IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Metal Chalcogenide-Carbon Nanocomposites for Advanced Energy Storage and Conversion Applications: A Review

Unmesh Shinde[1], Dr. S.G. Dahotre[2]

[1]*Unmesh Shinde, Research Scholar*
Dr. Babasaheb Ambedkar Technological University, Lonere, India, 402103

[2] Dr. S. G. Dahotre, *Professor,* *0000-0002-6320-8656*
Dr. Babasaheb Ambedkar Technological University, Lonere, India, 402103

Abstract – *Metal chalcogenide–carbon nanocomposites are gaining significant attention as advanced materials for modern energy storage and conversion technologies. Their effectiveness arises from the complementary properties of both components: metal chalcogenides provide high electrochemical activity and multiple redox states, while carbon materials enhance electrical conductivity, mechanical strength, and surface area. This review highlights recent progress in synthesis approaches, structural engineering, and applications of these nanocomposites in batteries, supercapacitors, electrocatalysis, and photocatalysis. Additionally, key limitations such as structural instability, volume expansion, and scalability challenges are critically discussed, along with future research directions for real-world applications.*

Keywords- Metal Chalcogenide, Carbon Nanocomposites, Energy Storage, Energy Conversion, Chemical Vapor Deposition, Electrospinning

INTRODUCTION

The growing need for sustainable and efficient energy solutions has accelerated research in advanced functional materials. Among them, transition metal chalcogenides (TMCs) have emerged as promising candidates due to their adjustable electronic properties, high electrochemical performance, and natural abundance. However, their practical implementation is limited by poor electrical conductivity and structural degradation during repeated use. To address these drawbacks, combining TMCs with carbon-based materials such as graphene, carbon nanotubes, and porous carbon has proven highly effective. These hybrid materials exhibit improved charge transport, enhanced ion diffusion, and better structural durability. Metal chalcogenides are compounds formed between metals (M) and chalcogen elements (X), where X typically includes sulfur (S), selenium (Se), tellurium (Te), or oxygen (O).

Their general formula can be expressed as: M_xX_y

Where x and y depend on the oxidation states of the elements involved.

.

LITERATURE REVIEW

Properties of Metal Chalcogenide-Carbon Nanocomposites:

Metal chalcogenides:

Metal chalcogenides such as MoS_2, WS_2, CoS_2, and FeSe are known for their high energy storage capacity due to multi-electron redox processes. Their transition metal ions can adopt different oxidation states, enabling reversible electrochemical reactions. Additionally, their relatively small band gap allows effective absorption of visible light, making them suitable for photocatalytic and solar energy applications.

Carbon-Based Materials:

Carbon materials, including graphene, carbon nanotubes, and amorphous carbon, are widely used due to their excellent electrical conductivity and large surface area. These features provide numerous active sites for electrochemical reactions and facilitate rapid electron movement. Their mechanical flexibility also helps accommodate structural changes during charge–discharge cycles, improving durability.

Synergistic Effects:

When metal chalcogenides are combined with carbon materials, the resulting composite exhibits enhanced performance due to synergistic interactions. The conductive carbon framework improves electron mobility, while also buffering the volume expansion of chalcogenides. This leads to better cycling stability, increased active surface area, and faster ion transport.

METHODOLOGY

Synthesis Methods:

Hydrothermal/Solvothermal Method:

This method enables uniform growth of metal chalcogenides in the presence of carbon materials such as graphene oxide or CNTs. It provides good control over particle size and morphology while ensuring strong interaction between components. It is widely preferred due to its cost-effectiveness, simplicity, and ability to produce high-quality nanocomposites.

