Supplementary Materials

Rui Sun[1], Huwei Lv[1], Gangjie Lian[2], Lei Wang[3,*], Mengqiu Huang[4], Wenbin You[4], Renchao Che[1,2,4,*]

[1]School of Physics and Materials Science, Nanchang University, Nanchang 330031, Jiangxi, China.
[2]International Institute for Materials Innovation, Nanchang University, Nanchang 330031, Jiangxi, China.
[3]School of Materials Science and Engineering, Tongji University, Shanghai 201804, China.
[4]Laboratory of Advanced Materials, Shanghai Key Lab of Molecular Catalysis and Innovative Materials, State Key Laboratory of Coatings for Advanced Equipment, College of Smart Materials and Future Energy, Fudan University, Shanghai 200438, China.

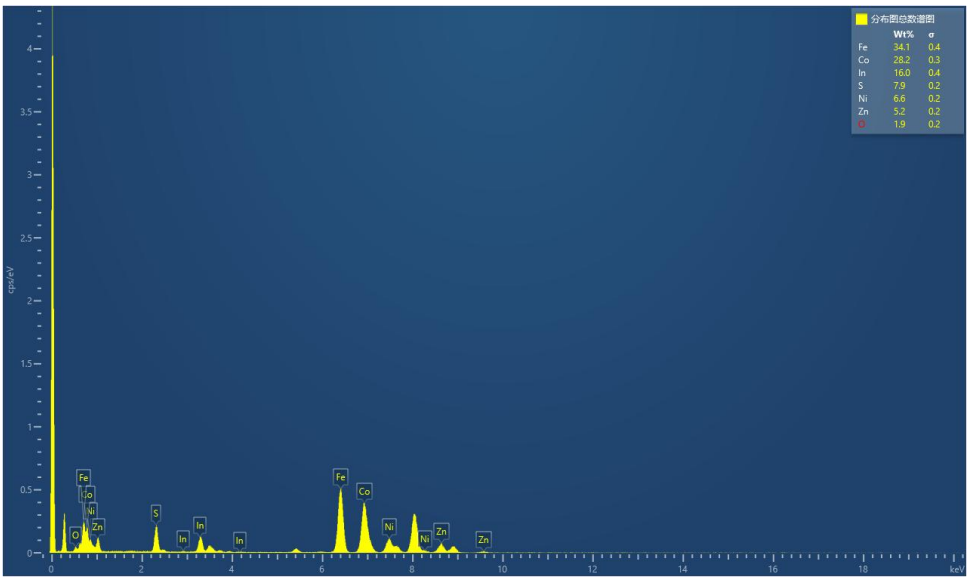
[*]**Correspondence to:** Prof. Renchao Che, School of Physics and Materials Science, Nanchang University, No. 999 Xuefu Road, Honggutan District, Nanchang 330031, Jiangxi, China. E-mail: rcche@fudan.edu.cn; Dr. Lei Wang, School of Materials Science and Engineering, Tongji University, No. 4800 Caoan Road, Jiading District, Shanghai 201804, China. E-mail: lei_wang@tongji.edu.cn

