**Supporting Information**

**Enhancement of microwave absorption bandwidth of MXene nanocomposites through macroscopic design**

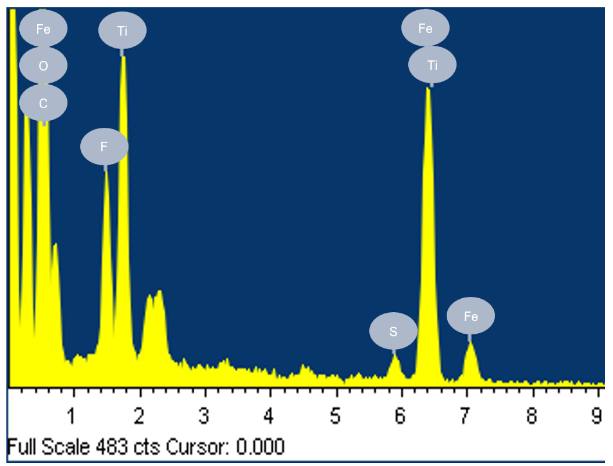
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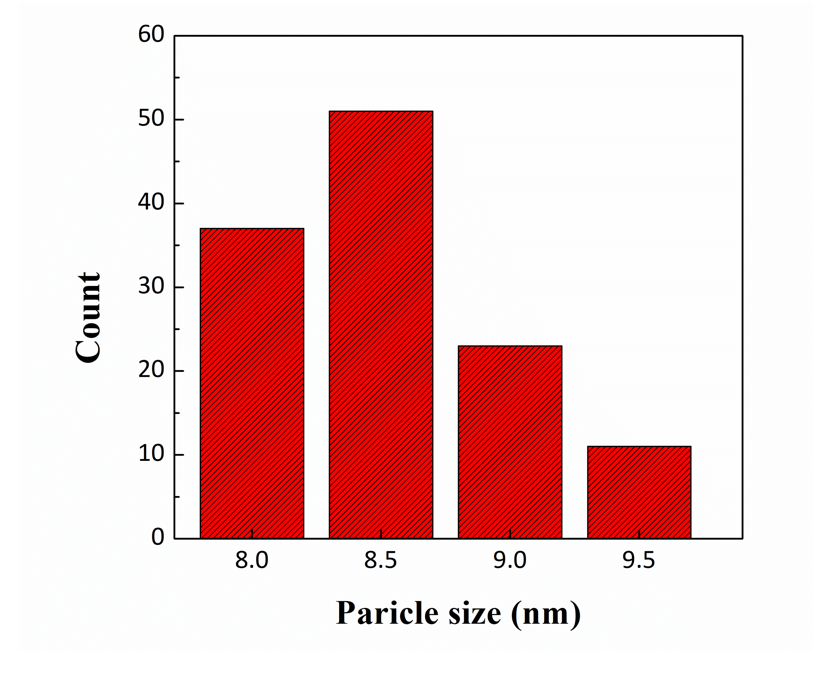
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**Figure S1.** EDX spectra of Fe3O4@TiO2-Ti3C2Tx MXene.



**Figure S2.** Particle size distribution of Fe3O4 nanoparticles in the TiO2-Ti3C2Tx MXene.

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**Figure S3.** (a) Real permittivity (b) Imaginary permittivity, (c) Real permeability and (d) imaginary permeability of Paraffin-TiO2-Ti3C2Tx and Paraffin -Fe3O4@TiO2-Ti3C2Tx, hybrids.

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**Figure S4.** Comparison of simulated RL of macroscopic pyramid and multi layered pyramidal design with the same width (10 mm) of the bottom for Fe3O4@TiO2-Ti3C2Tx, MXene hybrids.

* **Composite fabrications and measurements**

The samples used for EM parameter measurement were prepared by mixing the TiO2-Ti3C2Tx and Fe3O4@TiO2-Ti3C2Tx powders with paraffin at a mass content of 70%. In a typical composite preparation, powders and paraffin were well mixed mechanically at 80±2 ºC to avoid aggregation. After 5 min, the viscous mixtures were cast on the respective Teflon molds. A conducting aluminum tape was pasted at the bottom of the fabricated structure as a perfect electric conductor (PEC). Schematically, the fabrication process of both the meta structure (i.e., pyramidal and multi-layered pyramidal structure) was shown in Figure S4 and Figure S5 respectively.

