MXene–Metal Composites

Subjects: Materials Science, Composites
Contributor: Maaz Khan , Chunfeng Hu , , Salvatore Grasso

MXene, an advanced family of 2D ceramic material resembling graphene, has had a considerable impact on the field of research because of its unique physiochemical properties. MXene has been synthesized by the selective etching of MAX via different techniques. However, with the passage of time, due to the need for further progress and improvement in MXene materials, ideas have turned toward composite fabrication, which has aided boosting the MXene composites regarding their properties and applications in various areas.

MXene metals composite properties applications

1. Introduction

MXene is a novel class of two-dimensional materials, which is generated by etching the Al layer of Ti_3AlC_2 MAX phase with HF solutions under gentle mode. MXene has achieved substantial consideration because of its superior hydrophilicity, physiochemical stability, electrical conductivity, and favorable environmental characteristics. It has been stated that, when MXene is employed as an assisting substrate, the properties of composites (containing electro-catalytic activity, phosphate removal, and peroxymonosulfate activation) enhance significantly. It was found that, in comparison with pure Co_3O_4, the sandwiched Co_3O_4/MXene composite exhibited superior catalytic activity for peroxymonosulfate activation to degenerate BPA, thus prompting that the use of MXene as a substrate can effectively increase the catalytic activity of active components. Therefore, it is anticipated that MXene could be used as a support of $Fe_2CoTi_3O_{10}$ for activation of peroxymonosulfate [1]. The adsorption of albumin, which staved off re-aggregation of the few-layer nanoplates, resulted in stable colloidal solutions after delamination of manifolded MXenes into minute fine nanoplates. Monodisperse colloids were created using cascading centrifugation, which can be used to synthesize MXenes for biomedical purposes. Albumin coated MXenes may find uses in a variety of disciplines, involving medicine, biology, pharmaceuticals, and environmental engineering, where protein adsorption upon nanomaterial planes performs a remarkable function [2].

2. Critical Overview

The electromagnetic properties are crucial for absorption measurement that transforms the electromagnetic wave into heat energy. Facile preparation of MXene and metal composite is required for the exploration of new family members of MXene. The targeted ternary composite nanomaterial could produce a more diverse interface, a larger surface area, and, most significantly, enhance electrical properties, which is critical for managing EMI shielding effectiveness through conduction and polarization loss. There was a substantial contribution in the damping of EM waves due to the competing impact among conducting impedance and surface and interfacial polarization by the oxide nanoparticles located on the MXene surface. Mechanical flexibility and metallic conductivity are the two important factors for energy storage devices. The fabrication of MXene@Zn composite has helped researchers to achieve desirable systems. Energy efficiency requirements in different industries have been overcome by utilizing lightweight and high-performance materials. Al incorporation into MXene can effectively produce materials with high strength, hardness and fracture toughness. Mechanical properties of materials are greatly dependent on dispersion of particles as the wettability has an important role in the dispersion of particles. Excellent wettability of materials improved mechanical properties. Researchers need to design novel three-component MXene heterostructure for multifunctional applications such as supercapacitors, catalytic performance, etc. (as shown in **Table 1**) The catalytic performance could improve through considering bimetallic nanoparticles. The synergistic effect between Rh/Ni and Pt/Pd nanoparticles accurately adopted surface electric state of nanoparticles. MXene can be used as supportive materials for dehydrogenation. MXene and metal-based anode material can overcome challenges related to batteries because of their large electrical conductivity and significant energy density. Combination of MXene with metal composites consisted excellent capacities with long cycle stability. Metals cause corrosion when exposed to a favorable oxygen-containing environment. The issue can be resolved by applying coating agents to prevent corrosion and explore MXene with other elements, which act as anticorrosive materials. Hard ceramic nanostructures together with soft metal can remarkably upgrade the properties, such as fatigue, strength and corrosion resistance.

Table 1. MXene–metal composites synthesis, properties and application.

