Supporting Information

Hollow but Perforated C/Co/Mo_2C Cubes Enhance Electromagnetic Absorption

Xinghang Duan[1], Qiaolin Li[1], Tiantian Cao[1], Shengxiang Xiong[1], Gang Chen[1], Hongtao Guan[1], Chengjun Dong[1*], and Zongyou Yin[2*]

1 School of Materials and Energy, Yunnan University, Kunming 650091, China

2 Research School of Chemistry, Australian National University, Canberra, ACT 2601, Australia

* Corresponding Author: dongcj@ynu.edu.cn (C. J. Dong), zongyou.yin@anu.edu.au (Z. Y. Yin)

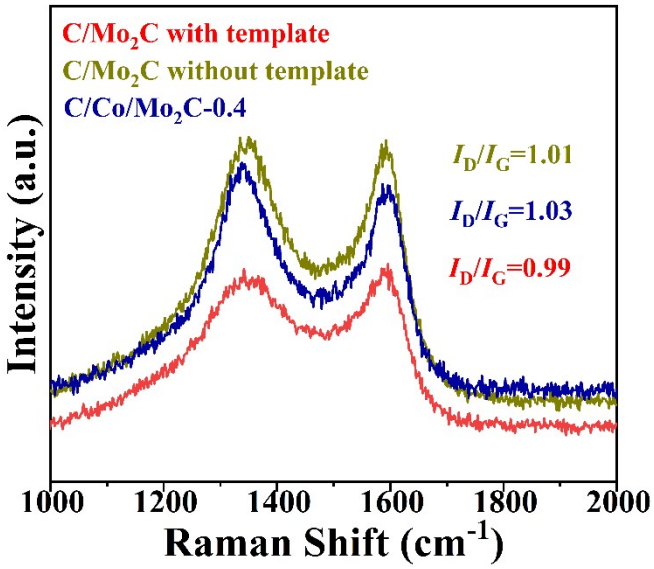


Fig. S1. Raman spectra of C/Mo_2C with/without-template, $C/Co/Mo_2C$-0.4 composites.

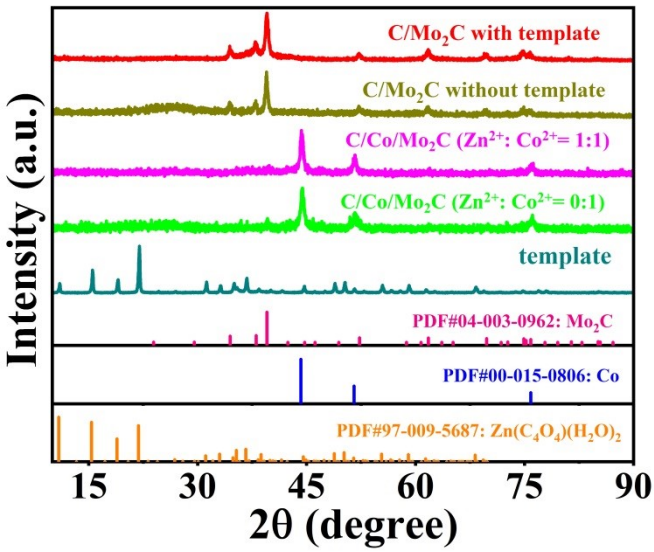


Fig. S2. XRD patterns of C/Mo_2C with/without-template, $C/Co/Mo_2C$ with ratio of Zn^{2+}: Co^{2+}= 1:1 and Zn^{2+}: Co^{2+}= 0:1 and $Zn/Co(C_4O_4)(H_2O)_2$ template.

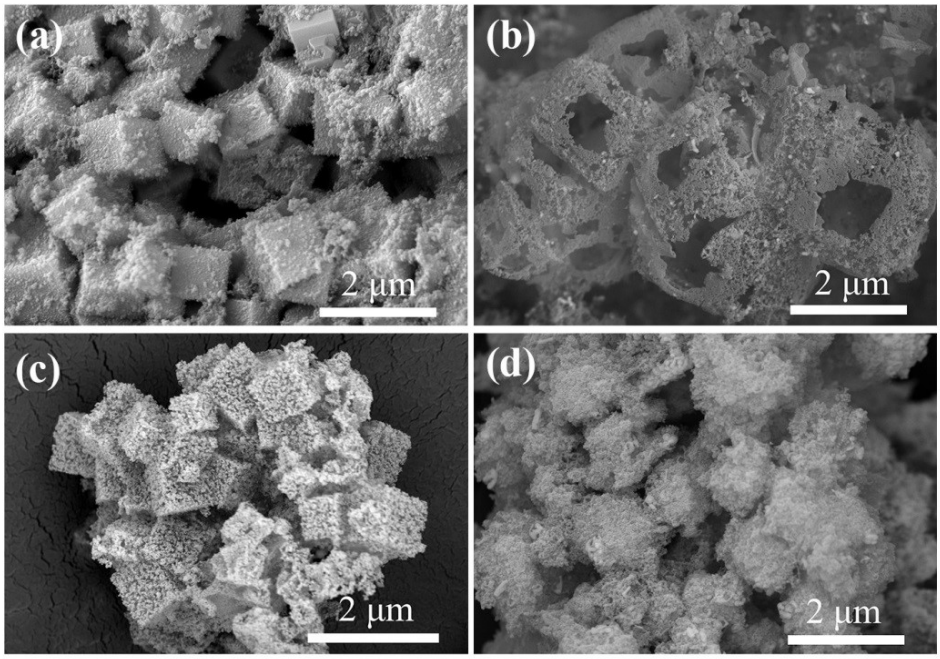


Fig. S3. SEM images of (a) Zn/Co(C_4O_4)(H_2O)$_2$@PPy/$Mo_2O_4^{2-}$ precursor, (b) C/Mo_2C-0.2, (c) C/Co/Mo_2C-0.4, (d) C/Co/Mo_2C-0.6 composites.