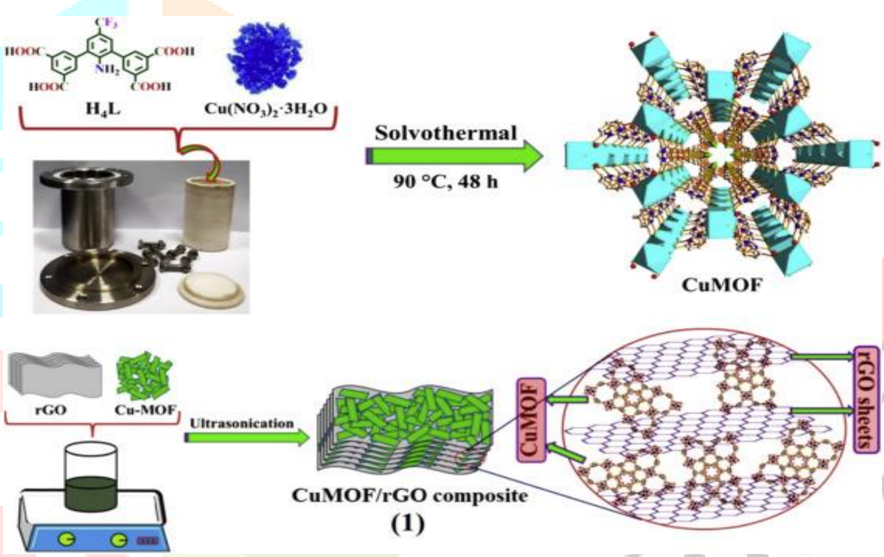

Fig: 1

Chemical Vapor Deposition (CVD):

CVD is a technique used to fabricate thin films and nanostructures from gaseous precursors. In this process, vaporized metal and chalcogen sources react at high temperatures on a substrate surface to form a solid layer. This method offers precise control over thickness, composition, and crystallinity, making it suitable for advanced coatings.

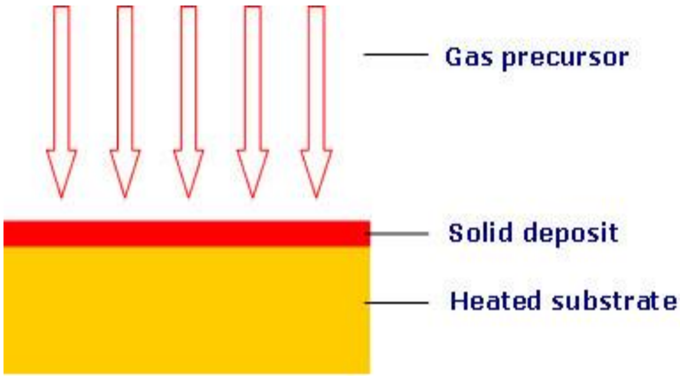

Fig: 2

Electrospinning:

Electrospinning is used to produce ultrafine nanofibers by applying a high-voltage electric field to a precursor solution. The fibers formed are later converted into composite materials through heat treatment. This approach results in highly porous and interconnected structures with large surface areas.

