

ABSTRACT AND REFERENCES

APPLIED PHYSICS

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REFINED CALCULATION OF INDUCTION MOTOR EQUIVALENT CIRCUIT NONLINEAR PARAMETERS BY AN ENERGY METHOD (p. 4-10)

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The topicality of the research aim is caused by the analysis of the processes of energy conversion taking into account the induction motor particular nonlinearities that reveal the physical properties and phenomena in structural materials under the action of electrical and electromagnetic impacts. Taking into consideration the nonlinearities of the induction motor equivalent circuit influences the accuracy of determination of the electric machine operating characteristics. Most conventional methods for parameter identification do not enable assessment of the induction motor nonlinear characteristics and properties.

It is proposed to use resistive impedance and inductance dependences on the rotor current to take into account the rotor nonlinear parameters. To form identification equations, the instantaneous power components for the rotor nonlinear resistive impedance and nonlinear inductance have been obtained. The solution of the identification equations resulted in determination of the equivalent circuit electromagnetic parameters taking into account the rotor nonlinear parameters and the amplitudes of the harmonics of the current cosine and sine components of the rotor and magnetization circuit. The results of identification of the induction motor equivalent circuit parameters taking into account the rotor nonlinear parameters have been obtained with sufficient accuracy. This is confirmed by a low error of determination of the electromagnetic parameters. The adequacy of the identified parameters is determined by comparison of the stator current experimental and calculated curves.

Keywords: induction motor, energy method, equivalent circuit, nonlinear electromagnetic parameters.

References

- Voldek, A. I., Popov, V. V. (2010). *Electrical Machines. Machines of alternating current*. Sankt-Peterburg, 356.
- Voliansky, R., Sadovoy, A. (2015). Synthesis of active compensation system of spring oscillation in two-mass electromechanical object. *Eastern-European Journal of Enterprise Technologies*, 4 (7 (76)), 21–26. doi: 10.15587/1729-4061.2015.47178
- Maga, D., Zagirnyak, M., Miljavec, D. (2010). Additional losses in permanent magnet brushless machines. *Proceedings of 14th International Power Electronics and Motion Control Conference EPE-PEMC 2010*. doi: 10.1109/epepmc.2010.5606520
- Zagirnyak, M., Romashykhina, Z., Kalinov, A. (2016). Diagnostic signs of induction motor broken rotor bars in electromotive force signal. *2016 17th International Conference Computational Problems of Electrical Engineering (CPEE)*. doi: 10.1109/cpee.2016.7738722
- Hasegawa, M., Ogawa, D., Matsui, K. (2008). Parameter Identification Scheme for Induction Motors Using Output Inter-Sampling Approach. *Asian Power Electronics Journal*, 2 (1), 15–22.
- Rodkin, D. I., Romashihin, Y. V. (2012). Rationale for settlement circuit for induction motors. *Technical Electrodynamics*, 2, 89–90.
- Park, J., Kim, B., Yang, J., Lee, S. B., Wiedenbrug, E. J., Teska, M., Han, S. (2010). Evaluation of the detectability of broken rotor bars for double squirrel cage rotor induction motors. *2010 IEEE Energy Conversion Congress and Exposition*. doi: 10.1109/ecce.2010.5617950
- Benecke, M., Doebbelin, R., Griepentrog, G., Lindemann, A. (2011). Skin effect in squirrel cage rotor bars and its consideration in simulation of non-steady-state operation of induction machines. *Piers online*, 7 (5), 421–425.
- Popenda, A. (2012). Model-simulation investigations of induction motor with the consideration of skin effect in rotor bars. *Przegląd elektrotechniczny*, 88 (12), 29–31.
- Lee, S.-H., Yoo, A., Lee, H.-J., Yoon, Y.-D., Han, B.-M. (2017). Identification of Induction Motor Parameters at Standstill Based on Integral Calculation. *IEEE Transactions on Industry Applications*, 53 (3), 2130–2139. doi: 10.1109/tia.2017.2650141
- Zagirnyak, M., Kalinov, A., Romashykhina, Zh. (2016). Decomposition of electromotive force signal of stator winding in induction motor at diagnostics of the rotor broken bars. *Scientific Bulletin of National Mining University*, 4 (154), 54–61.
- Emara, H. M., Elshamy, W., Bahgat, A. (2008). Parameter identification of induction motor using modified Particle Swarm Optimization algorithm. *2008 IEEE International Symposium on Industrial Electronics*. doi: 10.1109/isie.2008.4677254
- Karanayil, B., Rahman, M. F., Grantham, C. (2009). Identification of Induction Motor Parameters in Industrial Drives with Artificial Neural Networks. *Advances in Fuzzy Systems*, 2009, 1–10. doi: 10.1155/2009/241809
- Mosyundz, D. (2012). Energy method of nonlinear inductance parameters identification. *XIV International PhD Workshop, OWD*, 456–460.

15. Zagirnyak, M., Rodkin, D., Romashykhin, I., Rudenko, N., Chenchovoi, V. (2016). Identification of nonlinearities of induction motor equivalent circuits with the use of the instantaneous power method. 2016 17th International Conference Computational Problems of Electrical Engineering (CPEE). doi: 10.1109/cpee.2016.7738721
16. Shimoni, K. (2013). Theoretical electrical engineering. Moscow: Ripol Klassik, 778.
17. Akagi, H., Watanabe, M. (2007). Instantaneous Power Theory and Applications to Power Conditioning. New York: Wiley, 379.

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METHOD FOR THE EROSION RATE MEASUREMENTS OF STATIONARY PLASMA THRUSTER INSULATORS

(p. 11-17)

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Despite the fact that for many years the stationary plasma thruster (SPT) has been used in space, this technology has not yet been fully studied. One of the research directions to improve SPT characteristics is the increase of thruster lifetime. This can be achieved with the research of the discharge chamber (DCh) walls erosion rate as a function of different thruster operational modes.

The analysis of the SPT DCh wear rate diagnostics methods was carried out. It is shown that the considered methods cannot provide measurements of the insulators erosion rate separately during the experiment.

The method of optical emission spectroscopy with plasma scanning through collimator (OESSC) was developed. The method allows registration of radiation separately for each of SPT DCh walls directly during the experiment. According to this, the experimental time of different SPT operational regimes research was reduced by 98 %.

Experimental equipment of the OESSC method was developed, produced and tested. It consists of the high-resolution spectral block with the range of 240...820 nm and the optical detector positioning system.

A set of experiments were provided with the OESSC method. As a result, the inner and outer insulators erosion rates are researched as functions of thruster operational regimes. It is shown that for the outer and inner coils currents of 5 and 6 A, respectively, there is a uniform wear of DCh walls. For such SPT operational regime, the difference in the insulators specific relative erosion rates is 2 %.

