The temperature dependences of resistivity of spinel-nanocarbon-epoxy composites

O. Yakovenko[1], L. Matzui[1], L. Vovchenko[1], L. Kaykan[2], J. Mazurenko[1, 2, 3], D. Zaiats[1], K. Dubyk[1], D. Shpylka[1]

[1] Taras Shevchenko National University of Kyiv, Volodymyrs'ka str., 64/13, Kyiv, 01601, Ukraine;
[2] G.V. Kurdyumov Institute for Metal Physics, NAS of Ukraine, 36 Academician Vernadsky Boulevard, Kyiv, UA-03142, Ukraine;
[3]Department of Magnetism, Institute of Experimental Physics SAS, Watsonova 47, 040 01 Košice, Slovak Republic
*alenka-ya@ukr.net

INTRODUCTION

Spinel ferrites with the formula MFe_2O_4 exhibit high magnetic permeability, electrical conductivity, and are potentially interesting for electromagnetic interference (EMI) protection applications due to effective electromagnetic absorption [1, 2]. Understanding the electrical behavior of composite materials is crucial for the development of next-generation electronic devices and sensors [3]. These properties contribute to the possibility of using spinel ferrites and spinel-based composites in industries such as shielding in electronic devices, communication systems, and medical equipment. This study focuses on the temperature dependence of resistivity in spinel-nanocarbon-epoxy composites, a class of hybrid materials that combines the magnetic and semiconducting properties of spinels with the high conductivity and thermal stability of nanocarbon fillers, embedded within an epoxy matrix. These composites offer a unique synergy of properties that can be tuned for specific applications in electronics, electromagnetic shielding, and thermal management. The types, amounts, and positions of metal cations in the crystal structure MFe_2O_4 play a crucial role in determining the specific physicochemical characteristics of ferrites and their composites. Depending on the manufacturing method, ferrite nanoparticles vary in size and morphology, contributing to their fundamental properties and enabling the production of materials with tailored characteristics.

By systematically analyzing how resistivity varies with temperature, this work aims to elucidate the underlying conduction mechanisms and the role of interfacial interactions within the composite. The findings contribute to a deeper understanding of structure-property relationships in multifunctional materials, paving the way for their optimized use in smart technologies.

OBJECT:

Fillers
MWCNTs
GNPs
$CuFe_2O$, $CoFe_2O_4$, $NiFe_2O_4$

+

Polymer matrix
Epoxy resin Larit285 (viscosity of 600÷900 mPa×s)
hardening agent H285 (viscosity of 50÷100 mPa×s)

=

Polymer composites with 20 wt. % of ferrite fillers and with 5 wt. % of nanocarbon fillers

RESEARCH METHOD:

Four-probe method was used for DC electrical resistivity measurements in the temperature range of 77-293 K.

