

## Acknowledgements

The research work on the synthesis and investigation of electrophysical properties of memristor (capacitor-like) nanocomposite structures was supported by the International Project of the Ministry of Education and Science of the Russian Federation (MES RF) (No. RFMEFI58717X0042); the research work on the synthesis and investigation of electrophysical properties of nanocomposite films was supported by the MES RF in terms of the state task (Project No. 3.1876.2017/PCh).

The investigations of magnetic properties of nanocomposite films and structures were supported by the Russian Science Foundation (Grant No. 16-19-10233).

## References

- [1] I.S. Beloborodov, A.V. Lopatin, V.M. Vinokur, K.B. Efetov, Rev. Mod. Phys. 79 (2007) 469.
- [2] S. Bedanta, T. Eimuller, W. Kleemann, J. Rhensius, F. Stromberg, E. Amaladass, S. Cardoso, P. Freitas, Phys. Rev. Lett. 98 (2007) 176601.
- [3] A.A. Timopheev, I. Bdikin, A.F. Lozenko, O.V. Stognei, A.V. Sitnikov, A.V. Los, N.A. Sobolev, J. Appl. Phys. 111 (2012) 123915.
- [4] O.G. Udalov, I.S. Beloborodov, Phys. Rev. B 95 (2017) 045427; O.G. Udalov, I.S. Beloborodov, J. Phys. Condens. Matter 29 (2017) 155801.
- [5] V.V. Rylkov, A.V. Sitnikov, S.N. Nikolaev, V.A. Demin, A.N. Taldenkov, M.Yu. Presnyakov, A. V. Emelyanov, A.L. Vasiliev, Yu.E. Kalinin, A.S. Bugaev, V.V. Tugushev, A.B. Granovsky, J. Magn. Magn. Mater. (2017). <https://doi.org/10.1016/j.jmmm.2017.11.022>.
- [6] K.B. Efetov, A. Tschersich, Phys. Rev. B 67 (2003) 174205.
- [7] V.V. Rylkov, S.N. Nikolaev, K.Y. Chernoglazov, V.A. Demin, A.V. Sitnikov, M.Y. Presnyakov, A. L. Vasiliev, N.S. Perov, A.S. Vedeneev, Y.E. Kalinin, V.V. Tugushev, A.B. Granovsky, Phys. Rev. B 95 (2017) 144202.
- [8] X. Li, Y. Shi, J. Li, Y. Bai, J. Jia, Y. Li, X. Xu, Mater. Res. Express 4 (2017) 036407.
- [9] V.V. Rylkov, S.N. Nikolaev, V.A. Demin, A.V. Emelyanov, A.V. Sitnikov, K.E. Nikiruy, V.A. Levanov, M. Yu. Presnyakov, A.N. Taldenkov, A.L. Vasiliev, K.Yu. Chernoglazov, A.S. Vedeneev, Yu.E. Kalinin, A. B. Granovsky, V.V. Tugushev, A.S. Bugaev, J. Exp. Theor. Phys. 126 (2018) 353.
- [10] A.V. Vedyayev, N.V. Ryzhanova, N. Strelkov, B. Dieny, Phys. Rev. Lett. 110 (2013) 247204.
- [11] Y.E. Kalinin, A.N. Remizov, A.V. Sitnikov, Phys. Solid State, 46 (2004) 2146; S.A. Gridnev, Y.E. Kalinin, A. V. Sitnikov, O.V. Stogniy, Nonlinear Effects in Nano-and Microheterogeneous Systems, BINOM, Moscow, 2012 [in Russian].
- [12] W.C. Ellis, E.S. Greiner, Equilibrium relations in the solid state of the iron-cobalt system, Trans. Am. Soc. Met. 29 (1941) 415.
- [13] T. Yamasaki, S. Kanatani, Y. Ogino, T. Masumoto, M. Doyama, K. Kiribayashi, T. Kisi, Structure of Fe-Cr-X (X=N, C and B) powdered alloys prepared by mechanical milling, in: Advanced Materials '93: Computations, Glassy Materials, Microgravity and Nondestructive Methods, Elsevier, Amsterdam, 1994, , pp. 93–96.
- [14] L.B. Gurvich, G.B. Karachevtsev, V.N. Kondrat'ev, Y.A. Lebedev, V.A. Medvedev, V.K. Potapov, Y. S. Khodeev, Energy of Chemical Bond Rupture, Ionization Potentials and Electron Affinity, Nauka, Moscow, 1974 (in Russian).
- [15] B.I. Shklovskii, A.L. Efros, Electronic Properties of Doped Semiconductors, Springer-Verlag, New York, 1984.
- [16] A.L. Efros, Physics and Geometry of Disorder: Percolation Theory (Science for Everyone), Mir Publishers, Moscow, 1986; I. Fizika, Geometriia Besporiadka, Nauka, Moscow, 1982. Russian version available at [http://www.math.ru/lib/files/pdf/kvant\\_19.pdf](http://www.math.ru/lib/files/pdf/kvant_19.pdf).
- [17] R. Karplus, J.M. Luttinger, Phys. Rev. 95 (1954) 1154.
- [18] N. Nagaosa, J. Sinova, S. Onoda, A.H. MacDonald, N.P. Ong, Rev. Mod. Phys. 82 (2010) 1539.
- [19] Y. Tian, L. Ye, X. Jin, Phys. Rev. Lett. 103 (2009) 087206.