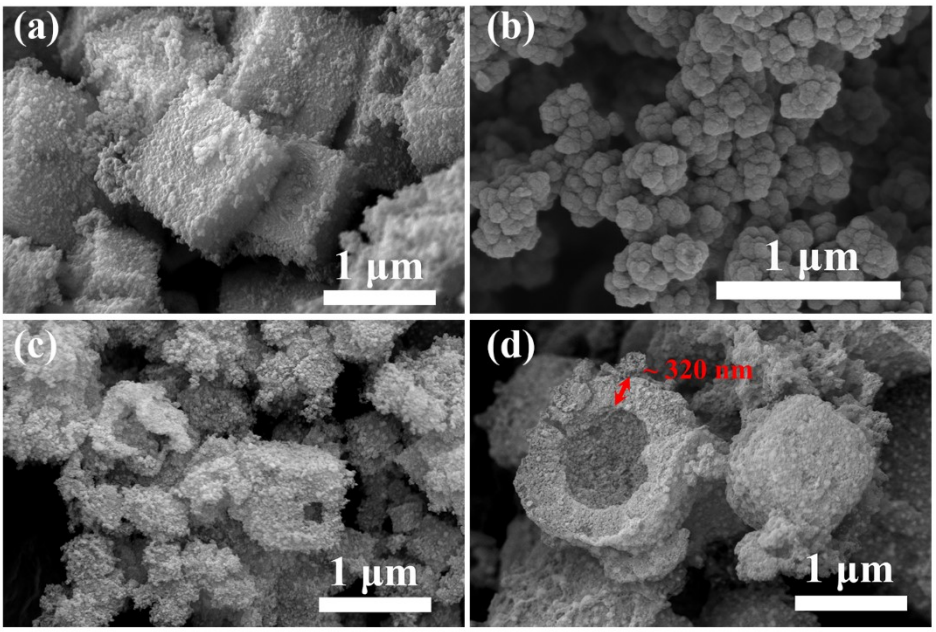


Fig. S4. SEM images of (a) $Zn/Co(C_4O_4)(H_2O)_2$@PPy/$Mo_2O_4^{2-}$ precursor, (b) C/Mo_2C without template, (c) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 1:1), (d) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 0:1) composites.

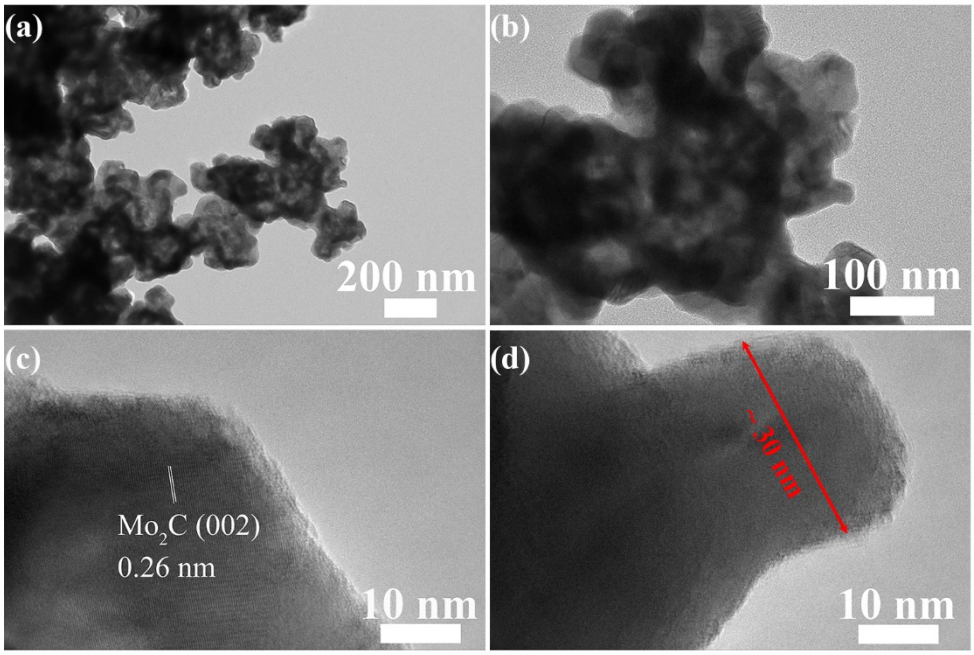
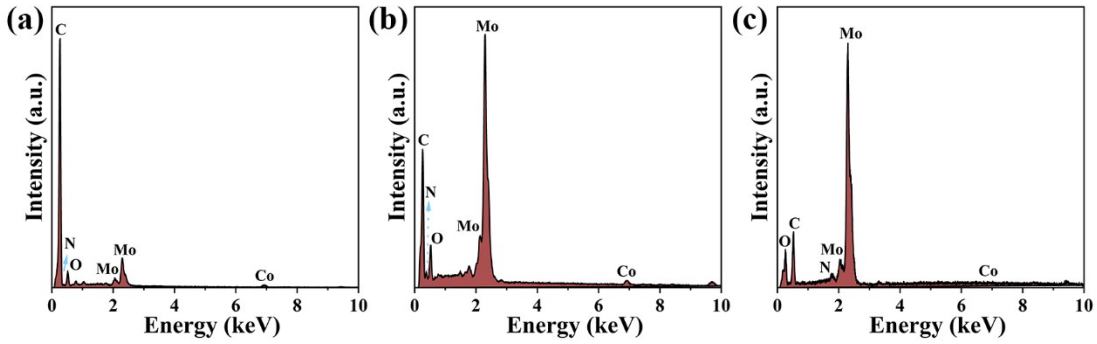


Fig. S5. (a, b) TEM and (c, d) HRTEM images of C/Mo_2C without template.



(d)

Samples \ Atomic %	C	Mo	Co	N	O
C/Co/Mo_2C-0.2	90.87	1.01	0.24	0.22	7.66
C/Co/Mo_2C-0.4	62.97	5.99	0.39	13.05	17.60
C/Co/Mo_2C-0.6	43.48	11.90	0.38	6.02	38.22

Fig. S6. EDS spectrum of (a) C/Co/Mo_2C-0.2, (b) C/Co/Mo_2C-0.4, (c) C/Co/Mo_2C-0.6 composites and (d) elemental content comparison chart.

