

CONTENTS AND ABSTRACTS

RADIO ENGINEERING AND COMMUNICATION SYSTEMS

E. P. VASILIEV, T. D. LUU. MODELING OF FILTERS ON COUPLED LINES

Keywords: filter, coupled lines, modeling method, microwave range, dispersion, losses, conductor multilayeriness and roughness.

A method for modeling various structural types of microwave functional devices based on coupled lines is proposed. The aim of the work is to develop a modeling method for different structural types of filters on coupled lines, taking into account dispersion, losses, multilayer structures, and conductor roughness. The results of experimental and theoretical studies of several microstrip bandpass filters, confirming the adequacy and practical significance of this article are presented.

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E. P. VASILIEV, NGUYEN DANG HOP. MODELING OF ELECTROMAGNETIC KEY ELEMENTS IN MICROWAVE RANGE

Keywords: reed switch module, mathematical model, optimization technique, objective function, switch, S and X-band.

In this paper, design and mathematical model of reed switch module (RSM) are proposed. RSM studies have been conducted up to X-band. RSM is implemented as coaxial irregular line section with required cross-section in the mode of closed and open contact parts. Main electrical parameters of various homogeneous sections of coaxial line (CL) and entire RSM are determined. RSM analysis and optimization is implemented based on the theory of four-terminal networks, matrices, and Fletcher-Powell method. The aim of the work is to develop and verify a mathematical model of RSM in microwave range (up to 10 GHz). The feasibility of using RSM at higher power levels, in contrast to MEMS (microelectronic electromagnetic systems) switches, is substantiated. The results of RSM modeling in S and X-bands confirm the effectiveness of the proposed method.

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V. A. OSANOV. COMPARATIVE ANALYSIS OF NETWORK TRAFFIC DECORRELATION METHODS

Keywords: network traffic, correlation traffic, quality of service, decorrelation, Karhunen – Loève decomposition, discrete cosine transform, Haar wavelet transform, S-random permutation, spiral permutation.

Based on experimental data confirming the relationship between network traffic autocorrelation and video frame losses and an increase in average packet transmission time, a method for solving the problem of improving service quality by decorrelation is proposed. The aim of this work is to select an efficient method for reducing the autocorrelation level to perform decorrelation process of time intervals sequence between packets in network based on their comparative assessment. Main criteria for comparison, of

which the priority is decorrelation process execution time with the least impact on network delay, are formulated. Known methods such as Karhunen – Loève decomposition, discrete cosine transform, and others, do not satisfy this criterion and, as a result, cannot be used for practical implementation of decorrelation process. Methods based on Haar wavelet transform and permutation are proposed. Their comparison is performed by software implementation of the methods, analysis of decorrelation results of simulated autocorrelation sequence, and calculation of computational complexity of execution algorithms for different input data parameters. The obtained results confirm the advantage of proposed methods and, in particular, spiral permutation method.

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V. T. DMITRIEV, D. M. MENSHIKOV, M. S. BUNIN. ALGORITHM TO CALCULATE PRIMARY CODECS PARAMETERS OF SOFTWARE-DEFINED SYSTEMS

Keywords: data transmission security, voice signal, packet transmission, encryption, authentication, correlation analysis, cryptographic stability, noise-resistant coding, adaptive improved.

In this paper, an algorithm for determining primary codec parameters of software-defined radio systems based on correlation function of received signal is considered. The aim of the work is to develop an algorithm for determining primary codecs parameters. The results of experimental studies on the assessment of autocorrelation functions for various types of transmitted data are presented. An algorithm for determining the parameters of primary codecs based on the analysis of correlation function maxima of the first, second, third and fourth order and determining the duration and structure of transmitted frame and, accordingly, primary coding algorithm based on the intervals between them is proposed. The performance of the proposed algorithm is studied for different analysis intervals and under the influence of interference and distortion with error probability in communication channel from 0 to 5 %.

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MATHEMATIC AND SOFTWARE COMPUTER SYSTEMS AND COMPUTER NETWORKS

K. A. SERMYAGIN, A. N. PYLKIN. BUILDING EFFICIENT ARCHITECTURE FOR HIGHLY LOADED AND SCALABLE SERVICES ON FASTAPI: PRINCIPLES AND BEST PRACTICES

Keywords: FastAPI, web framework, API, micro-services, design, architecture.

