Supplementary Material

Phase Interface Engineering of Rich-Defects 1T/2H-WX_2/RGO (X=S, Se) Nanosheets for Efficient Microwave Absorber and Supercapacitor Applications

Tengfei Wang [a], Qing Pang [a], Boyu Liu [a], Kaimin Fan [b,*], Hongyu Wang [a,*]

[a] Qinghai Provincial Key Laboratory of New Light Alloys, Qinghai Provincial Engineering Research Center of High-Performance Light Metal Alloys and Forming, Qinghai University, Xining 810016, PR China

[b] Center for General Education, Qinghai Institute of Technology, Xining, 810016 China

*Corresponding authors.
E-mail addresses: fankm128@163.com (K. Fan), wanghongyu07010310@163.com (H. Wang).

The relationship $\varepsilon^{'}$ and $\varepsilon^{''}$ can be expressed as formula S1 and S2 for further analyzed to clarify the dielectric loss mechanism:

$$(\varepsilon^{'} - \varepsilon_{\infty})^2 + (\varepsilon^{''})^2 = (\varepsilon_s - \varepsilon_{\infty})^2 \quad \text{(S1)}$$

$$\varepsilon^{''} = \varepsilon_p^{''} + \varepsilon_c^{''} = \frac{\varepsilon_s - \varepsilon_{\infty}}{1 + \omega^2\tau^2}\omega\tau + \frac{\sigma}{\omega\varepsilon_0} \quad \text{(S2)}$$

Among them, ε_s is the relative dielectric constant at static state, ε_{∞} is the relative dielectric constant at high frequency, ε_0 is the vacuum dielectric constant, ω is the angular frequency, τ is the relaxation time, and σ is the conductivity. Among, $\varepsilon^{''}$ can be divided into the conduction loss ($\varepsilon_c^{''}$) and polarization relaxation loss ($\varepsilon_p^{''}$), respectively.

The reflection loss (RL) is calculated by transmission line theory according to formula (S3) and formula (S4):

$$RL(dB) = 20lg\left|\frac{Z_{in} - Z_0}{Z_{in} + Z_0}\right|$$

(S3)

$$Z_{in} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}tanh(j\frac{2\pi fd}{c}\sqrt{\mu_r\varepsilon_r}d)$$

(S4)

In the formula, Z_0 represents the free space impedance, Z_{in} denotes the input characteristic impedance, f is the microwave frequency, d refers to the thickness of absorber and c is the speed of light. When RL<−10 dB, it means that more than 90 % of the electromagnetic waves are absorbed by the absorber.

The quarter-wavelength matching theory can be described as formula S5:

$$t_m = \frac{n\lambda}{4} = \frac{nc}{4f_m\left(|\varepsilon_r||\mu_r|\right)}(n = 1,3,5\cdots)$$

(S5)

In the above formula, t_m represents the matching thickness when reaching RL_{min}, and f_m represents the corresponding frequency.

The attenuation constants (α) and impedance matching (Z) can be calculated by formulas (S6) and (S7):

$$\alpha = \frac{\sqrt{2}\pi f}{c} \times \sqrt{(\mu''\varepsilon'' - \mu'\varepsilon')^2 + \sqrt{(\mu''\varepsilon'' - \mu'\varepsilon')^2 + (\mu'\varepsilon'' + \mu''\varepsilon')^2}}$$

(S6)

$$Z = \frac{Z_{in}}{Z_0} = \sqrt{\frac{\sqrt{(\mu''^2 + \mu'^2)}}{\sqrt{(\varepsilon''^2 + \varepsilon'^2)}}}$$

(S7)

The specific capacitance (C_m) was calculated from the GCD results using the following formula S8:

$$C_m = (I\Delta t)/(m\Delta V)$$

(S8)

Among them, I and Δt represent the test current (A) and discharge time (s), m and ΔV represent the mass of active material (g) and voltage window (V), respectively.

The capacitance control and diffusion control ratios can be quantitatively calculated by the following formula (S9):

$$i(v) = k_1 v + k_2 \quad \text{(S9)}$$

Where i, v, k_1, and k_2, represent the output current, scan rate, and two constants, respectively.