Characterization and Measurement Details

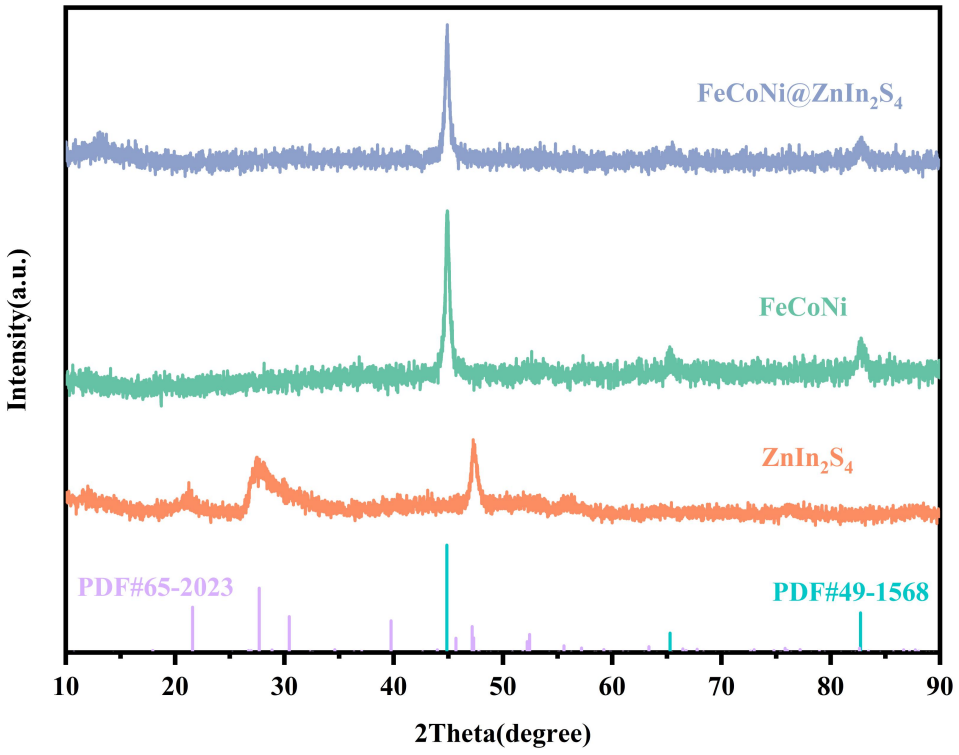
The crystal structure of the samples was analyzed by X-ray diffraction (XRD, Brucker, D8 ADVANCED) with Cu-Kα radiation (λ=1.5406 Å, 40 kV, 40 mA). The morphology of the samples was observed using field emission scanning electron microscope (FESEM, HITACHI, S4800) with a working voltage and current of 5.0 kV and 10 μA, respectively. The JEOL JEM-2100F transmission electron microscope (TEM) was used to analyse the material morphology, the operating voltage, current and current density of 200 kV, 212 μA and 511.8 pA/cm^2, respectively. The XPS spectra in this study were obtained using a Thermo Scientific ESCALAB 250Xi spectrometer equipped with a monochromatic X-ray source (Al kα). During X-ray photoelectron spectra acquisition, the energy resolution ≤ 0.5 eV, pass energy = 10 eV. Calibrate the main peak position of the C 1s peak for contaminated carbon to 284.8 eV, then use the Shirley background subtraction method, with the subtraction operation performed in Avantage. Based on the expected chemical states of the elements and a standard binding energy database, preliminary peak positions were set. The peak positions, peak areas, and half-widths were optimised using the non-linear least squares fitting function in Avantage. Finally, the fitting quality was assessed by visually inspecting the fit of the curve to the raw data and the randomness of the residual plot.

The mixtures of $ZnIn_2S_4$, FeCoNi, $ZnIn_2S_4$-500, $ZnIn_2S_4$-600, $ZnIn_2S_4$-700, FCNZ, FCNZ-500, FCNZ-600, and FCNZ-700 composites with 60 wt% paraffin was compacted into coaxial ring of 7 mm outer diameter and 3.04 mm inner diameter to assess EM wave absorption performance.

