Original Article | Published: 07 February 2023

Effect of Copper Substitution on the Electrocatalytic Activity of $ZnMn_2O_4$ Spinel Embedded on Reduced Graphene Oxide Nanosheet for the Oxygen Evolution Process

Salma Aman, Naseeb Ahmad, Sumaira Manzoor, Meznah M. Alanazi, Shaimaa A. M. Abdelmohsen, Rabia Yasmin Khosa, Abdullah G. Al-Sehemi, Ruimao Hua, Huda A. Alzahrani & Adeel Hussain Chughtai

Catalysis Surveys from Asia **27**, 165–179 (2023)

Abstract

The fabrication of a proficient and durable electrocatalyst for the OER process is the most crucial parameter in the water splitting process. A simple and basic procedure was used in this study to create Cu-substituted $ZnMn_2O_4$/rGO spinel nanosized composite as an electrode for OER. The morphological and structural investigations indicate that the carbon based spinel successfully bonds, and the addition of copper into rGO results in a substantial change in its electrocatalytic process for the oxygen evolution process.

$Zn_{1-x}Cu_xMn_2O_4$/rGO with x = 0.6 has a minimal overpotential of 150 mV at a current density of 10 $mAcm^{-2}$, low onset potential of 1.40 V and a smaller Tafel slope of 31 mV dec^{-1} than other substitution. The electrocatalyst also exhibits high ECSA (632.5 cm^2), R_f (1580), and exceptional stability, all of which improve OER performance. These analysis confirm the enhanced electrocatalytic efficiency of the hybrid material to catalyze OER for energy generation, and other fields.

Data Availability

Data sharing is not applicable to this article as no data sets were generated during the present study.

References

1. Nisa MU, Abid AG, Gouadria S, Munawar T, Alrowaili ZA, Abdullah M, Al-Buriahi MS, Iqbal F, Ehsan MF, Ashiq MN (2022) Boosted electron-transfer/separation of $SnO_2/CdSe/Bi_2S_3$ heterostructure for excellent photocatalytic degradation of organic dye pollutants under visible light. Surf Interfaces 31:102012. https://doi.org/10.1016/J.SURFIN.2022.102012

2. Manzoor S, Abdullah M, Abid AG, Ahmad Z, Katubi KM, Al-Buriahi MS, Aman S, Najam-Ul-Haq M, Ashiq MN (2022) Development of ZnCo alloy enclosed in N-doped carbon with hexagonal close packing crystal phase inspires potential oxygen evolution reaction. J Alloys Compds 924:166439. https://doi.org/10.1016/J.JALLCOM.2022.166439

3. Nisa MU, Manzoor S, Abid AG, Tamam N, Abdullah M, Najam-Ul-Haq M, Al-Buriahi MS, Alrowaili ZA, Mahmoud ZMM, Ashiq MN (2022) CdSe supported SnO_2 nanocomposite

PDF

Help

with strongly hydrophilic surface for enhanced overall water splitting. Fuel 321:124086. https://doi.org/10.1016/J.FUEL.2022.124086

4. Abdullah M, John P, Ahmad Z, Ashiq MN, Manzoor S, Ghori MI, Nisa MU, Abid AG, Butt KY, Ahmed S (2021) Visible-light-driven $ZnO/ZnS/MnO_2$ ternary nanocomposite catalyst: synthesis, characterization and photocatalytic degradation of methylene blue. Appl Nanosci 11:2361–2370. https://doi.org/10.1007/S13204-021-02008-X/TABLES/1

5. Manzoor S, Trukhanov SV, Ansari MN, Abdullah M, Alruwaili A, Trukhanov AV, Khandaker MU, Idris AM, El-Nasser KS, Taha TA (2022) Flowery ln_2MnSe_4 novel electrocatalyst developed via anion exchange strategy for efficient water splitting. Nanomaterials 12:2209. https://doi.org/10.3390/NANO12132209

6. Abdullah M, John P, Ashiq MN, Manzoor S, Ghori MI, Nisa MU, Abid AG, Butt KY, Ahmed S (2022) Development of $CuO/CuS/MnO_2$ ternary nanocomposite for visible light-induced photocatalytic degradation of methylene blue. Nanotechnol Environ Eng. https://doi.org/10.1007/S41204-022-00266-W

7. Khatiwada D, Vasudevan RA, Santos BH (2022) Decarbonization of natural gas systems in the EU: costs, barriers, and constraints of hydrogen production with a case study in Portugal. Renew Sustain Energy Rev 168:112775. https://doi.org/10.1016/J.RSER.2022.112775