Energy density (E, Wh/kg) and power density (P, W/kg) were calculated by formulas (S10) and (S11):

$$E = \frac{C\Delta V}{7.2} \quad \text{(S10)}$$

$$p = 3600\frac{E}{\Delta t} \quad \text{(S11)}$$

where C is specific capacitance (F/g), ΔV is the operating potential window (V) and Δt is discharge time (s).

Table S1. The microwave absorption properties of TMDs-based absorbing materials reported in the literature were compared.

Samples	Thickness (mm)	RL_{min} (dB)	EAB (GHz)	Filler Loading (wt%)	References
1T/2H-WS_2/RGO-15	2.60	-45.69	7.68	5	This work
1T/2H-WSe_2/RGO-4	2.60	-35.26	7.04	5	This work
$MoSe_2$@rGO hybrids	2.32	-68.70	5.04	60	[1]
$MoSe_2$@RGO	7.56	-22.8	3.86	40	[2]
1T@2H-MoS_2/RGO	2.50	-66.77	4.00	30	[3]
RGO/$MoSe_2$ VDWH	6.29	-65.34	4.20	30	[4]
Carbon nanofibers/$MoSe_2$	3.06	-53.33	4.04	20	[5]
Fe_3O_4/MoS_2/rGO/$Ti_3C_2T_x$	3.61	-66.92	6.08	5	[6]
WS_2–rGO	2.70	-41.5	3.50	40	[7]

2H/1T-$MoSe_2$@graphene	2.10	-52.3	6.40	40	[8]

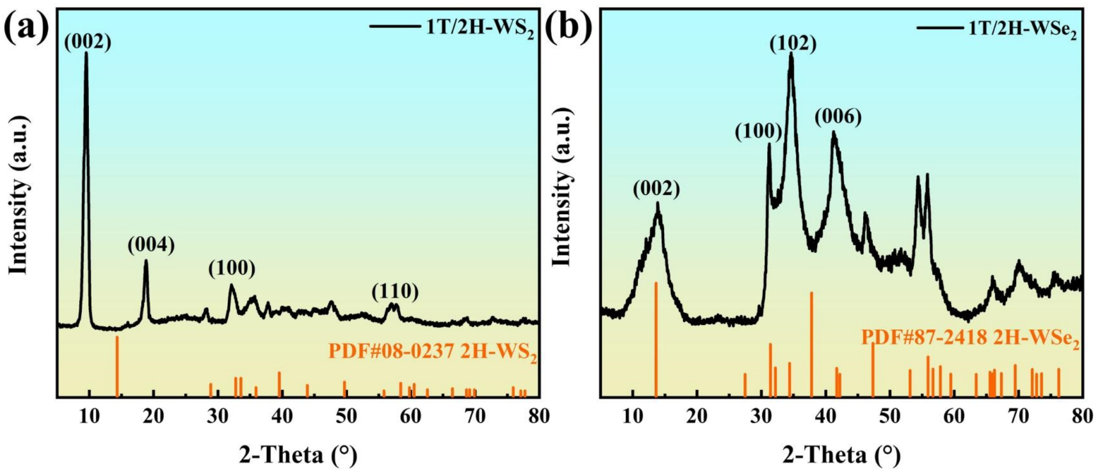

Fig. S1. (a, b) XRD spectrum of 1T/2H-WS_2 and 1T/2H-WSe_2.

