

<https://doi.org/10.15407/ujpe71.11.909>

O.V. PYLYPENKO, O.S. TANCHENKO, I.U. VOLK,¹ I.M. PAZUKHA,
YU.O. SHKURDODA

Sumy State University
(116, Kharkivska Str., Sumy 40007, Ukraine)

INVESTIGATION OF ELECTRICAL CONDUCTIVITY AND MAGNETORESISTIVE PROPERTIES OF THIN-FILM SYSTEMS BASED ON $\text{Fe}_{20}\text{Ni}_{80}$ AND SiO

This work explores the electrical conductivity and magnetoresistive properties of as-deposited and annealed at 600 K $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ granular thin films and $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers. It is shown that the magnetoresistance behavior is governed by the type of thin-film sample, the heat treatment, and the composition of components. Isotropic magnetoresistance is exhibited by the as-deposited granular thin films with a magnetic component volume content of 20–70 vol.%, by the granular thin films annealed at 600 K with a magnetic component volume content of 20–40 vol.%, and by the discontinuous multilayers annealed at 600 K with an effective magnetic-layer thickness of 4–5 nm. It has been established that an exponential temperature dependence of the resistivity is observed in $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ granular thin films with a magnetic component volume content of only 20–30 vol.%. In contrast, for $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers, the transition regime of conductivity is already observed at $d = 3$ nm.

Keywords: granular thin films, discontinuous multilayers, co-evaporation, sequential condensation, magnetoresistance, regime of conductance.

1. Introduction

The investigation of magnetic materials is a topical issue owing to their application in the development of high-density data storage media [1], biomedical nanorobots [2], and ultra-sensitive sensors [3]. Their use enables a significant reduction in device size, together with improvements in performance and energy efficiency, which form the basis for the next

generation of electronics [4, 5]. Such materials include ferromagnetic nanocomposites based on ferromagnetic metal nanoparticles embedded in polymer or inorganic matrices. These structures attract interest because of their fundamental and applied significance. Of particular interest from the standpoint of practical applications is their electrical conductivity in a magnetic field [6, 7]. The technical parameters of functional elements based on such structures depend not only on the size, volume concentration, and shape of the magnetic granules, but also on their distribution within the conducting or insulating matrix [8, 9]. This explains the ongoing search for and refinement of technologies to produce such structures and their subsequent processing [10, 11]. In particular, the method of sequential vacuum evaporation

Citation: Pylypenko O.V., Tanchenko O.S., Volk Iu.Iu., Pazukha I.M., Shkurdoda Yu.O. Investigation of electrical conductivity and magnetoresistive properties of thin-film systems based on $\text{Fe}_{20}\text{Ni}_{80}$ and SiO . *Ukr. J. Phys.* **71**, No. 11, 909 (2026). <https://doi.org/10.15407/ujpe71.11.909>.

© Publisher PH “Akademperiodyka” of the NAS of Ukraine, 2026. This is an open access article under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>)

ISSN 2071-0194. *Ukr. J. Phys.* 2026. Vol. 71, No. 11

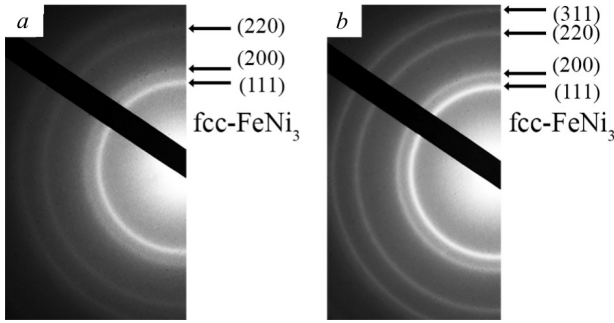


Fig. 1. Diffraction pattern for an $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ thin film annealed at 600 K with a volume content of magnetic material $x = 40$ vol.% (a) and $[\text{Fe}_{20}\text{Ni}_{80}(4)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers (b)

followed by heat treatment is used to prepare metal-insulator composite materials [12, 13]. This approach allows the production of composite materials with an amorphous insulating matrix free of ferromagnetic metal atoms and magnetic grains of nearly uniform size, whose dimensions can be tuned as required.

This work aims to conduct a comparative analysis of the electrotransport and magnetic properties of granular materials based on $\text{Fe}_{20}\text{Ni}_{80}$ and SiO prepared by electron-beam co-evaporation and sequential evaporation.