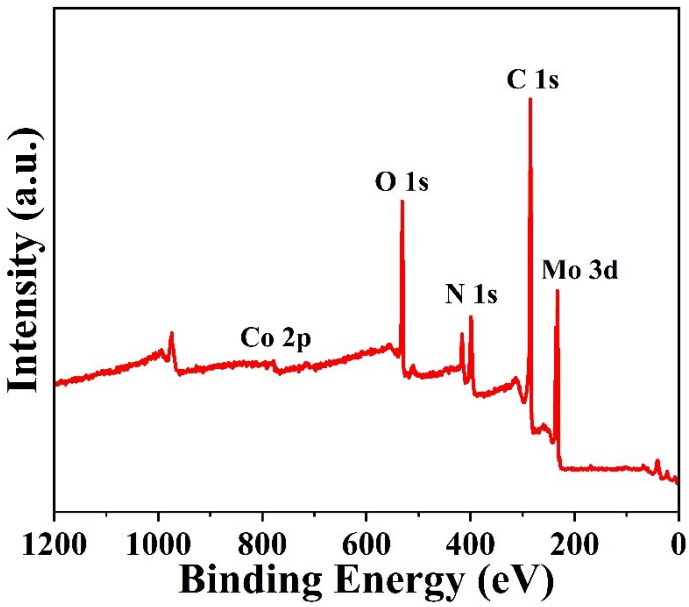


Fig. S7. Full XPS spectra of C/Co/Mo_2C-0.4 composites.

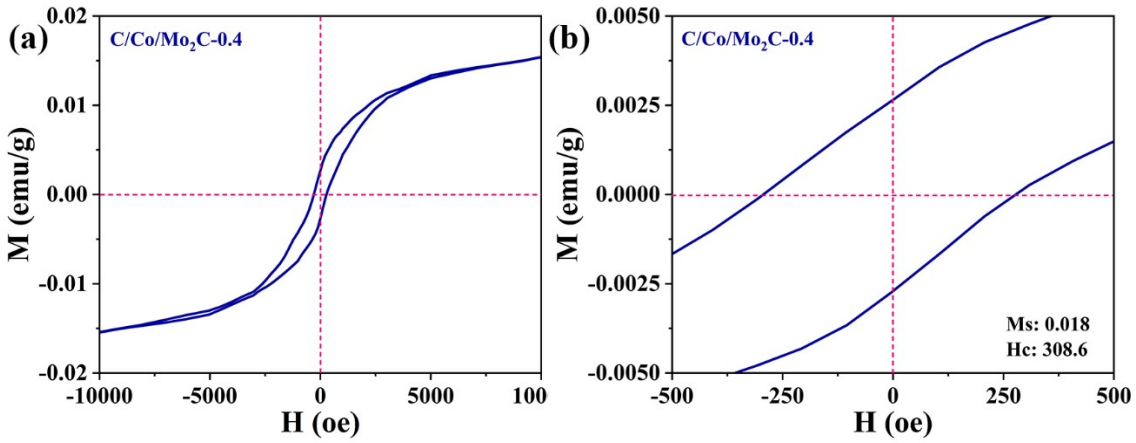


Fig. S8. Hysteresis loops of C/Co/Mo_2C-0.4 composites.

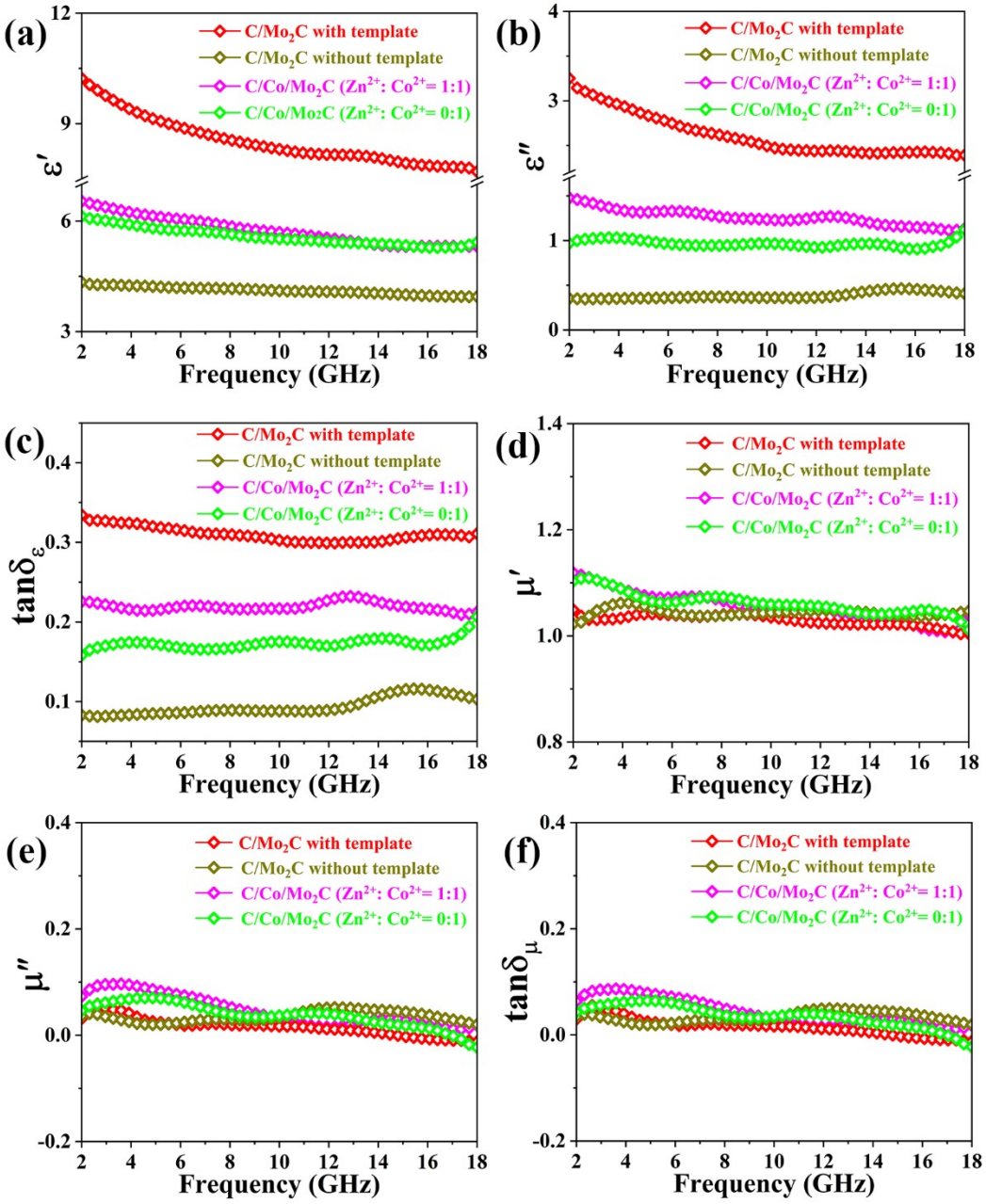


Fig. S9. EM parameters of C/Mo_2C with/without-template, C/Co/Mo_2C with ratio of Zn^{2+}: Co^{2+}= 1:1 and Zn^{2+}: Co^{2+}= 0:1: (a) ε', (b) ε'', (c) tanδ_ε, (d) μ', (e) μ'', (f) tanδ_μ.

