Supporting Information

A Novel Two-Dimensional $Ti_3C_2T_x$ MXenes/Nano-Carbon Spheres Hybrids for High-Performance Microwave Absorption

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Table S1. The interlayer spacing of the $Ti_3C_2T_x$ with different etching time

Etching time	S1	S2	S3	S4	S5
2θ (degree)	8.823	8.746	8.563	8.464	8.323
$d = n\lambda/2\sin\theta$ (Å)	10.011	10.099	10.314	10.434	10.611

(λ=0.154 nm； n=1)

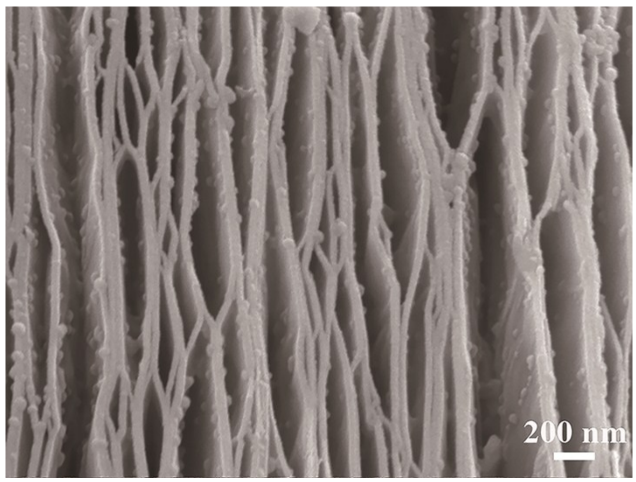

Figure S1. FESEM image of Ti_3AlC_2 powder after HF treatment for 12 h (S5).

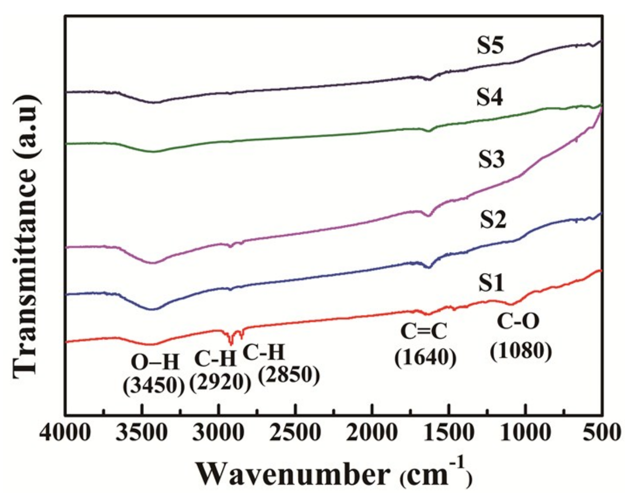

Figure S2. FTIR spectra of the as-prepared $Ti_3C_2T_x$ after HF treatment at room temperature for different etching time.

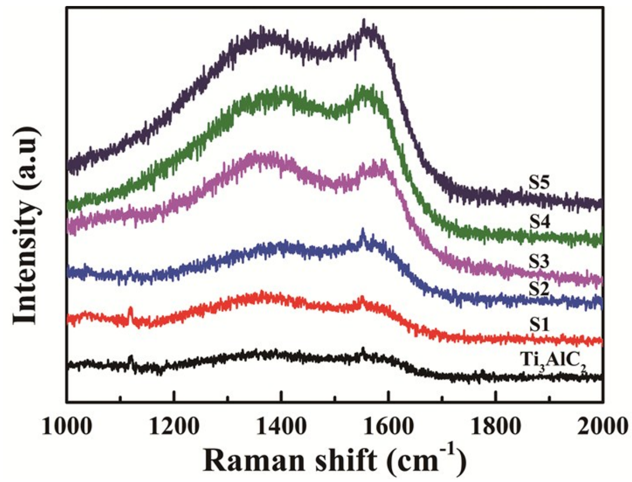

Figure S3. Raman spectra of Ti_3AlC_2 before and after HF treatment at room temperature for different etching time.

