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Facile hydrothermal synthesis of manganese-doped chromium sulfide with reduced graphene oxide nanocomposites for energy storage system

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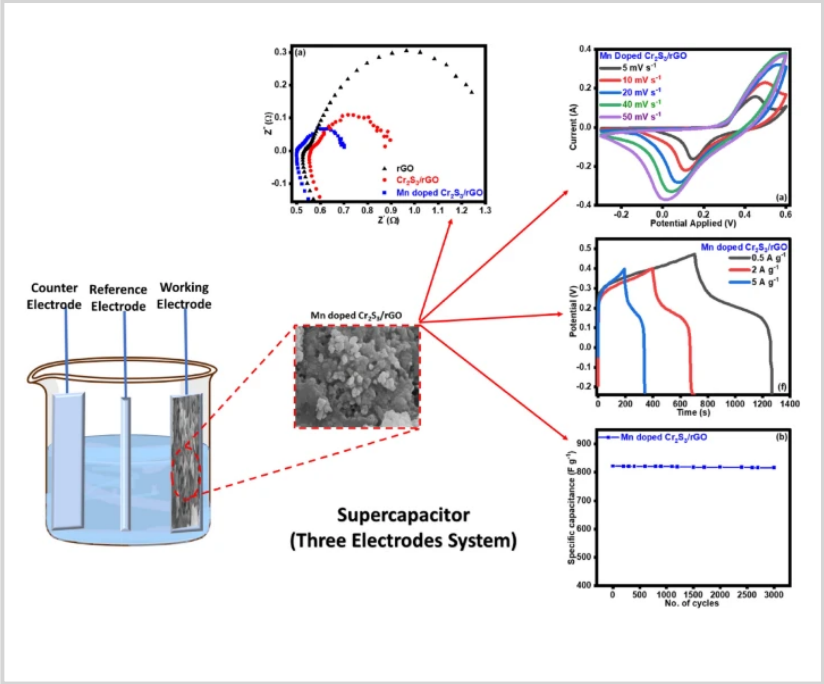
Abstract

Increasing energy demands and environmental degradation, have led to augmented demand for the production of cleaner energy. For this purpose, transition metal sulfides along with graphene-based materials have gathered attention as electrode materials for supercapacitor. Herein, manganese-doped chromium sulfide with reduced graphene oxide (Mn-doped Cr_2S_3/rGO) is synthesized by hydrothermal process as auspicious electrode material due to large specific capacitance, rapid

charging and discharging rates, larger energy density and additionally their easy preparatory method, less cost and earth rich resources. Mn-doped Cr_2S_3/rGO nanocomposite exhibits superb specific capacity of 886.7 F g^{-1} at 5 mV s^{-1} sweep rate in 1 M KOH electrolyte with outstanding 121.91 Wh kg^{-1} energy density, as well as 1040 W kg^{-1} power density. It determines longer cyclic stability having capacitance retention (99.4%) compared to initial capacitance after 3000 cycles.

Graphical abstract



Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

1. I. Dincer, C. Acar, A review on clean energy solutions for better sustainability. Int. J. Energy Res. **39**, 585–606 (2015)

2. U. Shahzad, The need for renewable energy sources. Energy **2**, 16–18 (2012)

3. M.D. Leonard, E.E. Michaelides, D.N. Michaelides, Substitution of coal power plants with renewable energy sources–shift of the power demand and energy storage. Energy Convers. Manage **164**, 27–35 (2018)

4. L. Kouchachvili, W. Yaïci, E. Entchev, Hybrid battery/supercapacitor energy storage system for the electric vehicles. J. Power Sources **374**, 237–248 (2018)

5. P. Taberna, P. Simon, J.-F. Fauvarque, Electrochemical characteristics and impedance spectroscopy studies of carbon-carbon supercapacitors. J. Electrochem. Soc. **150**, A292 (2003)

6. C. Du, N. Pan, High power density supercapacitor electrodes of carbon nanotube films by electrophoretic deposition. Nanotechnology **17**, 5314 (2006)

7. F. Zhang, T. Zhang, X. Yang, L. Zhang, K. Leng, Y. Huang, Y. Chen, A high-performance supercapacitor-battery hybrid energy storage device based on graphene-enhanced electrode materials with ultrahigh energy density. Energy Environ. Sci. **6**, 1623–1632 (2013)

8. C.C. Kwasi-Effah, T. Rabczuk, Dimensional analysis and modelling of energy density of lithium-ion battery. J. Energy Storage **18**, 308–315 (2018)

9. Y. Wu, C. Cao, The way to improve the energy density of supercapacitors: progress and perspective. Sci. China Mater. **61**, 1517–1526 (2018)

