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Dielectric properties and electrical conductivity of $FeGa_{0.8}In_{1.2}Se_4$ crystals on alternating current

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Dielectric permittivity and AC electrical conductivity of $FeGa_{0.8}In_{1.2}Se_4$ crystal were investigated over wide frequency and temperature ranges. It was determined that the real and imaginary parts of the dielectric permittivity exhibit significant dispersion of relaxation character. In the temperature range of 295–358 K and the frequency range of 2×10^4–10^6 Hz, the electrical conductivity follows a power-law dependence $\sigma(\omega) \propto \omega^s$ ($0.1 \leq s \leq 1.0$). The observed frequency and temperature dependences are consistent with a thermally activated hopping conduction mechanism. The activation energy of charge carriers in the $FeGa_{0.8}In_{1.2}Se_4$ crystal was determined from the temperature dependence on the electrical conductivity.

Keywords: crystal, dielectric permeability, electrical conductivity, scattering, frequency, temperature, hopping mechanism, activation energy.

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Introduction

In recent years, ternary chalcogenide compounds, which include elements that do not completely fill the d- and f- layers, belong to the class of multicomponent semiconductors and have been intensively studied because of their unusual physical properties and practical applications. Magnetic semiconductors with the general formula AB_2X_4 (A = Mn, Fe, Co, Ni; B = Ga, In; X = S, Se, Te), for which the physical processes are not yet comprehensively investigated, have attracted considerable attention owing to their potential to extend the functionality of new-generation optoelectronic [1–5], magnetic [4,5, 6–8], and photovoltaic devices [9–11]. Based on these connections, lasers, light modulators, photodetectors, thermoresistors, rectifiers, etc. it is promising to create functional devices. Changing the composition of these compounds via alloying and obtaining solid solutions based on them can be used to optimize their functional properties-such as magnetic [12–15], thermoelectric [16], and dielectric [17,18]. It should be noted that some compounds of the above type and heterojunctions based on them demonstrate high photocatalytic activity in water splitting [19–22], and wastewater treatment processes [23,24]. On the other hand, recent research has shown that some of these spinel structure compounds are good candidates for use as a new type of anode materials for stable ion storage in lithium (sodium) ion batteries [25–27].

The above shows that research in the field of these compounds and obtaining new phases based on them, and studying their properties is relevant. In the current work, the electrical properties of the $FeGa_{0.8}In_{1.2}Se_4$ crystal belonging to the mentioned class of compounds were studied in an alternating electric field.

I. Experimental

$FeGa_{0.8}In_{1.2}Se_4$ crystal was obtained from stoichiometric amount of high purity elements (99.99). The crystal was synthesized at a temperature of 1250 K and then homogenized at a temperature of 1000 K. Then the powder diffraction pattern of the synthesized alloy was recorded on a D2 Phaser diffractometer and analyzed in the TOPAS-4.2 program from Bruker. As a result of X-ray analysis, it was determined that $FeGa_{0.8}In_{1.2}Se_4$ crystallizes into trigonal syngonium (Sp. Gr. *R*-3*m*) with crystal lattice parameters *a* = 3.983 Å and *c* = 38.811 Å [28]. A typical diffractogram of the $FeGa_{0.8}In_{1.2}Se_4$ crystal at room temperature is shown in Fig. 1. To measure capacitance and resistance, capacitors were prepared by applying silver paste to $FeGa_{0.8}In_{1.2}Se_4$ crystal plates with a thickness of ~ 1 mm, and measurements were made using a digital impedance meter E7-20 (25 ÷ 10^6 Hz). The cryostat in which the crystals are placed is regulated in the temperature range of 293 ÷ 400K. The voltage applied to the samples is 1V.

The real part of the dielectric permittivity was calculated from the expressions $\varepsilon' = Cd/\varepsilon_0 S$, and the imaginary part $\varepsilon'' = tg\delta \cdot \varepsilon'$.

II. Results and discussion

Fig. 2a shows the graph of the frequency dependence of the real part of the dielectric permittivity (ε') for the $FeGa_{0.8}In_{1.2}Se_4$ crystal at a temperature of 295 K. It was determined that at frequencies of $2 \cdot 10^4 \div 10^6$ Hz, the value of ε' varies in the range of 23 ÷ 161 and significant dispersion occurs. At the studied temperature, ε' first decreases slowly as the frequency increases, and starting from the frequency of $2 \cdot 10^4$ Hz, ε' decreases more rapidly.

