Electromagnetic Interference Shielding Material for Super-broadband: Ultrathin, Sandwich structure Multi-walled Carbon Nanotube/Silver Nanowire Film

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Supporting information

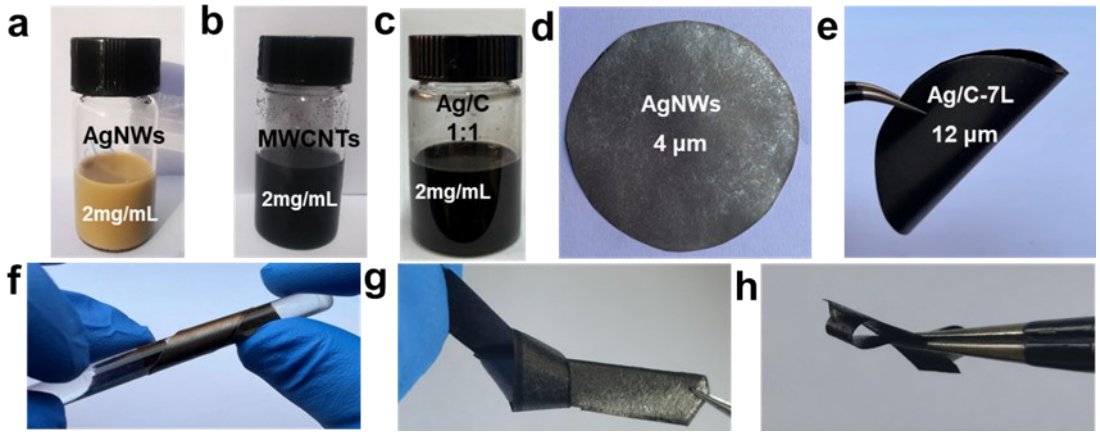

Figure S1. Digital photos of the building blocks of (a) AgNWs, (b) MWCNTs, and (c) Ag/C-PM. Digital photos of (d) AgNWs films and (e) Ag/C-7L. (f-h)Digital photograph of Ag/C-7L film with the state of twisting and buckling.

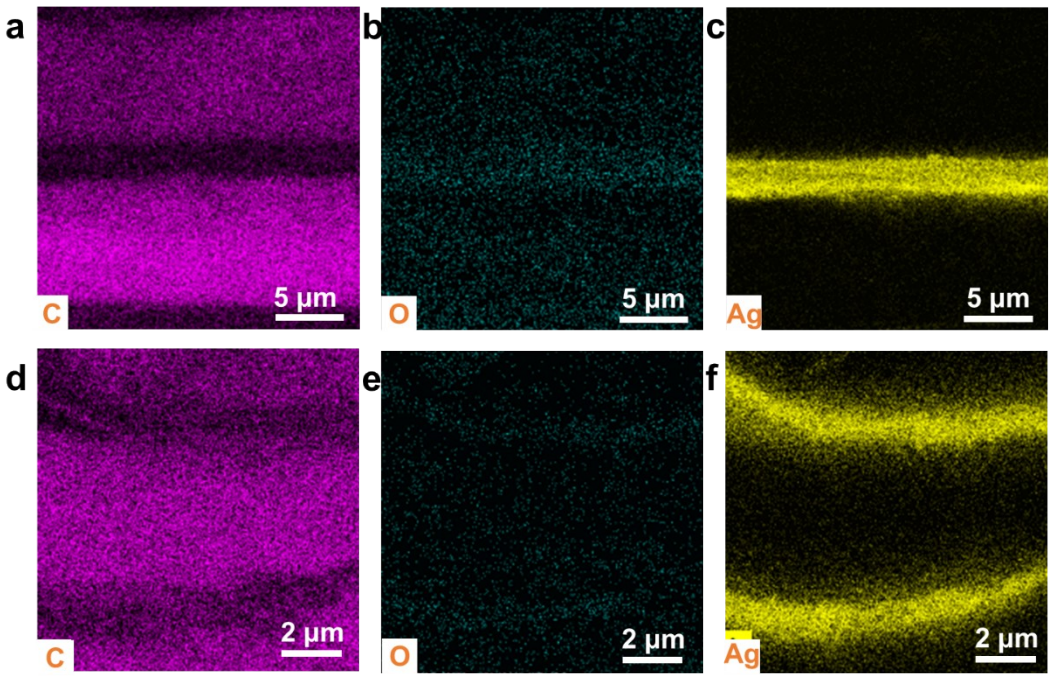

Fig. S2. Elemental mapping of (a-c) the Ag/C-3L film; Elemental mapping of (d-e) the Ag/C-5L film