8. RahimiAriaei A, Ahmadi R (2022) Power generation dynamics, using polymer membrane fuel cell, solar panel, wind turbine, and generator in Zahedan with Trnsys software and comparison of hybrid systems performance with single systems. SSRN Electron J. https://doi.org/10.2139/SSRN.4171565

9. Maiti TK, Majhi J, Maiti SK, Singh J, Dixit P, Rohilla T, Ghosh S, Bhushan S, Chattopadhyay S (2022) Zirconia- and ceria-based electrolytes for fuel cell applications: critical advancements toward sustainable and clean energy production. Environ Sci Pollut Res 2022:1–24. https://doi.org/10.1007/S11356-022-22087-9

10. Arsalis A, Papanastasiou P, Georghiou GE (2022) A comparative review of lithium-ion battery and regenerative hydrogen fuel cell technologies for integration with photovoltaic applications. Renew Energy 191:943–960. https://doi.org/10.1016/J.RENENE.2022.04.075

11. Kar SK, Bansal R, Harichandan S (2022) An empirical study on intention to use hydrogen fuel cell vehicles in India. Int J Hydrogen Energy 47:19999–20015. https://doi.org/10.1016/J.IJHYDENE.2022.04.137

12. Li X, Yang X, Xue H, Pang H, Xu Q (2020) Metal–organic frameworks as a platform for clean energy applications. EnergyChem 2:100027. https://doi.org/10.1016/J.ENCHEM.2020.100027

13. González EL, Llerena FI, Pérez MS, Iglesias FR, Macho JG (2015) Energy evaluation of a solar hydrogen storage facility: comparison with other electrical energy storage technologies. Int J Hydrogen Energy 40:5518–5525. https://doi.org/10.1016/J.IJHYDENE.2015.01.181

---

14. Escamilla A, Sánchez D, García-Rodríguez L (2022) Assessment of power-to-power renewable energy storage based on the smart integration of hydrogen and micro gas turbine technologies. Int J Hydrogen Energy 47:17505–17525. https://doi.org/10.1016/J.IJHYDENE.2022.03.238

---

15. Mehboob MY, Hussain R, Younas F, Jamil S, Iqbal MMA, Ayub K, Sultana N, Janjua MRSA (2022) Computation assisted design and prediction of alkali-metal-centered B12N12 nanoclusters for efficient h2 adsorption: new hydrogen storage materials. J Clust Sci 1:1–11. https://doi.org/10.1007/S10876-022-02294-7/FIGURES/4

---

16. Rajeshkhanna G, Singh TI, Kim NH, Lee JH (2018) Remarkable bifunctional oxygen and hydrogen evolution electrocatalytic activities

with trace-level fe doping in Ni- and Co-layered double hydroxides for overall water-splitting. ACS Appl Mater Interfaces 10:42453–42468. https://doi.org/10.1021/ACSAMI.8B16425/SUPPL_FILE/AM8B16425_SI_003.AVI

17. Zhang W, Cui L, Liu J (2020) Recent advances in cobalt-based electrocatalysts for hydrogen and oxygen evolution reactions. J Alloys Compds 821:153542. https://doi.org/10.1016/J.JALLCOM.2019.153542

18. Li Y, Jia B, Fan Y, Zhu K, Li G, Su CY (2018) Bimetallic zeolitic imidazolite framework derived carbon nanotubes embedded with co nanoparticles for efficient bifunctional oxygen electrocatalyst. Adv Energy Mater 8:1702048. https://doi.org/10.1002/AENM.201702048

19. Zhang X, Zhang W, Dai J, Sun M, Zhao J, Ji L, Chen L, Zeng F, Yang F, Huang B, Dai L (2022) Carboxylated carbon nanotubes with high electrocatalytic activity for oxygen evolution in acidic conditions. InfoMat 4:e12273. https://doi.org/10.1002/INF2.12273

20. Wang B, Ye Y, Xu L, Quan Y, Wei W, Zhu W, Li H, Xia J, Wang B, Ye Y, Xu L, Quan Y, Zhu W, Li H, Xia J, Wei W (2020) Space-confined yolk-shell construction of Fe_3O_4 nanoparticles inside N-doped hollow mesoporous carbon spheres as bifunctional electrocatalysts for long-term rechargeable zinc-air batteries. Adv Funct Mater 30:2005834. https://doi.org/10.1002/ADFM.202005834

