iJRASET

International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: V Month of publication: May 2025

DOI: https://doi.org/10.22214/ijraset.2025.70579

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

2D Material-Enhanced Phase Change Materials

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Abstract: Phase change materials (PCMs) are promising options for thermal energy storage systems because of their well-known high energy density and consistent thermal output. Nevertheless, the low thermal conductivity and phase transition leakage of conventional PCMs severely restrict their usefulness. A recent successful tactic to get around these issues is the incorporation of two-dimensional (2D) materials into PCMs. The impact of 2D material-enhanced PCMs on energy storage applications is highlighted in this review, which also discusses recent advancements, new trends, and difficulties related to these materials. It draws attention to how 2D materials can enhance structural integrity, thermal conductivity, and multifunctional responsiveness.

I. INTRODUCTION

The increasing focus on sustainable energy use and the integration of renewable energy sources has led to a significant increase in the demand for effective thermal energy storage systems worldwide. With their high latent heat capacities and energy density, PCMs are essential for the storage and release of thermal energy through solid-liquid phase transitions. Notwithstanding these benefits, inherent drawbacks like poor heat conductivity and melting leakage prevent them from being used in real-world situations.

Two-dimensional (2D) materials like graphene, MXenes, molybdenum disulfide (MoS2), graphene, and black phosphorus (BP) have been added to PCMs in order to address these problems. These materials are perfect for improving PCM performance because they have great stability, a large surface area, and superior thermal and electrical properties.

II. THERMAL CONDUCTIVITY ENHANCEMENT BY 2D MATERIALS

Figure 1. Thermal conductivity improvements for PCMs embedded with graphene, h-BN, MXenes, MoS_2, and black phosphorus compared to pristine PCMs.

III. APPLICATIONS

A. Battery Thermal Management

Effective heat dissipation from lithium-ion batteries is made possible by the notable increases in thermal conductivity shown by graphene and h-BN-enhanced PCMs. Specifically, h-BN offers vital electrical insulation that is necessary for battery security.

B. Solar-Thermal Energy Storage

Outstanding solar-to-thermal conversion efficiencies are demonstrated by MXene and MoS2-integrated PCMs; MXenes achieve over 97% solar-to-thermal conversion efficiency. Black phosphorus is positioned as an emerging candidate for sophisticated photothermal energy storage applications due to its broadband light absorption capabilities.

C. Electro-Thermal Systems

The Joule heating effect in PCMs is made possible by electrically conductive 2D materials like reduced graphene oxide (rGO) and MXenes. This effect enables reusability, fast thermal response, and programmable thermal energy release, enabling intelligent and flexible thermal management solutions.

IV. CHALLENGES AND FUTURE PERSPECTIVES

Although 2D material-enhanced PCMs show promise, their long-term and scalable deployment will require overcoming a number of obstacles.

- Agglomeration: 2D materials' propensity to group together at high loading concentrations, which impairs consistent performance and uniform dispersion.
- Compatibility problems include difficulties with interfacial adhesion between PCM matrices and 2D fillers, which compromise the stability of the composite.
- The ability to withstand repeated melting and solidification cycles over an extended period of time is known as thermal cycling stability.
- Scalability and Cost: The technical and financial difficulties involved in producing and integrating premium 2D materials on a large scale.

A. Future Directions

- Creation of 2D hybrid material systems for synergistic improvements, such as graphene-MXene composites.
- Methods for surface functionalization to enhance PCM composites' dispersion and interfacial bonding.
- Combining photothermal, electrothermal, and magnetothermal effects to create multifunctional PCMs for a range of energy applications

V. CONCLUSION

A potential solution to the inherent drawbacks of traditional PCMs is the use of 2D material-enhanced PCMs. Advanced thermal energy storage systems for a variety of applications are made possible by their exceptional thermal, electrical, and optical qualities. To reach their full potential, further advancements in application-driven integration, composite engineering, and material synthesis are essential.

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10.22214/IJRASET

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