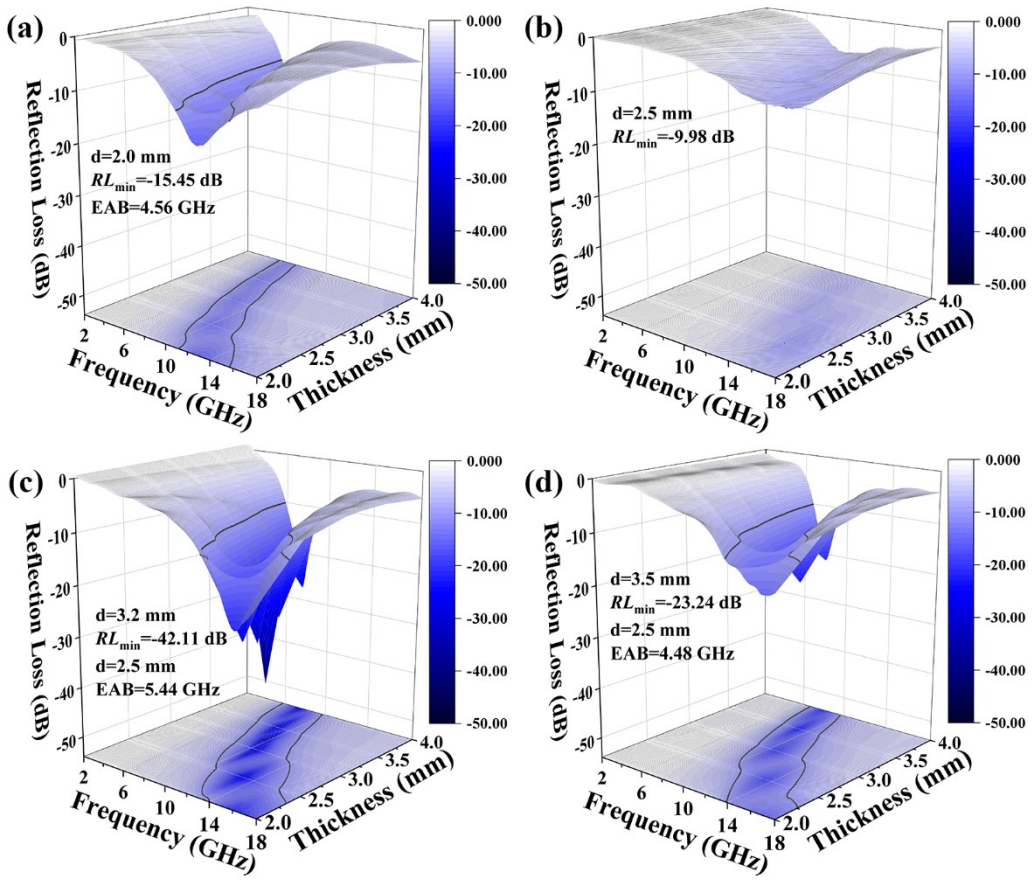


Fig. S10. 3D reflection loss properties of (a) C/Mo_2C with template, (b) C/Mo_2C without template, (c) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 1:1), (d) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 0:1).