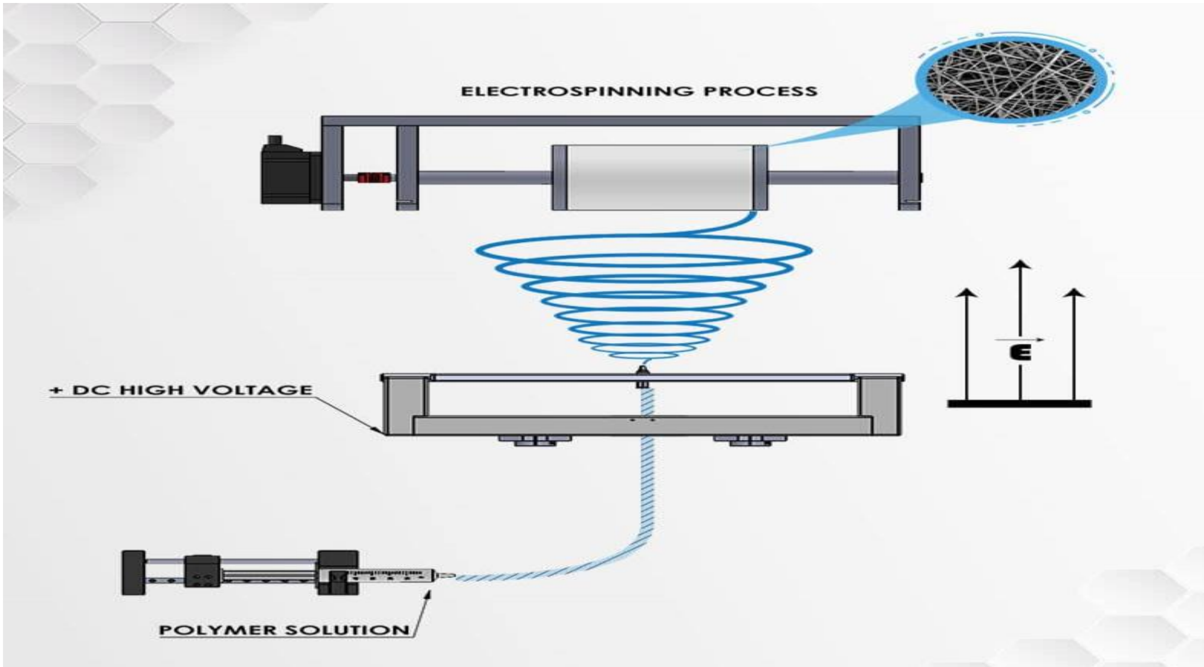

Fig: 3

Template-Assisted and Self-Assembly Method:

Template-assisted synthesis uses pre-designed hard or soft templates to shape metal chalcogenide nanostructures, such as nanotubes or hollow spheres. Precursors deposit onto the template, which is later removed to yield precise and uniform morphologies. Self-assembly relies on spontaneous organization of nanoparticles or molecules through non-covalent interactions to form ordered structures. This method can create hierarchical, porous, and well-dispersed nanostructures without external molds. Both approaches enhance active site exposure, electron transport, and structural stability in energy storage and conversion applications.

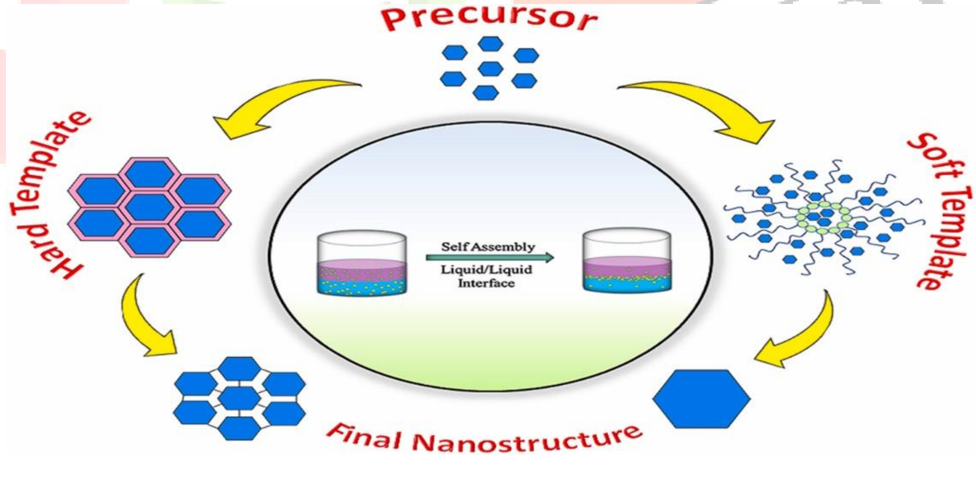

Fig: 4

Applications in Energy Systems:

Lithium-Ion and Sodium-Ion Batteries:

These nanocomposites are widely used as electrode materials in lithium-ion and sodium-ion batteries. Their high capacity is due to multiple redox reactions occurring at metal sites. The carbon matrix improves conductivity and stabilizes structural changes, leading to better performance and longer life cycles.

Supercapacitors:

Metal chalcogenide–carbon nanocomposites in supercapacitors offer high power density and rapid charge–discharge capability. In supercapacitors, these composites combine electric double-layer capacitance from carbon with pseudo capacitance from metal chalcogenides. This results in high power density, fast charging, and improved cycling stability.