Fig. 2b shows the dependence of $FeGa_{0.8}In_{1.2}Se_4$ crystal temperature ε' on T at a frequency of 10^6 Hz. At temperatures of 295÷358 K, the value of ε′ varies between 23÷63. As the temperature rises, the increase in the value of ε′ is due to the increase in the concentration of defects [29, 30].

Fig. 3 shows the graph of dependence of the imaginary part of the dielectric permittivity (ε'') on the electric field frequency in the temperature range of 295 ÷ 358K for the $FeGa_{0.8}In_{1.2}Se_4$ crystal. At frequencies $2 \cdot 10^4 \div 10^6$ Hz, as the frequency increases, the dependence has the character of a monotonous decrease, as the frequency increases, ε'' undergoes significant dispersion. The monotonous decrease of ε'' observed in the experiment as a function of frequency indicates the occurrence of relaxation dispersion in the $FeGa_{0.8}In_{1.2}Se_4$

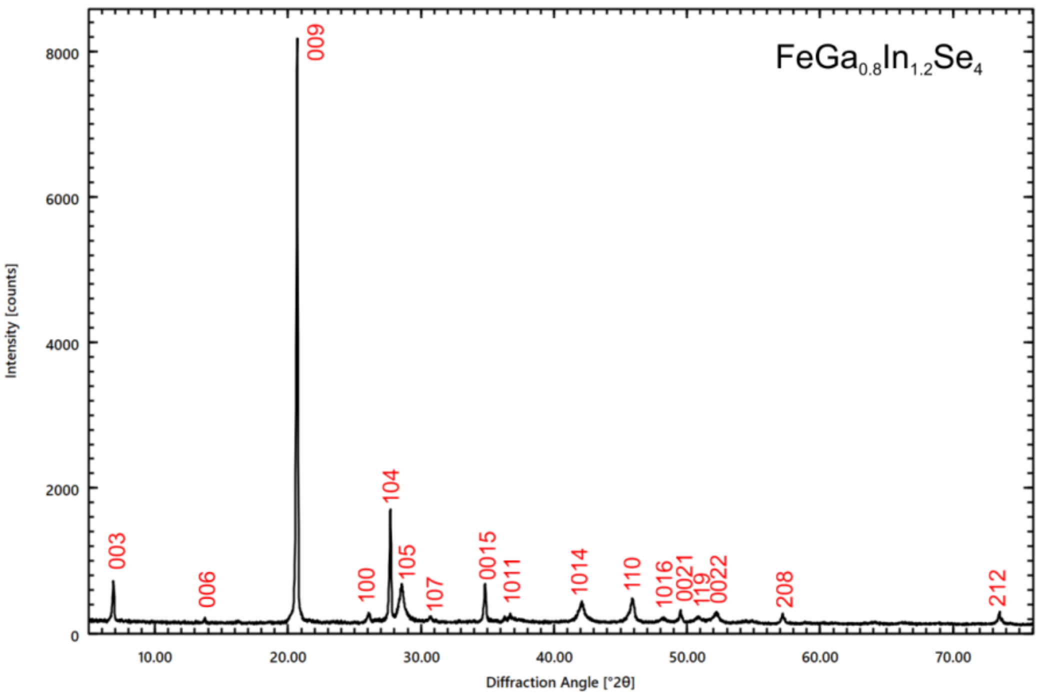

Fig. 1. X-ray diffraction pattern of a $FeGa_{0.8}In_{1.2}Se_4$ crystal at room temperature.

