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Research and development of a sensor based on monocrystalline diamond for measuring radiation fluxes of cosmic radiation

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Rationale

Exploration of near and outer space, with the aim of its development in the present and anticipated future, calls for a tendency to improve and search for new design and technological solutions for aerospace, transport spacecraft and systems in order to ensure reliable protection against exposure to the elements.

One of such elements that aerospace technology (AT) designers have to deal with when operating in outer space (OS) is the protection of life forms and functioning electronic components from the harmful effects of ionizing radiation (IR) in the OS. At this stage of the OS exploration, the anticipated service life of aerospace vehicles is up to 20 years or more. The tendency for longer periods of exposure to an aggressive environment promotes the search of alternative solutions of protections against IR. One of the ways to prevent the IR effect is to constantly monitor background radiation inside and outside aerospace vehicles and systems, predict spikes in background radiation and respond to such changes in a timely manner in order to protect electronic equipment and life forms from the harmful effects of IR.

The fundamental objective of global radiation safety is to control the harm caused to a life form when exposed to radiation sources, during their normal use and in emergencies. Therefore, in order to prevent and control the "harm" caused by radiation, which is imperceptible to human senses, we need devices and components for IR detection and measurement, which can process and transmit a signal in a form that is adequate and clear for processing and comprehending.

There are many ways to detect IR: ionization (ion chambers, gas-discharge counter tubes), scintillation, semiconductor, photographic, luminescent, chemical, tracking, activation, thermal methods.

For aerospace vehicles (AV) and space transportation systems (STS), IR detection can be divided into the following categories: internal detection - from internal IR sources and external IR detection, which acts on AV and STS units from the outside.

Internal IR is caused by nuclear systems set up on board of AV and STS. There are mainly nuclear reactors and nuclear engines used to supply power to aerospace vehicles, or radiation sources used as heating for AV and STS. Various detection equipment and complexes can be used for measurement and analysis of a material/unit surface using IR irradiation methods.

External IR is represented by space radiation fluxes (RF) and consist of: primary radiation, which is subdivided into galactic cosmic rays (GCR) and solar cosmic rays (SCR); secondary radiation, which refers to the radiation belt of the earth (ERB), planets, stars and celestial bodies.

Primary radiation includes fluxes of fast charged particles (mainly protons) with energy up to 10^{10}-10^{12} MeV. Secondary radiation manifests itself at altitudes below 20 km, and its high-energy component is represented mainly by small charged particles with an energy of ~ 100 MeV, and low-energy radiation consists of electron-positron pairs and γ-quanta.

The distribution of GCR kinetic energy is wide and depends on the ion type and the solar cycle phase, with peaks of about 1000 MeV for protons and 500-600 MeV for heavier nuclei and distribution tails reaching much higher energy levels.

Neutrons from solar flares with energy E can travel a much greater distance before decay (1 astronomical unit ≈ 150,000,000 km): 0.2 GeV, S ≈ 1 a. u.; 1.0 GeV, S ≈ 3 a. u.; 2.5 GeV, S ≈ 6 a. u.; 10 GeV, S ≈ 20 a. u.

Therefore, to control, analyze and predict changes in the IR inside and outside the AV and STS, monitor modules for the cosmic ray fluxes (CRF), the device constantly monitors the IR in real time. One of the crucial components of the CRF monitor module is the IR detection sensor, a measuring instrument that converts the energy received as a result of contact of the IR with the sensing element medium into an electrical signal for further processing by the radiation monitor module.

The use of the CRF monitoring instrument and the sensor unit(-s), as well as other functional parts used in VA and STS, is limited and defined by tight boundary conditions: weight and dimensions; resistance to aggressive environmental factors: radiation stability (accumulated dose 80-300 krad, exposure to heavy charged particles (HCP) with a threshold value of linear energy transfer (LET) of more than 60 MeV*cm^2/mg), resistance to thermal-vacuum factors (temperature from -60 to 125 ^{0}C, ultraviolet radiation, zero-gravity state, vacuum); high durability requirement (mean time between failures of at least 150,000 hours, unmaintainable equipment); limitations in terms of power supply (28V, 100V) and increased device lifetime - up to 20 years or more.