In the era of growing Internet services and high-load applications, developers are faced with the need to create systems that can handle large volumes of data and users. Key aspect for the successful design of such systems is the choice of appropriate architecture and tools. FastAPI stands out among other technologies for its speed, ease of use and support for modern standards. The aim of the work is to improve the efficiency of development in the context of FastAPI framework by developing layered service architecture.

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L. A. DEMIDOVA, V. V. MASLENNIKOV. APPLICATION OF MULTILEVEL QUANTUM SYSTEMS FOR PARALLEL EVALUATION OF SOLUTIONS IN MULTIOBJECTIVE OPTIMIZATION PROBLEMS

Keywords: optimization, multiobjective optimization, quantum-inspired algorithm, qudit, density matrix, Heisenberg-Weyl operators, quantum superposition, quantum interference, Pareto front, evaluation of solutions.

The article discusses a universal method for implementing quantum-inspired multiobjective optimization algorithms based on the usage of multilevel quantum systems for parallel evaluation of solutions. This method uses key principles of quantum mechanics, such as superposition, probabilistic representation of quantum states, and quantum interference. Special attention is paid to the concept of quantum superposition, which allows analyzing many potential solutions simultaneously, thereby increasing the speed of search for optimal solutions on the Pareto front. The mathematical principles of describing multilevel quantum systems using density matrix based on Heisenberg-Weyl operators are described, which makes it possible to interact with a multilevel quantum system in terms of its physical characteristics, as well as analyze the coherence and dynamics of the system. In addition, a mathematical description of the mechanisms for choosing promising solutions using the analogy of quantum interference is presented. Based on the proposed method, quantum-inspired version of NSGA-III multiobjective optimization genetic algorithm is implemented. The quality of the algorithm is evaluated on test tasks of multiparty multiobjective optimization. Test results show that the developed quantum-inspired algorithm surpasses classical multiobjective optimization algorithms in accuracy of approximation of the Pareto front and the ability to find uniformly distributed solutions.

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COMPUTING SYSTEMS AND DEVICES

D. V. LYULYAVA. APPLICATION OF OPTIMIZATION METHODOLOGY FOR PHYSICAL IMPLEMENTATION OF SPECIALIZED PIPELINED COMPUTING DEVICE

Keywords: FPGA, specialized computing device, pipeline, architecture, physical implementation, topology, placement, routing, optimization.

The problem of finding the optimal physical implementation for a specialized pipelined computing device is considered. The aim of this paper is to research the impact of pipeline stage placement topology on output characteristics of final design. When designing computing devices, the required output values for target performance indicators of final solution are determined. Exploring all possible design options requires significant time resources, which are generally incompatible with project deadlines. Therefore, optimization of computing device is carried out in discrete parameter space with prioritized criteria. The estimation of solution model with the required characteristics can be preliminarily assessed at the stage of creating logical implementation. However, a key challenge is the significant discrepancy between preliminary and actual performance estimates due to the topological features of physical implementation. This paper proposes an optimization methodology for physical implementation of a specialized pipelined

computing device, based on the hypothesis that pipeline stages should be placed in close proximity within a predefined overlap area. To validate the effectiveness of the proposed methodology, the paper presents experimental evaluation of formulated approaches for specialized pipelined computing devices implementing block encryption algorithms «Magma» and «Kuznechik» as well as the CORDIC algorithm for computing transcendental functions. The results of placement and routing of corresponding computing device circuits on FPGA hardware platform are provided. Additionally, quality criteria for evaluating the optimality of obtained solutions, based on central moments of statistical population, are proposed.

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N. A. DUKSIN. DESIGN OF PROGRAMMABLE LOGIC COMPUTING CLUSTERS

Keywords: massively parallel computing systems, cluster computers, FPGA, RTL, pattern matching, partial recon-figuration, programmable computer unit.