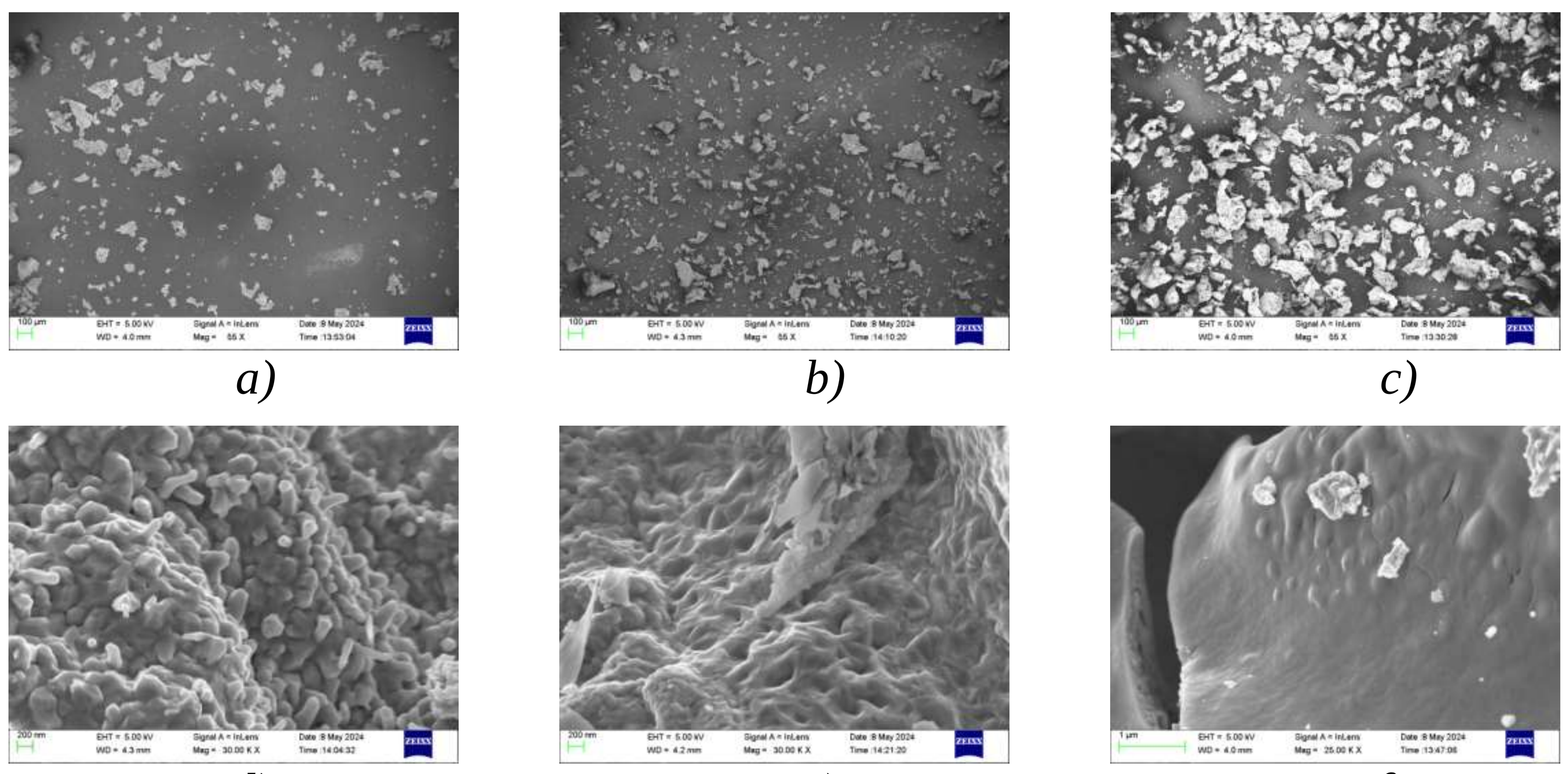
AIM

The aim of this work was to investigate the electrical properties of epoxy composites filled with 20 wt. % of $CoFe_2O_4$, $CuFe_2O_4$ and $NiFe_2O_4$ nanosized ferrites with a spinel structure, along with addition of 5 wt. % of multiwalled carbon nanotubes (MWCNTs) or graphene nanoplatelets (GNPs), in the temperature range of 77-293 K, and to reveal how the filler type affects the electrical properties of the prepared materials.

METHOD OF PREPARATION

Nanosized ferrites with the formulas $CuFe_2O_4$, $CoFe_2O_4$, $NiFe_2O_4$ were synthesized using a sol-gel autocombustion method [4]. Epoxy-based composites with ferrite fillers were prepared through solution mixing with the use of additional sonication. L285 epoxy resin with appropriate hardener H285 were used as polymer matrix.