MXene–Metal Composites	Methods	Properties	Applications	References
Au/$Ti_3C_2T_x$	chemical reduction	microstructure	electrochemical and catalytic performance	[3]
RhNi/MXene	one-step wet chemical	microstructure	catalytic performance	[4]
Ti_3C_2/DNA/Pd/Pt	In-situ process		sensor and catalytic performance	[5]
$Ti_3C_2T_x$ /Ni	In-situ hydrothermal	EMA	electromagnetic wave absorption	[6]
$Ti_3C_2T_x$/Al	pressureless sintering followed by hot extrusion	microstructure and mechanical properties	solid lubricant	[7]
Ti_3C_2@Au@CdS	self reduction	microstructure	photocatalytic hydrogen production activity	[8]
FLM/Al composite	self assembly protocol and powder metallurgy	microstructure, mechanical properties	automotive, aerospace,	[9]

MXene–Metal Composites	Methods	Properties	Applications	References
			packaging industries	
Ag-$Ti_3C_2T_x$ and Ag-Nb_2CT_x	self chemical reduction	electromagnetic Interference	EM wave shielding	[10]
Pd@MXene	one-step soft solution processing	microstructure, surface-enhanced Raman spectroscopy	Sensors, catalysis, biomedical	[11]
$Ti_3C_2T_x$MXene@Zn	facile in situ electroplating	flexibility, wettability, electronic conductivity	energy storage system	[12]
$Ti_3C_2T_x$ /Mg-Li	liquid metal gelation	mechanical properties	alloys, batteries and supercapacitor	[13]
MXene/Cu	high energy ball milling	microstructure, mechanical	automotive and aerospace industries	[14]
Ni-MXene/Cu composites	high energy ball milling	microstructure, mechanical and wettability	automotive and aerospace industries	[15]
FeNi/$Ti_3C_2T_x$	facile in situ hydrothermal	microstructure, magnetic and microwave absorption	Radar detection technology	[16]
Ag-$Ti_3C_2T_x$ and Ag-Nb_2CT_x Composites	simultaneous self-reduction and oxidation	EMI shielding	wireless technologies and radar systems	[17]
MXene/Ag	direct reduction method		lithium-ion batteries	[18]
Ti2C/Au-Ag	machine learning		electrochemical and SERS intelligent analysis	[19]
MOF-derived MnO_2/Mn_3O_4 and Ti_3C_2 MXene/Au	enzymatic inhibition		electrochemical pesticides detection	[20]
MXene@Sb	one-step electrodeposition approach	flexible	catalyst, batteries, sensors	[21]

MXene–Metal Composites	Methods	Properties	Applications	References
Lac/Au/MXene/GCE	reduction process		Electrochemical detection of catechol	[22]
MXene-$Ag_{0.9}Ti_{0.1}$	self reduction		electrocatalytic activity	[23]
MXene@AuNPs	self reduction		catalytic performance	[24]
$Ni/MoO_2@Mo_2CT_x$	wet impregnation method		catalytic performance	[25]
MXene/MgAl-LDHs	in situ synthesis		anticorrosion	[26]

3. Summary

ysical and omposites l, thermal , catalytic ic MXene n MXene. might be aluminum has led to reinforced improving MXene amount, size of particle, dispersion, and alloy composition will increase mechanical characteristics even further. Beyond excessive EMI shielding materials, the gained large conductivity and synthesis of ternary hybrid nanostructure offer promise for significances in energy storage, photocatalysis, and multifunctional importance. A bifunctional nanosensor has come up with the latest approach for food and agro-product safety. Furthermore, diabetes mellitus has been detected by using a suitable electrode as a GOx/Au/MXene/Nafion/GCE biosensor to determine the amount of glucose in biological specimens. The manufacturing of sensors based on MXene nanocomposite has unlocked its application in the biomedical field. Nanocomposite based on MXene could efficiently apprehend the disintegration of solar water. More efforts have been made on MXene@Metal composite to fabricate a dendrite-free, metal-based storage cell as well as potassium ion devices. Moreover, the manufacturing of functional nanocomposite extends MXene–metal composite for proceeding implementation in structural alloys as well as batteries and supercapacitors. MXene/Ag composite proved to be a promising electrode material for batteries as well as possess better electrocatalytic activity in alkaline fuel. The development of $Ni/MoO_2@Mo_2CT_x$ catalyst has overcome the issues of transportation and can be employed as fuel in cars. In addition, the detection of methamidophos utilizing composite materials has opened more opportunities in the field of electrochemical sensors for examining different environmental contaminants such as pesticides and other harmful chemicals. Besides, MXene also unbarred routes for its utilization as an anticorrosive agent.

