European Science Review 2025,
No 11–12
ISSN 2310-5577

PREMIER Publishing
ppublishing.org

Section 4. Engineering sciences in general

DOI:10.29013/ESR-25-11.12-44-46

HIGH-THERMAL AND HIGH-ELECTRICAL–CONDUCTIVITY COMPOSITE WITH A THREE-DIMENSIONAL NANOCAPSULE STRUCTURE FOR SMART HOME SYSTEMS

Aleksanian Artem Arturovich [1]

[1] Yuri Gagarin State Technical University of Saratov Head of Innovation and Strategic Product Development

Cite: *Aleksanian A.A. (2025). High-thermal and high-electrical-conductivity composite with a three-dimensional nanocapsule structure for smart home systems. European Science Review 2025, No 11–12.* https://doi.org/10.29013/ESR-25-11.12-44-46

Abstract

An innovative composite material characterized by the combination of high thermal conductivity, electrical conductivity, and mechanical strength is presented. The material is based on a three-dimensional structure composed of nanoscale multilayer spherical capsules forming a pseudo-spongy volume with uniform distribution of thermal and electrical flows. The composite demonstrates stable performance under high thermal loads and pulsed energy conditions, which makes it suitable for miniature high-energy electronic components and smart home infrastructure. The structure, fabrication principles, and key performance advantages of the material are examined.

Keywords: *Composite material; pseudo-spongy composite; pseudo-porous composite; nanoscale capsules; three-dimensional composite structure; mechanical strength; thermal conductivity; electrical conductivity; 3D lattice; microspheres; dielectric spheres; high-energy systems*

Introduction

The development of smart home technologies and compact high-energy electronic systems is accompanied by increasing demands for materials capable of providing both efficient heat dissipation and electrical conductivity. Traditional metal composites – such as copper–tungsten, copper–molybdenum, or diamond–copper materials – remain limited in their ability to dissipate thermal and electrical energy under high power density conditions.

The proposed composite material addresses these limitations through a three-dimensional nanocapsule architecture that enables uniform heat and current distribution within a pseudo-spongy structural volume.

Structure of the Innovative Composite

1) Nanocapsule Architecture

The material is formed from a multitude of identical nanoscale multilayer spherical capsules. Each capsule consists of:

- a **solid spherical core** made from a material featuring minimal thermal expansion, such as synthetic diamond;
- **plastic metal shells**, composed of highly conductive materials such as copper or silver.

This combination ensures a balanced set of properties: high structural rigidity due to the core and excellent conductivity and plasticity due to the metallic shells.

2) Formation of the Three-Dimensional Structure

The capsules assemble into a regular three-dimensional lattice in which each element has an equivalent system of contacts. This provides:

- stable geometric configuration;
- absence of internal deformation;
- precise calibration of structural parameters.

Physical and Technical Properties

1) Thermal and Electrical Conductivity

The pseudo-spongy organization of the composite ensures:

- uniform heat spreading;
- reduction of localized overheating zones;
- high-speed current transfer throughout the volume.

The nanoscale capsule architecture contributes to enhanced thermal and electrical conductivity.

2) Mechanical Strength and Stability

The combination of a solid core and plastic shells provides:

- resistance to mechanical impact and thermal shock;
- minimization of internal stresses;
- preservation of geometry under high pressures.

3) Resistance to Pulsed Loads

The material can efficiently absorb high-amplitude energy pulses while maintaining stable performance in rapidly changing operating modes, which is essential for miniature electronic components.

Composite Manufacturing Technology

The fabrication process includes several key stages:

1. Synthesis of nanoscale multilayer capsules.

2. Assembly of the capsules into a three-dimensional pseudo-spongy structure.

3. Final plastic calibration in a cold-flow regime, enabling:

- elimination of internal stresses,
- reduction of inter-capsule gaps,
- increased efficiency of heat and current dissipation.

Strict control at all stages ensures reproducibility and stability of the material's functional properties.

Applications and Prospects

The composite is particularly effective in environments with high energy concentration, such as:

- semiconductor laser packaging;
- miniature electronic modules;
- high-frequency and pulsed systems;
- smart home infrastructure components.

Example: Semiconductor Laser Package

The material:

- ensures efficient heat dissipation, stabilizing the operating temperature at 25–27 °C;
- enables reduction of device size without compromising heat dissipation performance;
- provides reliable operation in pulsed regimes with peak loads exceeding nominal values.

A distinctive advantage is the ability to combine functions of thermal and electrical conductivity within a single homogeneous structure, enabling simplified and more efficient device architectures.

Conclusion

The composite material featuring a three-dimensional nanocapsule structure presents a promising solution for high-energy electronic systems. Its key advantages include high thermal and electrical conductivity, mechanical durability, and resistance to pulsed loads.

The proposed material has strong potential for application in smart home systems, microelectronics, and modern devices requiring efficient management of thermal and electrical flows.

References

United States Patent Application US20210104744, Kind Code A1 OGUNI, Teppei; et al. *Secondary Battery and Manufacturing Method Thereof*. April 8, 2021.
United States Patent Application US20210104719, Kind Code A1 OIKAWA, Makiko. *Battery Electrode and Method for Manufacturing the Same*. April 8, 2021.
United States Patent Application US20210100579, Kind Code A1 Shelton, IV, Frederick E.; et al. *Modular Battery Powered Handheld Surgical Instrument and Methods Therefor*. April 8, 2021.
United States Patent Application US20210091416, Kind Code A1 SEKI, Hayato; et al. *Secondary Battery, Battery Pack, Vehicle, and Stationary Power Supply*. March 25, 2021.
United States Patent Application US20210091402, Kind Code A1 Londarenko, Yuriy Y. *Multi-Layer Battery Configurations*. March 25, 2021.
United States Patent Application US20210091363, Kind Code A1 Lane, Robert Clinton. *High Voltage Battery Module Parallel Cell Fusing System*. March 25, 2021.

submitted 29.11.2025;
accepted for publication 13.12.2025;
published 30.12.2025

Contact: aleksan1retail@gmail.com