Modern devices for monitoring cosmic ray fluxes and radiation monitoring devices used for VA and STS have critical drawbacks, as they are designed to function under intense radiation exposure, especially to such factors as HCP fluxes and/or the effects of special factors, and they are mainly based on silicon sensors for IR detection. Typical disadvantages of using silicon sensors include their low radiation stability and the fact that they cannot be used at high temperatures without special cooling systems. Using gas-discharge counter tubes and scintillation sensors for these purposes is limited by their weight and dimensions, as well as high supply voltage (hundreds and thousands of volts), total power consumption; there are also limitations in terms of maximum radiation flux, therefore, their use in high cosmic ray flux conditions is not optimal.

Alternative materials for the sensing element of the CRF detection sensor that meets the selection criteria for VA and STS are diamonds and diamond-like materials. These materials do not demonstrate many of the disadvantages of similar products based on conventional semiconductors (silicon, germanium, gallium arsenide, etc.) and can be used without auxiliary support and protection systems at temperatures equal to several hundred degrees Celsius and higher (in open space up to 500-1000 ^{0}C), in the particle flux range of up to 10^{20} cm^2 s^{-1}. The main advantages of a diamond-based sensor are simultaneous detection of all IR types, high resistance to radiation exposure and chemically aggressive factors. Diamond sensors have compact overall dimensions.

In view of the above, it is imperative to create and develop a methodology for designing and studying a sensor made of monocrystalline diamond for detecting cosmic ray fluxes, which would be able to operate in an aggressive environment and under vacuum, with a dynamic temperature fluctuations, be resistant to radiation effects, have low weight and compact dimensions and operate at a supply voltage of max. 100V, for the purpose of using such an instrument for VA and STS with a long service life.

These tasks would require a number of works to be performed using such methods as simulation, mathematical analysis and subsequent practical experiment to verify obtained scientific results. For this purpose, it is necessary to conduct a study and a comparative analysis of C (diamond) materials and main semiconductor materials (Si and Ge) used for sensing elements of a CRF detection sensor, to check their IR detection performance. Analyze and investigate IR interaction in the body of the sensing element of the diamond sensor (DS) with variable thickness, study the dependence of variations in IR detection performance on the DS temperature. Develop, structure, research and analyze data obtained for the diamond sensor model in order to optimize the DS design to increase the range of the IR detection performance, counting performance, without changing the circuit operating voltage at the sensor electrode contacts. The final stage is to develop a design of a multilayer DS for CRF detection, with specified parameters, followed by research and analysis of obtained scientific data.

Using DS for CRF detection and devices based on them for IR monitoring inside and outside the VA and STS and timely prediction of emergencies when the permissible radiation doses are exceeded, would not only significantly extend the lifetime of the VA and STS, but also protect life forms from critical exposure to radiation fluxes; which, of course, can be highly valuable and determine the relevance of this research.

Objective

The objective of the study is to develop a diamond sensor for cosmic ray flux detection, which will be used as part of instruments for monitoring and predicting the radiation situation inside and outside the aerospace vehicles and space transport systems, which operate in outer space for periods of up to 20 years or more.

To achieve this objective, the following **research tasks** have been identified:

1) Development of a methodology for designing a sensor based on monocrystalline diamond for IR detection.

2) Selection of a material for the active sensitive element of an ionization sensor with high radiation stability, which will operate reliably in aggressive

conditions and at over-temperatures from -60 to +125 C°. The weight and dimensions of such active element has to be optimal for aerospace applications.

3) Search for a design solution aimed at improving specifications of the ionization sensor in terms of detecting cosmic ray fluxes, such as: counting rate, absolute detection efficiency, energy resolution, detector noise.

4) Search for a solution to use the ionization sensor with 100 V supply voltage, without deterioration of the sensor performance.

5) Analysis of the sensor IR detection performance: electrons, protons and gamma radiation with a given energy.

6) Analysis of the sensor IR detection performance depending on the sensor thickness:

7) Analysis of the effect of temperature on operation stability and efficient detection of ionizing radiation by the sensor.