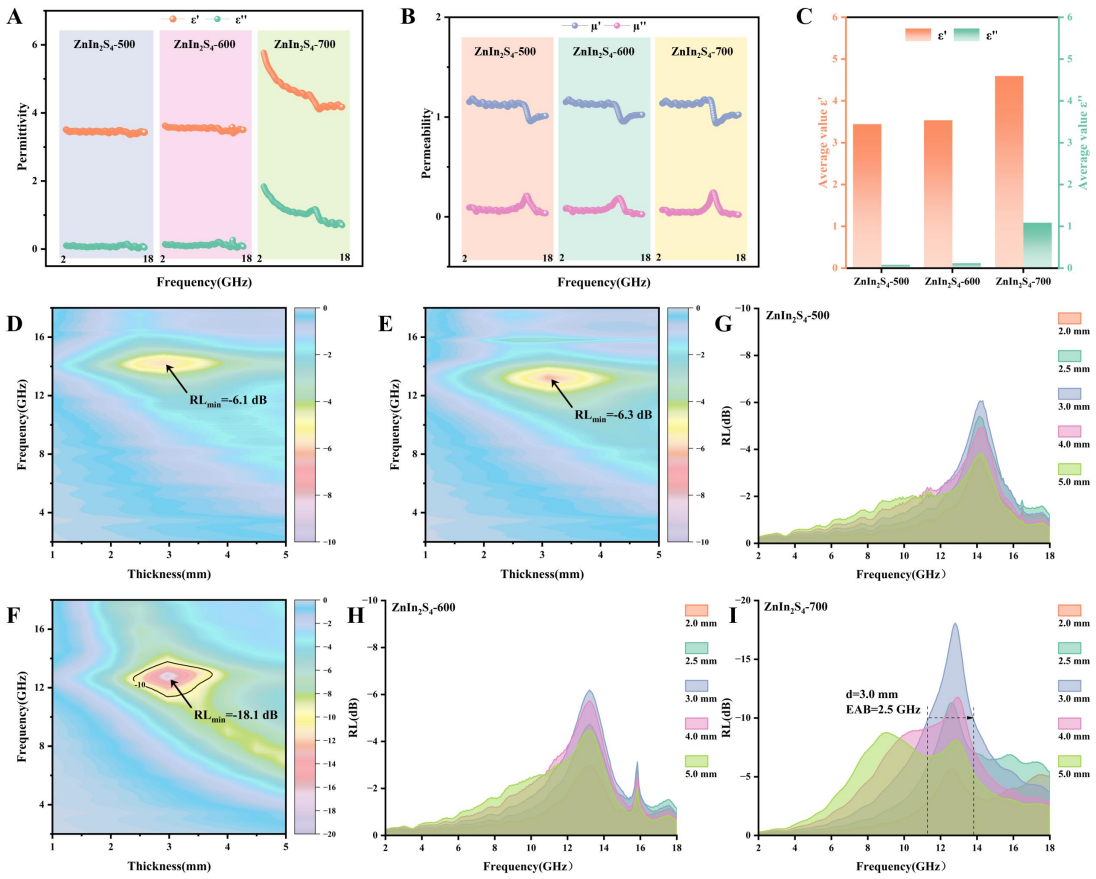
Supplementary Figures and Tables



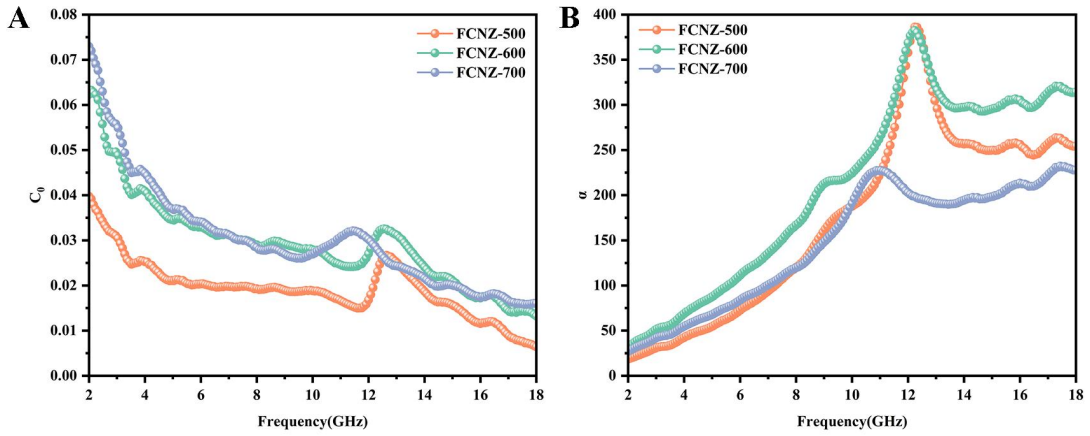
Supplementary Figure 1. EDS spectra of FCNZ-600.



Supplementary Figure 2. The XRD pattern of synthesized $ZnIn_2S_4$, FeCoNi, and FeCoNi@$ZnIn_2S_4$.



Supplementary Figure 3. (A) The complex permittivity, (B) complex permeability, (C) average complex permittivity, (D-F) 3D and (G-I) 2D reflection loss diagrams of $ZnIn_2S_4$-500, $ZnIn_2S_4$-600, and $ZnIn_2S_4$-700.



