Supplementary Information (SI) for Materials Advances.
This journal is © The Royal Society of Chemistry 2026

Unlocking High-Energy and Long-Life Supercapacitors via Zn–MnO_2/MoS_2 Heterostructure Engineering

Muhammad Shoaib Bilal [a, b], Muhammad Arslan [a, c], Saqib Javed [d], Amina Zafar [e], Atia Khalid [f], Shafqat Karim [a], Naeem Ahmad [g], Athar Javed [h], Abdul Ghaffar [*b], Amjad Nisar [*a] and Mashkoor Ahmad *a

a Nanomaterials Research Group, Physics Division, PINSTECH, Islamabad 44000, Pakistan.

b Department of Physics, Government College University, Lahore 54000, Pakistan.

c School of chemical & Material Engineering, NUST, Islamabad, Pakistan

d Theoretical Physics Division, PINSTECH, Islamabad 44000, Pakistan

e School of Material science and Engineering, Tsinghua University, Beijing, China.

f Central Analytical Facility Division, PINSTECH, Islamabad 44000, Pakistan

g Faculty of Basic & Applied Sciences, Department of Physics, IIU, Islamabad 44000, Pakistan.

h Department of Physics, University of the Punjab, Lahore, Pakistan.

** Corresponding authors:*

mashkoorahmad2003@yahoo.com (Mashkoor Ahmad)

chempk@gmail.com (Amjad Nisar)

abdulghaffar@gcu.edu.pk (Abdul Ghaffar)

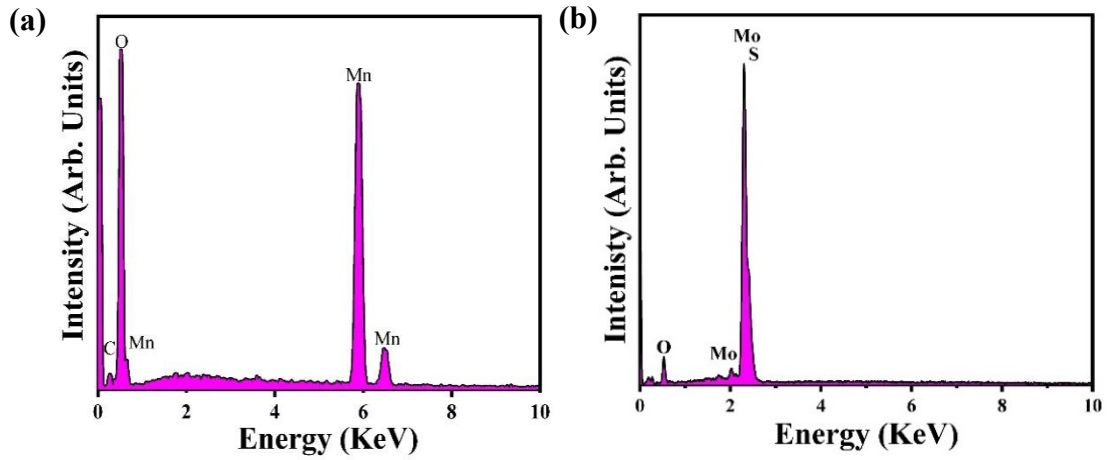


Fig. S1. EDX of **(a)** MnO_2 and **(b)** MoS_2 nanostructures.

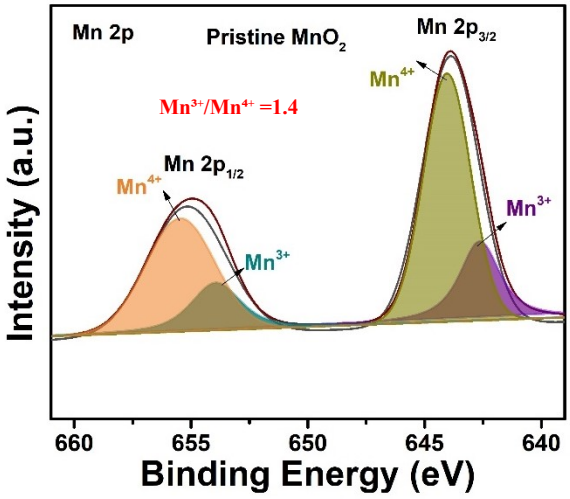


Fig. S2. High resolution XPS spectrum of Mn 2p peak of pristine MnO_2.