The research subject is the multilayer sensor based on type 2A monocrystalline diamond used for detection of cosmic ray fluxes. The research focus is the interaction of ionizing radiation in the body of the multilayer sensor for IR detection.

Degree of elaboration of the research topic

The design and process solutions for CRF detection sensors developed until now are limited to several solutions described in the list of references in this thesis paper. One of them is using a sensor for detection of a certain IR type, and hybrid units for CRF detection are designed using various detection sensors with limited functionalities.

Another thing worth noting is a change in the thickness of the sensor sensitive area and/or higher supply voltage at the electrode contacts of the IR detection sensor.

Using radiators/filters to create cutoffs, zones for incoming IR energies, which limit the energy measurement range for the detector selected for them.

Theoretical significance

1) The data obtained as a result of an experiment that involved heating of the diamond-based sensor model to a temperature of T = 5000C were studied; it can be

concluded that the temperature has immaterial effect on the readings and efficient operation of the diamond sensor when detecting IR.

2) The data of GEANT4 computer simulation and analysis of interaction of ionizing radiation with the sensor material based on diamond, Ge, Si were reviewed. Using the obtained simulation data, graphs of the spectra of the total energy absorption peak by the sensor body were plotted and analyzed with respect to the thickness and number of active sensor elements in the following energy range: electrons - 0.3; 0.5; 1 and 5 MeV; protons: 0.1; 0.5; 2.5; 2.5; 10; 50 and 200 MeV; radiation: 662 keV, helium ion HCP: 5; 10; 20 and 50 MeV. The data obtained make it possible to determine and select an appropriate sensing element for measuring a certain parameter of charged particle energy or a range of energies.

Practical significance

The design of a multi-element (three-element) CRF detection sensor made of type 2A monocrystalline diamond is presented. This design makes it possible to expand the sensor range in terms of IR energies, increase its detection efficiency due to its higher active IR detection capacity without a requirement to increase supply voltage on electrode contacts; for this purpose, several thin active sensing elements are used, they are assembled layer by layer and represent an individual monolithic structure.

The results obtained were used in applied research (AR) in the framework of the focus area "Transport and space systems" of the federal special-purpose program "R&D in focus areas of the science and technology sector of Russia for 2014-2020." The basis for the AR is Grant Agreement No. 14.605.21.0001 dd. July 08, 2014 between the Ministry of Education and Science of the Russian Federation and the Higher School of Economics with respect to the topic “Design of modules for monitoring cosmic radiation flux parameters based on wide-bandgap semiconductor sensors for advanced space transportation system with long service life”.

Research methods

The research is based on such methods as the theory of ionizing radiation interaction with matter, experimental model, computer simulation and mathematical calculation.

1) The computer simulation and mathematical calculation method affords an opportunity to conduct research, evaluate, compare and obtain scientific data on IR interaction with the sensing element material at specified parameters, such as: effect of the sensing element thickness on the overall sensor performance and sensitivity; dependence of energy absorbed by the sensing element material on the energy of electrons, protons, gamma and HCP emitted by the IR source.
2) The experimental method facilitates obtaining actual data from the prototype system and the data that are not always possible to simulate in an accurate way. Effect of high temperatures on the efficiency of the IR sensor detection. Additionally, it is used for verification of data obtained by the calculation and modeling methods.

The author's personal contribution to the research

The author's personal contribution includes the analysis of available literature sources, selection and rationale for selection of the sensor material, its study and comparative analysis with other materials used to manufacture IR detectors.

A method for designing a diamond-based sensor for detection of cosmic ray fluxes was developed.

Simulation, mathematical calculation and systematization of obtained scientific data were carried out in order to develop and optimize the diamond-based sensor design.

Setting up and experimental studies of interaction of gamma radiation, beta and temperature factors with the prototype - a sensor model based on natural type 2A monocrystalline diamond.

Design of the model of the IR interaction in a multi-element diamond sensor in order to increase its active detection capacity without increasing the supply voltage at the sensor contacts.

Development and research of an experimental model of a multi-element diamond sensor for the detection of cosmic ray fluxes.