- [20] V.V. Rylkov, B.A. Aronzon, A.S. Lagutin, V.V. Podol'skii, V. P. Lesnikov, M. Goiran, J. Galibert, B. Raquet, J. Léotin, *J. Exp. Theor. Phys.* 108 (2009) 149.
- [21] H. Meier, M.Y. Kharitonov, K.B. Efetov, *Phys. Rev. B* 80 (2009) 045122.
- [22] D. Chiba, A. Werbachowska, M. Endo, Y. Nishitani, F. Matsukura, T. Dietl, H. Ohno, *Phys. Rev. Lett.* 104 (2010) 106601.
- [23] X. Liu, S. Shen, Z. Ge, W.L. Lim, M. Dobrowolska, J.K. Furdyna, *Phys. Rev. B* 83 (2011) 144421.
- [24] X.-J. Liu, X. Liu, J. Sinova, *Phys. Rev. B* 84 (2011) 165304.
- [25] A. Shitade, N. Nagaosa, *J. Phys. Soc. Jpn.* 81 (2012) 083704.
- [26] A.V. Vedyayev, M.S. Titova, N.V. Ryzhanova, M.Y. Zhuravlev, E.Y. Tsymbal, *Appl. Phys. Lett.* 103 (2013) 032406.
- [27] Y.O. Mikhailovsky, D.E. Mettus, A.P. Kazakov, V.N. Prudnikov, Y.E. Kalinin, A. S. Sitnikov, A. Gerber, D. Bartov, A.B. Granovsky, *JETP Lett.* 97 (2013) 473.
- [28] D. Bartov, A. Segal, M. Karpovski, A. Gerber, *Phys. Rev. B* 90 (2014) 144423.
- [29] S.A. Meynell, M.N. Wilson, J.C. Loudon, A. Spitzig, F.N. Rybakov, M.B. Johnson, T.L. Monchesky, *Phys. Rev. B* 90 (2014) 224419.
- [30] D. Hou, G. Su, Y. Tian, X. Jin, S.A. Yang, Q. Niu, *Phys. Rev. Lett.* 114 (2015) 217203.
- [31] L.N. Oveshnikov, V.A. Kulbachinskii, A.B. Davydov, B.A. Aronzon, I.V. Rozhansky, N.S. Averkiev, K. I. Kugel, V. Tripathi, *Sci. Rep.* 5 (2015) 17158.
- [32] A. Matos-Abiague, J. Fabian, *Phys. Rev. Lett.* 115 (2015) 056602.
- [33] T. Huong Dang, H. Jaffres, T.L. Hoai Nguyen, H.-J. Drouhin, *Phys. Rev. B* 92 (2015) 060403.
- [34] G. Kopnov, A. Gerber, *Appl. Phys. Lett.* 109 (2016) 022404.
- [35] S. Onoda, N. Sugimoto, N. Nagaosa, *Phys. Rev. Lett.* 97 (2006) 126602; S. Onoda, N. Sugimoto, N. Nagaosa, *Phys. Rev. B* 77 (2008) 165103.
- [36] A.V. Vedyayev, A.B. Granovskii, O.A. Kotelnikova, *Transport Phenomena in Disordered Ferromagnetic Alloys*, Moscow State Univ., Moscow, 1992 (in Russian).
- [37] A.V. Vedyayev, A.B. Granovsky, A.V. Kalitsov, F. Brouers, *J. Exp. Theor. Phys.* 85 (1997) 1204.