21. Koutavarapu R, Venkata Reddy C, Babu B, Reddy KR, Cho M, Shim J (2020) Carbon cloth/transition metals-based hybrids with controllable architectures for electrocatalytic hydrogen evolution: a review. Int J Hydrogen Energy 45:7716–7740. https://doi.org/10.1016/J.IJHYDENE.2019.05.163

22. Li P, Zhao R, Chen H, Wang H, Wei P, Huang H, Liu Q, Li T, Shi X, Zhang Y, Liu M, Sun X, Li P, Zhao R, Chen H, Wei P, Huang H, Sun X, Zhang Y, Liu M, Wang H, Liu Q, Li T, Shi X (2019) Recent advances in the development of water oxidation electrocatalysts at mild pH. Small 15:1805103. https://doi.org/10.1002/SMLL.201805103

23. Chakrabarty S, Mukherjee A, Su WN, Basu S (2019) Improved bi-functional ORR and OER

catalytic activity of reduced graphene oxide supported $ZnCo_2O_4$ microsphere. Int J Hydrogen Energy 44:1565–1578. https://doi.org/10.1016/J.IJHYDENE.2018.11.163

24. Gouadria S, Abudllah M, Ahmad Z, John P, Nisa MU, Manzoor S, Aman S, Ashiq MN, Ghori MI (2023) Development of bifunctional Mo doped $ZnAl_2O_4$ spinel nanorods array directly grown on carbon fiber for supercapacitor and OER application. Ceram Int 49:4281–4289. https://doi.org/10.1016/J.CERAMINT.2022.09.312

25. Zhou W, Wang D, Zhao L, Yuan C, Zhang L, Zhu S, Shamitha C, Shetty AR, ChitharanjanHegde A, Anandhan S (2019) Sol-gel electrospun $ZnMn_2O_4$ nanofibers as bifunctional electrocatalysts for hydrogen and oxygen evolution reactions. Mater Res Express 6:11507. https://doi.org/10.1088/2053-1591/AB51AA

26. Shoaib S, Shah A, Najam T, Wen M, Zang S-Q, Waseem A, Jiang H-L (2022) Metal-organic framework-based electrocatalysts for CO_2 reduction. Small Struct 3:2100090. https://doi.org/10.1002/SSTR.202100090

27. Fito J, Kefeni KK, Nkambule TTI (2022) The potential of biochar-photocatalytic nanocomposites for removal of organic micropollutants from wastewater. Sci Total Environ 829:154648. https://doi.org/10.1016/J.SCITOTENV.2022.154648

28. Huang C, Wang Q, Zhang D, Shen G (2022) Coupling N-doping and rich oxygen vacancies in mesoporous $ZnMn_2O_4$ nanocages toward advanced aqueous zinc ion batteries. Nano Res 15:8118–8127. https://doi.org/10.1007/S12274-022-4498-9

29. Zhang Y, Senyang Xu, Wang Y, Hou L, Yuan C (2022) Spray drying construction of hierarchical hollow $ZnMn_2O_4$ folded microspheres as anode materials for lithium ion batteries. Mater Adv 3:9030–9039. https://doi.org/10.1039/D2MA00924B

30. Hasan M, Zawar S, Mustafa GM, Ghaffar A, Razaq A, Atiq S (2022) Porous Architecture of

PDF

Help

Ni substituted $ZnMn_2O_4$ nanospheres as an electrode material for supercapacitor applications. Phys B Condens Matter 633:413767. https://doi.org/10.1016/J.PHYSB.2022.413767

31. Lyu L, Kim CW, Dong Seong K, Kang J, Liu S, Yamauchi Y, Piao Y (2022) Defect engineering induced heterostructure of Zn-birnessite@spinel $ZnMn_2O_4$ nanocrystal for flexible asymmetric supercapacitor. Chem Eng J 430:133115. https://doi.org/10.1016/J.CEJ.2021.133115

32. Qin H, He Y, Xu P, Huang D, Wang Z, Wang H, Wang Z, Zhao Y, Tian Q, Wang C (2021) Spinel ferrites (MFe_2O_4): synthesis, improvement and catalytic application in environment and energy field. Adv Colloid Interface Sci 294:102486. https://doi.org/10.1016/J.CIS.2021.102486

33. Zhong F, Li Z, Luo Y, Chen C, Zhou C, Lin L, Cai G, Au C, Jiang L (2021) Geometric structure distribution and oxidation state demand of cations in spinel $Ni_xFe_{1-x}Co_2O_4$ composite cathodes for solid oxide fuel cells. Chem Eng J 425:131822. https://doi.org/10.1016/J.CEJ.2021.131822