Supplementary Figure 4. (A) C_0-f curve of composites, (B) α-f curve of composites.

Supplementary Table 1. Microwave absorption performance of core-shell structured absorbers in previous references and this work.

Sample	EAB (GHz)	RL_{min} (dB)	Thickness (mm)	Reference
Fe_3O_4@C	1.6	-47	2	[1]
Fe_3O_4@ppy	2.4	-46	5	[2]
Ni@C@ZnO	3.3	-55.8	2.50	[3]
	4.10	-27	2.00	
Ni@ppy	3.8	-48	5	[4]
H-Fe_3O_4@C	5.36	-51.85	2.1	[5]
Fe/Fe_3C@SiO_2@C	3.74	-48.68	1.24	[6]
Fe_3O_4@SiO_2@$MoSe_2$	4.96	-51.8	1.8	[7]
Fe_3Al@PPy	3.44	-40.53	2.0	[8]
$NiFe_2O_4$@PPy	5.2	-56.25	2.24	[9]
	7.12	-	2.6	
C@$NiCo_2O_4$@Fe_3O_4	2.1	-43	3.4	[10]
FCNZ-600	4.91	-52.4	1.9	This Work
	6.08	-34.7	1.53	This Work

REFERENCES

1. Adebayo, L.L. A Simple Route to Prepare Fe_3O_4@C microspheres as electromagnetic wave absorbing material. *J. Mater. Res. Technol.* **2021***, 12,* 1552-1563. DOI: 10.1016/j.jmrt.2021.03.094

2. Tian, X.; Xu, X.; Bo, G. A 3D flower-like Fe_3O_4@PPy composite with core-shell heterostructure as a lightweight and efficient microwave absorbent. *J. Alloys Compd.* **2022**, *923*, 166416. DOI:10.1016/j.jallcom.2022.166416

3. Wang, L.; Yu, X.; Li, X. MOF-derived yolk-shell Ni@C@ZnO schottky contact structure for enhanced microwave absorption. *Chem. Eng. J.* **2020**, *383*, 123099. DOI:10.1016/j.cej.2019.123099

4. Zhang, N.; Li, J.; Men, X. Cleaning synthesis of core–shell structured Ni@PPy composite as excellent lightweight electromagnetic wave absorber. *J Mater Sci: Mater. Electron.* **2020**, *31*, 1483–1490. DOI:10.1007/s10854-019-02663-5

5. Guo, J.; Sun, Y.; Li, X. Carbonization tuned core-shell Fe_3O_4@C nanostructures with enhanced electromagnetic wave absorption. *Adv Mater. Interfaces.* **2025**, 2500075. DOI:10.1002/admi.202500075

6. Deng, Z.; Wang, L.; Peng, B. Optimization of electromagnetic wave absorption properties by formation of magnetoelectric synergistic effect of COF-derived carbon composite Fe/Fe_3C. *Chem. Eng. J.* **2025**, *505*, 159457. DOI:10.1016/j.cej.2025.159457

7. Li, Q.; Yu, G.; Ye, M. Rational design of flower-like core–shell Fe_3O_4@SiO_2@$MoSe_2$ composites for high performance electromagnetic wave absorption. *J. Mater. Sci: Mater Electron.* **2023**, *34*, 1723. DOI:10.1007/s10854-023-11098-y

8. Shen, Y.; Song, P.; Zhang, F. Core-shell Fe_3Al@polypyrrole composites with tunable shell thickness and enhanced microwave absorption performance. *Colloid. Surface. A.* **2024**, *682*, 132814. DOI:10.1016/j.colsurfa.2023.132814

9. Shu, R.; Yun, K.; Liu, X. Fabrication of core–shell nickel ferrite@polypyrrole composite for broadband and efficient electromagnetic wave absorption. *Compos. Part A-Appl. S.* **2025**, *188*, 108558. DOI:10.1016/j.compositesa.2024.108558

10. Wei, S.; Wang, X.; Zhang, B. Preparation of hierarchical core-shell C@$NiCo_2O_4$@Fe_3O_4 composites for enhanced microwave absorption performance. *Chem. Eng. J.* **2017**, *314*, 477–487. DOI:10.1016/j.cej.2016.12.005