The author has personally formulated the conclusions and the thesis deliverables.

Key research findings

1) A mathematical model was proposed for calculating and simulating the IR detection efficiency by a sensor based on a monocrystalline diamond: electrons, protons and gamma radiation with a given energy.

   In the course of the study, the results of simulation of the IR interaction with diamond were obtained, as well as a comparison of detection efficiency characteristics of main semiconductor materials Si, Ge used globally to make IR detectors.

   The research data obtained allow for the conclusion that diamond is superior to Si, Ge as a material for making CRF detection sensors.

2) A mathematical model was proposed for calculating and simulating the IR detection efficiency depending on thickness of the monocrystalline diamond-based sensor.

   The study provided for obtaining and collecting statistical data on IR interaction in the range of energies of cosmic ray fluxes (electrons, protons, HCP and gamma radiation) with the diamond body of varied thickness.

   The research findings make it possible to analyze operation of the diamond sensor in order to design an optimal CRF radiation detection sensor.

3) A design solution was proposed that would improve specifications of the monocrystalline diamond-based sensor for IR detection, such as counting rate, absolute detection efficiency, energy resolution, detector noise.

   The design concept made as a multi-element structure allows for expanding the detected radiation range in terms of the IR power.

   The simulation of a multilayer sensor design in specified CRF ranges was conducted; based on the research data, a larger effective range of the IR detection by the diamond sensor was identified.

Based on the test results, the following conclusions can be made: improvement the absolute detection efficiency of the diamond sensor, counting performance and detection accuracy.

4) A method was developed for designing an IR diamond sensor with a max supply voltage of 100V, without compromising on IR sensor performance and increasing the sensing area of the IR detection body.

5) A methodology was proposed for experimental studies of a diamond ionization sensor, taking into account the effect of temperature on the CRF detection stability.

An experimental model of a diamond-based IR detection sensor was made; and the simulation and experiment of the temperature effects on the sensing element and on the complete sensor unit were carried out.

Based on the data obtained, an increase in temperature of the monocrystalline diamond-based active sensing element up to 500 ^{0}C does not affect the IR detection readings in any significant way. However, the temperature affects the structural materials of the sensor itself, which results in leakage current occurrence; therefore, appropriate temperature-resistant structural materials for making the sensor housing have to be selected.

A multi-element monocrystalline diamond-based sensor for detection of cosmic ray fluxes conforms to the required parameters in terms of weight, dimensions, temperature; it is suitable for special conditions, which is confirmed by the study results.

Due to this design concept it is possible to avoid technological challenges associated with manufacture of complex sensor structures, since the technology of making same-type single elements on one diamond plate with two electrical contacts in the form of a capacitor is quite common.

Scientific novelty

1) A methodology for designing a diamond-based sensor for detection of cosmic ray fluxes was developed; based on this methodology it is possible to study and design a working version of a diamond-based detection sensor.
2) A mathematical model and a GEANT4 computer model of the IR interaction in the multilayer sensor body were developed. The calculation and model parameters were preset based on the parameters of an actual diamond sensor prototype.
3) Mathematical models of IR diamond sensors in GEANT4 simulation environment were developed to analyze the passage of elementary particles through the sensor body. Scientific research was carried out using the sensor model made of diamond, Ge and Si materials, with the active sensing element dimensions of 5x5x2.5mm and the IR source: electrons: 0.5, 1 and 5 MeV; protons: 0.5, 2.5, 25 and 200 MeV; gammas: 0.5, 2.5, 25 and 200 MeV.
4) Comparative data on the parameters and characteristics of IR sensors based on diamond, Ge and Si materials were obtained by calculation and experiment; the scientific data analysis showed the advantages of monocrystalline diamond-based sensors.
5) A model was developed in GEANT4 simulation environment to study the IR interaction with the diamond sensor body, at various sensor thicknesses and varied IR energies. Based on the simulation and analysis results, graphs of the IR interaction with the diamond sensor active element, with the active sensing element dimensions of 5x5xd mm, where d = 0.1; 0.3; 0.5; 1; 2.5; 5 mm, and the charged particle radiation source: electrons: 0.3; 0.5; 1 and 5 MeV; protons: 0,1; 0,5; 2,5; 10; 25; 50; 100 and 200 MeV; gammas: 0,1; 0,5; 2,5; 10; 25; 50; 100 and 200 MeV; helium ion HCP: 5; 10; 20 and 50 MeV.
6) The analysis of experimental data on temperature T = 500 ^{0}C effect on the diamond sensor characteristics was carried out. Based on the experiment results, a graph of interaction of IR Sr90Y90 with an incoming electron energy E of 545.9 keV and 2.74 MeV with the diamond sensor active element