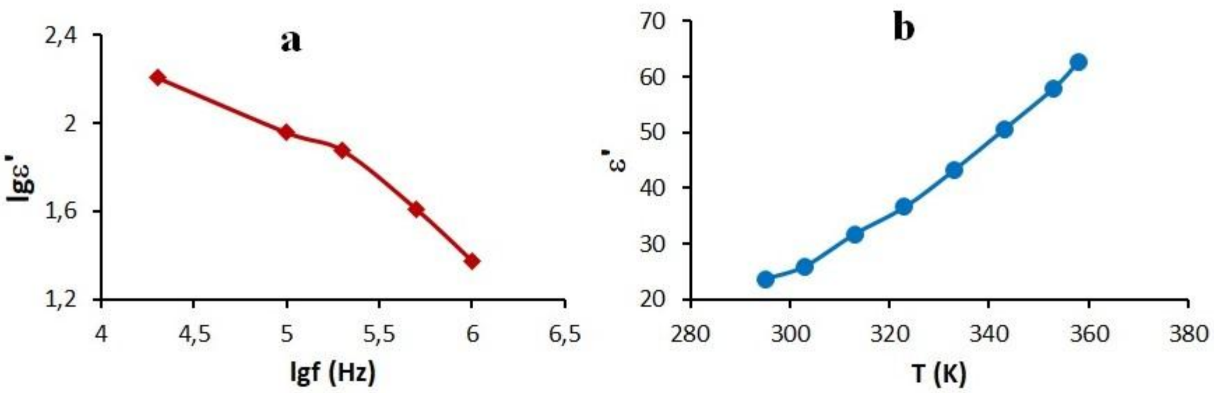

Fig. 2. Dependence of (a) lgε'~ lgf and (b) ε'~T (f = 10^6Hz) for $FeGa_{0.8}In_{1.2}Se_4$ crystal.

crystal [31].

The frequency and temperature dependences of the dielectric permittivity indicate that the dielectric response of $FeGa_{0.8}In_{1.2}Se_4$ crystals is governed by defect-related polarization mechanisms. Structural disorder and partial nonstoichiometry lead to the formation of localized states, which act as dipolar centers and give rise to dielectric relaxation. At low frequencies, the strong dispersion of the dielectric permittivity is associated with the inability of these dipoles to follow the rapidly alternating electric field.

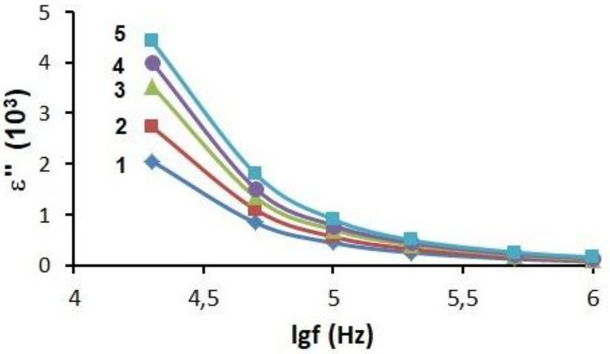

Fig. 3. Dependence of ε" ~ lgf of $FeGa_{0.8}In_{1.2}Se_4$ crystal at different temperatures. T, K:
1 – 295, 2 – 313, 3 – 333, 4 – 343, 5 – 358.

In addition to dipolar polarization, interfacial (Maxwell–Wagner) polarization contributes to the dielectric response due to electrical inhomogeneities within the crystal. Such polarization effects are typical for layered and disordered chalcogenide semiconductors and become more pronounced with increasing temperature.

Fig. 4 shows the graph of the dependence of the electric conductivity (σ) of the $FeGa_{0.8}In_{1.2}Se_4$ crystal on the electric field frequency (f) at different temperatures. It can be seen from the dependence of σ(f) that an increase of σ is observed in the studied frequency interval. For the $FeGa_{0.8}In_{1.2}Se_4$ crystal in the frequency range of $2\cdot10^4 \div 10^6$ Hz Hz

$$\sigma \sim f^S \quad (1)$$

the regularity shows itself. At temperatures of 295 ÷ 358 K and frequencies of $2\cdot10^4 \div 10^6$ Hz, the quantity S assumes values of 0.02 ÷ 0.38.

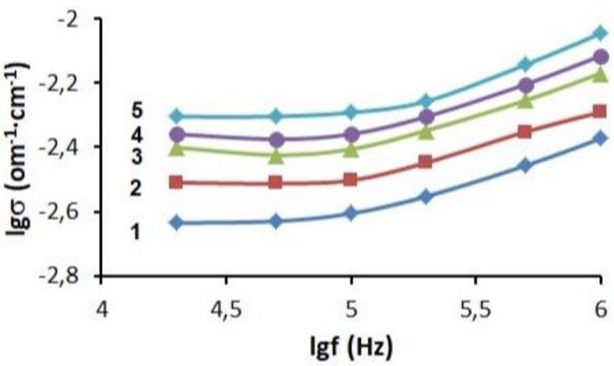

Fig. 4. Dependence of lgσ ~ lgf of $FeGa_{0.8}In_{1.2}Se_4$ crystal at different temperatures. T, K:
1 – 295, 2 – 313, 3 – 333, 4 – 343, 5 – 358.