34. Zha D, Fu Y, Gao X, Zhang L, Wang X (2017) Intimately coupled hybrid of carbon black/nickel cobaltite for supercapacitors with enhanced energy-storage properties and ultra-long cycle life. Electrochim Acta 257:494–503. https://doi.org/10.1016/J.ELECTACTA.2017.10.104

35. Zha D, Xiong P, Wang X (2015) Strongly coupled manganese ferrite/carbon black/polyaniline hybrid for low-cost supercapacitors with high rate capability. Electrochim Acta 185:218–228. https://doi.org/10.1016/J.ELECTACTA.2015.10.139

36. Kavinkumar T, Vinodgopal K, Neppolian B (2020) Development of nanohybrids based on porous spinel MCo_2O_4 (M = Zn, Cu, Ni and Mn)/reduced graphene oxide/carbon nanotube as promising electrodes for high performance energy storage devices. Appl Surf

PDF
Help

Sci 513:145781. https://doi.org/10.1016/J.APSUSC.2020.145781

37. Tatarchuk T, Paliychuk N, Pacia M, Kaspera W, Macyk W, Kotarba A, Bogacz BF, Pędziwiatr AT, Mironyuk I, Gargula R, Kurzydło P, Shyichuk A (2019) Structure–redox reactivity relationships in $Co_{1-x}Zn_xFe_2O_4$: the role of stoichiometry. New J Chem 43:3038–3049. https://doi.org/10.1039/C8NJ05329D

38. Dhiman M, Sharma R, Kumar V, Singhal S (2016) Morphology controlled hydrothermal synthesis and photocatalytic properties of $ZnFe_2O_4$ nanostructures. Ceram Int 42:12594–12605. https://doi.org/10.1016/J.CERAMINT.2016.04.115

39. Ranjith Kumar E, Arunkumar T, Prakash T (2015) Heat treatment effects on structural and dielectric properties of Mn substituted $CuFe_2O_4$ and $ZnFe_2O_4$ nanoparticles. Superlattices Microstruct 85:530–535. https://doi.org/10.1016/J.SPMI.2015.06.016

40. Luo Y, Fan S, Hao N, Zhong S, Liu W (2014) Multi-functional Au/CdS/Fe_3O_4/RGO hybrid

nanomaterials with enhanced photocatalytic activity. CrystEngComm 17:503–506. https://doi.org/10.1039/C4CE01600A

41. Shao P, Yu S, Duan X, Yang L, Shi H, Ding L, Tian J, Yang L, Luo X, Wang S (2020) Potential difference driving electron transfer via defective carbon nanotubes toward selective oxidation of organic micropollutants. Environ Sci Technol 54:8464–8472. https://doi.org/10.1021/ACS.EST.0C02645/ASSET/IMAGES/LARGE/ES0C02645_0006.JPEG

42. Zhou W, Yu B, Zhu J, Li K, Tian S (2022) Hierarchical ZnO/MXene (Nb_2C and V2C) heterostructure with efficient electron transfer for enhanced photocatalytic activity. Appl Surf Sci 590:153095. https://doi.org/10.1016/J.APSUSC.2022.153095

43. Sharifi T, Hu G, Jia X, Wågberg T (2012) Formation of active sites for oxygen reduction reactions by transformation of nitrogen functionalities in nitrogen-doped carbon nanotubes. ACS Nano 6:8904–8912. https://doi.org/10.1021/NN302906R/SUPPL_FILE/NN302906R_SI_001.PDF

PDF

Help

44. Wu J, Xue Y, Yan X, Yan W, Cheng Q, Xie Y (2012) Co_3O_4 nanocrystals on single-walled carbon nanotubes as a highly efficient oxygen-evolving catalyst. Nano Res 58(5):521–530. https://doi.org/10.1007/S12274-012-0237-Y

45. Khan MK, Tahir SA, Ashfaq A, Ali A, Ahmad W, Haneef M, Mushtaq S, Saeed R, Khan KM, Shabbir K (2022) Enhancement of the structural, optical and thermoelectric properties of thermally evaporated $AgMoO_3$ thin film by post-annealing. Opt Mater (Amst). 128:112406. https://doi.org/10.1016/J.OPTMAT.2022.112406

46. Chandramouli K, Rao PA, Suryanarayana B, Raghavendra V, Mercy SJ, Parajuli D, Taddesse P, Mulushoa SY, Mammo TW, Murali N (2021) Effect of Cu substitution on magnetic and DC electrical resistivity properties of Ni–Zn nanoferrites. J Mater Sci Mater Electron 32:15754–15762. https://doi.org/10.1007/S10854-021-06127-7/FIGURES/9

47. Kim JG, Kim Y, Noh Y, Kim WB (2015) $MnCo_2O_4$ nanowires anchored on reduced graphene oxide sheets as effective bifunctional catalysts for Li-O_2 battery cathodes.