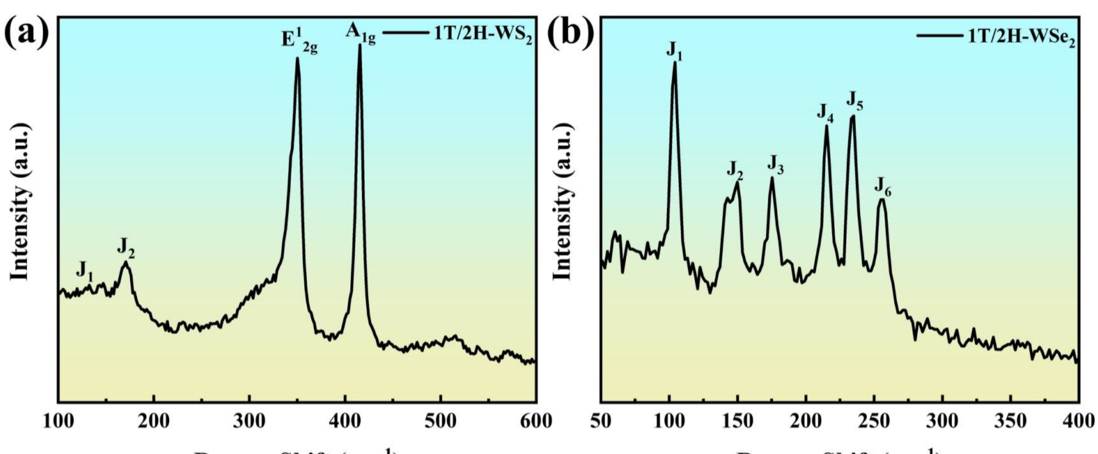

Fig. S2. (a, b) Raman images of 1T/2H-WS_2 and 1T/2H-WSe_2.

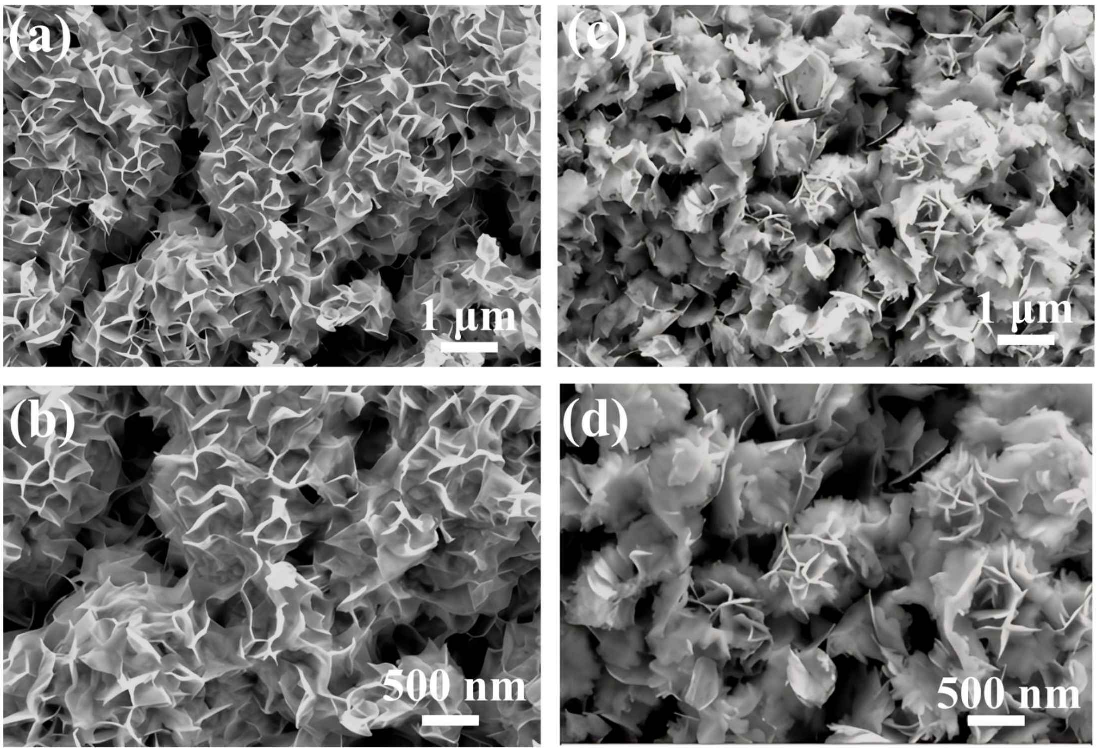

Fig. S3. SEM images of (a, b)1T/2H-WS_2 and (c, d) 1T/2H-WSe_2.