The AC electrical conductivity of $FeGa_{0.8}In_{1.2}Se_4$ crystals follows a power-law dependence $\sigma(\omega) \propto \omega^s$, where the exponent *s* remains smaller than unity, indicating non-Drude-type charge transport. To further clarify the conduction mechanism, the temperature dependence of *s* was analyzed at a fixed frequency of $f = 10^5$ Hz, as shown in fig. 5.

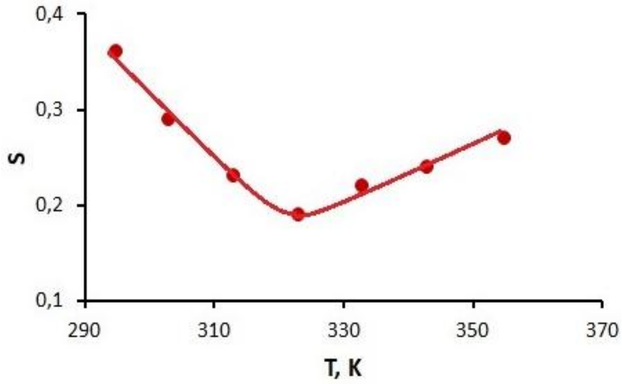

Fig. 5. Temperature dependence of the exponent s for $FeGa_{0.8}In_{1.2}Se_4$ crystal at 10^5 Hz.

As seen from the *s(T)* curve, the exponent *s* decreases with increasing temperature at lower temperatures, reaches a minimum around 320 K, and then increases at higher temperatures. This non-monotonic behavior cannot be explained by band-type conduction and is characteristic of thermally activated hopping of charge carriers between localized states. Such behavior is consistent with the Mott–Davis [32] and correlated barrier hopping (CBH) models [33-34].

The AC electrical conductivity of $FeGa_{0.8}In_{1.2}Se_4$ crystals follows a power-law dependence $\sigma(\omega) \propto \omega^s$ with $0.01 \leq s \leq 1.0$, which is characteristic of hopping-type charge transport in disordered semiconductors [32]. To further verify the hopping mechanism, the temperature dependence of ln(σ·T) was analyzed at a fixed frequency of $f = 10^6$ Hz.

As shown in Fig. 6, the dependence of ln(σ·T) on temperature exhibits linear behavior within a limited temperature interval, indicating thermally activated charge transport. This observation is consistent with theoretical models of hopping conduction in disordered systems, such as the Mott–Davis and correlated barrier hopping models.

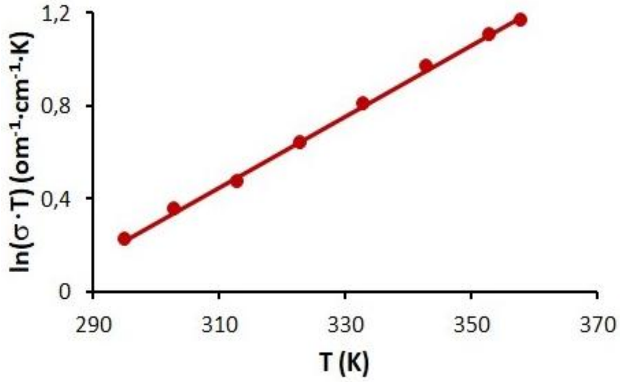

Fig. 6. ln(σ·T) ~ f(T) dependence for $FeGa_{0.8}In_{1.2}Se_4$ crystal ($f = 10^6$Hz).

The presence of structural disorder and defect-related localized states in $FeGa_{0.8}In_{1.2}Se_4$ crystals leads to charging carrier hopping between energetically near states. Therefore, Fig. 6 confirms that the hopping mechanism contributes to electrical conductivity in the studied temperature and frequency ranges.

It should be noted that AB_2X_4-type compounds exhibit properties characteristic of disordered and compensated semiconductors [35], for which hopping-type charge transport is typical [36–37]. Therefore, the observed frequency-dependent increase in the AC electrical conductivity of the $FeGa_{0.8}In_{1.2}Se_4$ crystal can be attributed to thermally activated hopping of charge carriers between localized states with close energies.

Charge transfer in the studied crystal is a thermally activated process, the temperature dependence of the specific conductivity for different frequencies follows the Arrhenius law:

$$\sigma = \sigma_0 e^{-\frac{\Delta E}{kT}}. \quad (4)$$

Here k is the Bolsman constant. Fig. 7 shows the graph of the temperature dependence of the electrical conductivity of the $FeGa_{0.8}In_{1.2}Se_4$ crystal at different frequencies of the alternating electric field. At the studied frequencies, the dependence of lgσ ~ $10^3/T$ consists of a straight line with the same trends. From these straight line dependences the activation energies were determined. At frequencies of $2 \cdot 10^4 \div 10^6$ Hz, the value of ΔE is ~ 0.11eV.