The results of the OESSC method measurements allowed increasing the anode block lifetime significantly.

Keywords: stationary plasma thruster, optical emission spectroscopy, discharge chamber, relative erosion rate.

References

1. Dyshlyuk, E. N. (2007). Izmerenie skorosti ehrozii keramicheskoi razryadnoi kamery uskoritelya s zamknutym dreyfom ehlektronov beskontaktnym metodom v hode dlitel'nyh resursnyh ispytaniy. Issledovano v Rossii, 1760–1769.

2. Burton, T., Schinder, A. M., Capuano, G., Rimoli, J. J., Walker, M. L. R., Thompson, G. B. (2014). Plasma-Induced Erosion on Ceramic Wall Structures in Hall-Effect Thrusters. *Journal of Propulsion and Power*, 30 (3), 690–695. doi: 10.2514/1.b34882
3. Fukushima, Y. (2007). Evaluation method of hall thruster's lifetime by using multilayer coating. *Transactions of JWRI*, 36 (1), 113–114.
4. Haustova, A. N. (2016). Vliyanie magnitnogo polya SPD-70 na otноситel'nyu ehroziiyu vnutrennej i naruzhnoj keramicheskikh vstavok po otdel'nosti. *Aviacionno-kosmicheskaya tekhnika i tekhnologiya*, 8 (135), 72–75.
5. Yalin, H., Jian, C., Wei, M., Yan, S., Jun, C. (2013). Lifetime assessment of Hall thruster. Presented at the 33rd International Electric Propulsion Conference. The George Washington University, Washington, D.C., USA.
6. Gorshkov, O. A., Dyshlyuk, E. N. (2008). Issledovanie primesej v plazmennoj strue uskoritelya s zamknutym dreyfom ehlektronov. *Pis'ma v ZHTE*, 34 (8), 77–84.
7. Haustova, A. N. (2015). Razrabotka spektral'nogo kompleksa vysokogo razresheniya dlya issledovaniya spektra stacionarnogo plazmennogo dvigatelya. *Aviacionno-kosmicheskaya tekhnika i tekhnologiya*, 9 (126), 113–118.
8. Pagnon, D., Balika, L., Pellerin, S. (2009). QCM and OES: two ways used to study simultaneously HET thruster chamber ceramic erosion. First QCM results on PPS100-ML validate previous OES measurements. 31st International Electric Propulsion Conference. Ann Arbor, MI.
9. Dannenmayer, K., Mazouffre, S., Merino-Martinez, M., Ahedo, E. (2012). Hall Effect Thruster Plasma Plume Characterization with Probe Measurements and Self-Similar Fluid Models. 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit. doi: 10.2514/6.2012-4117
10. Eagle, W., Boyd, I., Trepp, S., Sedwick, R. (2008). The Erosion Prediction Impact on Current Hall Thruster Model Development. 44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit. doi: 10.2514/6.2008-5087
11. Haustova, A. N., Loyan, A. V., Rybalov, O. P. (2015). Razrabotka spektral'nogo kompleksa vysokogo razresheniya dlya issledovaniya spektra stacionarnogo plazmennogo dvigatelya. *Vestnik dvigatel'stroeniya*, 2, 29–36.
12. Kim, V. P. (2014). Konstruktivnye priznaki i osobennosti rabochih processov v sovremennykh stacionarnykh plazmennyykh dvigatelyakh Morozova. *Zhurnal tekhnicheskoy fiziki*, 3, 45–59.

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RESEARCH INTO RESOURCE-SAVING MOLYBDENUM-CONTAINING ALLOYING ADDITIVE, OBTAINED BY THE METALLIZATION OF OXIDE CONCENTRATE (p. 18-23)

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We established that the phase composition of oxide molybdenum concentrate is represented mainly by MoO₃, as well as MoO₂, WO₃, Mo₂C and associated ore impurities of Al₂O₃, CaO, SiO₂ and MgO. We found non-uniform microstructure in the form of plates, granules of round shape, and thread-like formations. It was determined that phase composition of metallized molybdenum concentrate, obtained by carbon-thermal technique, is mostly composed of metal Mo with the presence of MoC and Mo₂C. Unrestored component is represented by the oxy-carbide compound (Mo, O, C) and the lower molybdenum oxide MoO₂. We noted fragmented presence of Mo₈O₂₃. Spongy microstructure revealed areas where the molybdenum oxide restoration products dominate. The presence of residual oxygen confirms the existence, along with metal Mo, of unrestored oxide or oxy-carbide compounds. The residual oxygen could also be contained in the oxide compounds of Si, Al, Ca, Mg, K, Na as associated ore impurities. This is confirmed by discovery of the specified elements in the examined areas. The detected phases and compounds do not display significant susceptibility to sublimation. High restorative ability, due to the excess of carbon in the form of carbides, provides the post-restoration of oxide component in the liquid metal in the process of alloying, as well as protection against secondary oxidation.

Keywords: molybdenum concentrate, carbon-thermal restoration, metallization, sublimation, phase analysis, microstructure, resource saving.

References

- Puttkammer, K., P. Fornkal' (2017). Kompleksnoe planirovanie proizvodstva – uchet ehnergo- i resursoehfektivnosti. *Chernye metally*, 2, 56–60.
- Yuzov, O. V., Sedyh, A. M. (2017). Tendencii razvitiya mirovogo rynka stali. *Stal'*, 2, 60–67.
- Orlov, V. M., Kolosov, V. N. (2016). Magnesiothermic reduction of tungsten and molybdenum oxide compounds. *Doklady Chemistry*, 468 (1), 162–166. doi: 10.1134/s0012500816050062
- Tarasov, A. V. (2011). Mineral'noe syr'e, novye tekhnologii i razvitie proizvodstva tugoplavkikh redkikh metallov v Rossii i stranah SNG. *Cvetnye metally*, 6, 57–66.
- Leont'ev, L. I., Grigorovich, K. V., Kostina, M. V. (2016). The development of new metallurgical materials and technologies. Part 1. *Steel in Translation*, 46 (1), 6–15. doi: 10.3103/s096709121601006x
- Dang, J., Zhang, G.-H., Chou, K.-C., Reddy, R. G., He, Y., Sun, Y. (2013). Kinetics and mechanism of hydrogen reduction of MoO₃ to MoO₂. *International Journal of Refractory Metals and Hard Materials*, 41, 216–223. doi: 10.1016/j.ijrmhm.2013.04.002
- Wang, L., Zhang, G.-H., Chou, K.-C. (2016). Synthesis of nanocrystalline molybdenum powder by hydrogen reduction of industrial grade MoO₃. *International Journal of Refractory Metals and Hard Materials*, 59, 100–104. doi: 10.1016/j.ijrmhm.2016.06.001
- Badenikov, A. V., Badenikov, V. Ya., Bal'chugov, A. V. (2015). Kinetika plazmennogo vosstanovleniya trekhokisi molibdena. *Vestnik Angarskogo gosudarstvennogo tekhnicheskogo universiteta*, 9, 8–10.