References

1. Ding, M.; Chen, W.; Xu, H.; Shen, Z.; Lin, T.; Hu, K.; Kong, Q.; Yang, G.; Xie, Z. Heterogeneous Fe2CoTi3O10-MXene composite catalysts: Synergistic effect of the ternary transition metals in the degradation of 2,4-dichlorophenoxyacetic acid based on peroxymonosulfate activation. Chem. Eng. J. 2019, 378, 122177.
2. Seredych, M.; Maleski, K.; Mathis, T.S.; Gogotsi, Y. Delamination of MXenes using bovine serum albumin. Colloids Surf. A Physicochem. Eng. Asp. 2022, 641, 128580.

3. Rakhi, R.; Nayak, P.; Xia, C.; Alshareef, H.N. Novel amperometric glucose biosensor based on MXene nanocomposite. Sci. Rep. 2016, 6, 36422.
4. Liu, T.; Wang, Q.; Yuan, J.; Zhao, X.; Gao, G. Highly dispersed bimetallic nanoparticles supported on titanium carbides for remarkable hydrogen release from hydrous hydrazine. ChemCatChem 2018, 10, 2200–2204.
5. Zheng, J.; Wang, B.; Ding, A.; Weng, B.; Chen, J. Synthesis of MXene/DNA/Pd/Pt nanocomposite for sensitive detection of dopamine. J. Electroanal. Chem. 2018, 816, 189–194.
6. Li, N.; Xie, X.; Lu, H.; Fan, B.; Wang, X.; Zhao, B.; Zhang, R.; Yang, R. Novel two-dimensional Ti3C2Tx/Ni-spheres hybrids with enhanced microwave absorption properties. Ceram. Int. 2019, 45, 22880–22888.
7. Hu, J.; Li, S.; Zhang, J.; Chang, Q.; Yu, W.; Zhou, Y. Mechanical properties and frictional resistance of Al composites reinforced with Ti3C2Tx MXene. Chin. Chem. Lett. 2020, 31, 996–999.
8. Yin, J.; Zhan, F.; Jiao, T.; Wang, W.; Zhang, G.; Jiao, J.; Jiang, G.; Zhang, Q.; Gu, J.; Peng, Q. Facile preparation of self-assembled CdS nanocomposite with enhanced photocatalytic hydrogen production activity. Sci. China Mater. 2020, 63, 2228–2238.
9. Zhou, W.; Zhou, Z.; Fan, Y.; Nomura, N. Significant strengthening effect in few-layered MXene-reinforced Al matrix composites. Mater. Res. Lett. 2021, 9, 148–154.
10. Rajavel, K.; Hu, Y.; Zhu, P.; Sun, R.; Wong, C. MXene/metal oxides-Ag ternary nanostructures for electromagnetic interference shielding. Chem. Eng. J. 2020, 399, 125791.
11. Satheeshkumar, E.; Makaryan, T.; Melikyan, A.; Minassian, H.; Gogotsi, Y.; Yoshimura, M. One-step solution processing of Ag, Au and MXene hybrids for SERS. Sci. Rep. 2016, 6, 32049.
12. Tian, Y.; An, Y.; Wei, C.; Xi, B.; Xiong, S.; Feng, J.; Qian, Y. Flexible and Free-Standing Ti3C2Tx Zn Paper for Dendrite-Free Aqueous Zinc Metal Batteries and Nonaqueous Lithium Metal Batteries. ACS Nano 2019, 13, 11676–11685.
13. Kamysbayev, V.; James, N.M.; Filatov, A.S.; Srivastava, V.; Anasori, B.; Jaeger, H.M.; Gogotsi, Y.; Talapin, D.V. Colloidal gelation in liquid metals enables functional nanocomposites of 2D metal carbides (MXenes) and lightweight metals. ACS Nano 2019, 13, 12415–12424.
14. Li, M.; Wang, S.; Wang, Q.; Ren, F.; Wang, Y. Preparation, microstructure and tensile properties of two dimensional MXene reinforced copper matrix composites. Mater. Sci. Eng. A 2021, 803, 140699.
15. Li, M.; Wang, S.; Wang, Q.; Ren, F.; Wang, Y. Microstructure and tensile properties of Ni nano particles modified MXene reinforced copper matrix composites. Mater. Sci. Eng. A 2021, 808, 140932.