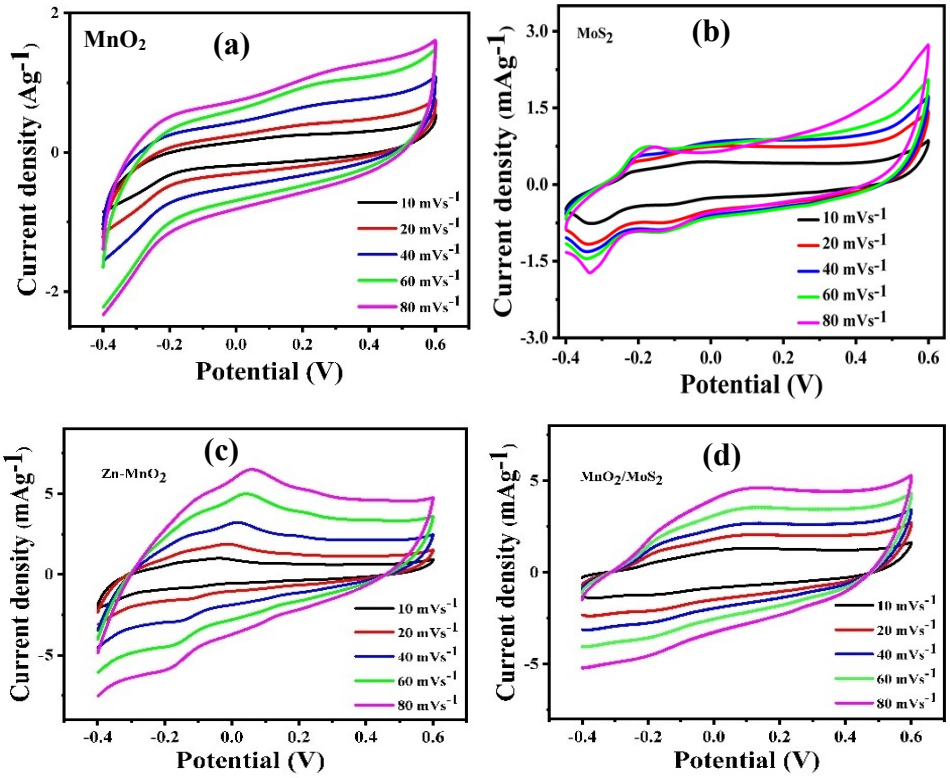


Fig. S3. (a,b,c,d) CV response of MnO_2, MoS_2, Zn-MnO_2 and MnO_2/MoS_2 electrode

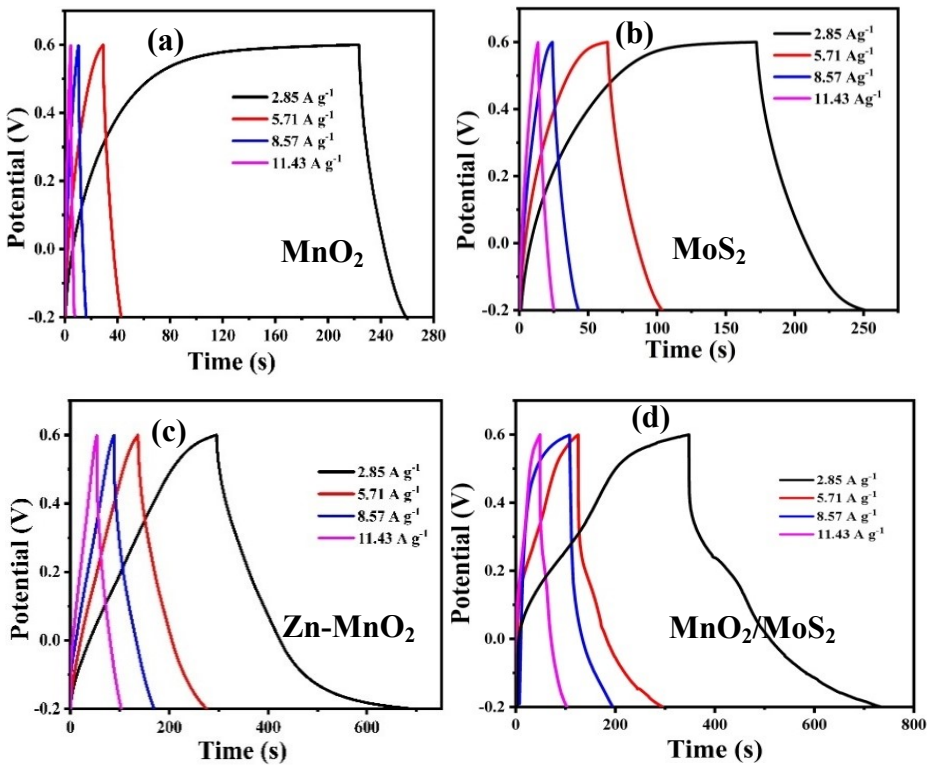


Fig. S4. (a,b,c,d) GCD curves of MnO_2,MoS_2, Zn-MnO_2 and MnO_2/MoS_2 electrode at different current densities

Table S1 Comparison of Zn-MnO_2/MoS_2//AC with other studies in terms of potential window, energy density, power density and areal capacitance.