PDF
Help

Chemsuschem 8:1752–1760. https://doi.org/10.1002/CSSC.201500123

48. Huerta-Aguilar CA, Ramírez-Alejandre AA, Thangarasu P, Arenas-Alatorre JA, Reyes-Dominguez IA, De La Luz-Corea M (2019) Crystal phase induced band gap energy enhancing the photo-catalytic properties of Zn–Fe2O4/Au NPs: experimental and theoretical studies. Catal Sci Technol 9:3066–3080. https://doi.org/10.1039/C9CY00678H

49. Ferrari AC, Rodil SE, Robertson J, Rodil SE, Robertson J (2003) Interpretation of infrared and Raman spectra of amorphous carbon nitrides. Phys Rev B 67:155306. https://doi.org/10.1103/PhysRevB.67.155306

50. Rebekah A, Ashok Kumar E, Viswanathan C, Ponpandian N (2020) Effect of cation substitution in $MnCo_2O_4$ spinel anchored over rGO for enhancing the electrocatalytic activity towards oxygen evolution reaction (OER). Int J Hydrogen Energy 45:6391–6403. https://doi.org/10.1016/J.IJHYDENE.2019.12.164

51. Murthy AP, Theerthagiri J, Madhavan J, Murugan K (2017) Highly active MoS_2/carbon electrocatalysts for the hydrogen evolution

PDF
Help

reaction: insight into the effect of the internal resistance and roughness factor on the Tafel slope. Phys Chem Chem Phys 19:1988–1998. https://doi.org/10.1039/C6CP07416B

52. Ramakrishnan S, Balamurugan J, Vinothkannan M, Kim AR, Sengodan S, Yoo DJ (2020) Nitrogen-doped graphene encapsulated FeCoMoS nanoparticles as advanced trifunctional catalyst for water splitting devices and zinc–air batteries. Appl Catal B Environ 279:119381. https://doi.org/10.1016/J.APCATB.2020.119381

53. Balamurugan J, Nguyen TT, Kim NH, Kim DH, Lee JH (2021) Novel core-shell CuMo-oxynitride@N-doped graphene nanohybrid as multifunctional catalysts for rechargeable zinc-air batteries and water splitting. Nano Energy 85:105987. https://doi.org/10.1016/J.NANOEN.2021.105987

54. Liu W, Bao J, Xu L, Guan M, Lei Y (2020) Chromium-modulated multifunctional electrocatalytic activities of spinel oxide for Zn-air batteries and overall water splitting. J Power Sources 479:229099.

https://doi.org/10.1016/J.JPOWSOUR.2020.229099

55. Manohar A, Vijayakanth V, Vattikuti SVP, Manivasagan P, Jang ES, Kim KH (2022) Electrochemical, oxygen evolution reaction and photoelectrochemical water splitting activity of Ca-doped $MgFe_2O_4$ nanoparticles. J Alloys Compds 907:164566. https://doi.org/10.1016/J.JALLCOM.2022.164566

56. Li J, Liang Z, Song Q, Xu X (2019) Strong-coupled CoOx nanoparticles/Bi_2WO_6 nanosheets hybrid as electrocatalyst for water oxidation under alkaline conditions. Mater Res Bull 113:152–160. https://doi.org/10.1016/J.MATERRESBULL.2019.02.005

57. Li J, Xu X, Zhang B, Hou W, Lv S, Shi Y (2020) Controlled synthesis and fine-tuned interface of NiS nanoparticles/Bi_2WO_6 nanosheets heterogeneous as electrocatalyst for oxygen evolution reaction. Appl Surf Sci 526:146718. https://doi.org/10.1016/J.APSUSC.2020.146718

58. Yang H, Liu Y, Luo S, Zhao Z, Wang X, Luo Y, Wang Z, Jin J, Ma J (2017) Lateral-size-mediated efficient oxygen evolution reaction: insights into the atomically thin quantum dot structure of $NiFe_2O_4$. ACS Catal 7:5557–5567. https://doi.org/10.1021/ACSCATAL.7B00007/ASSET/IMAGES/LARGE/CS-2017-000074_0008.JPEG