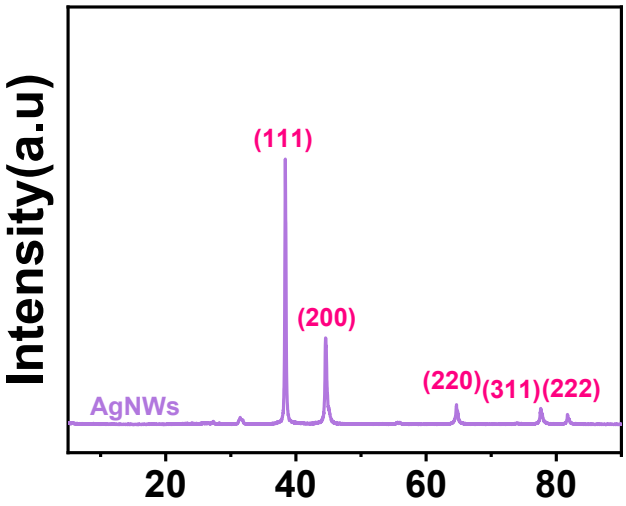

Figure S3. XRD spectra Ag NWs.

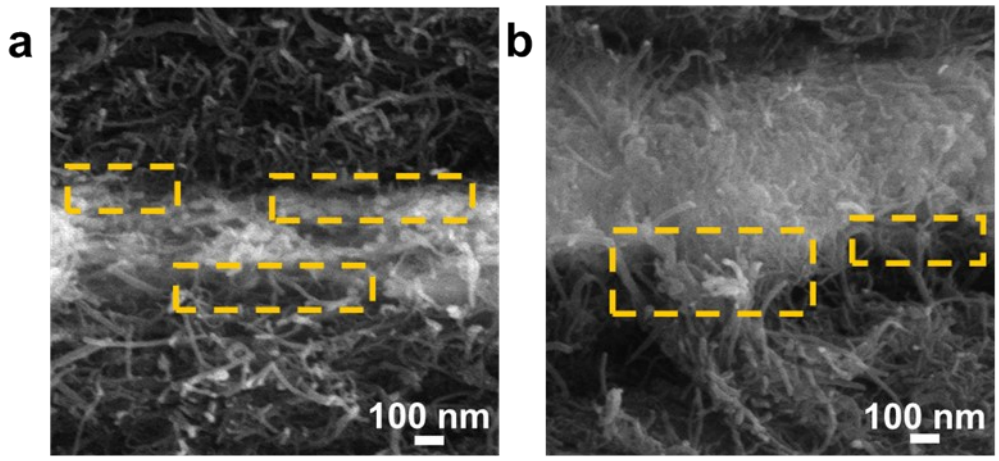

Figure S4. Cross-sectional SEM image of (a–b) the Ag/C-7L film.