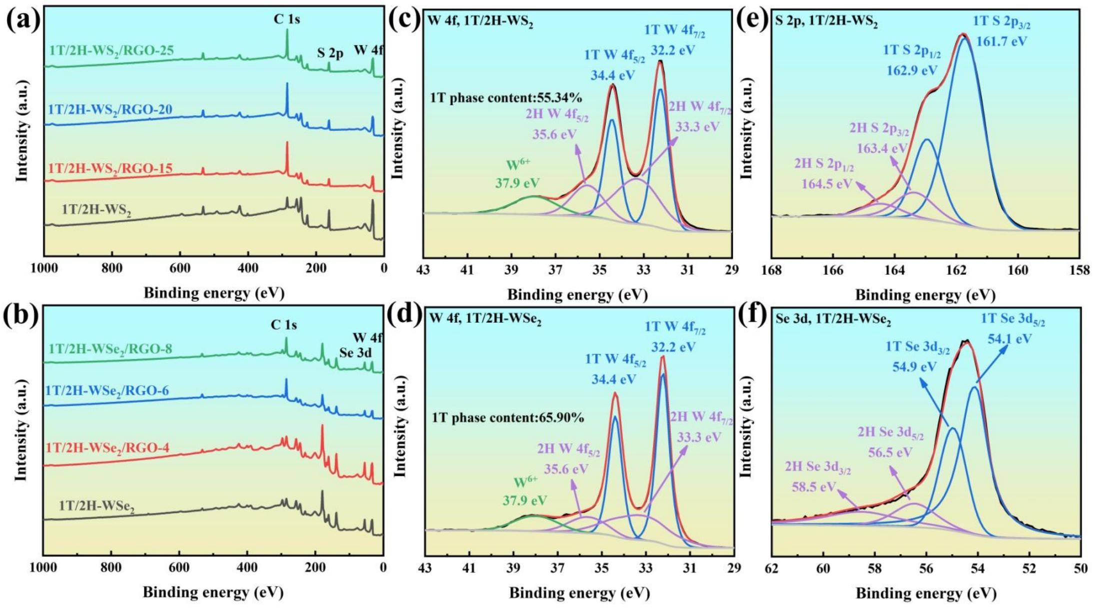

Fig. S4. The XPS survey spectra of (a) 1T/2H-WS_2/RGO and (b) 1T/2H-WSe_2/RGO, the high-resolution XPS of W 4f in (c) 1T/2H-WS_2 and (d) 1T/2H-WSe_2, the high-resolution XPS of (e) S 2p in 1T/2H-WS_2 and (f) Se 3d in 1T/2H-WSe_2.

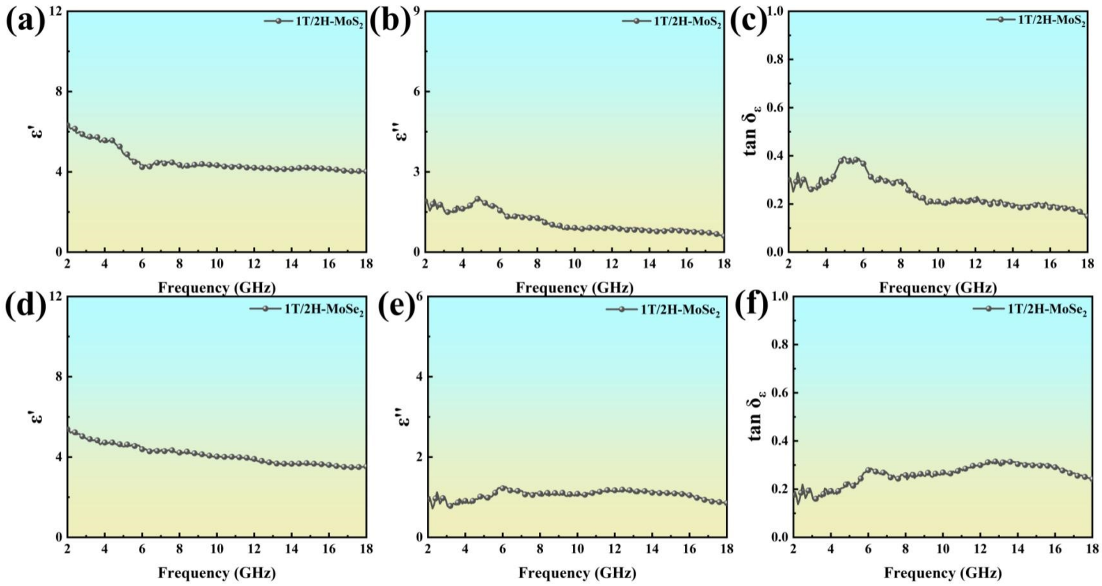

Fig. S5. Dielectric parameters of 1T/2H-WS_2 and 1T/2H-WSe_2 in the frequency range of 2-18 GHz: (a, d) ε',(b, e) ε'', and (c, f) $\tan\delta_{\varepsilon}$.