The problem of designing a computing system for massively parallel data processing is considered. The aim of the work is to form the architecture of a computing system based on cluster partitioning using programmable numerators. This approach makes it possible to optimize data processing process, ensuring the balance between performance and flexibility of a system. In particular, the use of field programmable gate array (FPGAs) makes it possible to implement adaptive computing re-sources that can be re-configured for specific data processing tasks. The problem is considered in the context of continuous flow of input data, which requires the development of effective mechanisms for distributing computing resources and controlling data flow. An approach to the organization of cluster structure of a computing device is described, including methods for dynamically distributing tasks between computing cluster nodes, as well as load balancing algorithms, special attention is paid to the tasks of control core of designed system. Additionally, the possibility of using a partial reconfiguration approach to increase the flexibility of using the final system is explored. As a practical implementation of the proposed approach, system layout based on programmable logic integrated circuits is de-scribed.

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D. O. SHCHEPUKHIN. CONFIGURATION ISSUES OF FPGA-BASED COMPUTING CLUSTERS

Keywords: combinatorial optimization, cluster computing, FPGA, pattern matching, programmable numerators.

The article considers the problem of optimally filling computing clusters of a massively parallel specialized FPGA-based accelerator in a heterogeneous system with processor cores of various types to verify the compliance of the input data stream with a set of regular expressions. The aim of the work is a mathematical formulation of the problem for the subsequent development of the corresponding CAD module based on it. The distribution of regular expressions across the nodes of a heterogeneous system is carried out using a specialized synthesizer, which also generates types of cores for placement in accelerator clusters. In this way, the synthesizer connects the system and RTL levels of design. Next, it all comes down to sequentially solving two subtasks using combinatori-

al optimization or dynamic programming methods. The solution to the problem is considered using the example of the placement of cores on the xc7a100tcs324-1 crystal of the Artyx-7 FPGA. Assumptions are made about the need for a feedback mechanism from the topology level.

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INTELLIGENT INFORMATION SYSTEMS AND TECHNOLOGIES

L. A. DEMIDOVA, V. E. ZHURAVLEV. AN APPROACH TO REGULAR EXPRESSION ANALYSIS USING GRAPH NEURAL NETWORKS AND CONTRASTIVE LEARNING

Keywords: regular expressions, machine learning, feature extraction, representation learning, graph neural networks, attention mechanism, contrastive learning, clustering, k-means.

The paper explores an approach to feature extraction from regular expressions using graph neural networks and contrastive learning. A novel method for constructing graph representations of regular expressions based on their textual form is proposed. The resulting graphs preserve both semantic and structural properties of original regular expressions. To analyze these graph representations, a machine learning model is introduced, leveraging graph neural network and global aggregation with attention mechanism. Model parameters are optimized using contrastive learning in self-supervised paradigm, where similar graphs are generated automatically through random augmentations. The experiments utilize a dataset of several thousand regular expressions collected from Regex101 website. The final model, trained on a dedicated training subset, is evaluated based on the quality and interpretability of vector representations for regular expressions it produces. To assess this, clustering is performed on validation subset, demonstrating high quality of feature extraction from regular expressions and confirming the effectiveness of graph neural networks and contrastive learning.

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I. YU. KASHIRIN. RESEARCH ON INTELLECTUAL PROBLEM SOLVERS USING ALGORITHMIC ALGEBRAIC SYSTEMS

Keywords: Algebraic systems, heuristic programming, variant trees, decision plans, intelligent solvers, regular displacement patterns, computer-aided design.

The original technology of using algorithmic algebras for the research and computer-aided design of solvers of multivariate artificial intelligence problems is considered. A family of algebraic systems is constructively defined allowing us to adequately describe the processes of searching alternative problem solving plans. The technology in question uses heuristic programming and graph theory methods. The possibility of effective application of universal algorithmic algebra expressions for automated analysis and synthesis of variant trees and networks of transitions is shown. The properties of algebraic operations of element composition from a set of solution plans in order to obtain compact solution schemes for complex heuristic problems are considered.

Using the example of planning the actions of autonomous unmanned aerial vehicle, we consider the ways to obtain movement tracing, regular and optimized irregular algebraic expressions that allow us to design decision plans corresponding to these expressions. An algorithm for constructing a regular displacement network convenient for its representation by algebraic expression is given.

The results of the study will be useful in the tasks of finding solution plans in intelligent solvers of complex problems using subtasks of different classes.

