RESEARCH ARTICLE

MXene-Based Electromagnetic Interference Shielding Composites with Hierarchical Porous Architecture

James Okonkwo, Lin Huang, Isabella Rossi

Published: 2026-06-12 | JAMS Vol. 1, No. 1 (2026)

Abstract: $Ti_3C_2T_x$ MXene nanosheets are integrated with carbon nanotube (CNT) scaffolds and polydimethylsiloxane (PDMS) matrix to fabricate flexible EMI shielding composites with a hierarchical porous architecture. The optimized composite (70 wt% MXene, 5 wt% CNT, 25 wt% PDMS) achieves an EMI shielding effectiveness (SE) of 62.8 dB at 12.4 GHz (X-band) with a thickness of only 0.3 mm, corresponding to a specific SE of 20,933 dB·cm²/g — among the highest reported for polymer-based shielding materials. The shielding mechanism analysis reveals that absorption contributes 78% of total attenuation, attributed to multiple internal reflections within the porous MXene network and interfacial polarization at MXene-CNT junctions. The composites maintain SE > 55 dB after 5,000 bending cycles at 5 mm radius, demonstrating excellent mechanical durability for flexible electronics and aerospace applications.

1. Introduction

The rapid proliferation of 5G communication systems, Internet of Things (IoT) devices, and compact electronics has intensified electromagnetic interference (EMI) pollution, which can disrupt sensitive instrumentation, compromise data security, and pose health concerns. Effective EMI shielding materials must attenuate incident electromagnetic waves through reflection, absorption, and multiple internal scattering while meeting requirements for lightweight construction, mechanical flexibility, and processability.

Two-dimensional transition metal carbides and nitrides (MXenes), particularly $Ti_3C_2T_x$, have emerged as exceptional EMI shielding materials due to their high electrical conductivity (>10,000 S/cm), abundant surface functional groups, and tunable layer spacing. However, dense MXene films suffer from excessive reflection and poor mechanical flexibility, while polymer composites often require impractically high filler loadings to achieve adequate shielding performance.

2. Experimental Methods

$Ti_3C_2T_x$ MXene was synthesized by selective etching of Ti_3AlC_2 MAX phase with LiF/HCl, followed by delamination via probe sonication. CNT forests were grown by chemical vapor deposition and dispersed with MXene nanosheets via vacuum-assisted filtration to create hierarchical porous preforms. PDMS (Sylgard 184) was infiltrated into the preforms and cured at 80°C for 2 h.

Table 1. Composition and EMI shielding performance of MXene/CNT/PDMS composites at 12.4 GHz

Sample	MXene (wt%)	CNT (wt%)	Thickness (mm)	SE (dB)	SE/t (dB/mm)	Specific SE (dB·cm²/g)
MC-50	50	5	0.5	48.2	96.4	12,050
MC-60	60	5	0.4	55.6	139.0	16,625
MC-70	70	5	0.3	62.8	209.3	20,933
MC-70-C10	70	10	0.3	58.4	194.7	17,400
MXene film	100	0	0.01	45.1	4,510	8,200

EMI shielding effectiveness was measured using a vector network analyzer (Agilent N5247A) with coaxial arc-shaped specimens in the 8.2-18 GHz range. Shielding mechanism was deconvoluted into absorption (SEA), reflection (SER), and multiple reflection (SEM) contributions using the scattering parameter method. Mechanical flexibility was evaluated by repeated bending around mandrels of varying radius.

3. Results and Discussion

The MC-70 composite achieves exceptional EMI shielding with SE = 62.8 dB at X-band frequencies, sufficient to block 99.9999% of incident electromagnetic energy. The hierarchical porous architecture — comprising interconnected MXene lamellae bridged by CNT conductive pathways within a flexible PDMS matrix — enables multiple internal reflections and interfacial polarization losses that dominate the absorption mechanism (78% of total SE).