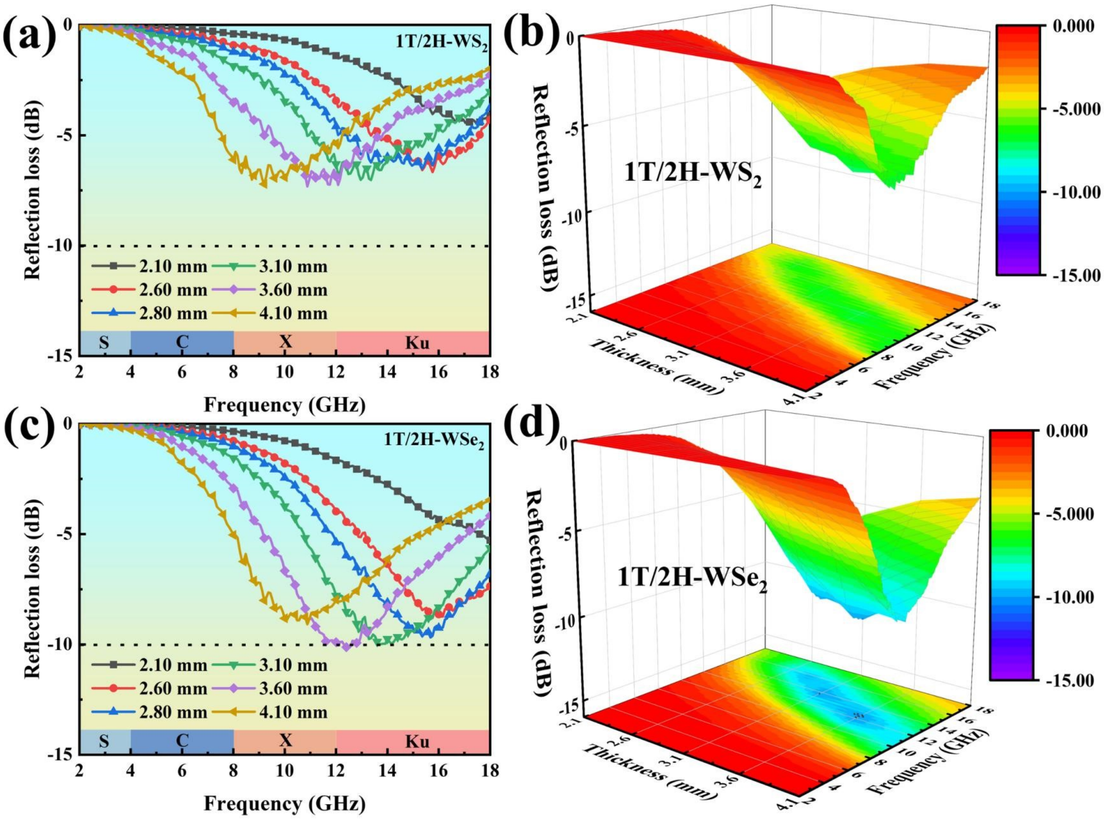

Fig. S6. The electromagnetic wave absorption properties of 2D and 3D RL curves plots of (a, b) 1T/2H-WS_2 and (c, d) 1T/2H-WSe_2.