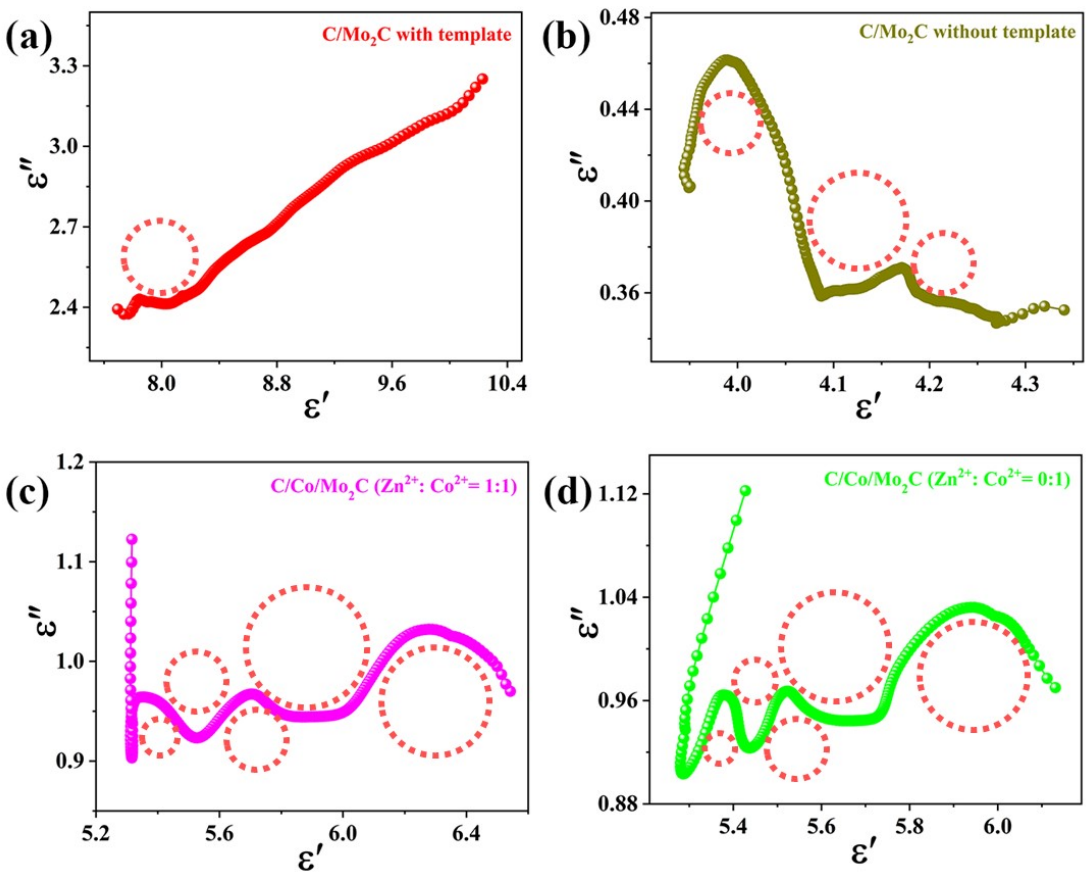


Fig. S11. Cole-Cole semicircle of (a) C/Mo_2C with template, (b) C/Mo_2C without template, (c) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 1:1), (d) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 0:1).

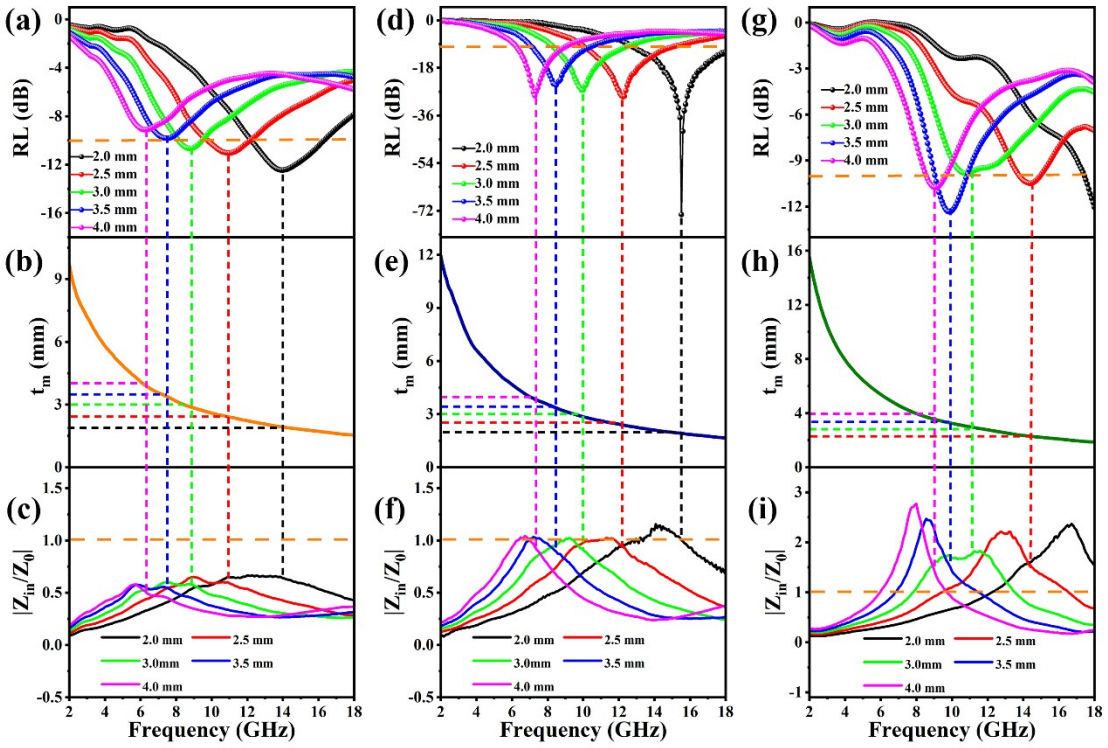


Fig. S12. 2D *RL* properties, $\lambda/4$ model, and $|Z_{in}/Z_0|$ values of (a-c) C/Co/Mo_2C-0.2, (d-f) C/Co/Mo_2C-0.4, (g-i) C/Co/Mo_2C-0.6 composites.

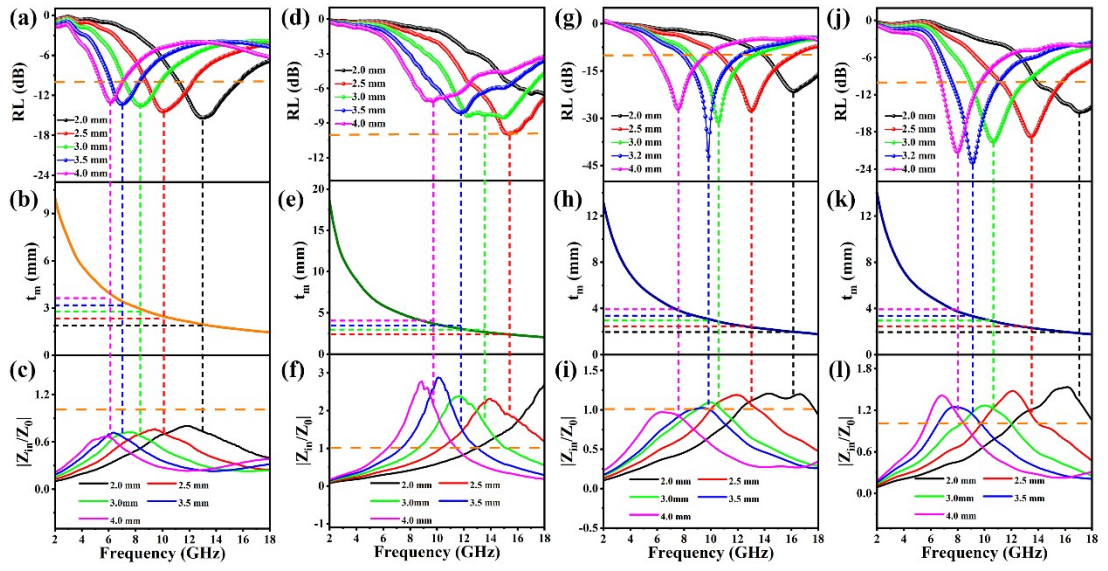


Fig. S13. 2D *RL* properties, $\lambda/4$ model, and $|Z_{in}/Z_0|$ values of (a-c) C/Mo_2C with template, (d-f) C/Mo_2C without template, (g-i) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 1:1), (j-l) C/Co/Mo_2C (Zn^{2+}: Co^{2+}= 0:1).