16. He, J.; Liu, X.; Deng, Y.; Peng, Y.; Deng, L.; Luo, H.; Cheng, C.; Yan, S. Improved magnetic loss and impedance matching of the FeNi-decorated Ti3C2Tx MXene composite toward the broadband microwave absorption performance. J. Alloy. Compd. 2021, 862, 158684.
17. Liu, P.; Yao, Z.; Ng, V.M.H.; Zhou, J.; Kong, L.B. Novel multilayer-like structure of Ti3C2Tx/CNZF composites for low-frequency electromagnetic absorption. Mater. Lett. 2019, 248, 214–217.
18. Zou, G.; Zhang, Z.; Guo, J.; Liu, B.; Zhang, Q.; Fernandez, C.; Peng, Q. Synthesis of MXene/Ag composites for extraordinary long cycle lifetime lithium storage at high rates. ACS Appl. Mater. Interfaces 2016, 8, 22280–22286.
19. Zhu, X.; Liu, P.; Xue, T.; Ge, Y.; Ai, S.; Sheng, Y.; Wu, R.; Xu, L.; Tang, K.; Wen, Y. A novel graphene-like titanium carbide MXene/Au–Ag nanoshuttles bifunctional nanosensor for electrochemical and SERS intelligent analysis of ultra-trace carbendazim coupled with machine learning. Ceram. Int. 2021, 47, 173–184.
20. Song, D.; Jiang, X.; Li, Y.; Lu, X.; Luan, S.; Wang, Y.; Li, Y.; Gao, F. Metal−organic frameworks-derived MnO2/Mn3O4 microcuboids with hierarchically ordered nanosheets and Ti3C2 MXene/Au NPs composites for electrochemical pesticide detection. J. Hazard. Mater. 2019, 373, 367–376.
21. Tian, Y.; An, Y.; Xiong, S.; Feng, J.; Qian, Y. A general method for constructing robust, flexible and freestanding metal anodes for high-performance potassium-ion batteries. J. Mater. Chem. A 2019, 7, 9716–9725.
22. Chandran, M.; Aswathy, E.; Shamna, I.; Vinoba, M.; Kottappara, R.; Bhagiyalakshmi, M. Laccase immobilized on Au confined MXene based electrode for electrochemical detection of catechol. Mater. Today Proc. 2021, 46, 3136–3143.
23. Zhang, Z.; Li, H.; Zou, G.; Fernandez, C.; Liu, B.; Zhang, Q.; Hu, J.; Peng, Q. Self-reduction synthesis of new MXene/Ag composites with unexpected electrocatalytic activity. ACS Sustain. Chem. Eng. 2016, 4, 6763–6771.
24. Li, K.; Jiao, T.; Xing, R.; Zou, G.; Zhou, J.; Zhang, L.; Peng, Q. Fabrication of tunable hierarchical AuNPs nanocomposites constructed by self-reduction reactions with enhanced catalytic performances. Sci. China Mater. 2018, 61, 728–736.
25. Liang, J.; Chen, T.; Liu, J.; Zhang, Q.; Peng, W.; Li, Y.; Zhang, F.; Fan, X. Chemoselective hydrodeoxygenation of palmitic acid to diesel-like hydrocarbons over Ni/MoO2@ Mo2CTx catalyst with extraordinary synergic effect. Chem. Eng. J. 2020, 391, 123472.
26. Wu, Y.; Wu, L.; Yao, W.; Jiang, B.; Wu, J.; Chen, Y.; Chen, X.-B.; Zhan, Q.; Zhang, G.; Pan, F. Improved corrosion resistance of AZ31 Mg alloy coated with MXenes/MgAl-LDHs composite layer modified with yttrium. Electrochim. Acta 2021, 374, 137913.