Table S2. The I_D/I_G ratio of the $Ti_3C_2T_x$ with different etching time

Etching time	S1	S2	S3	S4	S5
I_D/I_G	/	/	0.987	0.953	0.973

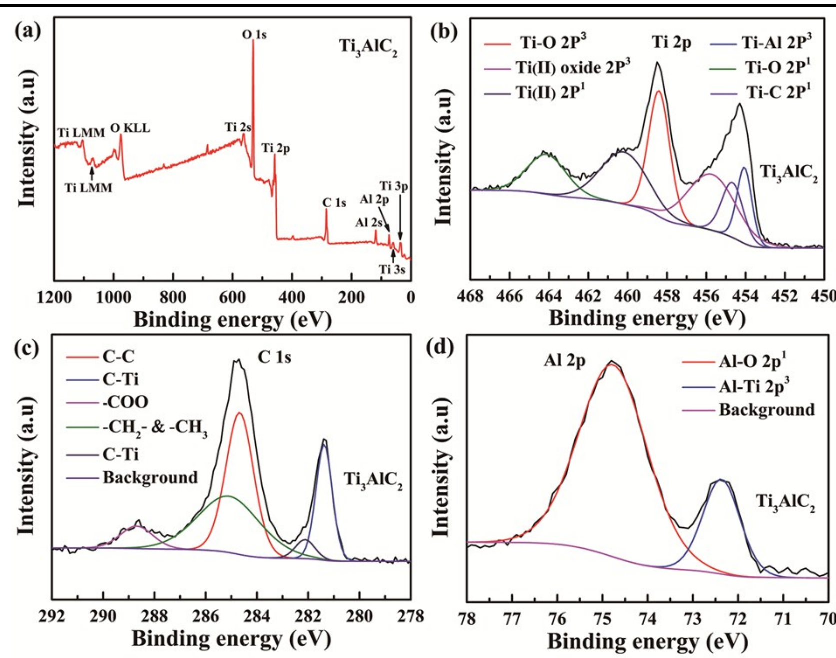

Figure S4. High-resolution XPS. (a) XPS spectra of Ti_3AlC_2. (b) Ti 2p spectra (c) C1s spectra and (d) Al 2p spectra of Ti_3AlC_2.

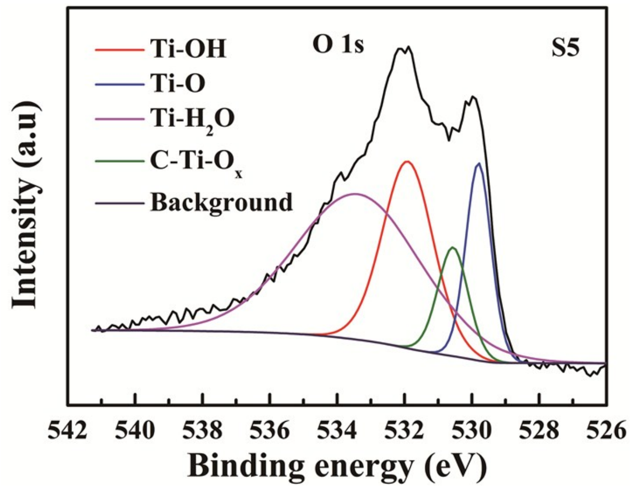

Figure S5. High-resolution O 1s XPS spectra of $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids with etching for 12 h.