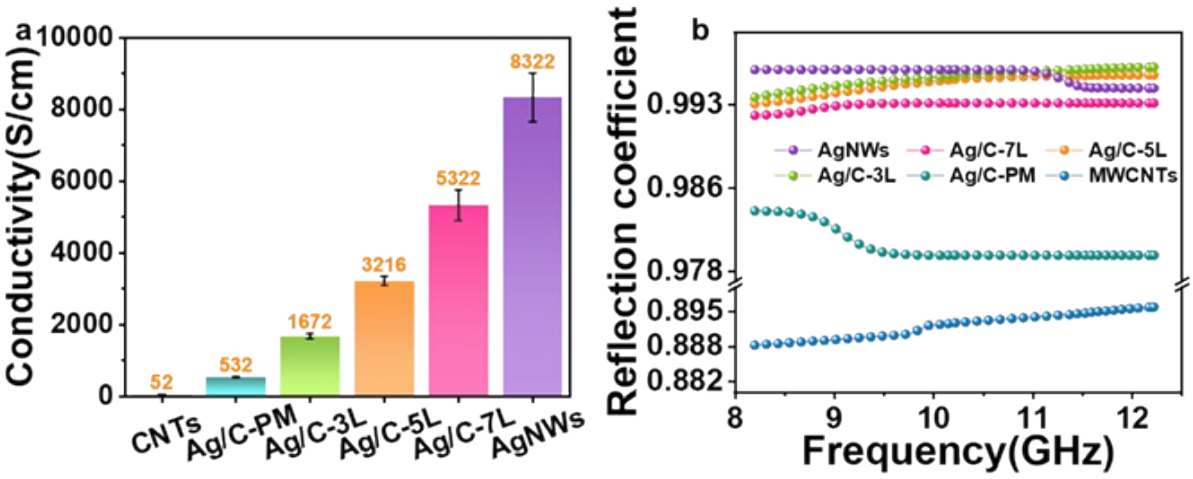

Figure S5 (a) Conductivity of all samples. (b) Reflection coefficient (R)

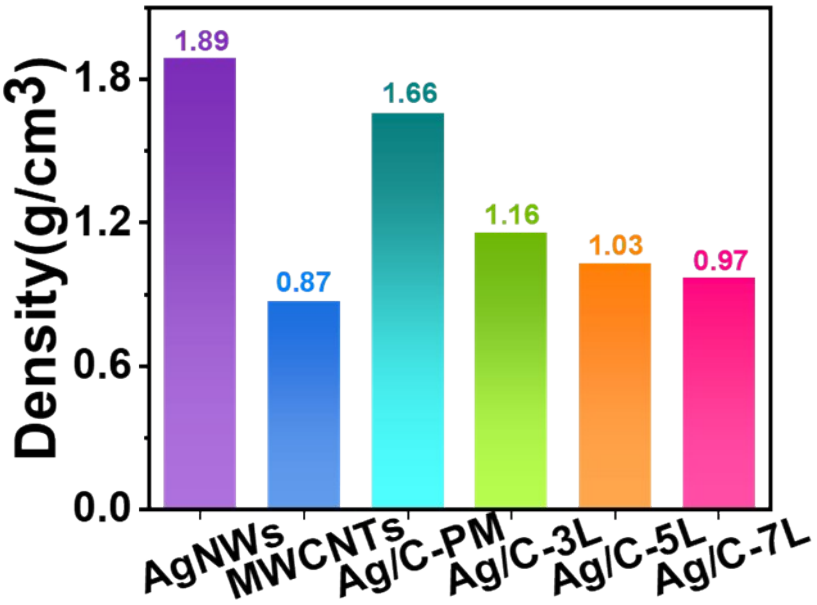

Figure S6. The density of Ag NWs, MWCNTs, Ag/C-PM, Ag/3L, Ag/C-5L, and Ag/C-7L films.

Table S1. Performance comparison of the current work of representative hollow-structure composites

Number	Samples	EMI SE (dB)	Thickness (μm)	EMI SE/t (dB/mm)	Ref.
1	MWCNT/cellulose/Ag NWs film	23.8	154	155	1
2	rGO/Ag NWs	24.0	100	240	2
3	graphene/ Ag NWs/graphene	38.0	10	3800	3
4	graphene/Ag NWs film	38.5	30	1283	4
5	MWCNTs/Ag NWs-PVDF	70.0	1174	60	5
6	CNTs/Polyurethane	43.5	2000	29	6

7	PVDF/CNTs/Ni@CNTs film	51.4	500	103	[7]
8	Al foil	66.0	8	8250	[8]
9	Cu foil	70.0	10	7000	[8]
10	MXene foam	32.0	6	5333	[9]
11	MXene/Nanocellulose film	24.0	47	511	[10]
12	MXene/RGO-epoxy solids	56.4	2000	28	[11]
13	MXene/CNT aerogel	62.8	1000	63	[12]
14	Graphene/PMMA foam	19.0	2400	8	[13]
15	Carbon/Graphene foam	24.0	24	1000	[14]
16	Graphene foam	25.0	300	83	[15]
17	MWCNT/WPU	24.0	50	480	[16]
18	SWCNT/epoxy	25.0	2000	13	[17]
19	Ag NW/PANI	48.0	13	308	[18]
20	Ag NW/epoxy	25.0	40	625	[19]
21	Ag NW/PVA	30.0	40	750	[19]
22	Ag NW/PS	32.0	800	40	[20]
23	Cu NW/PS	35.0	210	167	[21]
24	MWCNT/ Ag NWs/MWCNT film	72.0	12	60080	This works

References

1 X. Liang, J. Lu, T. Zhao, X. Yu, Q. Jiang, Y. Hu, P. Zhu, R. Sun and C. Wong, *Adv. Mater. Interfaces*, 2018, 1801635.

2 Y. Yang, S. Chen, W. Li, P. Li, J. Ma, B. Li, X. Zhao, Z. Ju, H. Chang, L. Xiao, H. Xu and Y. Liu, *ACS Nano*, 2020, **14**, 8754–8765.