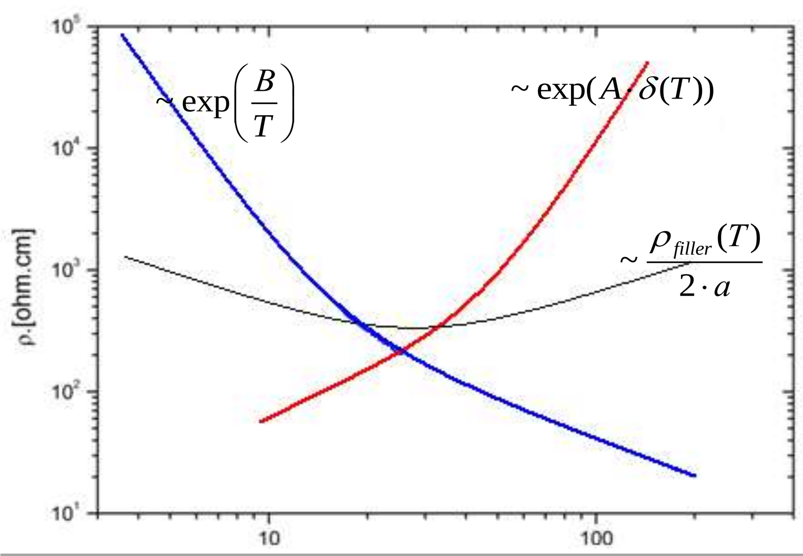
SEM OF THE PREPARED FERRITE FILLERS



a) b) c)
d) e) f)

Fig.1. SEM images of $CuFe_2O_4$ (a, d), $CoFe_2O_4$ (b, e), $NiFe_2O_4$ (c, f) nanosized ferrite fillers obtained by a sol-gel autocombustion method at different magnifications.

Temperature dependence of the DC conductivity (main mechanisms formulas)



Different carrier transport regimes temperature dependence

The temperature dependence of electrical resistance of CMs is determined by the temperature changing of three parameters:

- *the number of continuous electroconductive chains (current transition paths)* ***N***
- *contact electric resistance between graphite particles* $R_к$
- *electric resistance of graphite particles* r_{disk}

$$R_{CM}(T) = \frac{N_{nanocarbon\_in\_chain}}{N^*_{nanocarbon\_chain}(T)} \cdot (r_{nanocarbon}(T) + R_к(T))$$

$$R_{K\,eff}(T) = xR_{K1(direct)}(T) + (1-x)R_{K2(tun.)}(T)$$

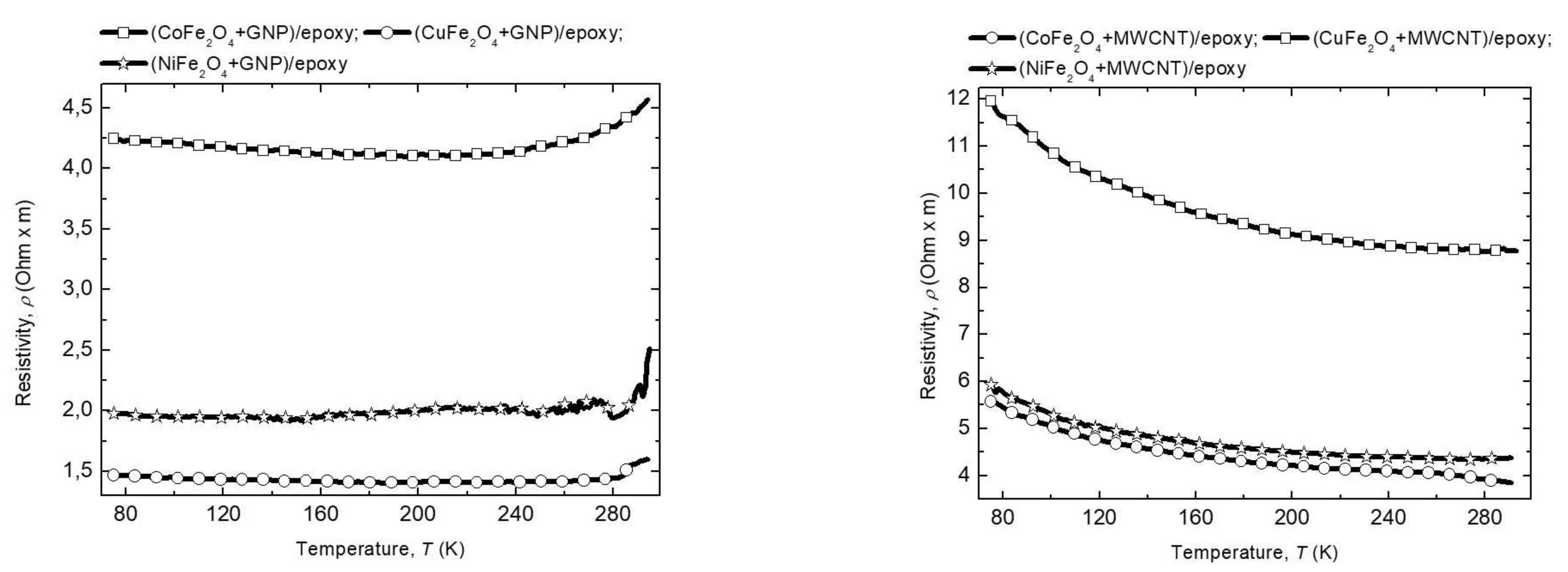
$$R_{K1(direct)}(T) \sim \frac{\rho_{filler}(T)}{2 \cdot a}$$