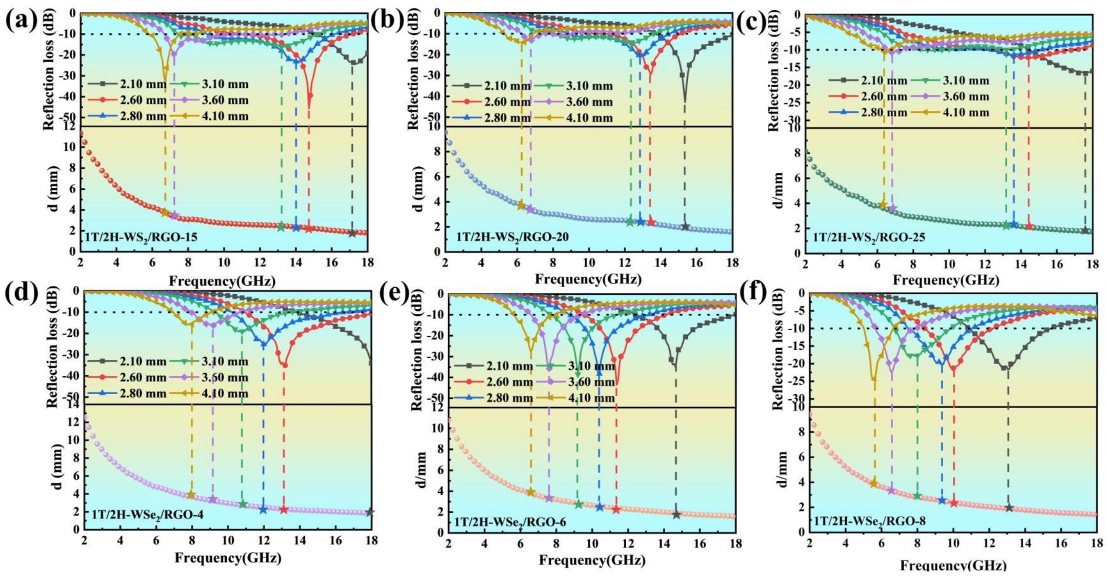

Fig. S7. The RL_{min} value and the quarter-wavelength matching of (a-c) 1T/2H-WS_2/RGO and (d-f)1T/2H-WSe_2/RGO.

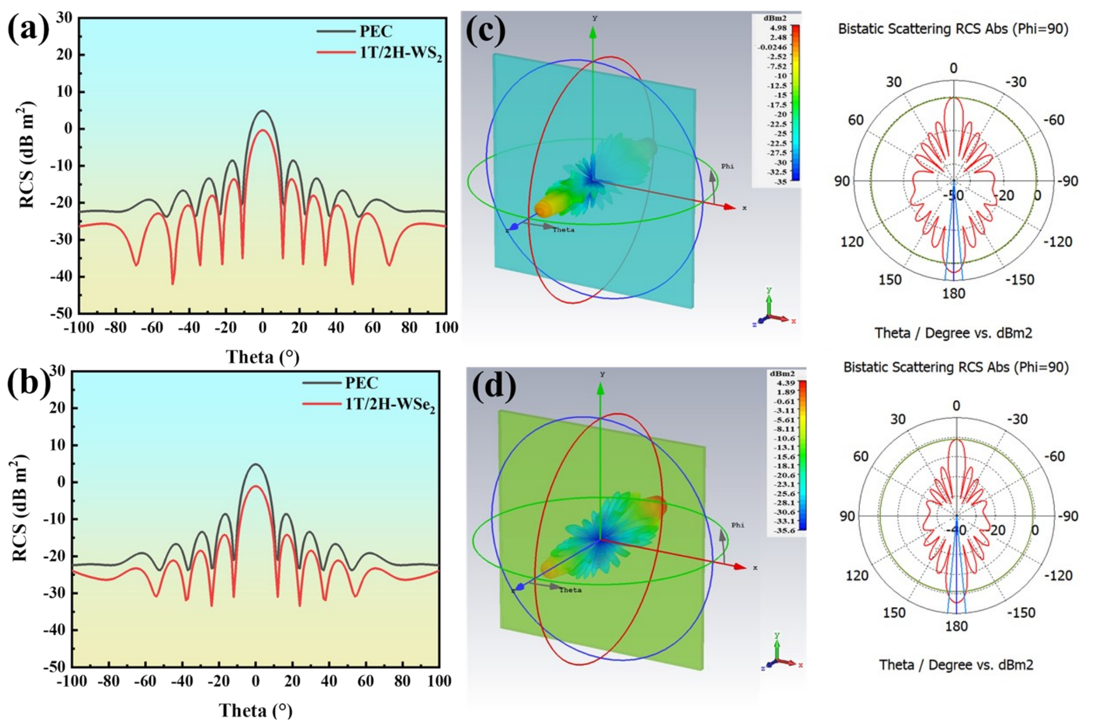

Fig. S8. (a, b) RCS reduction values of PEC and 1T/2H-WX_2 at different angles, (c, d) 3D and 1D RCS distribution for the PEC substrates covered with 1T/2H-WX_2.