3 R. R. da Silva, M. Yang, S.-I. Choi, M. Chi, M. Luo, C. Zhang, Z.-Y. Li, P. H. C. Camargo, S. J. L. Ribeiro and Y. Xia, *ACS Nano*, 2016, **10**, 7892–7900.

4 T. K. Gupta, B. P. Singh, V. N. Singh, S. Teotia, A. P. Singh, I. Elizabeth, S. R. Dhakate, S. K. Dhawan and R. B. Mathur, *J. Mater. Chem. A*, 2014, **2**, 4256.

5 M. Sang, S. Wang, S. Liu, M. Liu, L. Bai, W. Jiang, S. Xuan and X. Gong, *ACS Appl. Mater. Interfaces*, 2019, **11**, 47340–47349.

6 W.-C. Yu, T. Wang, Y.-H. Liu, Z.-G. Wang, L. Xu, J.-H. Tang, K. Dai, H.-J. Duan, J.-Z. Xu and Z.-M. Li, *Chem. Eng. J.*, 2020, **393**, 124644.

7 S. Zeng, X. Li, M. Li, J. Zheng, S. E, W. Yang, B. Zhao, X. Guo and R. Zhang, *Carbon*, 2019, **155**, 34–43.

8 F. Shahzad, M. Alhabeb, C. B. Hatter, B. Anasori, S. Man Hong, C. M. Koo and Y. Gogotsi, *Science*, 2016, **353**, 1137–1140.

9 W. Yuan, J. Yang, F. Yin, Y. Li and Y. Yuan, *Compos. Commun.*, 2020, **19**, 90–98.

10 C. Weng, T. Xing, H. Jin, G. Wang, Z. Dai, Y. Pei, L. Liu and Z. Zhang, *Compos. Part Appl. Sci. Manuf.*, 2020, **135**, 105927.

11 J.-Q. Luo, S. Zhao, H.-B. Zhang, Z. Deng, L. Li and Z.-Z. Yu, *Compos. Sci. Technol.*, 2019, **182**, 107754.

12 P. Sambyal, A. Iqbal, J. Hong, H. Kim, M.-K. Kim, S. M. Hong, M. Han, Y. Gogotsi and C. M. Koo, *ACS Appl. Mater. Interfaces*, 2019, **11**, 38046–38054.

13 A. L. Dyer, E. J. Thompson and J. R. Reynolds, *ACS Appl. Mater. Interfaces*, 2011, **3**, 1787–1795.

14 Y. Li, B. Shen, X. Pei, Y. Zhang, D. Yi, W. Zhai, L. Zhang, X. Wei and W. Zheng, *Carbon*, 2016, **100**, 375–385.

15 B. Shen, Y. Li, D. Yi, W. Zhai, X. Wei and W. Zheng, *Carbon*, 2016, **102**, 154–160.

16 Z. Zeng, M. Chen, H. Jin, W. Li, X. Xue, L. Zhou, Y. Pei, H. Zhang and Z. Zhang, *Carbon*, 2016, **96**, 768–777.

17 Y. Huang, N. Li, Y. Ma, F. Du, F. Li, X. He, X. Lin, H. Gao and Y. Chen, *Carbon*, 2007, **45**, 1614–1621.

18 D. Zhang, J. Yang, Q. Jiang, L. Fu, Y. Xiao, Y. Luo and Z. Zhou, *J. Mater. Chem. A*, 2016, **4**, 4188–4193.

19 Y.-H. Yu, C.-C. M. Ma, C.-C. Teng, Y.-L. Huang, S.-H. Lee, I. Wang and M.-H. Wei, *Mater. Chem. Phys.*, 2012, **136**, 334–340.

20 M. Arjmand, A. A. Moud, Y. Li and U. Sundararaj, *RSC Adv.*, 2015, **5**, 56590–56598.

21 M. H. Al-Saleh, G. A. Gelves and U. Sundararaj, *Compos. Part Appl. Sci. Manuf.*, 2011, **42**, 92–97.