- [38] A. Pakhomov, X. Yan, B. Zhao, *Appl. Phys. Lett.* 67 (1995) 3497.
- [39] B.A. Aronzon, D.Y. Kovalev, A.N. Lagarkov, E.Z. Meilikhov, V.V. Rylkov, M. A. Sedova, N. Negre, M. Goiran, J. Leotin, *JETP Lett.* 70 (1999) 90.
- [40] J.V. Kasiuk, J.A. Fedotova, J. Przewoznik, J. Zukrowski, M. Sikora, C. Kapusta, A. Grce, M. Milosavljevic, *J. Appl. Phys.* 116 (2014) 044301.
- [41] C. Kittel, *Introduction to Solid State Physics*, fourth ed., John Wiley & Sons Inc., New York, 1971
- [42] I. Isenberg, B.R. Russell, R.F. Greene, *Rev. Sci. Instrum.* 19 (1948) 685.
- [43] J. Volger, *Phys. Rev.* 79 (1950) 1023.
- [44] T. Fukumura, H. Toyosaki, K. Ueno, M. Nakano, T. Yamasaki, M. Kawasaki, *Jpn. J. Appl. Phys.* 46 (2007) L642.
- [45] S. Bedanta, W. Kleemann, *J. Phys. D. Appl. Phys.* 42 (2009) 013001.
- [46] Ed. by D. Ielmini and R. Waser, *Resistive Switching: From Fundamentals of Nanoionic Redox Processes to Memristive Device Applications*, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2016.
- [47] M. Prezioso, F. Merrikh-Bayat, B.D. Hoskins, G.C. Adam, K.K. Likharev, D.B. Strukov, *Nature* 521 (2015) 61.
- [48] M. Prezioso, F.M. Bayat, B. Hoskins, K. Likharev, D. Strukov, *Sci. Rep.* 6 (2016) 21331, <https://doi.org/10.1038/srep21331>.
- [49] A.V. Emelyanov, D.A. Lapkin, V.A. Demin, et al., *AIP Adv.* 6 (2016) 111301.
- [50] C.-C. Hsieh, A. Roy, Y.-F. Chang, D. Shahrjerdi, S.K. Banerjee, *Appl. Phys. Lett.* 109 (2016) 223501.
- [51] S.D. Ha, S. Ramanathan, *Adaptive oxide electronics: a review*, *J. Appl. Phys.* 110 (2011) 071101.
- [52] J.J. Yang, D.B. Strukov, D.R. Stewart, *Memristive devices for computing*, *Nat. Nanotechnol.* 8 (2013) 13.
- [53] J.S. Lee, S. Lee, T.W. Noh, *Resistive switching phenomena: a review of statistical physics approaches*, *Appl. Phys. Rev.* 2 (2015) 031303.
- [54] D. Ielmini, *Resistive switching memories based on metal oxides: mechanisms, reliability and scaling*, *Semicond. Sci. Technol.* 31 (2016) 063002.