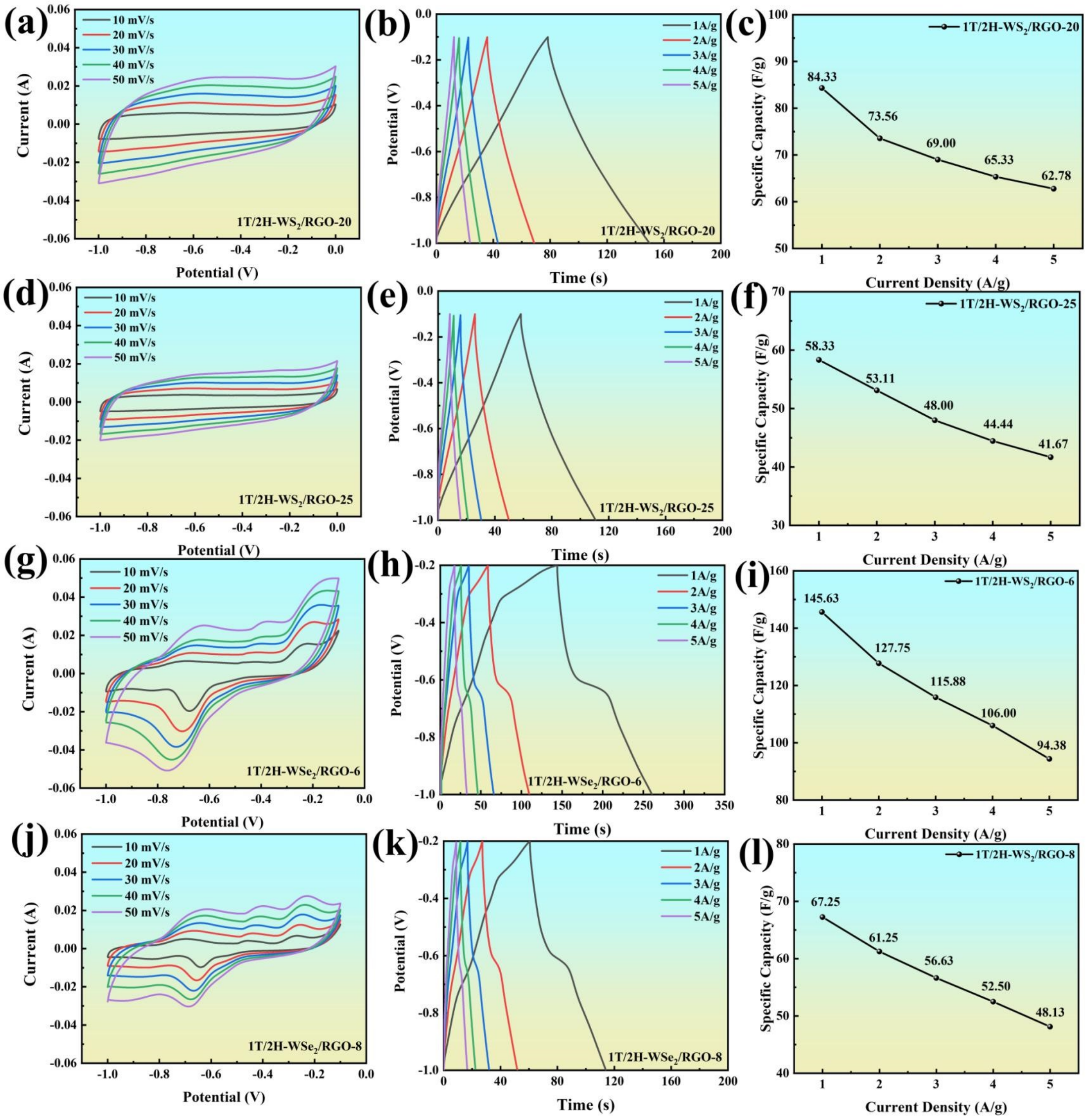

Fig. S9. CV curves, GCD curves, and specific capacitance at different current densities calculated from GCD test of (a-c) 1T/2H-WS_2/RGO-20, (d-f) 1T/2H-WS_2/RGO-25, (g-i) 1T/2H-WSe_2/RGO-6, and (j-l) 1T/2H-WSe_2/RGO-8.