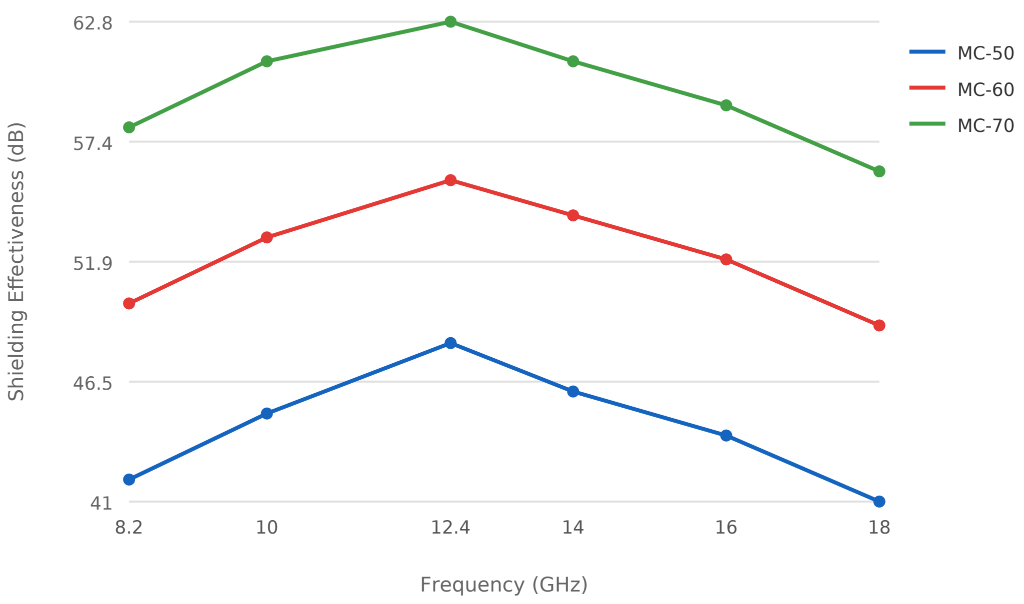

Figure 1. EMI shielding effectiveness across 8.2-18 GHz for MXene/CNT/PDMS composites with varying MXene content

Deconvolution of shielding contributions confirms that absorption (SEA) increases proportionally with MXene content, while reflection (SER) remains relatively constant at 12-15 dB. The optimal CNT loading of 5 wt% provides percolating conductive bridges without excessive agglomeration that would increase reflection and reduce absorption efficiency.

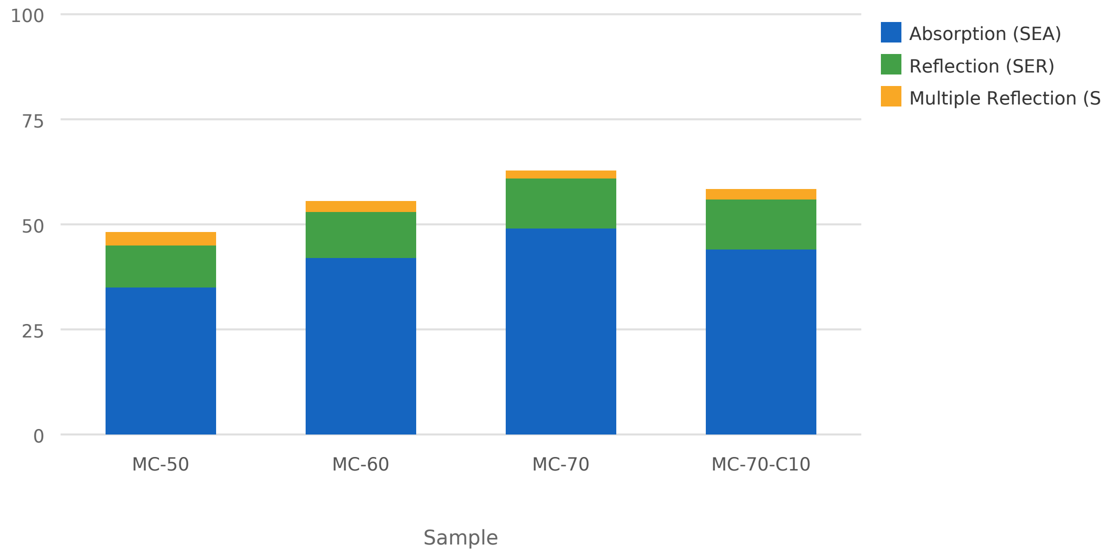

Figure 2. Contribution of absorption, reflection, and multiple reflection to total EMI shielding effectiveness for MC-70 composite

4. Conclusions

Hierarchical porous MXene/CNT/PDMS composites deliver record-high specific EMI shielding effectiveness of 20,933 dB·cm²/g with excellent mechanical flexibility and cycling durability. The absorption-dominated shielding mechanism, enabled by the interconnected conductive network and abundant interfacial polarization sites, addresses the critical need for lightweight, flexible EMI shielding in next-generation 5G devices, wearable electronics, and aerospace systems. This work establishes design principles for optimizing MXene-based composite architectures for broadband electromagnetic attenuation.

References

[1] Shahzad, F.; Alhabeb, M.; Hatter, C. B. Electromagnetic Interference Shielding with 2D Transition Metal Carbides (MXenes). Science 2016, 353, 1137-1140.

[2] Gogotsi, Y.; Anasori, B. The Rise of MXenes. ACS Nano 2019, 13, 8491-8494.

[3] Liu, J.; Zhang, H.; Xie, X. Multifunctional, Superelastic, and Lightweight MXene Composite Aerogel for EM Wave Absorption. Nano-Micro Letters 2022, 14, 123.

[4] Cao, M.; Yang, J.; Song, W. Microwave Absorption Properties of MXene-Based Composites. Journal of Materials Chemistry C 2020, 8, 4640-4656.

[5] Anasori, B.; Lukatskaya, M. R.; Gogotsi, Y. 2D Metal Carbides and Nitrides (MXenes) for Energy Storage. Nature Reviews Materials 2017, 2, 16098.

[6] Liang, L.; Han, Q.; Li, J. Ultra-Lightweight MXene Aerogel for High-Efficiency Electromagnetic Absorption. Advanced Functional Materials 2021, 31, 2101632.