2. Experimental Details

Two series of samples were prepared to accomplish the tasks set. The first series was produced by electron-beam co-evaporation from two independent sources ($\text{Fe}_{20}\text{Ni}_{80}$ and SiO) in a high-vacuum chamber at a base pressure of 10^{-4} Pa. Deposition was carried out at room temperature, with glass-ceramic plates used as substrates. $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ thin films with a total thickness of 80 nm and with a magnetic component volume fraction (x) of 20–80 vol.% were obtained. The deposition rate was 0.1 nm/s for both $\text{Fe}_{20}\text{Ni}_{80}$ and SiO and was monitored using two independent quartz sensors. The second series was prepared by sequential electron-beam evaporation under identical vacuum conditions and deposition parameters, yielding $[\text{Ni}_{80}\text{Fe}_{20}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers with a magnetic-layer thickness d ranging from 4 to 8 nm. Samples of both series were subsequently annealed within the temperature range of 300–600 K in vacuum at 10^{-4} Pa.

An energy-dispersive spectrometer (EDS) attached to the SEO-SEM was used to determine the composition of the samples. The crystal structure of the samples was examined using a transmission electron microscope (TEM-125 K).

The magnetoresistive properties were measured using a hardware-software system in the current-in-plane geometry, in an external magnetic field ranging from 0 to 600 mT. All measurements were performed at room temperature. The measuring current was $I = 1$ mA. The longitudinal magnetoresistance (with the magnetic field in the sample plane and parallel to the current) and the transverse magnetoresistance (with the magnetic field in the sample plane and perpendicular to the current) were calculated using the equation

$$\text{MR} = \frac{R(B) - R(B_0)}{R(B_0)}, \quad (1)$$

where $R(B)$ is the current value of the resistance in the magnetic field B , and $R(B_0)$ is the resistance of the sample in the field B_0 .

3. Results and Discussion

The structural properties of $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ and $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ thin-film systems were studied first. After heat treatment, the crystal structure of both series of samples corresponds to fcc- FeNi_3 , irrespective of the sample composition. Fig. 1 shows a typical diffraction pattern for an $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ thin film with a magnetic material volume content of $x = 40$ vol.% annealed at 600 K, and for $[\text{Fe}_{20}\text{Ni}_{80}(4)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers.

Let us consider the features of the magnetoresistive effect in as-deposited and annealed (at 600 K) $(\text{Ni}_{80}\text{Fe}_{20} + \text{SiO})/\text{Sub}$ granular thin films (Fig. 2) and $[\text{Ni}_{80}\text{Fe}_{20}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers (Fig. 3). Fig. 2, a, c shows the field dependences of the magnetoresistance for the granular thin films. As shown, isotropic magnetoresistance is observed in all as-deposited samples with a total thickness of 80 nm and a magnetic component volume fraction of 20–70 vol.%. The coincidence of the field dependences in the longitudinal and transverse measurement geometries indicates that these thin films are isotropic granular systems [9, 14]. Spin-dependent tunneling is therefore realized in such thin films, giving rise to

tunnel magnetoresistance [15]. The field dependence of the magnetoresistance shows no tendency towards saturation in magnetic fields up to 0.5 T. The magnitude of the isotropic magnetoresistance is 0.04–0.1% at room temperature.

The behavior is markedly different for the as-deposited $[\text{Ni}_{80}\text{Fe}_{20}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers (Fig. 3, *a, c*). For all as-deposited samples prepared by sequential condensation, anisotropic magnetoresistance [16] is observed: the magnetoresistance is positive in the longitudinal measurement geometry and negative in the transverse one. This behavior is typical of a single-layer, structurally continuous $\text{Ni}_{80}\text{Fe}_{20}$ thin-film alloy [17, 18]. Evidently, infinite ferromagnetic clusters within a single layer are formed in such structures during the condensation process, even at an effective magnetic-layer thickness of 4 nm. As a result, these structures are electrically continuous. The formation of extended ferromagnetic clusters leads to the appearance of anisotropic magnetoresistance, which arises from the interaction of conduction electrons with outer-shell electrons whose spin moments induce spontaneous magnetization.