at a temperature of T = 25 °C and 500 °C was plotted. As a result of the measurement analysis, a slight change in the readings is observed.

7) A manufacturing technology for a multi-element diamond sensor was developed, as well as an experimental model of a two-layer diamond sensor in order to address the task of increasing the active sensing area of IR detection with a view to expand the range of the sensor efficient performance without using a higher field strength between the sensor electrical contacts.
8) A prototype experimental multi-element (three-element) diamond sensor for IR detection was developed, with an extended range of IR energy detection and counting response, and max operating voltage at the contacts of 100V.
9) Experimental scientific data were obtained on interaction of ^{137}Cs gamma radiation with a gamma energy of 662 keV with a multilayer diamond-based CRF detection sensor. Analysis of the obtained measurements shows an increase in gamma radiation detection efficiency as a function of the number of active layers used in the diamond sensor.

Provisions presented for defense

1) Mathematical calculation model and simulation of efficiency of ionizing radiation detection by a diamond sensor: electrons, protons and gamma radiation with a given energy.
2) Mathematical model and simulation of efficiency of ionizing radiation detection by a diamond sensor as a function of its thickness.
3) A design solution aimed at improving specifications of the ionization sensor in terms of detecting cosmic ray fluxes, such as: counting rate, absolute detection efficiency, energy resolution, detector noise.
4) A methodology for designing an IR diamond sensor with a max supply voltage of 100V, without compromising on IR sensor performance and increasing the sensing area of the IR detection body.
5) A methodology for experimental studies of a diamond ionization sensor, taking into account the effect of temperature on the stability of operation and efficiency of IR flux detection.

Research evaluation

The reliability of results obtained in the course of the thesis research is confirmed by the following:

1) sufficient consistency (for practical calculations) of simulation results with experimental data and data obtained by mathematical calculations;
2) data in similar published works of domestic and foreign experts, confirming the results obtained in the course of the thesis research.

Main results of the thesis were announced and reviewed at the following conferences:

1) XVII International Scientific and Practical Conference "Innovative, Information and Communication Technologies" (INFO-2020), Sochi, Russia, October 1-10, 2020. "Simulation of gamma radiation detection using a three-layer monocrystalline diamond-based sensor."
2) Science and Technology Conference for Students, Postgraduates and Young Professionals of the Higher School of Economics named after E.V. Armensky, Moscow, Russia, February 25 - March 4, 2020 "Simulating the process of proton and electron energy detection using a coaxial diamond detector."
3) XVI International Scientific and Practical Conference "Innovative, Information and Communication Technologies" (INFO-2019), Sochi, Russia, October 1-10, 2019. "Simulation of passage of electrons with initial energies of 300 keV, 500 keV, 1 MeV and 5 MeV through a diamond with a thickness of 0.3 mm by the Monte Carlo method."
4) XVI International Scientific and Practical Conference "Innovative, Information and Communication Technologies" (INFO-2019), Sochi, Russia, October 1-10, 2019. "Using an artificial neural network in the study of radiation fluxes based on diamond sensors."
5) XV International Scientific and Practical Conference "Innovative, Information and Communication Technologies" (INFO-2018), Sochi, Russia, October 1-10, 2018. "Simulation of the absolute efficiency of a

monocrystalline diamond-based detector with a thickness of 0.03 to 1 cm and a gamma-ray source with an energy of 0.6 to 5000 eV."