Electrocatalysis:

Metal chalcogenide–carbon composites are effective catalysts for reactions such as hydrogen evolution (HER) and oxygen reactions. They serve as low-cost alternatives to noble metals and provide enhanced catalytic efficiency due to improved electron transfer and active site distribution.

CO_2 Reduction and Energy Conversion:

These materials facilitate efficient adsorption and conversion of CO_2 due to their high surface area and catalytic activity. Their conductive structure improves electron transfer, enhancing reaction efficiency.

Photocatalysis and Solar Energy:

Metal chalcogenide-carbon nanocomposites possess narrow band gaps, allowing them to efficiently absorb visible light. They are widely applied in photocatalytic hydrogen production through water splitting. These materials also degrade organic pollutants in water via photo-induced redox reactions. The carbon component enhances charge separation and electron transport, improving overall photocatalytic efficiency and stability.

Challenges and Limitations:

Despite their promising performance, metal chalcogenide-carbon nanocomposites face structural degradation during repeated charge-discharge cycles, reducing long-term capacity. Many synthesis methods are difficult to scale up, limiting Industrial applications. The materials can exhibit poor stability under real operating conditions, such as high temperatures, corrosive electrolytes, or prolonged cycling. Volume expansion of chalcogenides and agglomeration of nanoparticles further affect performance. Addressing these issues is essential to achieve practical, durable, and commercially viable energy devices.

Future Perspectives:

Future research on metal chalcogenide–carbon nanocomposites should focus on designing hierarchical and multi-dimensional nanostructures to maximize active sites and enhance electron/ion transport. Developing scalable and cost-effective synthesis methods is crucial for practical and commercial applications. A deeper understanding of charge-transfer mechanisms will help optimize electrochemical performance and durability. Integration with flexible and wearable energy devices represents a promising avenue for next-generation technologies.

CONCLUSION

Metal chalcogenide–carbon nanocomposites represent an important class of materials for future energy technologies. Their combined properties offer improved performance across various applications, including energy storage and catalysis. Despite current challenges such as stability and scalability, continued advancements in material design and synthesis techniques are expected to enable their practical implementation in next-generation devices. Nanostructuring and surface engineering further enhance the electrochemical performance. Metal Chalcogenide-Carbon Nanocomposites are used in Lithium-Ion and Sodium-Ion Batteries, Supercapacitors, Electrolysis, CO_2 Reduction and Energy Conversion and Photocatalysis and Solar Energy. Future research should focus on cost-effective large-scale synthesis and device integration.

REFERENCES

1. *CC Ahia et al.,* Journal (2025) *"Carbon-based transition metal chalcogenides for wearable sensors, energy storage, and photodetector applications"*
2. *Navneet Kaur et al.,* Journal of Power Sources *(2025) "Metal chalcogenide nanostructures: A promising class of materials for high-performance batteries and supercapacitors"*
3. *Palchoudhury, S., Ramasamy, K., Han, J., Chen, P., & Gupta, A. (2023),* Transition metal chalcogenides for next-generation energy storage.
4. *Ezema, F. I., Lokhande, C. D., & Lokhande, A. C. (2023),* Chemically deposited metal chalcogenide-based carbon composites for versatile applications.
5. *P. Salarizadeh et al.,* Nano Futures *(2022) "Transition metal chalcogenides /carbon composites: structural and electrochemical improvements"*
6. *Song, Y., Zhao, X., & Liu, Z. (2021).* Surface selenium doped hollow heterostructure/defects co-Fe sulfide nanoboxes for enhanced oxygen evolution and supercapacitors.
7. *Tang, G., et al. (2020),* Carbon-based transition metal chalcogenides for energy storage and sensing applications.
8. *Rao, C. N. R., et al. (2019),* Transition metal chalcogenides for energy storage and conversion applications.
9. *Kim, H. S., & Kuppusami, P. (2018),* Recent advances in metal chalcogenide nanostructures for supercapacitor applications.
10. *Tang, C., et al. (2017),* Metal chalcogenides for electrocatalysis: Progress and challenges.
11. *Hong Yuan et al.,* Chinese Chemical Letters *(2017) "A review of transition metal chalcogenide/graphene nanocomposites for energy storage and conversion"*