Let us now consider the effect of annealing on the field dependence and the magnitude of the magnetoresistance in granular thin films and discontinuous multilayers. It should be noted that, for the granular thin films, annealing at 600 K alters the character of the field dependences of the magnetoresistance only for films with $x = 50$ –70 vol.% (Fig. 2, *b*). After annealing, a transition to anisotropic magnetoresistance is observed. This behavior of the magnetoresistance can be explained by the growth of magnetic granules and the improvement of the crystal structure. As a result, the magnitude of the anisotropic magnetoresistance increases and becomes the governing contribution.

For the granular thin films with $x = 20$ –30 vol.%, annealing at 600 K does not alter the character of the field dependences of the magnetoresistance (Fig. 2, *d*). A slight increase in the longitudinal magnetoresistance and a more pronounced increase in the transverse magnetoresistance are observed.

For the $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers with $d = 4$ nm annealed at 600 K, a change in the character of the magnetoresistance is also observed (Fig. 3, *d*). As shown in Fig. 3, *d*, the field dependence of the magnetoresistance is isotropic

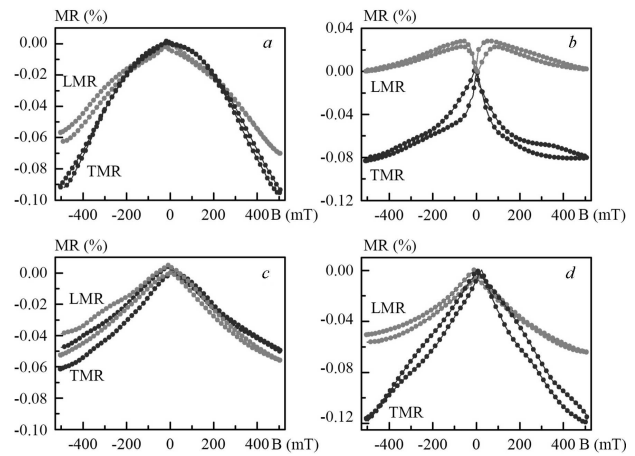


Fig. 2. Field dependences of LMR and TMR for as-deposited (*a, c*) and annealed at 600 K (*b, d*) $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ thin films with a total thickness of 80 nm with an $\text{Fe}_{20}\text{Ni}_{80}$ content of 70 vol.% (*a, b*) and 28 vol.% (*c, d*)

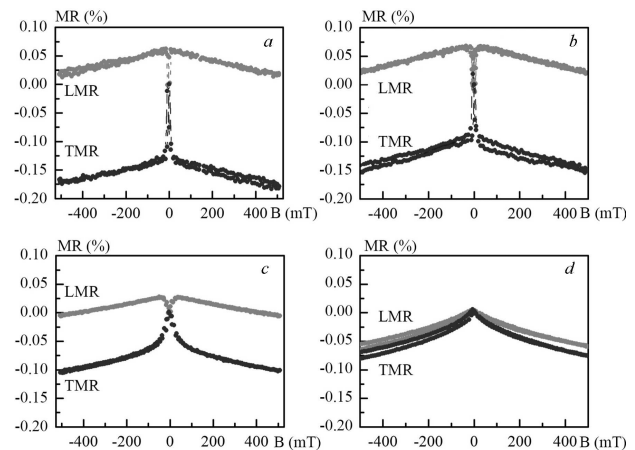


Fig. 3. Field dependences of LMR and TMR for as-deposited (*a, c*) and annealed at 600 K (*b, d*) $[\text{Fe}_{20}\text{Ni}_{80}(d) + \text{SiO}(5)]_5/\text{Sub}$ multilayer systems with an $\text{Fe}_{20}\text{Ni}_{80}$ layer thickness of $d = 8$ nm (*a, b*) and 4 nm (*c, d*)

in both the longitudinal and the transverse measurement geometries. Evidently, the reason for this change in the character of the field dependences in the case of the discontinuous multilayers is an increase in the mean grain size and a reduction in their density. This leads to the formation of magnetic granules separated by 1–2 nm-wide insulating channels. In such structures, the insulating layers retain their individuality and prevent direct ferromagnetic exchange between granules – both between adjacent metal lay-

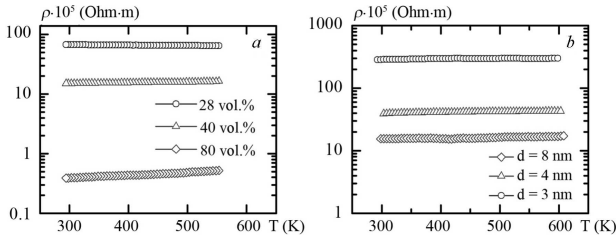


Fig. 4. Temperature dependences of the resistivity for $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ thin films with a total thickness of 80 nm (a) and $[\text{Fe}_{20}\text{Ni}_{80}(d) + \text{SiO}(5)]_5/\text{Sub}$ multilayer systems (b)

ers and within the same layer – while permitting inter-granular tunneling [19, 20].