The aim of the work as a scientific article is to present to specialists in the field of artificial intelligence the original technology of computer-aided design of effective intelligent problem solvers using a family of algorithmic algebras.

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V. P. KORYACHKO, S. D. VIKULIN. APPLICATION OF MACHINE LEARNING METHODS TO CLASSIFY MATERIALS BASED ON THEIR KEY CHARACTERISTICS

Keywords: machine learning, classification, neural network models, class imbalance, SMOTE, material properties, intelligent systems.

The problem of multiclass classification of materials by their key properties using machine learning methods and neural network models is considered. The aim of this work is to build an effective model for analyzing the properties of materials and for determining their class of affiliation. Special attention is paid to the problem of class imbalance that occurs when classifying rare types of materials. The method of synthetic increase of minority classes (SMOTE) is used to eliminate imbalance. The quality of the model is assessed using standard classification metrics, including accuracy, completeness, and F1-measure. The results obtained demonstrate the effectiveness of the proposed approach in the task of classifying materials and the possibility of its application in intelligent decision support systems in materials science.

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M. M. BLAGIREV, A. O. KOSTYRENKOV. ANALYSIS OF DECISION-MAKING METHODS IN DISTRIBUTED IOT SYSTEMS BASED ON MULTI-AGENT APPROACHES

Keywords: IoT, multi-agent systems, decision-making, neural network algorithms, ensemble methods, LLM, MARL, forecasting, distributed systems.

The article analyzes the existing methods of decision making in distributed IoT-systems based on multiagent approaches. Particular attention is paid to the architectures of multi-agent systems, data processing and prediction algorithms, deep learning models used in the systems under consideration. The aim of the paper is to identify advantages, disadvantages and areas of applicability of each approach, which will allow forming a holistic view of current state and development prospects of decision-making methods in distributed IoT. The paper discusses the architectures of SPDPs that incorporate modern methods of learning (MARL, VDN) and high-level control using large language models (LLM). Neural network models (GRU, LSTM) to work with temporal data and ensemble methods (Random Forest, XGBoost, CatBoost) for the tasks of determining accurate forecasting are used. The analysis of neural network models performance in tabular comparison form is given to reveal quantitative and qualitative indicators in comparison

with model prediction with real values, as well as comparison of models by mean absolute error and coefficient of determination.

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V. P. KUZNETSOV. COMPLEX RECURRENT NEURAL NETWORK

Keywords: difference equation, neural network, weight coefficient, activation function, error signal, learning algorithm, target function, gradient, partial derivative.

The concept of complex feed-forward neural network is used to recurrent networks. The network contains complex weights and complex activation functions as a complex variable function. Complex recurrent neural network may be used for identification and pre-distortion of dynamic objects with complex input and output signals. The aim of the work is to work out mathematical support for complex recurrent neural network learning. The results of experimental research of complex recurrent neural network for identification of non-linear power amplifier are presented.

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A. H. TANCEROV, E. A. DANILOV. KINEMATIC MODEL FOR GENERATING REFERENCE DYNAMIC PARAMETERS OF A USER'S SIGNATURE

Keywords: dynamic signature, identification, user authentication, neural networks, Kohonen map, standardization, biometric authentication, neural network algorithms.

One of the approaches to enhance the reliability of biometric user identification, based on the standardization of dynamic signature implementations, is considered. Identification and authentication as key processes in information security ensure the verification of user's identity and their right to access system, data, or resources. Biometric identification is carried out through registration, recording, and mathematical encoding of biometric samples (both constant physiological traits and variable behavioral characteristics), which allows the provided sample to be compared – using «one-to-many» principle – with data stored in the system, while verification follows «one-to-one» principle. Particular attention is paid to the issue of variability of behavioral traits and low discriminative capability of static signatures, which complicates their use for authentication. The aim of this work is to develop and analyze a method for the standardization of dynamic signatures based on a kinematic model that assumes approximation of additional dynamic parameter values dependence on the tuple of standard parameters. This approach allows, by knowing the characteristics of analytically constructed dependency, the formation of a partially synthetic full sample from each reduced sample, which is then used for training user identification models. The model is implemented as two- or three-layer neural network with a large number of neurons in hidden layers, and it provides for the clustering of several stable yet different signature realizations using a SOM network. The study confirms the efficiency of the proposed method, its relevance for practical applications, and the prospects for further improving the procedures for storing and utilizing dynamic signature curve samples under real-time conditions.