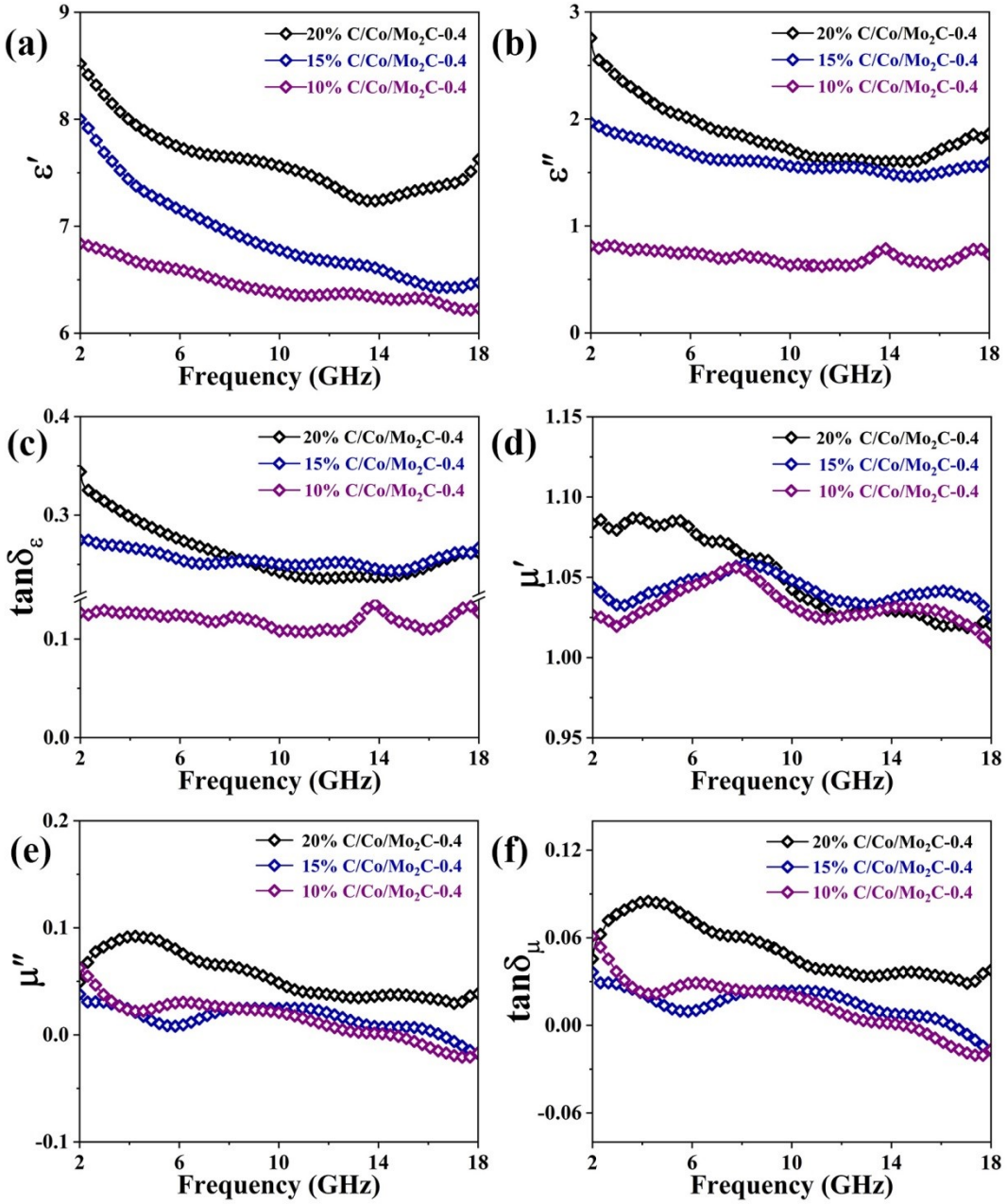


Fig. S14. EM parameters of C/Co/Mo_2C-0.4 composites with different filling ratios: (a) ε', (b) ε'', (c) $\tan\delta_{\varepsilon}$, (d) μ', (e) μ'', (f) $\tan\delta_{\mu}$.

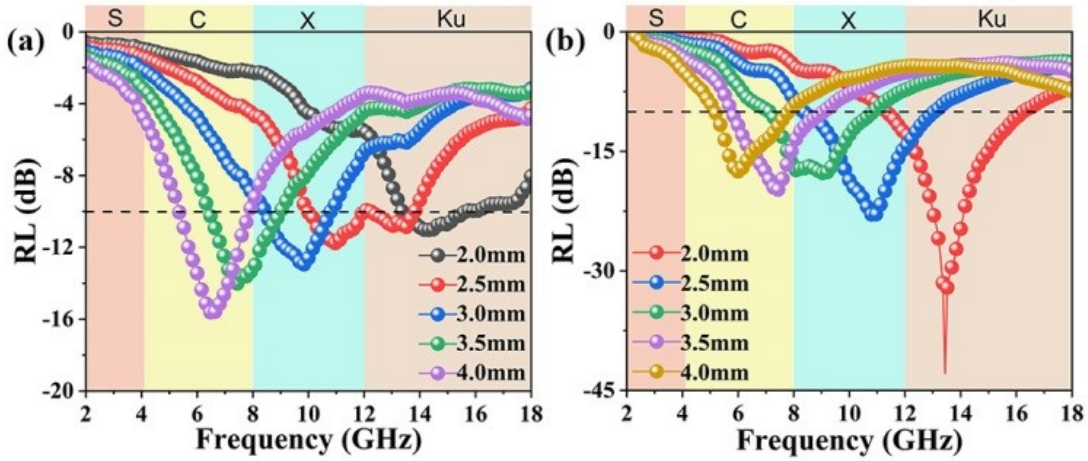


Fig. S15. 2D reflection loss properties of C/Co/Mo_2C-0.4 composites with different filling ratios: (a) 10 wt.%, (b) 20 wt.%.