Devices	Potential window (V)	Power density (μW cm^{-2})	Areal capacitance (mF cm^{-2})	Energy density (μWh cm^{-2})	Ref.
Si/C/MnO_2//AC	0.8	117	29	2	1
GCNC/MnO_2//AC	1.2	282	60	10	2
S-MnO_2/MoS_2//AC	1.0	50	27.5	3.8	3
MnO_2@Ppy@MWCNT //AC	1.6	136	21	12	4
MnO_2/CDCC//AC	1.5	150	96	30	5
NiO@MnO_2//Fe_2O_3//AC	1.2	29	43	9	6
Zn-MnO_2/MoS_2//AC	**1.7**	**423**	**205**	**82**	**Our work**

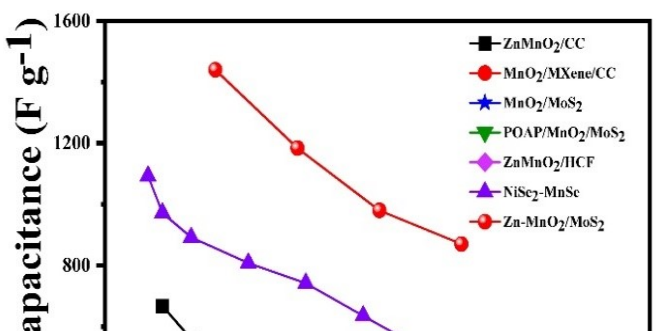
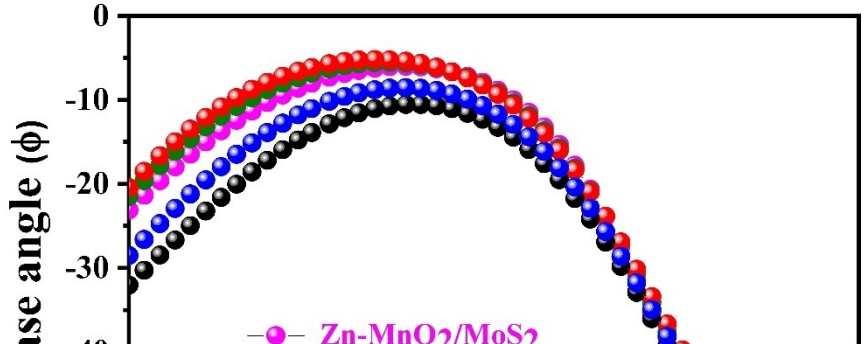
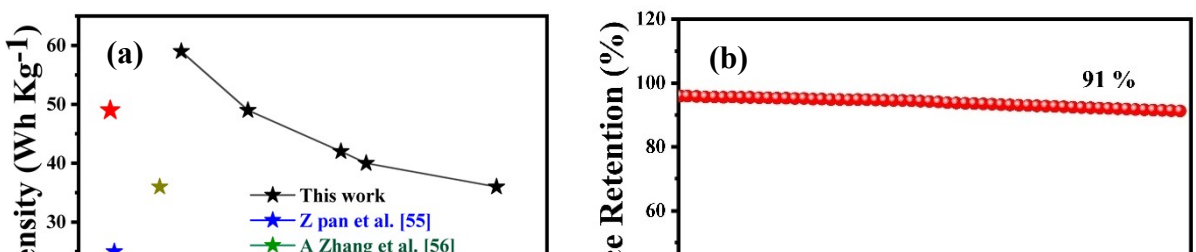


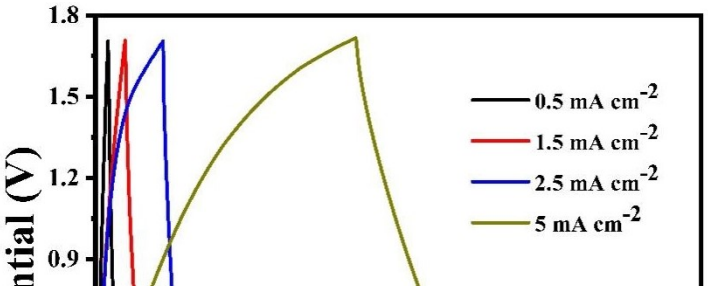
Fig. S5. Comparative analysis of specific capacitance between proposed Zn-MnO_2/MoS_2 electrode and previously reported MnO_2-based electrodes