- Grigor'ev, S. M., Petrishchev, A. S. (2015). Refining metallized molybdenum concentrate by means of a low-temperature plasma-forming mixture. *Steel in Translation*, 45 (12), 954–958. doi: 10.3103/s0967091215120049
- Zhu, H., Li, Z., Yang, H., Luo, L. (2013). Carbothermic Reduction of MoO₃ for Direct Alloying Process. *Journal of Iron and Steel Research, International*, 20 (10), 51–56. doi: 10.1016/s1006-706x(13)60176-4
- Torabi, O., Golabgir, M. H., Tajzadegan, H., Torabi, H. (2014). A study on mechanochemical behavior of MoO₃-Mg-C to synthesize molybdenum carbide. *International Journal of Refractory Metals and Hard Materials*, 47, 18–24. doi: 10.1016/j.ijrmhm.2014.06.001
- Novoselova, L. Y. (2014). Mo and MoO₃ powders: Structure and resistance to CO. *Journal of Alloys and Compounds*, 615, 784–791. doi: 10.1016/j.jallcom.2014.07.006
- Long, T. V., Palacios, J., Sanches, M., Miki, T., Sasaki, Y., Hino, M. (2012). Recovery of Molybdenum from Copper Slags. *ISIJ International*, 52 (7), 1211–1216. doi: 10.2355/isijinternational.52.1211
- Long, T. V., Miki, T., Sasaki, Y., Hino, M. (2012). Recovery of Molybdenum from Spent Lubricant. *ISIJ International*, 52 (7), 1217–1224. doi: 10.2355/isijinternational.52.1217
- Ryabchikov, I. V., Belov, B. F., Mizin, V. G. (2014). Reactions of metal oxides with carbon. *Steel in Translation*, 44 (5), 368–373. doi: 10.3103/s0967091214050118
- Grigor'ev, S. M., Kolobov, G. A., Karpunina, M. S., Grigor'ev, D. S. (2005). Osobennosti legirovaniya stali 38HNM molibdenom metalizovannogo koncentrata. *Metallurgiya*, 11, 24–30.

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INVESTIGATION OF PROPERTIES OF ELECTROCONDUCTING NANOZONES IN MATERIALS OF VARIOUS NATURE BY THE ELECTRON PARAMAGNETIC RESONANCE METHOD (p. 24-30)

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This work studied properties of conductive nanozones in dependence on the material nature by the method of electron paramagnetic resonance. Delocalization of charge carriers and strong exchange interactions between paramagnetic centers take place in annealed biominerals, like in polyaniline in a form of emeraldine salt. Since biominerals, unlike polyaniline, can be subjected to a high-temperature anneal, this extends potentials of the EPR method in solving issues associated with the properties of conductive zones in nano-sized polyaniline. It was shown that the EPR signals in the materials under consideration are conditioned by the electrical charge carriers and variations of electrical properties result in variation of the EPR signal characteristics. Consequently, information on the mechanisms of the EPR signal induction in one group of specimens can be used

for interpretation of the signal nature and elucidation of properties of local conductive zones in other materials.

It was ascertained that the characteristics of electron paramagnetic resonance of conductive nanozones in biominerals and the textile materials containing nanoparticles of polyaniline are similar. This feature is due to the similarity of paramagnetic charge carriers localized in nano-sized conductive zones of biominerals and organic polymers. Interconnected electron paramagnetic resonance studies of conductive zones in various materials can promote a more successful application of electron paramagnetic resonance in developing nanotechnologies for creation of conductive textile materials containing nanoparticles, especially nanoparticles of polyaniline with a high level of oxidation.

Keywords: nanoparticles, polyaniline, biomineral, enamel, bones, textile material, electron paramagnetic resonance, conductive nanozones.

References

- Betekhtin, A. G. (2007). Kurs mineralogii. Moscow: KDU, 720.
- Bauerlein, E. (Ed.) (2007). Handbook of Biomineralization: Biological Aspects and Structure Formation. WILEY-VCH Verlag GmbH & Co. KGaA, 440. doi: 10.1002/9783527619443
- Stejskal, J., Prokes, J., Trchova, M. (2008). Reprotonation of polyaniline: A route to various conducting polymer materials. *Reactive and Functional Polymers*, 68 (9), 1355–1361. doi: 10.1016/j.reactfunct-polym.2008.06.012
- Blinova, N. V., Stejskal, J., Trchova, M., Sapurina, I., Ciric-Marjanovic, G. (2009). The oxidation of aniline with silver nitrate to polyaniline–silver composites. *Polymer*, 50 (1), 50–56. doi: 10.1016/j.polymer.2008.10.040
- Brik, A. B., Radchuk, V. V. (2009). Structure and properties of biominerals localized in human organism. *Heokhimiya ta rudoutvorennya*, 27, 63–66.
- Soni, A., Mishra, D. R., Polymeris, G. S., Bhatt, B. C., Kulkarni, M. S. (2014). OSL and thermally assisted OSL response in dental enamel for its possible application in retrospective dosimetry. *Radiation and Environmental Biophysics*, 53 (4), 763–774. doi: 10.1007/s00411-014-0554-5
- Weil, J. A., Bolton, J. R. (2006). Electron paramagnetic resonance: elementary theory and practical applications. John Wiley & Sons, Inc., Hoboken, New Jersey, 688.
- Red'ko, Ya. V., Romankevich, O. V., Shekhunova, S. B. (2011). Vzaimosvyaz' usloviy sinteza nanodispersnogo polianilina s elektroprovodnost'yu voloknistogo materiala. *Problemy legkoy i tekstil'noy promyshlennosti Ukrainy*, 1, 69–73.
- Red'ko, Ya. V., Yushchishina, A. N., Romankevich, O. V. (2016). Elektroprovodyashchie volknistyie materialy so sloevoy strukturoy. *Elektronnaya obrabotka materialov*, 52 (6), 103–108.
- Abdallah, M.-N., Eimar, H., Bassett, D. C., Schnabel, M., Ciobanu, O., Nelea, V. et. al. (2016). Diagenesis-inspired reaction of magnesium ions with surface enamel mineral modifies properties of human teeth. *Acta Biomaterialia*, 37, 174–183. doi: 10.1016/j.actbio.2016.04.005
- Karray, F., Kassiba, A. (2012). EPR investigations of silicon carbide nanoparticles functionalized by acid doped polyaniline. *Physica B: Condensed Matter*, 407 (12), 2119–2125. doi: 10.1016/j.physb.2012.02.018
- Krinichnyi, V. I., Konkin, A. L., Monkman, A. P. (2012). Electron paramagnetic resonance study of spin centers related to charge transport in metallic polyaniline. *Synthetic Metals*, 162 (13-14), 1147–1155. doi: 10.1016/j.synthmet.2012.04.030
- Bykov, I. P., Brik, A. B., Glinchuk, M. D., Bezv, V. V., Kalinichenko, E. A., Konstantinova, T. E., Danilenko, I. A. (2008). Zmneneniya EPR-harakteristik nanorazmernih chastic dioksida cirkoniya pri rentgenovskom obluchenii i otzhige v atmosfere vodoroda. *Fizika tverdogo tela*, 50 (12), 91–99.
- Gizdavic-Nikolaidis, M. R., Jevremovic, M. M., Allison, M. C., Stanisavljev, D. R., Bowmaker, G. A., Zujovic, Z. D. (2014). Self-assembly of nanostructures obtained in a microwave-assisted oxidative polymerization of aniline. *Express Polymer Letters*, 8 (10), 745–755. doi: 10.3144/expresspolymlett.2014.77
- Poklonskiy, N. A., Gusakov, G. A., Baev, V. G., Lapchuk, N. M. (2009). Opticheskie i paramagnitnye svoystva obluchennyh ehlektronami i otozhzhennyh kristallov sinteticheskogo almaza. *Fizika i tekhnika poluprovodnikov*, 43 (5), 595–603.

