition metal carbides [4-5], excellent redox activity, and large capacitance [4-7], and its electrical, mechanical and stability properties can be controlled by the types and quantity ratios of transition metals, nitrogen atoms or carbon atoms, and surface functional groups, which are more and more widely used in supercapacitors, batteries, electromagnetic interference shielding and composite materials [8-9].

Due to the hierarchical structure of transition metal atoms with carbon or nitrogen atoms, MXene enjoys extraordinary composition diversity and tunable properties. This may be the largest 2D material family known so far. Compared with MXene materials such as graphene, it has undoubtedly become

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one of the most popular materials in materials science. Figure1 shows the structure of MAX phase and the corresponding MXene.

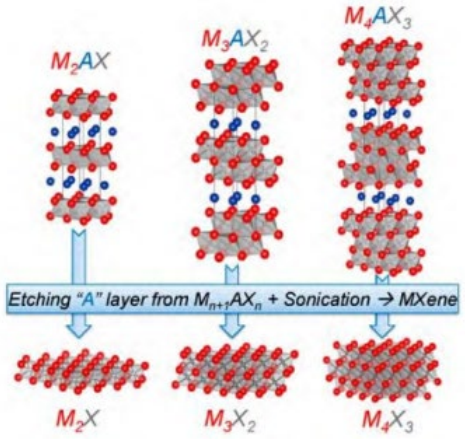

Figure 1: Structure of MAX phase and corresponding MXene[3].

3. Research status of MXene new materials

At present, MXene not only has high specific surface area, high electrical conductivity and high mechanical strength comparable to graphene, but also has the advantages of flexible and adjustable components and controllable minimum nano-layer thickness, which has attracted wide attention of researchers at home and abroad. Therefore, the application research of Mxene in energy storage, electromagnetic shielding, composite materials and other fields is very popular. However, after the research and investigation, it is found that this material has a good application prospect in the field of clothing.

Yury Gogotsi et al [10] used MXene-based fibers, yarns and fabrics for wearable energy storage devices. Fabric equipment benefited from the discovery of new conductive materials and the innovation of fabric equipment design. These devices include fabric-based supercapacitors (TSCs), including fiber, yarn and fabric supercapacitors, which have practical value in power supply for wearable devices. Mashtalir et al [11] studied the adsorption properties of $Ti_3C_2T_x$ on dye molecules. The surface of $Ti_3C_2T_x$ is negatively charged, so it has the characteristics of selective adsorption of dye molecules. In addition, he also found that Ti3C2Tx can exhibit photocatalytic properties similar to titanium dioxide under UV light. The antibacterial effect of $Ti_3C_2T_x$ colloidal solution was first found by Rasool et al [12], $Ti_3C_2T_x$ colloidal solution had better antibacterial effect than graphene. Shahzad et al [13] confirmed that the electromagnetic shielding effect of $Ti_3C_2T_x$ film with a thickness of 45μm could reach 92 dB, which was the material with the best shielding performance in the synthesized materials so far.

These experimental results show that MXene has many kinds and different properties. At present, many experiments have been carried out in the fields of composite materials, lubricants, environmental pollution control, energy storage, catalysis, sensors, antibacterial and electromagnetic shielding. With the continuous progress of materials technology, MXene has made great progress in preparation, structure, performance and application, and this two-dimensional material will usher in a great application prospect.

4. MXene performance and its application in clothing

Genevieve Dion, University of Dicken, Australia, Yury Gogotsi and Joselito M. Razal, University of Drexel, the United States, reported the progress in technology, equipment design and performance indicators for the production of MXene-based fibers, yarns and fabrics, and discussed the challenges faced by introducing this new material into the structures of fibers, yarns and fabrics, which will help the development of textile equipment outside the application of energy storage [10]. As shown in Figure 2, by adding technical features to the fiber, the new features are woven into textiles without compromising their wear resistance, thus enabling the fabric to possess multiple properties of MXene materials, which will make it possible for MXene materials to be applied to garment fabrics. Through the investigation and study, it is found that MXene has multi-functionality and is combined with polymer, so that it is more and more applied in the textile field, and makes the clothing develop

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towards intelligence. In the future, intelligence has become one of the new development trends of the textile industry.