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SYSTEM ANALYSIS, MANAGEMENT AND INFORMATION PROCESSING

K. I. VASILIEV, A. I. NOVIKOV. METHODS OF MASKING AND RESTORING IMAGES

Keywords: mathematical methods, linear and nonlinear operators, affine and projective transformations, interpretation of indirect measurements, complex contour analysis.

When transmitting information over open communication channels, it is often necessary to conceal this information without using special encryption methods. The simplest methods are based on blurring the original image using a linear filter with a properly selected transformation core (mask). On the receiving side, with this approach, it becomes necessary to restore masked information. The task of restoring blurred signals belongs to the class of incorrect tasks. Neglecting transformation core by third parties and the need to use sufficiently complex mathematical apparatus to restore information on the receiving side create conditions for more reliable concealment of official information. The article discusses two approaches to masking and, accordingly, to information recovery. In the first case, blurring is performed on transmitting side and restoration on receiving side using either a regularization algorithm or an iterative method. In the second approach, a direct discrete Fourier transform (DFT) of original signal is performed first. Then the matrix of coefficients of forward DFT is blurred. On the receiving side, information recovery is performed in two stages in reverse order. The results of experimental studies of information masking and recovery with each approach are presented.

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A. A. KUZMENKO, V. A. SHKABERIN, V. M. SKANTSEV, I. A. YEREMIN, E. S. MUZALEVSKY, O. V. LABUZ. MANAGEMENT SYSTEM FOR CONSTRUCTING INDIVIDUAL EDUCATIONAL TRAJECTORIES IN «UNIVERSITY-ENTERPRISE» SPACE

Keywords: individualization of learning, learning analytics, individual learning path, learning optimization, competency matrices.

The article examines the problem of imbalance between the competencies of university graduates and current labor market requirements. A model for constructing individual educational trajectories in «University-Enterprise» system based on a number of formalized data analysis methods is proposed. Data processing algorithms are considered in the context of educational analytics, allowing for real-time adjustment of trajectories taking into account academic performance, student preferences, and labor market trends.

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Y. B. SHCHENEVA. MULTI-CRITERIA DATA ANALYSIS ALGORITHM FOR DECISION SUPPORT SYSTEMS

Keywords: multi-criteria data analysis, decision support systems, mathematical model, technical equipment, multi-criteria optimization problem, method algorithm, information system.

The problem of developing a decision support system based on multi-criteria data analysis is considered in this article. The aim of the work is to develop an algorithm for

multi-criteria data analysis for decision support systems on the basis of which the automation of decision-making process will be implemented taking into account criteria and constraints of the problem being solved. Automated approaches to find the main criteria that determine «technical readiness» coefficient are offered to be used. A distinctive feature of the results obtained using the considered method from those previously studied is the comprehensive consideration of the necessity for technical support of technical equipment repair processes. The development of information system for decision-making based on multi-criteria data analysis allows choosing the best result taking into account criteria and limitations of functional module of mobile equipment repair facilities. Practical result of the research is the methodology of the information system created to solve the problem of automated determination of the necessity for technical support of technical equipment repair processes.

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A. H. TANCEROV, E. A. DANILOV, A. I. MARTYSHKIN. REVIEW AND COMPARISON OF SELECTED METHODS FOR SIGNATURE AUTHENTICATION BASED ON DYNAMIC PARAMETERS

Keywords: signature authentication, dynamic signature, features, parametric methods, functional methods, support vector machine, neural networks.

The article highlights trends in the development of dynamic signature authentication systems market, which is projected to experience significant growth with a 21.5 % CAGR from 2023 to 2028. The relevance of this research is supported by the increasing number of patents and scientific publications in the field. The paper presents a comprehensive classification of features used in signature authentication procedure, systematized by categories. The aim of the work is to conduct a comprehensive review and critical analysis of existing parametric and functional methods for dynamic signature authentication. A comparative evaluation of effectiveness and computational costs of the methods under consideration is carried out, their strengths and weaknesses are identified, and practical application scenarios for verification systems are justified. In addition, the study examines prospects for integrating machine learning and artificial intelligence techniques to enhance reliability and security of signature authentication processes, and emphasizes the need to address information security issues and further optimize data processing algorithms in light of the growing number of patent applications and scientific publications in this field.