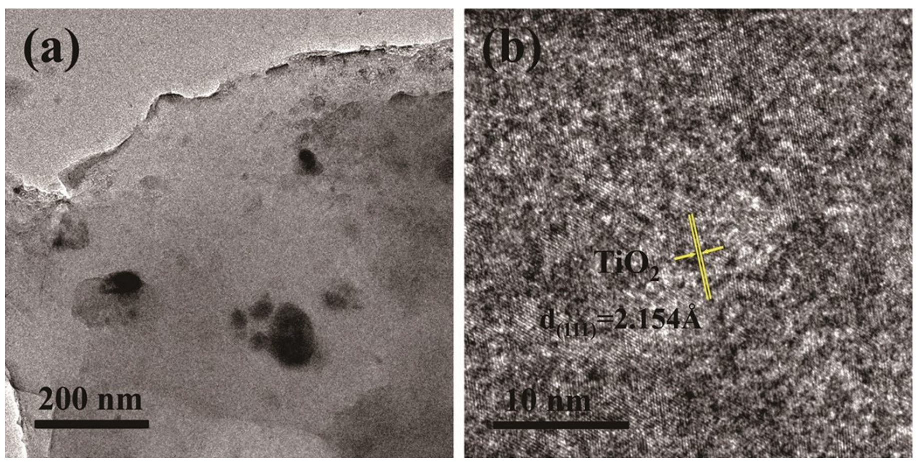

Figure S6. (a) TEM micrograph of Ti_3AlC_2 powder after HF treatment for 12 h (S5). (b) High-resolution TEM image of the denoted rectangular region in (a).