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RESULTS OF APPROBATION OF THE INNOVATIVE METHOD OF ION NITRIDING FOR STEELS WITH LOW TEMPERATURES OF TEMPERING (p. 31-36)

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The innovation technique of complex treatment for steels with the low temperature of tempering is proposed and tested in the course of present study. It includes nitriding in the vacuum gas discharge before hardening and tempering. In this case, during nitriding, the heating temperature influences little the process of high-temperature treatment. In this case, the process of diffusion of nitrogen atoms is accelerated considerably (since nitrogen atoms penetrate untempered steel more easily), which leads to an increase to 2000 μm in the depth of penetration of nitrogen atoms and in

the thickness of the formed region with changed structure and hardness. It was established that, according to the properties, the region of exposure is divided into a surface layer (with a thickness of about 200 μm) with lowered hardness and the deeper operating layer with enhanced hardness. Layer with the greatest hardness is at depth of 400–800 μm . In this case, enhanced hardness, in comparison with the base, is maintained at depth that exceeds 2000 μm . The surface layer with low hardness makes it possible to implement the allowance for finishing, in order to obtain the required accuracy of dimensions and surface finish. Hardness of the surface of articles after this sequence of operations for the steels with low temperature of tempering is at the level of 8–10 GPa. The phase composition of the nitrided layer with high hardness, detected by the X-ray diffraction method, is the lowest nitride Fe₄N and the solution of nitrogen in α -Fe.

Keywords: ionic nitriding, complex treatment, diffusion, depth of impact, diffraction spectra.