6) Science and Technology Conference for Students, Postgraduates and Young Professionals of the Higher School of Economics named after E.V. Armensky, Moscow, Russia, February 17 - March 1, 2017 “High-temperature ionizing radiation detector with a diamond sensing element."
7) XII International Siberian Conference on Control and Communications (SIBCON), Moscow, Russia, May 12-14, 2016 «Review the space radiation CVD diamond multi-layer detector».
8) Science and Technology Conference for Students, Postgraduates and Young Professionals of the Higher School of Economics named after E.V. Armensky, Moscow, Russia, February 3 - 13, 2015 “Design features of the monocrystalline diamond-based sensor assembly for detection of cosmic rays."
9) XV All-Russian Scientific and Technical Conference, Voronezh, Russia, October 5 - 17, 2014 “New designs based on diamond detectors for space transport systems."
10) XV International Scientific and Practical Conference "Innovations Based on Information and Communication Technologies" (INFO-2014), Sochi, Russia, October 1-10, 2014. “Innovative technical solutions used in the design of cosmic ray spectrometers based on diamond detectors."

List of published articles, which contain key thesis results.

The conceptual issues of the thesis are presented in papers published by the author in leading peer-reviewed scientific journals. Publications in journals indexed in the Web of Science and Scopus citation bases:

1) Bolshakov A.P., Zyablyuk K.N., Kolyubin V.A., Dravin V.A., Khmelnitskii R.A., Nedosekin P.G., Pashentsev V.N., Tyurin E.M., Ralchenko V.G. Thin CVD diamond film detector for slow neutrons with buried graphitic electrode. // Nuclear Instruments and Methods in Physics Research, Section A:

Accelerators, Spectrometers, Detectors and Associated Equipment. Volume 871, 1 November 2017. P. 142-147.

2) Gladchenkov E., Zakharchenko K. V., Kaperko A., Kolyubin V., Kulagin V., Nedosekin P. A Diamond Detector for Registration of Ionizing Radiation with Low Linear Energy Transfer. // Measurement Techniques. 2017. Vol. 60. No. 1. P. 75-81.

3) Gladchenkov, E.V., Ibragimov, R.F., Kolyubin, V.A., Nedosekin P. A, Tyurin, E.M., Zaharchenko, K.V. A Investigation of the diamond based detectors characteristics with different thickness of the sensor element. // Journal of Physics: Conference Series. 2017. 798(1). 012173. P. 1-6.

4) Gladchenkov E., Zakharchenko K. V., Ibragimovich R., Kaperko A., Kolyubin V., Kulagin V., Nedosekin P., Tyurin E. Experimental Investigations and Mathematical Simulation of the Operation of Ionizing-Radiation Diamond Detectors. // Instruments and Experimental Techniques 2017. Vol. 60. No. 3. P. 339-344.

5) Nedosekin P., Gladchenkov E., Zakharchenko K. V., Kolyubin V. Review the space radiation CVD diamond multi-layer detector. // 2016 International Siberian Conference on Control and Communications (SIBCON). Vol. 502. June 2016. P. 600-604.

6) Zyablyuk, K.N., Kolyubin, V.A., Pashentsev, V.N., Nedosekin, P.G., Tyurin, E.M., Afanas'ev, S.A. Gamma sensitivity of single-crystal CVD diamond neutron detectors. // Inorganic Materials. Vol. 52. I. 3. March 2016. P. 262-267.

7) Ibragimov R. F., Tyurin E. M., Kadilin V. V., Kolyubin V., Zakharchenko K. V., Nedosekin P. Research of work stability of diamond detectors used in SCR DDIR. // Journal of Physics: Conference Series. 2016. Vol. 675. 042013. P. 1-4.

8) Altukhov A. A., Zakharchenko K. V., Kolyubin V., Lvov S. A., Nedosekin P., Tyurin E. M., Ibragimov R. F., Kadilin V. V., Nikolaev I. V. Selective

detector of cosmic particles based on diamond sensitive elements. // Journal of Physics: Conference Series. 2016. Vol. 675. No. 4. 042027. P. 1-4.