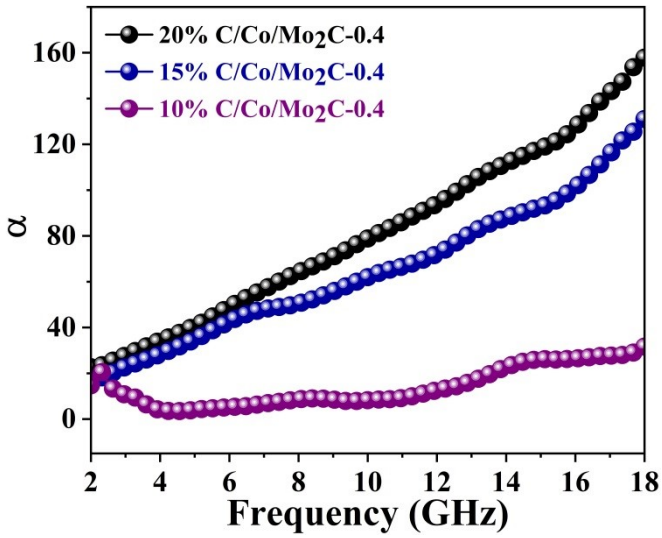


Fig. S16. Attenuation constants (α) of C/Co/Mo_2C-0.4 composites with different filling ratios.

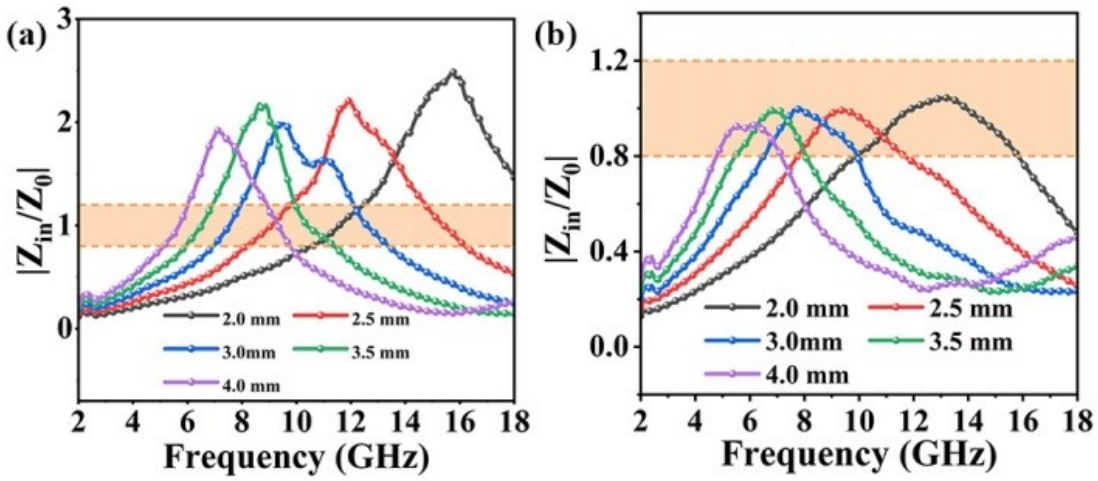


Fig. S17. $|Z_{in}/Z_0|$ values of C/Co/Mo_2C-0.4 composites with different filling ratio: (a) 10 wt.%, (b) 20 wt.%.

Table S1. Comparison of C/Co/Mo_2C-0.4 composites with other molybdenum carbide based composites.

Samples	Shapes	Loading (wt. %)	d_1 (mm)	RL_{min} (dB)	d_2 (mm)	EAB (GHz)	Ref.
MoC powders	Sphere	71	1.5	-42.2	1.5	4.2	[1]
Mo_2C/C	Porous	20	3.0	-20.38	1.8	5.04	[2]
MoC_{1-x}/C	Double-shell	20	1.8	-50.55	2.0	5.36	[3]
Mo_2C@C	Nanorods	10	2.0	-39.0	2.0	3.1	[4]
Mo_2C/NC	Porous	30	1.5	-61.53	3.5	9.6	[5]
Mo_2C@NPC	Sphere	40	2.5	-50.6	2.5	5.4	[6]
Mo_2C/C NCs	Porous	20	2.6	-49.19	1.7	4.56	[7]
PL-Mo_2C@C	Sphere	40	1.9	-48.0	2	4.1	[8]
DS-Mo_2C/C	Dual-Shell	40	5.0	-22.0	1.5	4.4	[9]
S-Mo_2C/C	Polyhedrons	50	1.5	-60.4	1.5	4.8	[10]
FCN-Mo_2C	Flower-like	10	2.3	-36.8	2.9	7.04	[11]
H-MoC/NC	Hollow	15	2.0	-41.2	2.0	5.2	[12]
$FeNi_3$/Mo_2C	Fibers	30	2.0	-51.5	2.0	5.1	[13]
Ni/Mo_2C-C	Nanowires	15	2.7	-55.91	2.7	3.5	[14]
Mo_2C/Co/C	Nanorods	30	3.0	-48.0	3.0	2.0	[15]
Sn@Mo_2C/C	Double-shell	30	2.0	-52.1	2.0	6.76	[16]
Mo_2C@Co/C	Polyhedrons	20	2.3	-37.9	1.9	5.52	[17]
Mo_2C/Co/C	Nanorods	50	1.77	-54.6	2.61	4.08	[18]
Mo_2C/Co@C	Nanorods	35	1.7	-47.98	1.6	6.0	[19]
Mo_xC-Co/C	Porous	30	1.5	-59.69	2.09	4.08	[20]
η-MoC/Co@NC	Polyhedrons	15	2.0	-47.72	2.0	4.58	[21]
Co/NC/Mo_xC/NC	Nanoflowers	16.7	1.5	-41.27	1.5	4.88	[22]
Mo_2C/NC@MXene	Sphere	25	2.5	-59.36	2.5	4.6	[23]
MoO_2/Mo_2C/Mo_2N	Porous	60	2.0	-38.0	1.5	4.11	[24]
$Co_6Mo_6C_2$/Mo_2C@NC	Porous	45	1.7	-65.89	2	6.4	[25]
NiMo/MoC/NC	Flower-like	35	1.52	-70.1	1.4	4.4	[26]
Mo_2C/FeCo/NC	Sphere	25	2.2	-77.37	2.2	7.25	[27]
Mo_2C/NiFe-NC	Nanosheets	60	1.4	-51.56	1.4	3.7	[28]
H-CoNi@MoC/NC	Hollow	15	3.1	-60.05	2.5	3.52	[29]
Mo_2C/$La_{0.6}Sr_{0.4}MnO_3$	Nanorods	30	1.2	-39	1.2	3	[30]
MoO_3-MoC/Co@NC	Short rod-like	40	3.875	-64.3	3.875	1.78	[31]
C/Co/Mo_2C	Hollow tubes	15	2.0	-73.46	2.0	5.20	This work