References

- Ducros, C., Sanchette, F. (2006). Multilayered and nanolayered hard nitride thin films deposited by cathodic arc evaporation. Part 2: Mechanical properties and cutting performances. *Surface and Coatings Technology*, 201 (3-4), 1045–1052. doi: 10.1016/j.surfcoat.2006.01.029
- Pogrebnyak, A. D., Yakushchenko, I. V., Abadias, G., Chartier, P., Bondar, O. V., Beresnev, V. M. et. al. (2013). The effect of the deposition parameters of nitrides of high-entropy alloys (TiZrHfVNB)N on their structure, composition, mechanical and tribological properties. *Journal of Superhard Materials*, 35 (6), 356–368. doi: 10.3103/s106345761306004x
- Morton, B. D., Wang, H., Fleming, R. A., Zou, M. (2011). Nanoscale Surface Engineering with Deformation-Resistant Core–Shell Nanostructures. *Tribology Letters*, 42 (1), 51–58. doi: 10.1007/s11249-011-9747-0
- Sobol', O. V. (2011). Control of the structure and stress state of thin films and coatings in the process of their preparation by ion-plasma methods. *Physics of the Solid State*, 53 (7), 1464–1473. doi: 10.1134/s1063783411070274
- Sun, Y., Bloyce, A., Bell, T. (1995). Finite element analysis of plastic deformation of various TiN coating/ substrate systems under normal contact with a rigid sphere. *Thin Solid Films*, 271 (1-2), 122–131. doi: 10.1016/0040-6090(95)06942-9
- Sobol', O. V., Andreev, A. A., Stolbovoi, V. A., Fil'chikov, V. E. (2012). Structural-phase and stressed state of vacuum-arc-deposited nanostructural Mo-N coatings controlled by substrate bias during deposition. *Technical Physics Letters*, 38 (2), 168–171. doi: 10.1134/s1063785012020307
- Sobol', O. V. (2016). The influence of nonstoichiometry on elastic characteristics of metastable β -WC_{1-x} phase in ion plasma condensates. *Technical Physics Letters*, 42 (9), 909–911. doi: 10.1134/s1063785016090108
- Sobol', O. V. (2016). Structural Engineering Vacuum-plasma Coatings Interstitial Phases. *Journal of Nano- and Electronic Physics*, 8 (2), 02024-1–02024-7. doi: 10.21272/jnep.8(2).02024
- Ivashchenko, V. I., Dub, S. N., Scrynskii, P. L., Pogrebnyak, A. D., Sobol', O. V., Tolmacheva, G. N. et. al. (2016). Nb–Al–N thin films: Structural transition from nanocrystalline solid solution nc-(Nb,Al)N into nanocomposite nc-(Nb, Al)N/a–AlN. *Journal of Superhard Materials*, 38 (2), 103–113. doi: 10.3103/s1063457616020040
- Barmin, A. E., Sobol', O. V., Zubkov, A. I., Mal'tseva, L. A. (2015). Modifying effect of tungsten on vacuum condensates of iron. *The Physics of Metals and Metallography*, 116 (7), 706–710. doi: 10.1134/s0031918x15070017
- Rissel, H., Ruge, I. (1975). *Ionnaya implantaciya*. Moscow: Energiya, 97.
- Pastuh, I. M. (2006). *Teoriya i praktika bezvodородnogo azotirovaniya v tleyushchem razryade*. Kharkiv: NNC HFTI, 364.
- Gerasimov, S. A., Gress, M. A., Lapteva, V. G., Muhin, G. G., Bayazitova, V. V. (2008). Soprotivlenie iznashivaniyu gazobaricheskikh azotirovannykh sloev na stali 12H18N10T. *Metallovedenie i termicheskaya obrabotka metallov*, 2, 34–37.
- Lahtin, Yu. M., Kogan, Ya. D., Shpis, G. I., Bemmer, Z. (1991). *Teoriya i tekhnologiya azotirovaniya*. Moscow: Metallurgiya, 320.
- Zinchenko, V. M., Syropyatov, V. Ya., Prusakov, B. A., Perekatov, Yu. A. (2003). Azotnyy potencial: sovremennoe sostoyanie problemy i koncepciya razvitiya. Moscow: FGUP «Izdatel'stvo «Mashinostroenie», 90.
- Andreev, A. A., Sablev, L. P., Grigor'ev, S. N. (2010). *Vakuumno-dugovye pokrytiya*. Kharkiv: NNC HFTI, 317.
- Torchane, L., Bilger, P., Dulcy, J., Gantois, M. (1996). Control of iron nitride layers growth kinetics in the binary Fe-N system. *Metallurgical and Materials Transactions A*, 27 (7), 1823–1835. doi: 10.1007/bf02651932
- Pinedo, C. E., Monteiro, W. A. (2004). On the kinetics of plasma nitriding a martensitic stainless steel type AISI 420. *Surface and Coatings Technology*, 179 (2-3), 119–123. doi: 10.1016/s0257-8972(03)00853-3
- Wei, C. C. (2012). Analyses of Material Properties of Nitrided AISI M2 Steel Treated by Plasma Immersion Ion Implantation (PIII) Process. *Advanced Science Letters*, 12 (1), 148–154. doi: 10.1166/193666112800850833
- Manova, D., Hirsch, D., Richter, E., Mandl, S., Neumann, H., Rauschenbach, B. (2007). Microstructure of nitrogen implanted stainless steel after wear experiment. *Surface and Coatings Technology*, 201 (19-20), 8329–8333. doi: 10.1016/j.surfcoat.2006.10.060
- Campos, M., de Souza, S. D., de Souza, S., Olzon-Dionysio, M. (2011). Improving the empirical model for plasma nitrided AISI 316L corrosion resistance based on Mossbauer spectroscopy. *Hyperfine Interactions*, 203 (1-3), 105–112. doi: 10.1007/s10751-011-0351-3
- Ozturk, O., Williamson, D. L. (1995). Phase and composition depth distribution analyses of low energy, high flux N implanted stainless steel. *Journal of Applied Physics*, 77 (8), 3839–3850. doi: 10.1063/1.358561
- Fernandes, B. B., Mandl, S., Oliveira, R. M., Ueda, M. (2014). Mechanical properties of nitrogen-rich surface layers on SS304 treated by plasma immersion ion implantation. *Applied Surface Science*, 310, 278–283. doi: 10.1016/j.apsusc.2014.04.142
- Koster, K., Kaestner, P., Brauer, G., Hoche, H., Troßmann, T., Oechsner, M. (2013). Material condition tailored to plasma nitriding process for ensuring corrosion and wear resistance of austenitic stainless steel. *Surface and Coatings Technology*, 228, S615–S618. doi: 10.1016/j.surfcoat.2011.10.059
- Maistro, G., Perez-Garcia, S. A., Norell, M., Nyborg, L., Cao, Y. (2016). Thermal decomposition of N-expanded austenite in 304L and 904L steels. *Surface Engineering*, 33 (4), 319–326. doi: 10.1080/02670844.2016.1262989
- Williamson, D. L., Ozturk, O., Wei, R., Wilbur, P.J. (1994). Metastable phase formation and enhanced diffusion in f.c.c. alloys under high

dose, high flux nitrogen implantation at high and low ion energies. *Surface and Coatings Technology*, 65 (1-3), 15–23. doi: 10.1016/S0257-8972(94)80003-0

27. Yang, S., Cooke, K., Sun, H., Li, X., Lin, K., Dong, H. (2013). Development of advanced duplex surface systems by combining CrAlN multilayer coatings with plasma nitrided steel substrates. *Surface and Coatings Technology*, 236, 2–7. doi: 10.1016/j.surfcoat.2013.07.017
28. Grigor'ev, S. N., Metel', A. S., Fedorov, S. V. (2012). Modifikaciya struktury i svoystv bystrorezhushchih staley putem kombinirovannoy vakuumno-plazmennoy obrabotki. *Metallovedenie i termicheskaya obrabotka*, 1, 9–14.
29. Bogachev, I. I., Klimov, V. N. (2016). Razrabotka tekhnologii glubokogo ionno-plazmennogo azotirovaniya. *Nauchnaya diskussiya: voprosy tekhnicheskikh nauk*, 33 (3), 53.
30. Sobol', O. V., Shovkoplyas, O. A. (2013). On advantages of X-ray schemes with orthogonal diffraction vectors for studying the structural state of ion-plasma coatings. *Technical Physics Letters*, 39 (6), 536–539. doi: 10.1134/s1063785013060126

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RESEARCH INTO REGULARITIES OF PORE FORMATION ON THE SURFACE OF SEMICONDUCTORS (p. 37-44)

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A general procedure is devised to control the process of formation of porous layers on semiconductor surfaces by the method of electrochemical etching. When controlling the process of pore formation on the surface of crystal, it is necessary to consider: conditions of pore formation, requirements that are put forward to quality of the obtained nanostructures, and mechanisms that underlie the process of pore formation. It is shown that the built scheme could be used for different cases of the synthesis of nanostructured semiconductors. We investigated the processes

that underlie pore formation and define morphological properties of nanostructures. A thermodynamic analysis of processes at the boundary of contact «semiconductor – electrolyte» was performed. We examined a relative drop in potential in the Helmholtz layer, which is an important characteristic of the process of pore formation on the surface of crystal. Main morphological criteria are selected of quality of porous nanostructures for their application in solar batteries. These include diameter and depth of the pore, a degree of porosity of the surface of a nanostructured crystal. Taking into account these criteria, we received porous spaces on the surface of semiconductors A3V5 that could be used for solar cells. We determined the value of boundary voltage of the early pore formation for semiconductors of group A3V5 during etching in the electrolyte HF:C2H5OH:H2O=1:2:1 for 15 min. It was established that at chosen conditions of etching, the largest capacity to pore formation is displayed by crystals of indium phosphide. The results obtained demonstrate that at the same conditions of etching semiconductors possess different ability to form pores.