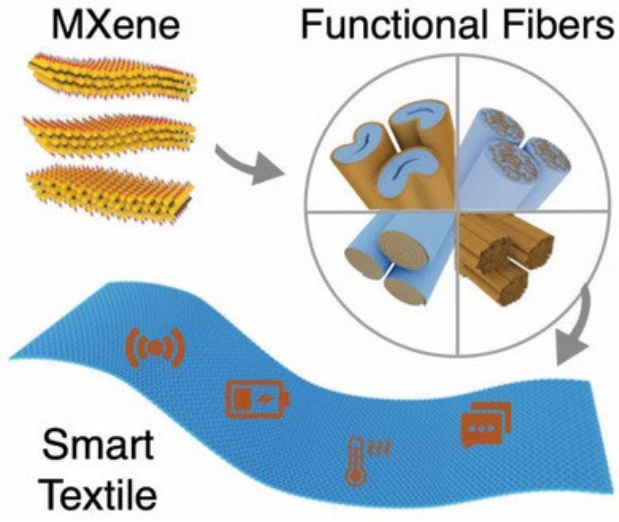

Figure 2: MXene woven into other materials.

4.1 Flexible force sensitive materials and applications

With the rapid development of science and technology and intelligent industry, new micro and wearable products are gradually being widely promoted, and innovative mobile sensing and feedback devices and related services are also developing rapidly. However, in practical applications, traditional sensors are difficult to withstand large deformation and pressure. The new flexible sensor makes up for this defect, and can withstand large deformation and pressure in complex human interaction, which has a good application prospect. Therefore, it has become an important task for researchers to develop yarns with flexible, electrochemical and electromechanical activities that can be woven into whole fabrics for mass production of fabric-based equipment.

In recent years, flexible pressure sensors have developed rapidly. At present, the application of MXene flexible force sensitive material is mainly in wearable electronic equipment, which is mainly manifested in the monitoring of physiological signals and subtle human movements. For the subtle motion monitoring of complex signals such as human heart and pulse, it is necessary for the force-sensitive materials to have minimal detection limit, high sensitivity and short response time [14-16]. Tensile strain sensor, joint bending motion will produce tensile effect, strain is large, need MXene-based flexible force sensitive material has high working strain; pressure sensor, for the application of signal tracing, is mainly based on pressure sensor.

Zhao et al [17] developed an intelligent fabric. $Ti_3C_2T_x$ nanosheets were deposited on cellulose fiber nonwovens by impregnation process, and a multifunctional fabric based on MXene was constructed. It can be used for respiratory detection and low pressure hyperthermia platform. This fabric has great development space in medical textiles and clothing.

4.2 Electromagnetic shielding and absorbing and its application

With the progress of science and technology, communication equipment, microwave products, household appliances, electronic products and other electromagnetic radiation sources widely appear in people's daily life, the harm of electromagnetic radiation has gradually been paid attention to. At present, the use of electromagnetic shielding materials in clothing is mainly metal fiber and silver fiber, but there are metal fiber fabric easy to wash but lack of softness and easy to cause skin allergy, silver fiber oxidation and other pain points. Therefore, some researchers have begun to use carbon materials such as carbon nanotubes (CNT) and graphene [18-19] to prepare electromagnetic shielding materials, but these materials have shown high cost and process defects. At present, layered films, foams, aerogels and other materials based on MXene have shown excellent electromagnetic shielding properties [20-23]. Two-dimensional material MXene has high specific capacity, excellent electromagnetic interference shielding performance, and the electromagnetic wave absorbed in the material in the form of heat dissipation has been widely concerned.

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In order to develop MXene materials with excellent electromagnetic shielding effect, Chong Min Koo of the Korean Academy of Science and Technology and Yury Gogotsi of the University of Drexel reported Ti_3CNT_x MXene, a two-dimensional transition metal carbide material with appropriate conductivity, and showed shielding ability higher than that of Ti_3CT_x or metal film materials with the same thickness. The experiment shows that when the electromagnetic wave meets the interface of MXene material, some electromagnetic waves reflect (the carrier concentration in the material with high conductivity is high, which improves the electromagnetic wave reflection performance) [24]. At the same time, the functional groups on the interface of MXene material produce interfacial dipole effect, resulting in certain electromagnetic wave absorption capacity. This electromagnetic shielding process can make electromagnetic waves do not pollute the environment, in line with the concept of green sustainable development. Therefore, exploring the performance of MXene in the future clothing application prospect is great.