10. M. Sajjad, M. Amin, M.S. Javed, M. Imran, W. Hu, Z. Mao, W. Lu, Recent trends in transition metal diselenides (XSe_2: X= Ni, Mn, Co) and their composites for high energy faradic supercapacitors. J. Energy Storage **43**, 103176 (2021)

11. Y. Gao, L. Zhao, Review on recent advances in nanostructured transition-metal-sulfide-based electrode materials for cathode materials of asymmetric supercapacitors. Chem. Eng. J. **430**, 132745 (2022)

12. B.J. Rani, S. Pradeepa, Z.M. Hasan, G. Ravi, R. Yuvakkumar, S.J. Hong, Supercapacitor and OER activity of transition metal (Mo Co, Cu) sulphides. J. Phys. Chem. Solids **138**, 109240 (2020)

13. J. Rehman, K. Eid, R. Ali, X. Fan, G. Murtaza, M. Faizan, A. Laref, W. Zheng, R.S. Varma, Engineering of transition metal sulfide nanostructures as efficient electrodes for high-performance supercapacitors. ACS Appl. Energy Mater. (2022). https://doi.org/10.1021/acsaem.1c03937

14. A.C. Forse, C. Merlet, J.M. Griffin, C.P. Grey, New perspectives on the charging mechanisms of supercapacitors. J. Am. Chem. Soc. **138**, 5731–5744 (2016)

15. T. Huang, X.-Z. Song, X. Chen, X.-L. Chen, F.-F. Sun, Q.-F. Su, L.-D. Li, Z. Tan, Carbon coated nickel–cobalt bimetallic sulfides hollow dodecahedrons for a supercapacitor with enhanced electrochemical performance. New J. Chem. **42**, 5128–5134 (2018)

16. S. Liu, L. Kang, J. Hu, E. Jung, J. Henzie, A. Alowasheeir, J. Zhang, L. Miao, Y. Yamauchi, S.C. Jun, Realizing superior redox kinetics of hollow bimetallic sulfide nanoarchitectures by defect-induced manipulation toward flexible solid-state supercapacitors. Small **18**, 2104507 (2022)

17. H.-M. Ji, A.-L. Luan, C.-C. Dai, M. Li, G. Yang, W.-H. Hou, Highly active free-standing and

flexible MoS_2/rGO sandwich-structured films for supercapacitor applications. Solid State Commun. **297**, 45–49 (2019)

18. M. Husnah, H.A. Fakhri, F. Rohman, A.H. Aimon, F. Iskandar, A modified Marcano method for improving electrical properties of reduced graphene oxide (rGO). Mater. Res. Express **4**, 064001 (2017)

19. B. Zhao, P. Liu, Y. Jiang, D. Pan, H. Tao, J. Song, T. Fang, W. Xu, Supercapacitor performances of thermally reduced graphene oxide. J. Power Sources **198**, 423–427 (2012)

20. L. Li, E. Han, L. Dou, L. Zhu, C. Mi, M. Li, J. Niu, Enhanced electrochemical performance of Li_2FeSiO_4/C as cathode for lithium-ion batteries via metal doping at Fe-site. Solid State Ion. **325**, 30–42 (2018)

21. L. Meng, R. Guo, X. Sun, F. Li, J. Peng, C. Chen, T. Li, J. Deng, Enhanced electrochemical performance of a promising anode material $FeVO_4$ by tungsten doping. Ceram. Int. **46**, 21360–21366 (2020)

22. U. Rana, S. Aman, M.N. Ashiq, M.F. Iqbal, S. Manzoor, M. Mahmoud, A. Alhadhrami, H.O.

Elansry, D.O. El-Ansari, T. Taha, Outstanding electrochemical behavior of reduced graphene oxide wrapped chromium sulfide nanoplates directly grown on nickel foam for supercapacitor applications. J. Sol-Gel Sci. Technol. **103**, 704–712 (2022)

23. M.M. Gul, K.S. Ahmad, Nanocomposite Zr_2S_3-BaS-Cr_2S_3 ternary-metal chalcogenide: an impressive supercapacitor electrode and environmental remediant of toxic pollutants. Int. J. Energy Res. **46**, 18697–18710 (2022)

24. R.K. Mishra, G.J. Choi, Y. Sohn, S.H. Lee, J.S. Gwag, A novel RGO/N-RGO supercapacitor architecture for a wide voltage window, high energy density and long-life via voltage holding tests. Chem. Commun. **56**, 2893–2896 (2020)