9) Kaperko A. F., Kolyubin V. A., Kulagin V. P., Lvov S.A., Nedosekin P. G., Chumachenko E. N., Zakharchenko K.V. Spectrometric Diamond Detector of Fluxes of Ionizing Radiation for Space Transportation Systems. // Measurement Techniques. 2015. Vol. 58. No. 6. P. 713-718.

10) Gulyaev Yu. V., Mityagin A. Yu., Chucheva G. V., Afanas'ev M. S., Zyablyuk K. N., Talipov N. Kh., Nedosekin P. G., Nabiev A. E. FET on hydrogenated diamond surface. // Journal of Communications Technology and Electronics. March 2014. Vol. 59. I. 3. P. 282–287.

Papers published in peer-reviewed scientific journals included in the list of high-ranking journals compiled by the Higher School of Economics:

1) Kaperko A.F., Nedosekin P.G. Model of a diamond coaxial sensor for detection of protons and electrons. //Sensors and Systems 2020 No.6 pages 45-51.

2) Nedosekin P. Three-layer diamond-based gamma ray detector. // Sensors and Systems 2019 No.4. pages 20-26.

3) Kadilin V.V., Kolyubin V.A., Lvov S.A., Nedosekin P.G., Idalov V.A., Tyurin E.M., Kolesnikov S.V., Samosadny V.T. Prospects for using diamond detectors for detection of charged cosmic-ray particles. // Nuclear Physics and Engineering. 2014. V. 5. No.2. Pages 138-144.

Thesis content and structure

The thesis includes introduction, 4 chapters and conclusion.

Chapter 1 contains an analytical review of the current status in terms of existing process and design solutions and approaches to the development and research of sensors and detectors for ionizing radiation in the outer space, as well as methods for checking their main parameters. Factors and parameters applicable to cosmic rays were reviewed. Analysis of state-of-the-art Russian and foreign devices and methods for CRF detection and monitoring, as well as their design and implementation options, was conducted. Comparison of sensors for the detection of IR in the OS made of silicon and germanium, promising developments based on CdTl, HgI_2 and diamond (C) was made. Based on the performed analysis of designs and specifications of sensors made of different materials, it was concluded that the most promising sensors for the detection of IR in the OS are diamond sensors (DS).

Chapter 2 deals with the selection and rationale for the research scope. Principles of designing devices for radiation monitoring and main problems and challenges for CRF detection are presented, the issue of certification of measuring instruments for particle detection is put forward, and the possibility of using an artificial neural network (ANN) to reconstruct the CRF spectra is described. A conclusion was made regarding the requirement to detect and monitor cosmic ray fluxes, obtain metrological certificates for measuring instruments, as well as the requirement to develop a physical and mathematical model for accurate CRF detection and to use ANN to reconstruct the CRF spectra using the measurement results.

Chapter 3 contains a methodology for designing a diamond sensor for CRF detection with subsequent design of a device as per the presented methodology. In particular, the selection of material to manufacture the sensor was reviewed, IR detection efficiency for the selected material was analyzed using GEANT4 mathematical simulation, the sensor design was selected, the experimental study of high temperature effect on the sensor performance was carried out, the sensor was optimized using GEANT4 mathematical simulation for various types of ionizing radiation, an experimental study and mathematical simulation of interaction of ionizing radiation of in the two-layer diamond-based sensor body was carried out. Based on the results of experimental studies and simulations, it was concluded that at least two sensing elements of a diamond-based sensor are required, as it would expand the measurement range, increase the output signal amplitude and the sensor counting rate while maintaining the supply voltage level.

Chapter 4 includes the results of a study of the multilayer (three-element) diamond sensor for detecting electrons, protons and gammas using GEANT4 software. Based on the results obtained for interaction of gamma radiation with the multilayer diamond sensor, a mathematical model to evaluate the sensor detection efficiency was developed. A comparison of the simulation results with the experimental study results using ^{137}Cs isotope is presented. Based on the comparison of the simulation results and experimental results, it was confirmed that the DS performance increases as a function of the larger number of working elements.

The thesis **conclusion** contains the scientific work results, recommendations and prospects for further research into the topic.