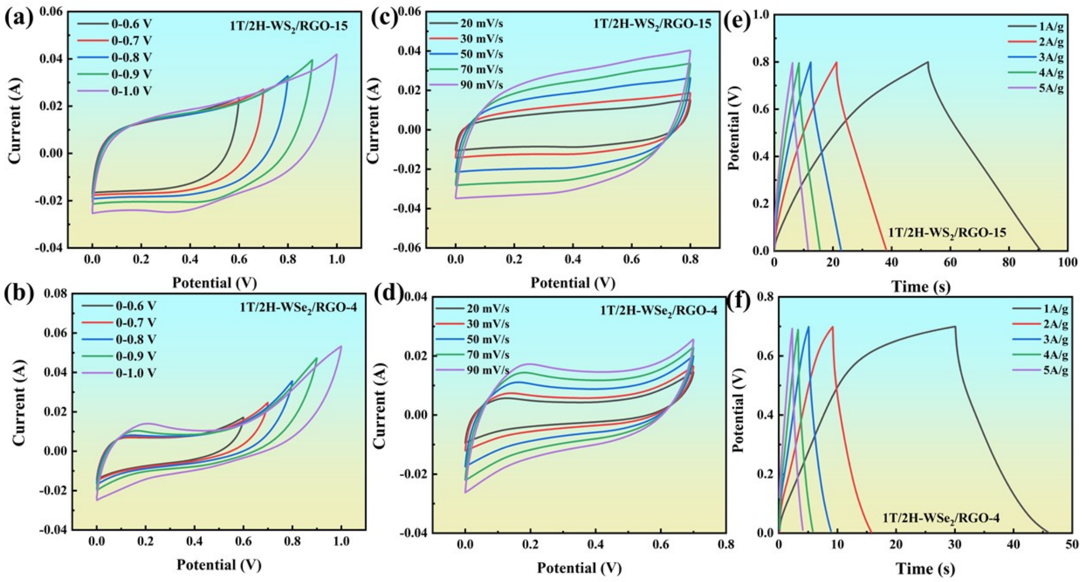

Fig. S10. (a, b) Voltage windows, (c, d) CV curves, and (e, f) GCD curves of assembled symmetrical supercapacitors of 1T/2H-WS_2/RGO-15 and1T/2H-WSe_2/RGO-4.

References

1. W.-Q. Cao, Q. Zheng, L. Li, C.-B. Cao and M.-S. Cao, *J. Adv. Ceram.* **2024**, *13*, 1461-1472.
2. X.-Y. Fu, Q. Zheng, L. Li and M.-S. Cao, *Carbon* **2022**, 197, 324-333.
3. H. Guo, L. Wang, W. You, L. Yang, X. Li, G. Chen, Z. Wu, X. Qian, M. Wang and R. Che, *ACS Appl. Mater. Interfaces* **2020**, *12*, 16831-16840.
4. L. Xiang, A. K. Darboe, Z. Luo, X. Qi, J.-j. Shao, X.-J. Ye, C.-S. Liu, K. Sun, Y. Qu and J. Xu, *Adv. Compos. Hybrid Mater.*, **2023**, *6*, 215.
5. Z. Xu, M. He, Y. Zhou, S. Nie, Y. Wang, Y. Huo, Y. Kang, R. Wang, R. Xu and H. Peng, *Nano Res.* **2021**, *14*, 738-746.
6. S. Yan, S. Shao, Y. Tang, X. Zhang, C. Guo, L. Wang, J. Liu, L. Wu and F. Wang, *ACS Appl. Mater. Interfaces* **2024**, *16*, 36962-36972.
7. D. Zhang, T. Liu, J. Cheng, Q. Cao, G. Zheng, S. Liang, H. Wang and M.-S. Cao, *Nano-Micro Lett.* **2019**, *11*, 38.
8. Y. Zhang, L. Zhang, B. Zhou, H. Cheng, Q. Zhang and B. Zhang, *Carbon* **2023**, *205*, 562-572.