Keywords: quality of nanostructures, electrochemical etching, porous semiconductors, Helmholtz layer, morphology, semiconductors.

References

1. Huang, Y. M., Ma, Q. L., Meng, M., Zhai, B. G. (2010). Porous Silicon Based Solar Cells. *Materials Science Forum*, 663-665, 836–839. doi: 10.4028/www.scientific.net/msf.663-665.836
2. Salman, K. A., Omar, K., Hassan, Z. (2011). The effect of etching time of porous silicon on solar cell performance. *Superlattices and Microstructures*, 50 (6), 647–658. doi: 10.1016/j.spmi.2011.09.006
3. Dubey, R. S. (2013). Electrochemical Fabrication of Porous Silicon Structures for Solar Cells. *Nanoscience and Nanoengineering*, 1 (1), 36–40.
4. Khrypunov, G., Vambol, S., Deyneko, N., Sychikova, Y. (2016). Increasing the efficiency of film solar cells based on cadmium telluride. *Eastern-European Journal of Enterprise Technologies*, 6 (5 (84)), 12–18. doi: 10.15587/1729-4061.2016.85617
5. Suchikova, Y. (2016). Provision of environmental safety through the use of porous semiconductors for solar energy sector. *Eastern-European Journal of Enterprise Technologies*, 6 (5 (84)), 26–33. doi: 10.15587/1729-4061.2016.85848
6. Bremus-Koebberling, E. A., Beckemper, S., Koch, B., Gillner, A. (2012). Nano structures via laser interference patterning for guided cell growth of neuronal cells. *Journal of Laser Applications*, 24 (4), 042013. doi: 10.2351/1.4730804
7. Beckemper, S. (2011). Generation of Periodic Micro- and Nanostructures by Parameter-Controlled Three-beam Laser Interference Technique. *Journal of Laser Micro/Nanoengineering*, 6 (1), 49–53. doi: 10.2961/jlmn.2011.01.0011
8. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2011). Influence of dislocations on the process of pore formation in n-InP (111) single crystals. *Semiconductors*, 45 (1), 121–124. doi: 10.1134/s1063782611010192
9. Dzhafarov, T. (2013). Silicon Solar Cells with Nanoporous Silicon Layer. *Solar Cells – Research and Application Perspectives*. doi: 10.5772/51593
10. Heidari, M., Yan, J. (2017). Ultraprecision surface flattening of porous silicon by diamond turning. *Precision Engineering*, 49, 262–277. doi: 10.1016/j.precisioneng.2017.02.015
11. Hooda, S., Khan, S. A., Satpati, B., Uedono, A., Sellaiyan, S., Asokan, K. et. al. (2016). Nanopores formation and shape evolution in

- Ge during intense ionizing irradiation. *Microporous and Mesoporous Materials*, 225, 323–330. doi: 10.1016/j.micromeso.2016.01.006
12. Chen, F., Xu, L., Fang, D., Tang, J., Wang, H., Fan, J. et al. (2015). Defect related photoluminescence emission from etched GaAs microstructure introduced by electrochemical deposition. 2015 International Conference on Optoelectronics and Microelectronics (ICOM). doi: 10.1109/icoom.2015.7398848
 13. Md Taib, M. I., Zainal, N., Hassan, Z. (2014). Improvement of Porous GaAs (100) Structure through Electrochemical Etching Based on DMF Solution. *Journal of Nanomaterials*, 2014, 1–7. doi: 10.1155/2014/294385
 14. Tiginyanu, I., Monaico, E., Sergentu, V., Tiron, A., Ursaki, V. (2014). Metallized Porous GaP Templates for Electronic and Photonic Applications. *ECS Journal of Solid State Science and Technology*, 4 (3), P57–P62. doi: 10.1149/2.0011503jss
 15. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2010). Influence of the Carrier Concentration of Indium Phosphide on the Porous Layer Formation. *Journal of Nano- and Electronic Physics*, 2 (4), 142–147.
 16. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2010). Preparation of nanoporous n-InP(100) layers by electrochemical etching in HCl solution. *Functional Materials*, 17 (1), 131–134.
 17. Sato, T., Kumazaki, Y., Kida, H., Watanabe, A., Yatabe, Z., Matsuda, S. (2015). Large photocurrents in GaN porous structures with a redshift of the photoabsorption edge. *Semiconductor Science and Technology*, 31 (1), 014012. doi: 10.1088/0268-1242/31/1/014012
 18. Monaico, E., Tiginyanu, I., Volciuc, O., Mehrtens, T., Rosenauer, A., Gutowski, J., Nielsch, K. (2014). Formation of InP nanomembranes and nanowires under fast anodic etching of bulk substrates. *Electrochemistry Communications*, 47, 29–32. doi: 10.1016/j.elecom.2014.07.015
 19. Gerngross, M.-D., Carstensen, J., Foll, H. (2014). Electrochemical growth of Co nanowires in ultra-high aspect ratio InP membranes: FFT-impedance spectroscopy of the growth process and magnetic properties. *Nanoscale Research Letters*, 9 (1), 316. doi: 10.1186/1556-276x-9-316
 20. Zhu, C., Zheng, M., Xiong, Z., Li, H., Shen, W. (2014). Electrochemically etched triangular pore arrays on GaP and their photoelectrochemical properties from water oxidation. *International Journal of Hydrogen Energy*, 39 (21), 10861–10869. doi: 10.1016/j.ijhydene.2014.05.022
 21. Janovska, M., Sedlak, P., Kruisova, A., Seiner, H., Landa, M., Grym, J. (2015). Elastic constants of nanoporous III-V semiconductors. *Journal of Physics D: Applied Physics*, 48 (24), 245102. doi: 10.1088/0022-3727/48/24/245102
 22. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2009). Influence of type anion of electrolyte on morphology porous inp obtained by electrochemical etching. *Journal of Nano- and Electronic Physics*, 1 (4), 78–86
 23. Sato, T., Zhang, X., Ito, K., Matsumoto, S., Kumazaki, Y. (2016). Electrochemical formation of N-type GaN and N-type InP porous structures for chemical sensor applications. 2016 IEEE SENSORS. doi: 10.1109/icsens.2016.7808443
 24. Ulin, V. P., Konnikov, S. G. (2007). Nature of Electrochemical Pore Formation Processes in AIIIBV Crystals (Part I). *Fiz. Tekh. Poluprovodn*, 41 (7), 854–866.
 25. Sychikova, Y. A., Kidalov, V. V., Sukach, G. A. (2013). Dependence of the threshold voltage in indium-phosphide pore formation on the electrolyte composition. *Journal of Surface Investigation. X-Ray, Synchrotron and Neutron Techniques*, 7 (4), 626–630. doi: 10.1134/s1027451013030130
 26. Yana, S. (2015). Porous Indium Phosphide: Preparation and Properties. *Handbook of Nanoelectrochemistry*, 283–305. doi: 10.1007/978-3-319-15266-0_28
 27. Rani, S., Rajalakshmi, N. (2015). Effect of Nanotube Diameter on Photo-Electro-Chemical Properties of Carbon Quantum Dot Functionalized TiO₂ Nanotubes. *Journal of Clean Energy Technologies*, 3 (5), 367–371. doi: 10.7763/jocet.2015.v3.225
 28. Ulin, V. P., Ulin, N. V., Soldatenkov, F. Y. (2017). Anodic processes in the chemical and electrochemical etching of Si crystals in acid-fluoride solutions: Pore formation mechanism. *Semiconductors*, 51 (4), 458–472. doi: 10.1134/s1063782617040212
 29. Sairi, M., Arrigan, D. W. M. (2015). Electrochemical detection of ractopamine at arrays of micro-liquid | liquid interfaces. *Talanta*, 132, 205–214. doi: 10.1016/j.talanta.2014.08.060
 30. Wloka, J., Mueller, K., Schmuki, P. (2005). Pore Morphology and Self-Organization Effects during Etching of n-Type GaP(100) in Bromide Solutions. *Electrochemical and Solid-State Letters*, 8 (12), B72. doi: 10.1149/1.2103507
 31. Suchikova, Y. A. (2015). Synthesis of indium nitride epitaxial layers on a substrate of porous indium phosphide. *Journal of Nano- and Electronic Physics*, 7 (3), 03017-1–03017-3.
 32. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2010). Blue shift of photoluminescence spectrum of porous InP. *ECS Transactions*, 25 (24), 59–64. doi: 10.1149/1.3316113
 33. Sparvoli, M., Mansano, R. D., Chubaci, J. F. D. (2013). Study of indium nitride and indium oxynitride band gaps. *Materials Research*, 16 (4), 850–852. doi: 10.1590/s1516-14392013005000063
 34. Vambol, S., Vambol, V., Sychikova, Y., Deyneko, N. (2017). Analysis of the ways to provide ecological safety for the products of nanotechnologies throughout their life cycle. *Eastern-European Journal of Enterprise Technologies*, 1 (10 (85)), 27–36. doi: 10.15587/1729-4061.2017.85847