(d_1: matched thickness for minimum reflection loss, d_2: matched thickness for maximum effective absorption bandwidth)

References

[1] W. Wang, G. Sun, X. Sun, M. Huang, Y. Liang, J. Bi, *J. Mater. Sci.: Mater. Electron.* 2021, **32**, 24351.

[2] Y. Zhang, Y. Fang, X. Hou, J. Wen, J. Chen, S. Wang, K. Cao, W. Ye, R. Zhao, W. Wang, W. Xue, *Carbon* 2023, **214**, 118323.

[3] T. Zhao, Z. Jia, Y. Zhang, G. Wu, *Small* 2023, **19**, 2206323.

[4] C.-Q. Li, X. Shen, R.-C. Ding, G.-S. Wang, *RSC Adv.* 2019, **9**, 21243.

[5] Q. Li, L. Liu, H. Kimura, X. Zhang, X. Liu, X. Xie, X. Sun, C. Xu, W. Du, C. Hou, *J. Colloid Interface Sci.* 2024, **655**, 634.

[6] Z. Wu, C. Jin, Z. Yang, R. Che, *Carbon* 2022, **189**, 530.

[7] S. Dai, Y. Cheng, B. Quan, X. Liang, W. Liu, Z. Yang, G. Ji, Y. Du, *Nanoscale* 2018, **10**, 6945.

[8] Y. Wang, X. Han, P. Xu, D. Liu, L. Cui, H. Zhao, Y. Du, *Chem. Eng. J.* 2019, **372**, 312.

[9] X. Deng, Y. Wang, L. Ma, Z. Li, Z. Chen, X. Lv, Y. Chang, Y. Liu, J. Shi, in *Int. J. Mol. Sci.*, Vol. 2022, **23**.

[10] Y. Wang, C. Li, X. Han, D. Liu, H. Zhao, Z. Li, P. Xu, Y. Du, *ACS Appl. Nano Mater.* 2018, **1**, 5366.

[11] L. Wang, J. Lu, J. Zhang, J. Zhu, *J. Colloid Interface Sci.* 2023, **641**, 729.

[12] W. Huang, W. Gao, S. Zuo, L. Zhang, K. Pei, P. Liu, R. Che, H. Zhang, *J. Mater. Chem. A* 2022, **10**, 1290.

[13] C. Wu, K. Bi, M. Yan, *J. Mater. Chem. C* 2020, **8**, 10204.

[14] S. Gao, J. Feng, G.-S. Wang, B.-L. Liang, *Front. Chem.* 2019, **7**.

[15] Y. Wang, X. Li, X. Han, P. Xu, L. Cui, H. Zhao, D. Liu, F. Wang, Y. Du, *Chem. Eng. J.* 2020, **387**, 124159.

[16] X. Qian, Y. Zhang, Z. Wu, R. Zhang, X. Li, M. Wang, R. Che, *Small* 2021, **17**, 2100283.

[17] G. Yang, B. Wen, Y. Wang, X. Zhou, X. Liu, S. Ding, *Nanotechnology* 2023, **34**, 185704.

[18] B. Zhao, N. Wu, S. Yao, Y. Yao, Y. Lian, B. Li, Z. Zeng, J. Liu, *ACS Appl. Nano Mater.* 2022, **5**, 18697.

[19] S. Dai, B. Quan, B. Zhang, X. Liang, G. Ji, *Dalton Trans.* 2018, **47**, 14767.

[20] X. Duan, Z. Wang, T. Cao, Q. Li, G. Chen, H. Guan, C. Dong, *J. Alloys Compd.* 2024, **993**, 174538.

[21] W. Huang, J. Chen, W. Gao, L. Wang, P. Liu, Y. Zhang, Z. Yin, Y. Yang, *Carbon* 2022, **197**, 129.

[22] Y. Ge, G. I. N. Waterhouse, J. Sui, Z. Zhang, L. Yu, *Synth. Met.* 2022, **287**, 117052.

[23] K. Yang, Y. Cui, L. Wan, Y. Wang, M. R. Tariq, P. Liu, Q. Zhang, B. Zhang, *ACS Appl. Mater. Interfaces* 2022, **14**, 7109.

[24] T. Wei, X. Zhu, J. Xu, C. Kan, D. Shi, *Langmuir* 2023, **39**, 890.

[25] Y. Ning, X. Zeng, X. Peng, X. Jiang, Z.-Y. Shen, C. Liu, R. Yu, *J. Mater. Sci. Technol.* 2024, **187**, 15.

[26] H. Luo, S. Lv, G. Liu, Y. Cheng, X. Ge, X. Wang, R. Gong, F. Chen, *Carbon* 2022, **196**, 828.

[27] N. Zhang, P. Chen, Y. Wang, M. Zong, W. Chen, *Compos. Sci. Technol.* 2022, **221**, 109325.

[28] X. Zeng, Y. Ning, H. Guo, N. Xie, R. Yu, *Mater. Today Phys.* 2023, **34**, 101077.

[29] X. Yang, W. Gao, J. Chen, X. Lu, D. Yang, Y. Kang, Q. Liu, Y. Qing, W. Huang, *Chin. J. Chem.* 2023, **41**, 64.
[30] J. Huang, I. Mahariq, S. M. Kumar, S. Abdullaev, S. Kannan, N. Thi Xuan Dieu, Y. Fouad, *Colloids Surf., A* 2024, **689**, 133664.
[31] Y. Yin, X. Zeng, L. Xia, G. Xiong, H. Zhang, G. Wei, *Colloids Surf., A* 2023, **668**, 131427.