- [55] A. Wedig, M. Luebben, D.-Y. Cho, M. Moors, K. Skaja, V. Rana, T. Hasegawa, K. Adeppalli, B. Yildiz, R. Waser, I. Valov, *Nat. Nanotechnol.* 11 (2016) 67.
- [56] D. Xu, X.N. Shangguan, S.M. Wang, H.T. Cao, L.Y. Liang, H.L. Zhang, J.H. Gao, W.M. Long, J. R. Wang, F. Zhuge, *AIP Adv.* 7 (2017) 025102.
- [57] A.V. Shaposhnikov, T.V. Perevalov, V.A. Gritsenko, C.H. Cheng, A. Chin, *Appl. Phys. Lett.* 100 (2012) 243506.
- [58] D.-H. Kwon, K.M. Kim, J.H. Jang, J.M. Jeon, M.H. Lee, G.H. Kim, X.-S. Li, G.-S. Park, B. Lee, S. Han, M. Kim, C.S. Hwang, *Nat. Nanotechnol.* 5 (2010) 148.
- [59] Y. Yang, P. Gao, S. Gaba, T. Chang, X. Pan, W. Lu, *Nat. Commun.* 3 (2012) 732, <https://doi.org/10.1038/ncomms1737>.
- [60] J.-Y. Chen, C.-W. Huang, C.-H. Chiu, Y.-T. Huang, W.-W. Wu, *Adv. Mater.* 27 (2015) 5028.
- [61] M.K. Yang, H. Ju, G.-H. Kim, J.-K. Lee, H.-C. Ryu, *Sci. Rep.* 5 (2015) 14053, <https://doi.org/10.1038/srep14053>.
- [62] X. Pan, Y. Shuai, C. Wu, W. Luo, X. Sun, H. Zeng, S. Zhou, R. Bottger, X. Ou, T. Mikolajick, W. Zhang, H. Schmidt, *Appl. Phys. Lett.* 108 (2016) 032904.
- [63] S.E. Savel'ev, F. Marchesoni, A.M. Bratkovsky, *Eur. Phys. J. B.* 86 (2013) 501.
- [64] S. Tang, F. Tesler, F.G. Marlasca, P. Levy, V. Dobrosavljevic, M. Rozenberg, *Phys. Rev. X* 6 (2016) 011028.
- [65] B. Huděc, A. Paskaleva, P. Jančovič, J. Dérer, J. Fedor, A. Rosová, E. Dobročka, K. Fröhlich, *Thin Solid Films* 563 (2014) 10.
- [66] L. Alekseeva, T. Nabatame, T. Chikyow, A. Petrov, *Jpn. J. Appl. Phys.* 55 (2016) 08PB02.
- [67] Y.V. Khrapovitskaya, N.E. Maslova, Y.V. Grishchenko, V.A. Demin, M.L. Zanaveskin, *Tech. Phys. Lett.* 40 (2014) 317; A.V. Emel'yanov, V.A. Demin, I.M. Antropov, G.I. Tselikov, Z.V. Lavrukhina, P. K. Kashkarov, *Tech. Phys.* 60 (2015) 112.
- [68] D.I. Aladashvili, Z.A. Adamiya, K.G. Lavdovski, E.I. Levin, B.I. Shklovskii, *Sov. Phys. Semicond.* 23 (1989) 132.
- [69] M. Pollak, J.J. Hauser, *Phys. Rev. Lett.* 31 (1973) 1304. M.E. Raikh, I.M. Rusin, *Sov. Phys. JETP Lett.* 43 (1986) 562.
- [70] O.G. Udalov, N.M. Chtchelkatchev, A. Glatz, I.S. Beloborodov, *Phys. Rev. B* 89 (2014) 054203.
- [71] L.V. Lutsev, T.K. Zvonareva, V.M. Lebedev, *Tech. Phys. Lett.* 27 (2001) 659.
- [72] L.V. Lutsev, Y.E. Kalinin, A.V. Sitnikov, O.V. Stognei, *Phys. Solid State* 44 (2002).