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INFORMATION AND MEASURING SYSTEMS

A. M. ABRAMOV. HARDWARE AND SOFTWARE IMPLEMENTATION AND EXPERIMENTAL STUDY OF THE RELATED HISTOGRAM METHOD FOR TESTING THE ANALOG INPUT AND CONVERSION CHANNEL OF THE NI PCIE-6321 DATA ACQUISITION BOARD

Keywords: histogram, integral nonlinearity, code, data acquisition board, analog-to-digital converter, measuring signal, analog adder, module, experiment.

The paper considers the problem of hardware and software implementation of a new method of metrological testing of ADCs, called coupled histograms method, which re-

duces the requirements for reference measuring instruments in terms of accuracy class due to the consideration of nonlinear component of measuring signal (MS). The aim of the work is to experimentally study the method of coupled histograms to confirm the validity of its theoretical conclusions. The object of the study was a 16-bit channel of analog input and con-version of NI PCIe-6321 data acquisition board with integral non-linearity of 4 LSB (least significant bit). The 16-bit block of NI PCIe-6321 analog output was used to generate initial MS (periodic voltage of triangular shape) and displacement signal (reference voltage). Analog adder was used to shift initial MS up and down. Maximum deviation of actual shape of generated MS from ideal linear shape during the experiment was 3.1 % of MS input range. The results of the experiment showed that a new method, with IC generator bit depth and the object of study being the same, can accurately estimate the boundaries of integral nonlinearity (INL) of the latter compared to histogram method with nonlinear IC. In addition, the results of testing analog input and conversion channel of NI PCIe-6321 data acquisition board using coupled histograms method and sliding histogram method were compared.

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PHYSICAL ELECTRONICS AND NANOELECTRONICS

V. S. KHILOV, V. V. TREGULOV, A. I. IVANOV, N. N. MELNIK, V. G. LITVINOV, N. V. RYBINA, N. B. RYBIN. STRUCTURE AND ELECTROPHYSICAL PROPERTIES OF POROUS SILICON FILMS WITH A P-N JUNCTION FORMED BY PULSED LASER IRRADIATION

Keywords: porous silicon, metal-stimulated etching, p-n junction, laser ablation, Raman scattering, photoelectric characteristics, current-voltage characteristics, capacitance-voltage characteristics, deep energy levels.

The possibility of forming a p-n junction inside a porous silicon film grown by metal-assisted etching by irradiating it with nanosecond laser pulses of ytterbium fiber laser with wavelength of 1064 nm is shown. The study of current-voltage and capacitance-voltage characteristics of the samples showed that their electrophysical characteristics are significantly affected by traps with deep levels. The irradiation modes in which the base region of p-n junctions has quantum size effect caused by the decrease in nanosized silicon crystallites generation were established. The mechanisms of porous films structure transformation under laser irradiation were established. The influence of traps and quantum size effect on electrophysical and photoelectric characteristics of the structures studied is shown.

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E. A. KOZLOV, A. A. TRUBITSYN, E. YU. GRACHEV. LIMIT ESTIMATES OF MINIMUM FOCAL SPOT SIZES IN MICROFOCUS X-RAY TUBES

Keywords: microfocus X-ray tube, focal spot diameter, electron optical brightness, spherical aberration, cathodes, magnetic lenses.

The paper presents a theoretical analysis of maximum achievable focal spot size in microfocus X-ray tubes. The aim of the work is to determine theoretical limits of focal spot size reduction in microfocus

X-ray tubes taking into account the influence of electron beam parameters (current, brightness) and spherical aberration of magnetic objective lens. Analytical dependences of focal spot diameter on the angle of convergence of electron beam, brightness, spherical aberration coefficient, and the focal length of magnetic lens are established. The authors show that the use of modern cathodes (LaB6, Schottky) and magnetic lenses with a radial gap makes it possible to achieve submicron sizes of the focal spot (0,1 – 1 μm). The results of the work are important for the development of domestic X-ray systems of nondestructive testing and microtomography, providing competitiveness with foreign analogs.

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