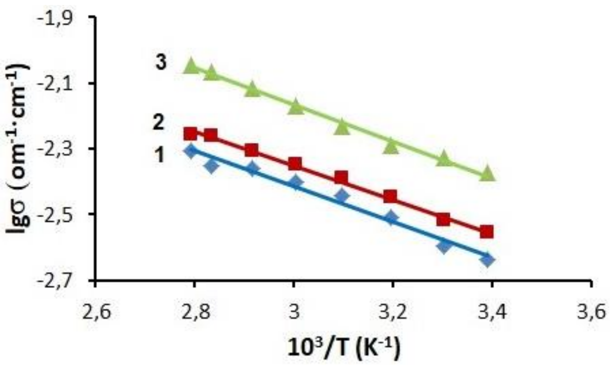

Fig. 7. Dependence on lgσ ~ $10^3/T$ of the $FeGa_{0.8}In_{1.2}Se_4$ crystal at different frequencies of the electric field. f, Hz: 1 – $2 \cdot 10^4$, 2 – $2 \cdot 10^5$, 3 – 10^6.

The temperature dependence of the AC electrical conductivity exhibits Arrhenius-type behavior only within a limited temperature range, where a linear dependence of lgσ on $10^3/T$ is observed. The extracted activation energy (~0.11 eV) is relatively small and therefore cannot be attributed to intrinsic band conduction. Instead, it is associated with thermally activated hopping of charge carriers between defect-related localized states near the Fermi level.

The Arrhenius approximation was applied exclusively in the temperature interval exhibiting linear behavior, and the uncertainty of the activation energy was estimated from the linear fitting procedure. This analysis indicates that charge transport in $FeGa_{0.8}In_{1.2}Se_4$ crystals is governed by defect-mediated hopping processes rather than intrinsic carrier excitation.

Conclusions

The real and imaginary parts of the dielectric permittivity and the AC electrical conductivity of $FeGa_{0.8}In_{1.2}Se_4$ crystals were investigated in the temperature range of 295–358 K and at frequencies from $2 \cdot 10^4$ to 10^6 Hz. An increase in the real part of the dielectric permittivity with temperature is observed, which is attributed to thermally activated polarization processes involving defect-related localized states. Both ε′ and ε″ exhibit relaxation-type dispersion within the studied frequency range, indicating the contribution of dipolar and interfacial (Maxwell–Wagner) polarization mechanisms.

The AC electrical conductivity follows a power-law dependence $\sigma(\omega) \propto \omega^s$ with $0.1 \le s \le 1.0$. The temperature dependence on the exponent s supports a thermally activated hopping conduction mechanism. This behavior is associated with charge carrier hopping between localized states formed by structural defects and disorder in the crystal lattice. The relatively low activation energies extracted from the temperature dependence of the conductivity further confirm that charge transport is dominated by hopping processes rather than intrinsic band conduction. The obtained results clarify the dielectric response and charge transport mechanisms in $FeGa_{0.8}In_{1.2}Se_4$ crystals within the investigated temperature and frequency ranges.

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[1] J. Gainza, O.N. Guinazu, E. Cespedes, H. Falcon, J.L. Martinez, J.A. Alonso. *Tunable inversion degree of $MnIn_2S_4$ thiospinels prepared by high-pressure synthesis, and its implication in the optical and magnetic properties*. Journal of Alloys and compounds. 969, 172413 (2023); https://doi.org/10.1016/j.jallcom.2023.172413.

[2] H. Kim, X. Liu, M. Kim, Y. Cho, J. J. Lee, T. A. Le, N. Q. Tran, A. Jadhav and H. Lee. *Layer-Dependent Band Structure of Ternary Metal Chalcogenides: Thickness-Controlled Hexagonal $FeIn_2S_4$,* Chemistry of Materials, 33(1), 164(2021); https://doi.org/10.1021/acs.chemmater.0c03146.

[3] N.N. Niftiyev. *Optical absorption of $MnGa_2S_4$ single crystals,* İntermetallics, 11(9), 975 (2003); https://doi.org/10.1016/S0966-9795(03)00051-7.