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RESEARCH INTO THE PROCESS OF PREPARATION OF UKRAINIAN COAL BY THE OIL AGGREGATION METHOD (p. 45-53)

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We conducted a study into concentration of Donetsk coal with varying degrees of coalification – anthracite and grade G – by the method of oil aggregation. We determined the character of impact of the following factors on the results of oil aggregation of coal: the ash content of original coal, pulp agitation duration, pulp density, consumption and type of reagent-binder.

The research demonstrated a possibility of effective preparation of finely- and thinly dispersed Donetsk coal the size of 0–0.1; 0–1 (2) mm and ash content from 10–15 % to 65–70 % by the method of oil aggregation.

In this case, it was established that with an increase in the ash content of original coal, the process of oil aggregation displays a capacity of self-leveling. By reducing the speed of aggregation, it is possible to attain practically stable technological results over the entire examined range of ash content of original coal – from 10–15 % to 65–70 %.

Obtained results substantiate the possibility of employing the process of oil aggregation for the re-preparation of waste, in particular, waste of flotation and gravitation separation of coal preparation.

Keywords: oil aggregation, coal preparation, ash content of coal, aggregation, self-leveling of oil aggregation.

References

- Filippenko, Y. N., Morozova, L. A., Fedoseeva, S. O. (2013). Analysis of the granulometric composition of coal mined. *Coal of Ukraine*, 3, 12–14.
- Novak, V. I., Kozlov, V. A. (2012). A review of modern methods for the enrichment of coal slurries. *GIAB*, 5, 130–138. Available at: <http://coalprep.ru/publikatsii/obzor-sovremennykh-sposobov-obogashcheniya-ugolnykh-shlamov/>
- Smirnov, V. A., Beletsky, V. S. (2010). Flotation methods of enrichment of minerals. Donetsk: East Publishing House, NTSh-Donetsk, 496.
- Beletskiy, V. S., Sergeev, P. V., Papushyn, Y. L. (1996). Theory and practice of selective oil aggregation of coal. Donetsk: Grand, 264.
- Trass, O., Vasquez, E. R., Campbell, P. D., Gandolfi, E. A. J., Koka, V. R. (1994). Modified oil agglomeration process for coal beneficiation. iv. pilot-plant demonstration of the simultaneous grinding-agglomeration process. *The Canadian Journal of Chemical Engineering*, 72 (1), 113–118. doi: 10.1002/cjce.5450720117
- Sergeev, P., Beletskiy, V. (1999). Selective flocculation of coal. Donetsk: East Publishing House, 136.
- Zlobina, E. S., Papin, A. V., Ignatova, A. Y. (2016). Enrichment of solid hydrocarbon wastes by the oil agglomeration method. *Math Designer*, 1, 18–21. Available at: http://www.mathdesigner.ru/journal/2016_1/articles/2016-1_4.pdf
- Rafaqat, U., Akhtar, J., Sheikh, N. U., Munir, S. (2015). Cleaning of Dukki (Baluchistan) coal by oil agglomeration process. *International Journal of Oil, Gas and Coal Technology*, 9 (1), 79. doi: 10.1504/ijogct.2015.066948
- Wang, Q., Kashiwagi, N., Apaer, P., Chen, Q., Wang, Y., Maezono, T. (2010). Study on coal recovery technology from waste fine Chinese coals by a vegetable oil agglomeration process. *The Sustainable World*. doi: 10.2495/sw100311
- Beletskiy, V., Shendrik, T. (2011). Ennobling of salty coals by means of oil agglomeration. *Technical and Geoinformational Systems in Mining*, 135–139. doi: 10.1201/b11586-23
- Lin, S., Chen, B., Chen, W., Li, W., Wu, S. (2012). Study on Clean Coal Technology with Oil Agglomeration in Fujian Province. *Procedia Engineering*, 45, 986–992. doi: 10.1016/j.proeng.2012.08.270
- Sahinoglu, E., Uslu, T. (2008). Amenability of Muzret bituminous coal to oil agglomeration. *Energy Conversion and Management*, 49 (12), 3684–3690. doi: 10.1016/j.enconman.2008.06.026
- Singh, A. V., Bhargava, P. K., Singh, R., Menaria, K. L. (2012). The Selective Oil Agglomeration of Combustibles in Fines of Low Grade Lignite of Barmer Rajasthan (India). *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 34 (16), 1491–1496. doi: 10.1080/15567036.2010.485174
- Temel, H. A., Bozkurt, V., Majumder, A. K. (2009). Selective Oil Agglomeration of Lignite. *Energy & Fuels*, 23 (2), 779–784. doi: 10.1021/ef8005096
- Temel, H. A. (2010). The Aggoflotation of a Mixture of Subbituminous Coal and Gangue Minerals Using Şirnak Asphaltite and the Concentrate Obtained from Zonguldak Bituminous Coal. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 32 (13), 1248–1259. doi: 10.1080/15567030802706762
- Debroin, N., Guvink, R. (1949). Adhesion. Moscow: Publishing House of the USSR Academy of Sciences, 580.
- Sergeev, P. V., Beletskij, V. S., Elishevich, A. T. (1993). The trial-and modification principles of couplings for the processes of oil agglomeration of coal. *Solid Fuel Chemistry*. Available at: https://www.researchgate.net/publication/291065518_The_trial-and_modification_principles_of_couplings_for_the_processes_of_oil_agglomeration_of_coal
- Levich, V. G. (1959). Physicochemical hydrodynamics. Moscow: Izdat. Fiz.-mat. liter., 700.
- Deryagin, B. V., Samygin, V. D., Livshits, A. K. (1964). Study of flocculation of minerals in turbulent mode. *Colloid Journal*, 26 (2), 179–185.