$$R_{K2(tun.)}(T) \sim \delta(T) \cdot \exp\left(\frac{B}{T}\right) \cdot \exp(A \cdot \delta(T))$$

$$if\ x=1:\ R_{K\,eff}(T) = R_{K(direct)}(T)$$

$$\delta(T) = \delta_0(1 + \alpha_{T(p)}T)$$

Temperature dependence of the DC resistivity of the prepared spinel-nanocarbon-epoxy composites



a) b)

Fig.2. The temperature dependences of the electrical resistivity of spinel-nanocarbon-epoxy composites with 20 wt. % of spinel ($CoFe_2O_4$, $CuFe_2O_4$, $NiFe_2O_4$) and 5 wt. % of nanocarbon of different types: GNPs (a), MWCNTs (b)

CONCLUSION

- In this work spinel ferrites $CuFe_2O_4$, $CoFe_2O_4$, $NiFe_2O_4$ were synthesized using a sol-gel autocombustion method and spinel/MWCNTs/epoxy, spinel/GNPs/epoxy composites were fabricated by mixing in solution with ultrasound treatment.
- Their electrical resistivity measurements were carried in the temperature range of 77-293 K.
- In composites with spinel and disc-shaped nanocarbon particles (GNPs), the temperature dependences of electrical resistivity is determined mainly by the resistivity of the graphite nanoparticles themselves, contact resistance at direct interparticle junctions and partly tunneling resistance across narrow gaps between adjacent particles.
- In contrast, the temperature dependence of the electrical resistivity of composites with spinel and cylindrical nanocarbon particles (MWCNTs) shows that electron transport is predominantly governed by a tunneling mechanism across the entire investigated temperature range.

ACKNOWLEDGMENT

The work contains results of studies conducted within the framework of the research grants from the Ministry of Education and Science of Ukraine 24BF051-01M (0124U001654), 24BF051-04, National Research Foundation of Ukraine NRFU2023-03/193.

REFERENCES

1. H. Qin, Y. He, P. Xu, D. Huang, Z. Wang, H. Wang, Z. Wang, Y. Zhao, Q. Tian, C. Wang, Spinel ferrites (MFe_2O_4): Synthesis, improvement and catalytic application in environment and energy field," Adv. Colloid Interface Sci., vol. 294, pp. 102486, August 2021.
2. X. Xie, B. Wang, Y. Wang, C. Ni, X. Sun, W. Du, "Spinel structured MFe_2O_4 (M = Fe, Co, Ni, Mn, Zn) and their composites for microwave absorption: a review," Chem. Eng. J., vol. 428, pp. 131160, July 2022.
3. B. Reddy, Advances in Nanocomposites – Synthesis, Characterization and Industrial Applications (InTech, Rijeka, Croatia 2011).
4. J. Mazurenko, L. Kaykan, A. K. Sijo, M. Moiseienko, M. Kuzyshyn, N. Ostapovych, M. Moklyak, "The influence of reaction medium pH on the structure, optical, and mechanical properties of nanosized Cu-Fe ferrite synthesized by the sol-gel autocombustion method," J. Nano Res., vol. 81, pp. 65–84, December 2023.

V International Conference **C**ondensed **M**atter & **L**ow **T**emperature **P**hysics 2025,
2 -6 June 2025, Kharkiv, Ukraine