For the $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers with $d = 8$ nm, annealing at 600 K results in no change in either the character of the magnetoresistance or its magnitude (Fig. 3, b).

To correctly interpret the conduction mechanisms in granular and layered films, a detailed analysis of the temperature dependence of the resistivity was performed. Fig. 4 shows the temperature dependence of the resistivity over the 300–600 K range for both series of samples. An exponential temperature dependence with a negative temperature coefficient of resistance (TCR) is observed for the $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ granular thin films with a magnetic component volume content of 20–30 vol.% (Fig. 4, a). Hence, the insulating regime of conductance is realized in such thin films. This regime of conductance can be attributed to thermally activated electron tunneling between metal granules separated by an insulating channel. This mechanism is characteristic of thin films with a metal-phase concentration below the percolation threshold [21, 22]. These results are in good agreement with the magnetoresistance study cited above.

For the discontinuous multilayers, an exponential temperature dependence is not observed even at an effective magnetic-layer thickness of 3 nm (Fig. 4, b). For the $[\text{Fe}_{20}\text{Ni}_{80}(3) + \text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers, the resistivity remains virtually unchanged up to 600 K, with a TCR close to zero. Evidently, at these layer thicknesses, an infinite metal cluster is formed, while a large number of isolated metal granules also remain. As a result, the transition regime of conductance is realized. As noted above, at this effective magnetic-layer thickness, isotropic magnetoresistance is observed. However, its magnitude is

half that of the granular thin films produced by co-evaporation. This suggests that, for the same composition of components, a greater number of small metal particles are formed in the granular thin films than in the discontinuous multilayers.

For all $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ thin films with a magnetic component volume content exceeding 30 vol.% and for all $[\text{Fe}_{20}\text{Ni}_{80}(d) + \text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers with $d > 3$ nm, typical metallic temperature dependences of the resistivity are observed. Hence, the electrical transport processes in such samples are governed by conduction through electrically continuous metal clusters and are determined by the scattering of conduction electrons at metal–insulator interfaces, grain boundaries, impurities, and phonons [23].

4. Conclusions

Based on the results of the investigation of the electrotransport and magnetoresistive properties of $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ granular thin films prepared by co-evaporation and $[\text{Fe}_{20}\text{Ni}_{80}(d) + \text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers prepared by sequential condensation, the following features can be highlighted. First, isotropic magnetoresistance is observed for the as-deposited $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ granular thin films over the wide range of magnetic component volume contents studied (20–70 vol.%). In contrast, for all as-deposited $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers with $d = 4$ –10 nm, only anisotropic magnetoresistance is observed. Second, a transition to anisotropic magnetoresistance occurs after annealing at 600 K in granular thin films with $x = 40$ –70 vol.%. The opposite trend is observed after annealing at 600 K in discontinuous multilayers with $d = 4$ –5 nm, indicating a transition to isotropic magnetoresistance. Third, an exponential temperature dependence of the resistivity with a negative TCR is observed for $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ granular thin films only at a magnetic component volume content of 20–30 vol.%. For $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ discontinuous multilayers, the resistivity increases only slightly with temperature up to 600 K (the TCR is close to zero), even at $d = 3$ nm. These features arise because, for the same composition of the $(\text{Ni}_{80}\text{Fe}_{20} + \text{SiO})/\text{Sub}$ and $[\text{Ni}_{80}\text{Fe}_{20}(d)/\text{SiO}(5)]_5/\text{Sub}$ samples, the granular thin films contain a greater number of small metal particles than the discontinuous multilayers.

This work was funded by the NATO Programme “Science for Peace and Security” (Project No. G6131) and by the Ministry of Education and Science of Ukraine (Projects Nos. 0224U033036 and 0126U000589).