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RESEARCH INTO CONSTRUCTIVE AND TECHNOLOGICAL FEATURES OF EPITAXIAL GALLIUM-ARSENIDE STRUCTURES FORMATION ON SILICON SUBSTRATES (p. 54-61)

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The technology of formation of LSI structures on GaAs epitaxial layers, formed on Si-substrates of large diameter, is developed, which makes it possible at least by an order of magnitude to reduce the production cost of crystals due to epitaxial growth of GaAs layers and the use of technological equipment of silicon technology. This technology also enables the use of heterostructures to increase the speed of the LSI.

An analysis of complex structures of different architecture of IC/LSI on GaAs epitaxial layers, formed on Si-substrates, is carried out. The influence of the scattering processes of charge carriers on the potential fluctuations on the magnitude and profile of the mobility of electrons along the thickness of the epitaxial structure is investigated. When using epitaxial technology in structures, there are no isoconcentric impurities of oxygen and carbon, which are the factors of scattering of charge carriers, which makes it possible to achieve high values of mobility of charge carriers.

It is shown that the use of epitaxial layers of gallium arsenide eliminates the effects of isoconcentration impurities of oxygen and carbon in gallium arsenide layers that increases their purity.

A test element was implemented that allows non-destructive measurement of the mobility of charge carriers in the technological cycle of the formation of LSI structures. This allows us to realise the electrophysical diagnosis of the reliability of the LSI at the stage of crystal manufacturing.

Keywords: complementary structures, semiconductors, epitaxy, integrated circuits, technological features.

References

- Colinge, J.-P., Colinge, C. A. (2007). *Physics of Semiconductor Devices*. Springer Science & Business Media, 436.
- Edwards, P. (2012). *Manufacturing Technology in the Electronics Industry: An introduction*. Springer Science & Business Media, 248.
- Hezel, R. (2013). *Silicon Nitride in Microelectronics and Solar Cells*. Springer Science & Business Media, 401.
- Salazar, K., Marcia, K. (2012). *Mineral commodity summaries*. U. S. Geological Survey, Reston, Virginia, 58–60.
- Naumov, A. V. (2005). *Obzor mirovogo rynka arsenida galliya. Tekhnologiya i konstruirovaniye v ehlektronnoy apparature*, 6, 53–57.
- Kamineneni, V. K., Raymond, M., Bersch, E. J., Doris, B. B., Diebold, A. C. (2010). *Optical metrology of Ni and NiSi thin films used in the self-aligned silicidation process*. *Journal of Applied Physics*, 107 (9), 093525. doi: 10.1063/1.3380665
- Yatabe, Z., Asubar, J. T., Hashizume, T. (2016). *Insulated gate and surface passivation structures for GaN-based power transistors*. *Journal of Physics D: Applied Physics*, 49 (39), 393001. doi: 10.1088/0022-3727/49/39/393001
- Thompson, S., Alavi, M., Hussein, M., Jacob, P., Kenyon, C., Moon, P. et. al. (2002). *130nm Logic Technology Featuring 60 nm Transistors, Low-K Dielectrics, and Cu Interconnects*. *Intel Technology Journal*, 6 (2), 5–9.
- Simmons, J. G., Wei, L. S. (1974). *Theory of transient emission current in MOS devices and the direct determination interface trap parameters*. *Solid-State Electronics*, 17 (2), 117–124. doi: 10.1016/0038-1101(74)90059-8
- Aspnes, D. E. (1981). *Studies of surface, thin film and interface properties by automatic spectroscopic ellipsometry*. *Journal of Vacuum Science and Technology*, 18 (2), 289–295. doi: 10.1116/1.570744
- Ossi, P. M., Miotello, A. (2007). *Control of cluster synthesis in nanoglassy carbon films*. *Journal of Non-Crystalline Solids*, 353 (18-21), 1860–1864. doi: 10.1016/j.jnoncrysol.2007.02.016
- Gaan, S., Feenstra, R. M., Ebert, P., Dunin-Borkowski, R. E., Walker, J., Towe, E. (2012). *Structure and electronic spectroscopy of steps on GaAs(110) surfaces*. *Surface Science*, 606 (1-2), 28–33. doi: 10.1016/j.susc.2011.08.017
- Polyakov, V. I., Perov, P. I., Ermakov, M. G., Ermakova, O. N. (1991). *Spektry Q-DLTS geterostruktur na osnove soedineniy GaAs i AlGaAs*. *Mikroelektronika*, 20 (2), 155–165.
- Pizzini, S. (2015). *Physical Chemistry of Semiconductor Materials and Processes*. John Wiley & Sons, 440. doi: 10.1002/9781118514610
- Novosyadlyj, S. P., Terlets'kyj, A. I. (2016). *Diahnostyka submikronnykh struktur VIS*. Ivano-Frankivs'k: Simyk, 478.
- Novosyadlyj, S. P. (2007). *Fizyko-tekhnologichni osnovy submikronnoyi tekhnolohiyi VIS*. Ivano-Frankivs'k: Simyk, 370.
- Novosyadlyj, S. P. (2010). *Sub- i nanomikronna tekhnolohiya struktur VIS*. Ivano-Frankivs'k: Misto NV, 455.