[4] Y. Shi, Y. Wang, L. Wu. *Hexagonal MIn_2S_4 (M = Mn, Fe, Co): Formation and Phase Transition*. Journal of Physical Chemistry C. 117(39), 20054 (2013); https://doi.org/10.1021/jp407067d.

[5] Z. D. Kovalyuk, V.A. Zaslonkin, V.M. Katerynchuk. *$FeIn_2Se_4$ layered magnetic semiconductor and heterojunction on its base,* Journal of Optoelectronics and Advanced Materials. 10(2), 277 (2008); https://www.semanticscholar.org/paper/d8be4d57a5ec638c6ec3041ce4338273b0db83f0.

[6] J. Yang, Z. Zhou, J. Fang, H. Wen, Z. Lou, G. Shen, Z. Wei. *Magnetic and transport properties of a ferromagnetic layered semiconductor $MnIn_2Se_4$*. Applied Physics Letters, 115 (22), 222101 (2019); https://doi.org/10.1063/1.5126233.

[7] B.R. Myoung, J. T. Lim, C.S. Kim. *Investigation of Magnetic Properties on Spin-ordering Effects of $FeGa_2S_4$ and $FeIn_2S_4$*. 438, Journals of Magnetism and Magnetic. Materials. 121 (2017); https://doi.org/10.1016/j.jmmm.2017.04.056.

[8] V. Sagredo, M. Morón, L. Betancourt, G. Delgado. *Antiferromagnetic versus spin-glass like behavior in $MnIn_2S_4$*. Journal of Magnetism and Magnetic Materials, 312(2), 294 (2007);https://doi.org/10.1016/j.jmmm.2006.10.609.

[9] Y. Hwang, J. Choi, Y. Ha, S. Cho, H. Park. *Electronic and optical properties of layered chalcogenide $FeIn_2Se_4$*. Current Appled Physics. 20(1), 212 (2020); https://doi.org/10.1016/j.cap.2019.11.005.

[10] W. Hou, Y. Xiao, G. Han. *An Interconnected Ternary MIn_2S_4 (M=Fe, Co, Ni) Thiospinel Nanosheet Array: A Type of Efficient Platinum-Free Counter Electrode for Dye-Sensitized Solar Cells*. Angewandte Chemie. 129(31), 9274 (2017); https://doi.org/10.1002/ange.201705399.

[11] K. Takubo,T. Mizokawa, Y. Nambu, S. Nakatsuji. *Electronic structure study of triangular lattices in $FeGa_2S_4$, $Fe_2Ga_2S_5$, and $NiGa_2S_4$: Photoemission spectroscopy and Hartree-Fock calculations*. Physical Review B, 79(13), 134422 (2009); https://doi.org/10.1103/PhysRevB.79.134422.

[12] A.V. Tarasov, T.P. Makarova, A.A. Estyunin, V.D. Eryzhenkov, I.I. Klimovskikh, V.A. Golyashov, K.A. Kokh, O.E. Tereshchenko, A.M. Shikin. *Topological Phase Transitions Driven by Sn Doping in $(Mn_{1-x}Snx)Bi_2Te_4$*, Symmetry, 15(2), 469(2023); https://doi.org/10.3390/sym15020469.

[13] H. Djieutedjeu, J.S. Lopez, R. Lu, B. Buchanan, X. Zhou, H. Chi, K.G.S. Ranmohotti, C. Uher, P.F.P Poudeu. *Charge Disproportionation Triggers Bipolar Doping in $FeSb_{2-x}Sn_xSe_4$ Ferromagnetic Semiconductors, Enabling a Temperature-Induced Lifshitz Transition*, Journal of the American Chemical Society, 141 (23), 9249 (2019); https://doi.org/10.1021/jacs.9b01884.

[14] I. Levy, C. Forrester, X. Ding, C. Testelin, L. Krusin-Elbaum, M.C. Tamargo. *High Curie temperature ferromagnetic structures of $(Sb_2Te_3)_{1-x}(MnSb_2Te_4)_x$ with $x = 0.7–0.8$*, Scientific Reports, 13, 781 (2023); https://doi.org/10.1038/s41598-023-34585-y.

[15] N.A. Moroz, J.S. Lopez, H. Djieutedjeu, K.G. S. Ranmohotti, A. Olvera, P. Ren, A. Page, N.J. Takas, C. Uher P.F.P. *Indium Preferential Distribution Enables Electronic Engineering of Magnetism in $FeSb_{2-x}In_xSe_4$ p‑Type High-Tc Ferromagnetic Semiconductors*, Chemistry of Materials, 28 (23), 8570 (2016); https://doi.org/10.1021/acs.chemmater.6b03293.