1. B.J. Chen, M. Zeng, K.H. Khoo, D. Das, X. Fong, S. Fukami, S. Li, W. Zhao, S.S.P. Parkin, S.N. Piramanayagam, S.T. Lim. Spintronic devices for high-density memory and neuromorphic computing – A review. *Mater. Today* **70**, 193 (2023).
2. X. Deng, Y. Su, M. Xu, D. Gong, J. Cai, M. Akhter, K. Chen, S. Li, J. Pan, C. Gao, D. Li, W. Zhang, W. Xu. Magnetic micro/nanorobots for biological detection and targeted delivery. *Biosens. Bioelectron.* **222**, 114960 (2023).
3. N. Afonso, C. Lopes, G. Siqueira, M.A. Correa, A. Morais, J. Laranjeira, F. Vaz, M. Andritschky, A. Ferreira. The duality of thermal and magnetic properties of Ni-Ta thin films: A new generation of sensing devices. *Measurement* **246**, 116758 (2025).
4. Yuanwei Lin. Ultra-thin films in electronics and micro-electronics. *Reference Module in Materials Science and Materials Engineering*, 1 (2024).
5. Mengjuan Mi, Han Xiao, Lixuan Yu, Yingxu Zhang, Yuan-shuo Wang, Qiang Cao, Yilin Wang. Two-dimensional magnetic materials for spintronic devices. *Mater. Today Nano* **24**, 100408 (2023).
6. M. Nichterwitz, S. Honnali, J. Zehner, S. Schneider, D. Pohl, S. Schiemenz, S.T.B. Goennenwein, K. Nielsch, K. Leistner. Control of positive and negative magnetoresistance in iron oxide-iron nanocomposite thin films for tunable magnetoelectric nanodevices. *ACS Appl. Electron. Mater.* **2**, 2543 (2020).
7. Bao-Huei Huang, Yu-Hsiang Fu, Chao-Cheng Kaun, Yu-Hui Tang. Determining perpendicular magnetic anisotropy in Fe/MgO/Fe magnetic tunnel junction: A DFT-based spin-orbit torque method. *J. Magn. Magn. Mater.* **585**, 171098 (2023).
8. I.M. Pazukha, Yu.O. Shkurdoda. Crystal structure, phase state, and magnetoresistive properties of nanostructured thin-film systems based on permalloy and noble metals. *Prog. Phys. Met.* **23**, 613 (2022).
9. I.M. Pazukha, V.V. Shchotkin, Yu.O. Shkurdoda. Structure, magnetic and magnetoresistive properties of composite materials based on ferromagnetic metals and alloys with different types of dielectric matrix. *Prog. Phys. Met.* **20**, 672 (2019).
10. V.B. Tarelnyk, Ie.V. Konoplianchenko, O.P. Gaponova, N.V. Tarelnyk, V.S. Martsynkovskyy, B.O. Sarzhanov, O.A. Sarzhanov, B. Antoszewski. Effect of laser processing on the qualitative parameters of protective abrasion-resistant coatings. *Powder Metall. Met. Ceram.* **58**, 703 (2020).
11. J.B. Wang, L.S. Wang, H.Z. Guo, M. Lei, Q.F. Zhang, G.H. Yue, Y. Chen, D.L. Peng. Structural and magnetic properties of $\text{Fe}_{65}\text{Co}_{35}\text{@Ni}_{0.5}\text{Zn}_{0.5}\text{Fe}_2\text{O}_4$ composite thin films prepared by a novel nanocomposite technology. *J. Alloys Compd.* **608**, 323 (2014).
12. Xiaoli Li, Yanchun Li, Yana Shi, Fanfan Du, Yuhao Bai, Zhiyong Quan, Xiaohong Xu. Electrically-controlled resistance and magnetoresistance in a SiO_2 -Co film. *Mater. Lett.* **194**, 227 (2017).
13. J.C. Denardin, M. Knobel, L.S. Dorneles, L.F. Schelp. Structural, magnetic and transport properties of discontinuous granular multilayers. *J. Magn. Magn. Mater.* **294**, 206 (2005).
14. I. Shpetnyi, S. Vorobiov, V. Komanicky, I. Iatsunskyi, V. Grebinaha, Yu.I. Gorobets, V. Tkachenko, P. Skokowski, T. Luciński, S. Jurga. Thickness and composition dependences of magnetic and magnetoresistive properties of $\text{Co}_x\text{Ag}_{100-x}$ alloy thin films. *J. Magn. Magn. Mater.* **527**, 167762 (2021).
15. O. Vitayaya, P.Z.Z. Nehan, D.R. Munazat, M.T.E. Manawan, B. Kurniawan. Magnetoresistance (MR) properties of magnetic materials. *RSC Adv.* **14**, 18617 (2024).
16. P. Ritzinger, K. Výborný. Anisotropic magnetoresistance: materials, models and applications. *R. Soc. Open Sci.* **10**, 230564 (2023).
17. G.W. Huang, F.T. Yuan, P.H. Lin, K.Y. Wei, H.W. Chang. Enhancement of anisotropic magnetoresistance for NiFe films with IrMn capping layer. *Surf. Coat. Technol.* **525**, 133325 (2026).
18. Shuyun Wang, Tiejun Gao, Cuntao Wang, Jianfang He. Studies of anisotropic magnetoresistance and magnetic property of $\text{Ni}_{81}\text{Fe}_{19}$ ultra-thin films with the lower base vacuum. *J. Alloys Compd.* **554**, 405 (2013).
19. M.A.S. Boff, B. Canto, F. Mesquita, R. Hinrichs, G.L.F. Fraga, L.G. Pereira. Non-ohmic behavior of metal-insulator granular thin films in low-field regime ($eV \ll k_B T$). *J. Appl. Phys.* **120**, 155103 (2016).
20. Ping Sheng. Electronic transport in granular metal films. *Philos. Mag. B* **65**, 357 (1992).
21. E.B. Dokukin, R.V. Erhan, A.Kh. Islamov, M.E. Dokukin, N.S. Perov, E.A. Gan'shina. Formation of the magnetic fractal structure in Co- SiO_2 granular nanocomposite system at percolation threshold. *Phys. Status Solidi B* **250**, 1656 (2013).
22. A. García-García, A. Vovk, J.A. Pardo, P. Strichovanec, C. Magén, E. Snoeck, P.A. Algarabel, J.M. De Teresa, L. Morellón, M.R. Ibarra. Determination of the percolation threshold in Fe/MgO magnetic granular multilayers. *J. Phys.: Condens. Matter* **22**, 056003 (2010).
23. C.R. Tellier, A.J. Tosser. *Size Effects in Thin Films* (Elsevier, 1982) [ISBN: 978-0-444-42106-7].