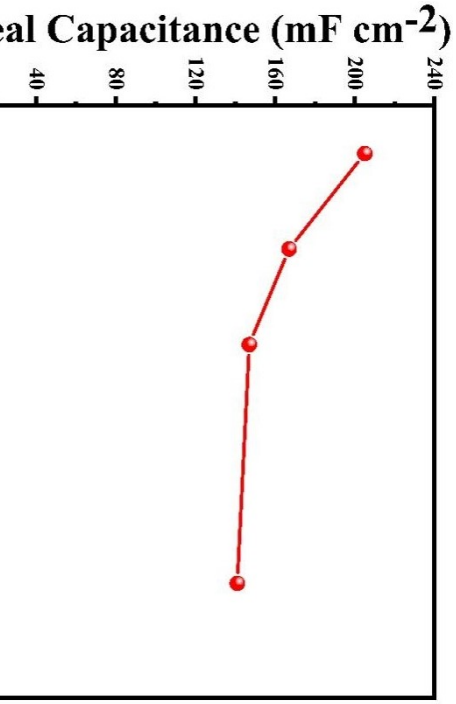
Table S2 Comparison of Zn-MnO_2/MoS_2//AC with other studies in terms of potential window, energy density, power density and specific capacitance.

Devices	Potential window (V)	Power density (W kg^{-1})	Specific capacitance (F g^{-1})	Energy density (Wh kg^{-1})	Ref.
$AgCo_3O_4$/FeMn-O//AC	1.6	522	128	11.5	[7]
MnO_2/Co_2CH@C//AC	1.7	255	38	15	[8]
Al doped MnO_2//AC	1.6	400	52	18.5	[9]
MoS_2/graphene//AC	1.4	690	61	16	[10]
MnO_2/CeO_2/MW//AC	1.4	800	102	36	[11]
ZnS/MnO_2/MOF//AC	1.4	1050	112	30	[12]
K doped MnO_2//AC	1.5	432	78	24	[13]
Zn-MnO_2/MoS_2//AC	**1.7**	**1145**	**147**	**59**	**Our work**




(a)
Energy density (Wh Kg-1)
60
50
40
30
This work
Z pan et al. [55]
A Zhang et al. [56]
(b)
91 %
120
100
80
60


1.8
1.5
1.2
0.9
ntial (V)
0.5 mA cm-2
1.5 mA cm-2
2.5 mA cm-2
5 mA cm-2


eal Capacitance (mF cm-2)
40
80
120
160
200
240

References

1. Y. Wang, L. Sun, D. Xiao, H. Du, Z. Yang, X. Wang, L. Tu, C. Zhao, F. Hu and B. Lu, ACS Applied Materials & Interfaces, 2020, 12, 43864-43875.
2. L. Chen, T. Shen, Z. Hu, Z. Li and H.-Y. Yu, International Journal of Biological Macromolecules, 2024, 282, 137406.
3. H. Zhang, J. Wei, Y. Yan, Q. Guo, L. Xie, Z. Yang, J. He, W. Qi, Z. Cao and X. Zhao, Journal of Power Sources, 2020, 450, 227616.
4. J. Gao, C. Shao, S. Shao, F. Wan, C. Gao, Y. Zhao, L. Jiang and L. Qu, Small, 2018, 14, 1801809.

5. C. Wan, Y. Jiao, D. Liang, Y. Wu and J. Li, Electrochimica Acta, 2018, 285, 262-271.
6. X. Liu, J. Wang and G. Yang, Chemical Engineering Journal, 2018, 347, 101-110.
7. M. Anwar, A. Fazal, M. J. Iqbal, B. S. Almutairi, M. Z. Khan, M. Irshad, M. A. Raza, M. S. Butt, M. Saleem and W. Ahmed, Journal of Energy Storage, 2025, 105, 114602.
8. A. Zhang, N. Mao, Y. Zhong, W. Zheng, L. Cui, C. Barrow, J. Razal, W. Yang and J. Liu, Composites Part B: Engineering, 2021, 215, 108756.
9. X. Cheng, L. Zhang, L. Li, H. Wu, J. Zheng, J. Yao and G. Li, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2025, 709, 136163.
10. Y. Zhang, K. Li, X. Wang, S. Xiong, F. Chen and Y. Li, Scientific Reports, 2026, 16, 301.
11. M. M. A. Siddiqui, S. Abbas, F. Faiz, A. Zafar, S. Karim, H. Sun, A. Khalid, Y. Faiz, Y. Yu and H. Sultan, New Journal of Chemistry, 2025, 49, 8888-8897.
12. O. P. Nanda, P. Singh, Y. N. Banothu, R. Kumar and S. Badhulika, Journal of Energy Storage, 2024, 75, 109729.
13. X. Zhang, F. Zhang, D. Wei, Z. Cai, Y. Song and X. Wang, Journal of Energy Storage, 2023, 72, 108468.