[16] Y. Liu, Ch. Kang, E. Stavitski, K. Attenkofer, G. Kotliar, C. Petrovic. *Polaronic transport and thermoelectricity in $Fe_{1-x}Co_xSb_2S_4$ (x = 0, 0.1, and 0.2),* Physical Review B, 97 (15), 155202 (2018); https://doi.org/10.1103/PhysRevB.97.155202.

[17] [S.H. Jabarov, A.K. Nabiyeva, E.M.Huseynov. *Dielectric and electrical properties of $La_{0.5}Ba_{0.5}MnO_3$ and $La_{0.97}Ba_{0.03}MnO3$ perovskites,* Journals Porous Mater, 31, 1811 (2024); https://doi.org/10.1007/s10934-024-01632-6.

[18] S. H. Jabarov, A. Kh. Nabiyeva, A. V. Trukhanov, S. V. Trukhanov, H. J. Huseynov, Y. I. Aliyev. *Dıelectrıc and electrıcal propertıes of the $La_{0.73}Ba_{0.27}MnO_3$ compound at hıgh temperatures*. SOCAR Proceedings, 4, 171 (2023); http://dx.doi.org/10.5510/OGP20230400931.

[19] C. Zeng, Y. Hu. *Hydrothermal synthesis of a $CoIn_2S_4$/g-C_3N_4 heterojunctional photocatalyst with enhanced photocatalytic H_2 evolution activity under visible light illumination*, Nanotechnology, 31 (50), 505711 (2020); https://doi.org/10.1088/1361-6528/abb72c.

[20] Y. Song, Y. Guo, S. Qi, K. Zhang, J. Yang, B. Li, J. Chen, Y. Zhao, Y. Lou. *Cu_7S_4/$MnIn_2S_4$ heterojunction for efficient photocatalytic hydrogen generation*, Journal of Alloys and Compounds, 884, 161035 (2021); https://doi.org/10.1016/j.jallcom.2021.161035.

[21] H. Liang T., Feng, S. Tan, K. Zhao, W. Wang, B. Dong, L.Cao. *Two-dimensional (2D) $MnIn_2Se_4$ nanosheets with porous structure: a novel photocatalyst for water splitting without sacrificial agents*, Chemical Communications, 55, 15061 (2019); https://doi.org/10.1039/C9CC08145C.

[22] A. Sharan, M. Sajjad, D.J. Singh, N. Singh. *Two-dimensional ternary chalcogenides FeX_2Y_4 (X = Ga, In; Y = S, Se, Te): Promising materials for sustainable energy*, Physical Review Materials, 6, 099405 (2022); https://doi.org/10.1103/PhysRevMaterials.6.094005.

[23] W. Chen., Z.-C.He, G.-B. Huang, C.-L. Wu, W.-F. Chen, X.-H. Liu. *Direct Z-scheme 2D/2D $MnIn_2S_4$/g-C_3N_4 architectures with highly efficient photocatalytic activities towards treatment of pharmaceutical wastewater and hydrogen evolution*, Chemical Engineering Journal, 359, 244 (2019); https://doi.org/10.1016/j.cej.2018.11.141.

[24] B. Zhang, Y. Liu, H. Zhu, D. Gu, K. Zhou, J, Hao. *Enhanced visible light photocatalytic performance of a novel $FeIn_2S_4$ microsphere/BiOBr nanoplate heterojunction with a Z-scheme configuration*, Environmental Science and Pollution Research, 30, 13438 (2023); https://doi.org/10.1007/s11356-022-22929-6.

[25] R. Muruganantham, J.-A. Chen, C.-C. Yang, *Spinel phase $MnIn_2S_4$ enfolded with reduced graphene oxide as composite anode material for lithium-ion storage,* Materials Today Sustainability, 21, 100278 (2023); https://doi.org/10.1016/j.mtsust.2022.100278.

[26] P. Wu, Ch. Huang, Ch. Hsieh, W. Liu. *Synthesis and characterization of $MnIn_2S_4$/single-walled carbon nanotube composites as an anode material for lithium-ion batteries*, Nanomaterials, 14(18), 716 (2024); https://doi.org/10.3390/nano14080716.