25. W. Li, W. Song, H. Wang, Y.-M. Kang, In situ self-assembly of Ni_3S_2/MnS/CuS/reduced graphene composite on nickel foam for high power supercapacitors. RSC Adv. **9**, 31532–31542 (2019)

26. Z. Peng, C. Yang, Y. Hu, F. Bai, W. Chen, R. Liu, S. Jiang, H.-C. Chen, Double-shelled Mn-doped $NiCo_2S_4$ hollow nanowire arrays for

high-reactivity hybrid supercapacitors. Appl. Surf. Sci. **573**, 151561 (2022)

27. I. Hussain, D. Mohapatra, G. Dhakal, C. Lamiel, S.G. Mohamed, M.S. Sayed, J.-J. Shim, Different controlled nanostructures of Mn-doped ZnS for high-performance supercapacitor applications. J. Energy Storage **32**, 101767 (2020)

28. J. Cao, Y. Hu, Y. Zhu, H. Cao, M. Fan, C. Huang, K. Shu, M. He, H.C. Chen, Synthesis of mesoporous nickel-cobalt-manganese sulfides as electroactive materials for hybrid supercapacitors. Chem. Eng. J. **405**, 126928 (2021)

29. G.S. Kaliaraj, A. Ramadoss, Nickel–zinc sulfide nanocomposite thin film as an efficient cathode material for high-performance hybrid supercapacitors. Mater. Sci. Semicond. Process. **105**, 104709 (2020)

30. M.B. Poudel, G.P. Ojha, H.J. Kim, Manganese-doped tungsten disulfide microcones as binder-free electrode for high performance asymmetric supercapacitor. J. Energy Storage **47**, 103674 (2022)

31. I. Hussain, D. Mohapatra, G. Dhakal, C. Lamiel, M.S. Sayed, S. Sahoo, S.G. Mohamed, J.S. Kim, Y.R. Lee, J.-J. Shim, Uniform growth of ZnS nanoflakes for high-performance supercapacitor applications. J. Energy Storage **36**, 102408 (2021)

32. S. Shinde, M. Jalak, S. Kim, H. Yadav, G. Ghodake, A. Kadam, D.-Y. Kim, Effect of Mn doping on the chemical synthesis of interconnected nanoflakes-like CoS thin films for high performance supercapacitor applications. Ceram. Int. **44**, 23102–23108 (2018)

33. H. Chu, F. Zhang, L. Pei, Z. Cui, J. Shen, M. Ye, Compounds, Ni, Co and Mn doped SnS_2-graphene aerogels for supercapacitors. J. Alloys Compd. **767**, 583–591 (2018)

34. K.V. Sankar, R.K. Selvan, Improved electrochemical performances of reduced graphene oxide based supercapacitor using redox additive electrolyte. Carbon **90**, 260–273 (2015)

35. Y. Li, J. Gong, X. Xing, J. Du, P. Xu, K. Cheng, K. Ye, K. Zhu, J. Yan, D. Cao, High-performance all-solid-state supercapacitor with binder-free binary transition metal

sulfide array as cathode. Int. J. Energy Res. **45**, 5517–5526 (2021)

36. W. Liu, H. Niu, J. Yang, K. Cheng, K. Ye, K. Zhu, G. Wang, D. Cao, J. Yan, Ternary transition metal sulfides embedded in graphene nanosheets as both the anode and cathode for high-performance asymmetric supercapacitors. Chem. Mater. **30**, 1055–1068 (2018)

37. L.-B. Kong, C. Lu, M.-C. Liu, Y.-C. Luo, L. Kang, X. Li, F.C. Walsh, The specific capacitance of sol–gel synthesised spinel $MnCo_2O_4$ in an alkaline electrolyte. Electrochim. Acta **115**, 22–27 (2014)

38. U. Holzwarth, N. Gibson, The Scherrer equation versus the “Debye-Scherrer equation.” Nat. Nanotechnol. **6**, 534–534 (2011)

39. V. Khomenko, E. Frackowiak, F. Beguin, Determination of the specific capacitance of conducting polymer/nanotubes composite electrodes using different cell configurations. Electrochim. Acta **50**, 2499–2506 (2005)

40. S. Manzoor, M.F. Ashiq, M. Usman, M. Sadaqat, K. Mahmood, T. Munawar, F. Iqbal, M.M. Al-Anazy, M.N. Ashiq, M. Najam-ul-Haq, Development of excellent and novel flowery zirconia/cadmium sulfide nanohybrid electrode: for high performance electrochemical supercapacitor application. J. Energy Storage **40**, 102718 (2021)

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Ethics declarations

Conflict of interest

The authors declare that they have no conflict of interest.

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