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**Figure S5.** Schematic of pyramidal MXene hybrid-matrix material preparation.

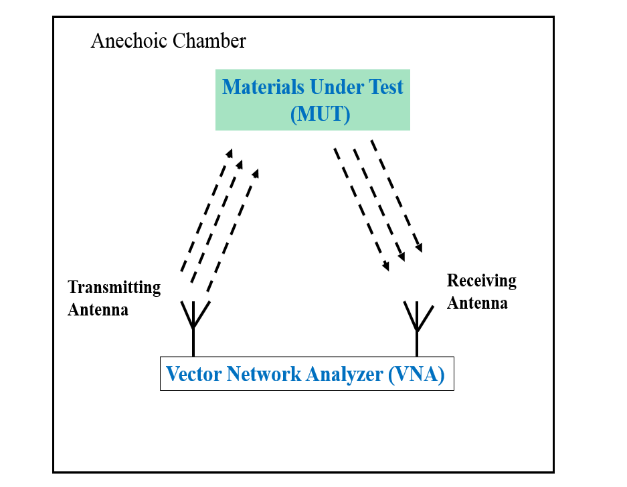
C:\Users\pritom.bora\Desktop\Scheme_multi layerd.tif

**Figure S6.** Schematic of multi-layer MXene hybrid-matrix material pyramid design preparation.

Reflection loss (*S*-parameters) were measured inside anechoic chamber by using an Agilent PNA N523A vector network analyzer using two horn antenna. In the measurement set-up, a pair of horn antenna was used as a transmitter to send off the electromagnetic wave onto the composite sample, whereas the other antenna was used to receive the reflection from the sample. All the horn antennas were connected to the vector network analyzer (VNA) during the entire measurements. The entire broadband absorption measurement technique was shown schematically in **Figure S6.** The pyramidal meta structure was 80×80 mm2 in area whereas the multi-layered pyramid was 84×84 mm2.

**(b)**

**(a)**



**Figure S7.** (a) Schematic of broadband microwave absorption measurement technique, (b) prepared multi-layer MXene hybrid-matrix pyramid design

**Table S1.** Comparison of microwave absorption bandwidth of 2D (MXene- and graphene- based) nanocomposites in pyramidal optimized macroscopic design (a is the width of the bottom of the pyramid).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Polymer** | **Filler** | **Mass content of Filler** | **Absorption bandwidth**  **( RL ≤ -10 dB )** | **a (mm)** | **Reference** |
| Paraffin | Graphene | 70 % | 4-5 GHz, 10-11 GHz, 15.5-18 GHz | 5 | 10 |
| Paraffin | MXene | 70 % | 6-18 GHz  (12 GHz bandwidth) | 5 | This work  (Both Simulated and Experimental) |
| Paraffin | Fe3O4-graphene | 70 % | 7-9 GHz, 10.5-18 GHz | 8 | 10 |
| Paraffin | Fe3O4-MXene | 70 % | 6.2-9 GHz, 13-18 GHz | 8 | This work |
| Paraffin | Fe3O4-MXene | 70 % | 5.9-18 GHz | 8 | This work  (Experimental) |

**Table S2.** Comparison of microwave absorption bandwidth of 2D (MXene- and graphene- based) nanocomposites in optimized multi-layered pyramidal macroscopic design (m is the sweeping parameter in mm) for the same length (8 mm).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Polymer** | **Filler** | **Absorption bandwidth**  **(RL ≤ -10 dB)** | **m**  **(mm)** | **RLmin**  **(dB)** | **Reference** |
| Paraffin | Graphene | 10.5-18 GHz | 1.4 | ~ -15 | 10 |
| Paraffin | MXene | 10.3-18 GHz | 1.4 | ~ -15 | This work |
| Paraffin | Fe3O4-graphene | 9-18 GHz | 1.4 | ~ -30 | 10 |
| Paraffin | Fe3O4-MXene | 4-6 GHz, 8-18 GHz | 1.4 | ~ -47 | This work  (Simulated) |
| Paraffin | Fe3O4-MXene | 3-18 GHz | 1.4 | ~ -45 | This work  (Experimental) |