Received 12.05.26

*О.В. Пилипенко, О.С. Танченко,
Ю.Ю. Волк, І.М. Пазуха, Ю.О. Шкурдода*

ДОСЛІДЖЕННЯ ЕЛЕКТРОПРОВІДНОСТІ
ТА МАГНІТОРЕЗИСТИВНИХ ВЛАСТИВОСТЕЙ
ПЛІВКОВИХ СИСТЕМ НА ОСНОВІ $\text{Fe}_{20}\text{Ni}_{80}$ ТА SiO

У роботі досліджено електропровідність і магніторезистивні властивості тонких гранульованих плівок $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ у вихідному стані та після відпалу за температури 600 К, а також дискретних багатошарових структур $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$. Показано, що поведінка магнітоопору визначається типом тонкоплівкового зразка, термічною обробкою та складом компонентів. Ізотропний магнітоопір спостерігається у гранульованих тонких плівках у вихідному стані з вмістом магнітного компо-

нента 20–70 об.%, у гранульованих тонких плівках, відпалених за температури 600 К, із вмістом магнітного компонента 20–40 об.%, а також у дискретних багатошарових структурах, відпалених за температури 600 К, з ефективною товщиною магнітного шару 4–5 нм. Встановлено, що експоненціальна температурна залежність питомого опору спостерігається у гранульованих тонких плівках $(\text{Fe}_{20}\text{Ni}_{80} + \text{SiO})/\text{Sub}$ лише за вмісту магнітного компонента 20–30 об.%. На відміну від них, для дискретних багатошарових структур $[\text{Fe}_{20}\text{Ni}_{80}(d)/\text{SiO}(5)]_5/\text{Sub}$ перехідний режим провідності спостерігається вже для $d = 3$ нм.

Ключові слова: гранульовані тонкі плівки, дискретні багатошарові структури, спільне випаровування, послідовна конденсація, магнітоопір, режим провідності.