[27] D. Yan, K. Li, Y. Yan, S. Huang, Y. V. Lim, Y. Shang, D. Fang, L. K. Ang, H. Y. Yang. *Cubic Spinel XIn_2S_4 (X = Fe, Co, Mn): A New Type of Anode Material for Superfast and Ultrastable Na-Ion Storage*, Advanced Energy Materials, 11, 2102137 (2021); https://doi.org/10.1002/aenm.202102137.

[28] F. M.Mammadov, I.R. Amiraslanov, S.Z. Imamaliyeva, M.B. Babanly. *Phase Relations in the FeSe–$FeGa_2Se_4$–$FeIn_2Se_4$ System: Refinement of the Crystal Structures of $FeIn_2Se_4$ and $FeGaInSe_4$,* Journal of Phase Equilibria and Diffusion, 40(6), 787 (2019); https://doi.org/10.1007/s11669-019-00768-2.

[29] N.N. Niftiyev, F.M. Mammadov, A.O. Dachdemirov, M.B Muradov. *Frequency dispersion of dielectric coefficients of $MnGaInTe_4$ crystals. Semiconductor Physics*, Quantum Electronics and Optoelectronics. 27(2), 189 (2024); https://doi.org/10.15407/spqeo27.02.189.

[30] R. M. Sardarly, O.A. Samedov, A.P. Abdullaev, F.T. Salmanov. *Giant dielectric relaxation in $TlGaTe_2$ crystals*, Physics of the Solid State, 53, 1564 (2011); https://doi.org/10.1134/S1063783411080269.

[31] N.N. Niftiev, A.O. Dashdemirov, F.M. Mammdov, M.B. Muradov, *Dielectric Properties of Layered $MnGaInSe_4$ Single Crystals in an Alternating Electric Field*, Surface Engineering and Applied Electrochemistry 59(5), 644 (2023); https://doi.org/10.3103/S1068375523050137.

[32] N.F.Mott, E.A.Davis, Electronic Processes in Non-Crystalline Materials (OUP Oxford, 2012,590 p.); https://**books**.google.com/books/about/Electronic_Processes_in_Non_Crystalline.html?id=Pl1b_yhKH-YC

[33] S.R. Elliot. *Ac conduction in amorphous chalcogenide and pnictide semiconductors.* Adv. Phys., 36 (2), 135 (1987); https://doi.org/10.1080/00018738700101971.

[34] N.N. Niftiyev, F.M. Mammadov, R.M. Sardarli, F.T. Salmanov, N.I. Orujov, M.B. Babanly. *Dielectric properties of $FeGaInSe_4$ crystal in an alternating electric field.* Solid State Communications. 405, 116134 (2025); https://doi.org/10.1016/j.ssc.2025.116134.

[35] N.N. Niftiev, M.A. Alijanov, O.B. Tagiyev, M. B.Muradov. *Electrical properties of $FeIn_2S_4$*, Ukrainian Journal of Physics. 47(11), 69(2002); http://archive.ujp.bitp.kiev.ua/files/journals/47/11/47_11_09.pdf.

[36] H. Bettger, V.V. Bruksin, *Hopping Conductivity in Ordered and Disordered Systems (III*). Phus. stat. sol. (b), 113(1), 9 (1982); https://doi.org/10.1002/pssb.2221130102.

[37] B.I. Shklovskii A.L. Efros, *Electronic Properties of Doped Semiconductors*. Springer-Verlag, (1984); https://link.springer.com/book/10.1007/978-3-662-02403-4.

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Діелектричні властивості та електропровідність кристалів $FeGa_{0.8}In_{1.2}Se_4$ на змінному струмі

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Досліджено діелектричну проникність і електропровідність змінного струму кристала $FeGa_{0.8}In_{1.2}Se_4$ у широких діапазонах частот і температур. Встановлено, що дійсна та уявна частини діелектричної проникності демонструють значну дисперсію релаксаційного характеру. У температурному інтервалі 295–358 K та частотному діапазоні 2×10^4–10^6 Гц електропровідність підпорядковується степеневій залежності $\sigma(\omega) \propto \omega^s$ ($0.1 \le s \le 1.0$). Виявлені частотні та температурні залежності узгоджуються з термічно активованим стрибковим механізмом провідності. Енергію активації носіїв заряду в кристалі $FeGa_{0.8}In_{1.2}Se_4$ визначено з температурної залежності електропровідності.

Ключові слова: кристал, діелектрична проникність, електропровідність, розсіювання, частота, температура, стрибковий механізм, енергія активації.