59. Bao W, Xiao L, Zhang J, Jiang P, Zou X, Yang C, Hao X, Ai T (2021) Electronic and structural engineering of $NiCo_2O_4$/Ti electrocatalysts for efficient oxygen evolution reaction. Int J Hydrogen Energy 46:10259–10267. https://doi.org/10.1016/J.IJHYDENE.2020.12.126

60. Li T, Lv Y, Su J, Wang Y, Yang Q, Zhang Y, Zhou J, Xu L, Sun D, Tang Y, Li T, Lv Y, Su J, Wang Y, Yang Q, Xu L, Sun D, Tang Y, Zhang Y, Zhou J (2017) Anchoring $CoFe_2O_4$ nanoparticles on N-doped carbon nanofibers for high-performance oxygen evolution reaction. Adv Sci 4:1700226. https://doi.org/10.1002/ADVS.201700226

61. Li J, Liang Z, Song Q, Xu X (2019) NiFeOx nanosheets tight-coupled with Bi_2WO_6 nanosheets to improve the electrocatalyst for

PDF

Help

oxygen evolution reaction. Appl Surf Sci 478:969–980. https://doi.org/10.1016/J.APSUSC.2019.02.029

62. Wang Q, Wang H, Qi S, Su Z, Chen K, Yu X, Xie A, Luo S (2022) Coral-like $LaNi_xFe_{1-x}O3$ perovskite catalyst for high-performance oxygen evolution reaction. J Electrochem Soc 169:026508. https://doi.org/10.1149/1945-7111/AC4AB0

63. Verkerk MJ, Burggraaf AJ (1983) Oxygen transfer on substituted ZrO_2, Bi_2O_3, and CeO_2 Electrolytes with Platinum Electrodes: II. A-C Impedance study. J Electrochem Soc 130:78–84. https://doi.org/10.1149/1.2119687/XML

Acknowledgements

The authors express their gratitude to Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2023R132), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Funding

Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2023R132), Princess Nourah bint Abdulrahman University, Riyadh, Saudi

Arabia. Deanship of Scientific Research at King Khalid University is greatly appreciated for funding this work under grant number R.G.P.2/215/44.

Author information

Authors and Affiliations

Institute of Physics, Khwaja Fareed University of Engineering and Information Technology, Abu Dhabi Road, Rahim Yar Khan, 64200, Pakistan

Salma Aman & Naseeb Ahmad

Institute of Chemical Sciences, Bahauddin Zakariya University, Multan, Pakistan

Sumaira Manzoor & Adeel Hussain Chughtai

Department of Physics, College of Science, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh, 11671, Saudi Arabia

Meznah M. Alanazi & Shaimaa A. M. Abdelmohsen

University of Education, Lahore, Dera Ghazi Khan Campus, D. G. Khan, 32200, Pakistan

Rabia Yasmin Khosa

Department of Chemistry, College of Science, King Khalid University, Abha, 61413, Saudi Arabia

Abdullah G. Al-Sehemi

Department of Chemistry, Tsinghua University, Key Laboratory of Organic Optoelectronics & Molecular Engineering of

PDF

Help

Ministry of Education, Beijing, 100084, China

Ruimao Hua

Department of Physics, College of Science, Taif University, P.O. Box 11099, Taif, 21944, Saudi Arabia

Huda A. Alzahrani

Contributions

Sumaira Manzoor : Write the original article. Muhammad Abdullah: Work in labs. Salma Aman: Supervision.

Corresponding author

Correspondence to Salma Aman.

Ethics declarations

Conflict of interest

The authors declare that they have no conflict of interest.

Additional information

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Rights and permissions

About this article

Cite this article

Aman, S., Ahmad, N., Manzoor, S. *et al.* Effect of Copper Substitution on the Electrocatalytic Activity of $ZnMn_2O_4$ Spinel Embedded on Reduced Graphene Oxide Nanosheet for the Oxygen Evolution Process. *Catal Surv Asia* **27**, 165–179 (2023). https://doi.org/10.1007/s10563-023-09389-9

Received	Accepted	Published
30 October 2022	29 January 2023	07 February 2023

Issue Date

June 2023

DOI

https://doi.org/10.1007/s10563-023-09389-9

Keywords

$Zn_{0.4}Cu_{0.6}Mn_2O_4$/rGO **Hydrothermal route** **Ni foam** **Electrocatalyst** **OER**

PDF

Help