4.3 Antibacterial performance and application

The antibacterial property of MXene is better than that of graphene. The material has large surface area, excellent antibacterial property and strong drug loading capacity. The antibacterial property of a single material is enhanced by compounding MXene with other antibacterial materials. Due to the super antibacterial property of MXene, many researchers have compounded MXene with other materials to prepare antibacterial fibers, or used it as antibacterial agent for antibacterial finishing of textiles.

At present, MXene material has been combined with cotton fabric, cellulose fiber nonwovens, silk and other fabrics in terms of antibacterial finishing fabrics, and other materials have achieved better antibacterial effect. Zhao Bing et al [25] invented a patent for MXene and AgNPs synergistic antibacterial cotton fabric. AgNPs can be loaded on the surface of MXene nanosheets to form MXene-AgNPs antibacterial composites, which improves the binding fastness and durability of antibacterial composites. This experiment proves that MXene has excellent antibacterial properties, and MXene-bonded composites can be used to make clothing with antibacterial properties. In addition, MXene materials are often compounded with other antibacterial materials in the biomedical field to prepare antibacterial fibers or antibacterial dressings for wound sites, preventing bacterial infection and promoting wound healing.

4.4 Hydrophobic performance and application

Two-dimensional material MXene has unique wetting properties, self-cleaning, antifouling and other functions. Integrated hydrophobicity has broad application prospects in the field of smart clothing. Wang et al [26] constructed MXene / Ni chain / ZnO array hybrid nanostructures on cotton fabrics. This study found that the fabric had excellent microwave absorption and hydrophobic properties. Through the combination of this MXene material with other fabrics such as cotton fabrics and silk, MXene was firmly combined with the fabric, creating new fabrics that could still maintain good hydrophobic properties under harsh conditions.

5. Analysis of development prospects

At present, the research on MXene is still in the initial stage, but MXene is a kind of two-dimensional layered material with many kinds and different properties. At present, the research on composite materials, lubricants, environmental pollution control, energy storage, catalysis, sensors, antibacterial, electromagnetic shielding and other aspects has been more prominent.

Although MXene has made great achievements in many fields, at the same time, due to its many properties, such as electromagnetic shielding, intelligent clothing and other excellent properties, it can be developed and used in the field of textile and clothing. The author summarizes the application prospect of MXene new materials in clothing as follows:(1) The materials made from superhydrophobic surface based on MXene show excellent electromagnetic shielding performance and are not easy to oxidize, which can be used to develop radiation protection clothing for special occupational groups with large radiation, and make up for the defects of radiation protection fabrics on the market. (2) Based on MXene, flexible force sensitive material properties with high sensitivity can be developed, which can be applied to the development of intelligent clothing fields such as physiological signal, subtle human action, joint motion signal monitoring and signal tracking. (3) Based

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on the excellent antibacterial properties and strong drug loading capacity of MXene, the antibacterial composite material combined with MXene can be used to make clothing with antibacterial properties. (4) The fabric made of MXene has excellent microwave absorption and hydrophobic properties.The fabric developed by this material can still maintain good hydrophobic properties under harsh conditions, which is a direction for the application of MXene to clothing.

MXene has made great progress in the preparation, structure, performance and application in a short period of time since its birth. With the continuous progress of materials technology, the research system and research methods of MXene will also be continuously improved. However, although MXene has shown strong vitality in many fields, there are still many technical problems in this material. Researchers need to continuously explore this MXene material, introduce this new material into the structure of fiber, yarn and fabric, and give full play to the excellent performance between MXene and matrix materials, which will help the development of textile equipment outside the application of energy storage. The MXene material has gradually developed in the clothing field, bringing more possibilities to the clothing industry.

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