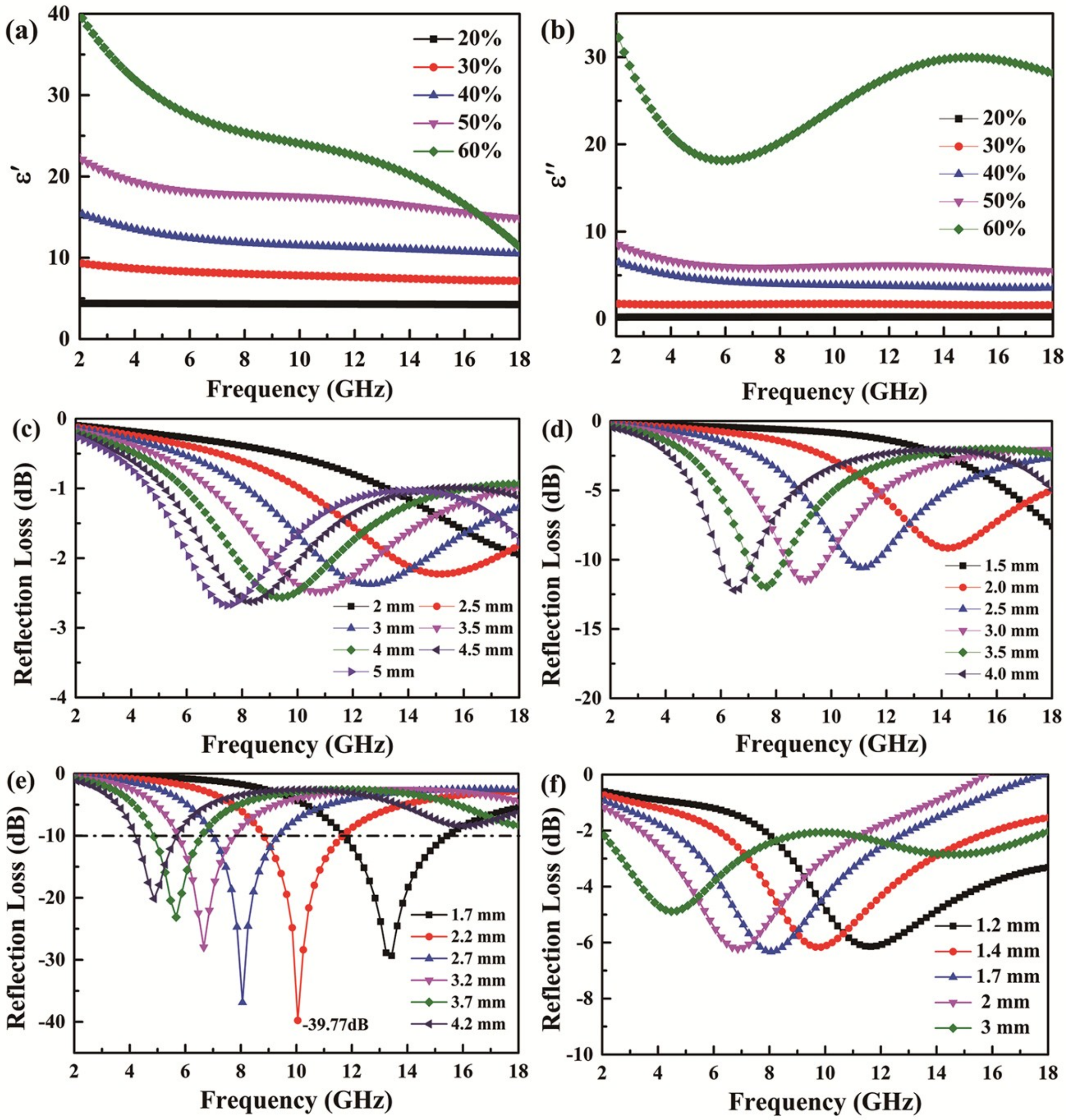

Figure S7. (a) The real part (ε′) and (b) imaginary part (ε″) of the complex permittivity of loading 20%, 30%, 40%, 50% and 60% $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids (12 h) mixed with paraffin wax at 2−18 GHz. (c), (d), (e) and (f) show reflection loss (RL) curves of 20%, 30%, 40% and 60% $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids (12 h) mixed with paraffin wax at 2−18 GHz.

Figure S7 shows (a) the real part (ε′) and (b) imaginary part (ε″) of the complex permittivity of loading 20%, 30%, 40%, 50% and 60% $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids (12 h) mixed with paraffin wax at 2−18 GHz. With the increase of sample content, the real part (ε′) and imaginary part (ε″)

of the complex permittivity increase gradually and the case of loading 60% $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids (12 h) is the highest. However, the loading 60% $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids (12 h) did not exhibit excellent microwave absorption (MA) properties (shown in Figure S7f), while the loading 50% $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids (12 h) exhibited the best MA properties (shown in Figure 7). This is related to another important determinant of MA materials--impedance matching. The complex dielectric constant of the material is too large and is not conducive to the impedance matching of MA material. In addition, the imaginary part of the dielectric constant, according to the free electron theory, $\varepsilon'' \approx {}^{1}\!/_{2\pi\varepsilon_0\rho f}$ where ρ is the resistivity, suggests that high ε″ value means high conductivity, which may cause the reflection of electromagnetic wave instead of the incident, is not conducive to the absorption of electromagnetic waves.[1] Furthermore, EM absorbing materials need a suitable relative complex permittivity to meet impedance match and energy loss. Generally speaking, the real part of permittivity is required to be smaller than 30 while the imaginary part should be lower than 15.[2] Figure 7S(c), (d) and (e) show reflection loss (RL) curves of 20%, 30% and 40% $Ti_3C_2T_x$ MXenes/nano-carbon-spheres hybrids (12 h) mixed with paraffin wax at 2−18 GHz.

Table S3. Comparison of EM wave absorbing properties of $Ti_3C_2T_x$ MXenes based composites.

Samples	**Matrix**	Filler loading (wt%)	Thickness (d;mm)	EAB (GHz)	RL_{min} (dB)	Ref.
$Ti_3C_2T_x$ MXenes	Wax	55	1.7	2.8	-30	[3]
Annealed-$Ti_3C_2T_x$	Wax	50	2.0	2.8	-48.4	[3]
$Ti_3C_2T_x$/CNTs	Wax	35	1.55	4.46	-52.9	[4]
$Ti_3C_2T_x/Ni_{0.5}Zn_{0.5}Fe_2O_4$	Wax	5	6.5	3	-42.3	[5]
Co_2Z/Ti_3C_2 Mxenes	PVB	/	2.8	1.6	-46.3	[6]
Ti_3C_2	PVB	/	2	0.8	-14.4	[6]
ZnO-$Ti_3C_2T_x$	Wax	25	4.0	1.4	-26.3	[7]
$Ti_3C_2T_x$ nanosheets	Wax	50	1.4	5.6	-18	[8]
2 wt%N-GP+30wt% Ti_3C_2 nanosheets	epoxy	/	1.4	3	-52	[9]
$Ti_3C_2T_x$/nano-carbon-spheres hybrids	Wax	50	4.8	1.1	-54.7	This work

References

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