INVESTIGATING THE PHYSICAL AND INFORMATION PARAMETERS OF NANOSCALE ELEMENTS AS PART OF THE COMPUTING SYSTEMS WITH THE NEURAL NETWORK ARCHITECTURE

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I. INTRODUCTION

In today's world computing devices define the level of efficiency relating to a multiple problem-solving process in science and technology. The performance of a computing system is considered a critical parameter, in pursuit of which they create more and more up-to-date and sophisticated technologies in the field of their hardware implementation.

Nowadays conceptually new opportunities for building high-performance computing systems appear at the confluence of nanoscale technologies and neural network technologies [1]. The reason for this is that a system acquires some extra opportunities due to a combination of parallel information processing and nanoscale electronic element base [2, 3].

However, as a rule, the application of nanoscale electronic elements reduces a system's reliability indices which should be established at the design engineering stage and which are not achieved automatically [4]. The reliability indices of such systems are characterized by their operation accuracy. As for the elements of computing systems, they should be studied as uniform physical and information objects. Consequently, the operation accuracy of the systems under study represents the degree of conformity of the real value of the physical and information parameters in question to the theoretical (nominal) values of the parameters of the system's electronic elements.

Thus, this study aims to define a correlation between the physical and information parameters of the nanoscale electronic elements integrated into a computing system and it also aims to define the impact of variation of these parameters on the system's reliability indices.

II. METHODS

A computer model of the artificial neural network (ANN), built in the MATLAB environment, has been investigated in the course of the research. The model has been taught to make an approximation of the differential equation with maximum precision.

Using nanoscale electronic elements as the research object is an essential part of the experiment. In particular, the research involves models of the nanoscale titanium oxide-based memristors as synaptic connections (synapses) between the layers of neurons and the nanoscale field-effect graphene-based transistors which control signals inside the system [5].

Several models of nanoscale titanium oxide-based memristors have been developed on the basis of the stated-above mathematical model in the SIMSCAPE environment, which is used to simulate physical systems, integrated into the MATLAB mathematical computation toolkit.

Besides, the field-effect graphene-based transistor has been selected as one of the nanoscale electronic elements integrated into a computation system. Such field-effect transistors function as the control matrix elements inside a computation system under development. A mathematical model of the nanoscale graphene-based transistor has been formulated on the basis of the theory [6, 7].

Several models of nanoscale graphene-based transistors have been developed on the basis of the mathematical model in the Simscape environment, which is used to simulate physical systems and which is part of the MATLAB mathematical computation toolkit. A two-phase methodology has been used within the scope of the experimental research into the physical parameters of memristors.

In the first phase it is intended to formulate and apply some possible mechanisms for impacting various properties of the nanoscale objects under study, capable of triggering the system's reaction in the form of variation of its parameters' values.

The second phase is needed to define qualitative and quantitative dependences between the variation of the parameters of the system's elements and the properties of its elements predetermining such a variation. The methods for analyzing the physical parameters of the memristor, based on the proposed approach, come down to a few procedures:

- Synthesizing computer models of the memristors meeting the specified requirements.
- Developing a computation system in the form of ANN to define the indices of information conversion accuracy when the information state of the system's elements has been varied.

- Modeling various impacts on the geometrical parameters of the memristors functioning as synaptic connections in the ANN.
- Measuring the system's technical indices and forming statistical data on variations of the elements' parameters when there are different levels within the factor impacting the memristor's geometrical parameters.
- Obtaining analytical estimation and defining the target dependence of the variation in the system's operation and the variation in the elements' parameters caused by the impact on their properties.
- A few geometrical parameters of the memristor, acting as the factor impacting the parameter properties of synaptic connections made via use of the memristor, have been brought out: the top contact's surface, the lower contact's surface and the dielectric layer's thickness.
- The overall research results are demonstrated in tables 1 and 2.

Table 1 – The results of the experimental research into the geometrical parameters of memristors

Factor affecting the properties of memristor	Changes the geometrical parameter of the synapse	Changing the information parameter of the synapse	Errors of functioning the system (SSE criterion)
The thickness of memristor's doped region	0 nm	0 %	1.01·10-15
	0.25 nm	0.4 %	3.02·10-15
	0.5 nm	0.9 %	7.20·10-15
	0.75 nm	1.5 %	8.42·10-15
	1 nm	2.7 %	1.17·10-14
	1.25 nm	3.5 %	2.62·10-14
	1.5 nm	5.1 %	6.32·10-14
	1.75 nm	6.2 %	8.52·10-14
	2 nm	8.6 %	5.62·10-13
	2.25 nm	14 %	2.41·10-12
	2.5 nm	18.1 %	7.15·10-11
	2.75 nm	22.8 %	4.51·10-10
	3 nm	28.2 %	5.05·10-7
	3.25 nm	32.2 %	2.31·10-5
	3.5 nm	36.2 %	5.13·10-1
	3.75 nm	45.8 %	1.96·101

Table 2 – The results of the experimental research into the geometrical parameters of memristors

Factor affecting the properties of memristor	Changes the geometrical parameter of the synapse	Changing the information parameter of the synapse	Errors of functioning the system (SSE criterion)
Upper contact surface of memristor	0 nm	0 %	7.54·10-15
	4 nm	0.6 %	9.39·10-15
	8 nm	0.7 %	9.40·10-15
	12 nm	1.1 %	1.23·10-15
	16 nm	1.2 %	1.34·10-15
	20 nm	1.6 %	5.05·10-15
	24 nm	1.7 %	5.71·10-14
	28 nm	2.1 %	1.55·10-14
	32 nm	17 %	7.72·10-10
	36 nm	25 %	3.21·10-5
	40 nm	34 %	6.30·10-2
Bottom contact surface of memristor	0 nm	0 %	3.57·10-15
	4 nm	0.5 %	4.31·10-15
	8 nm	0.6 %	5.15·10-15
	12 nm	0.9 %	8.68·10-14
	16 nm	1.2 %	9.61·10-14
	20 nm	1.3 %	9.76·10-13
	24 nm	1.5 %	1.67·10-13
	28 nm	1.5 %	1.67·10-12
	32 nm	13 %	6.60·10-11
	36 nm	21 %	1.15·10-5
	40 nm	27 %	5.11·10-3

A set of memristors has programmatically been exposed to a variation of the quantitative values of the factors at different levels. Each time the memristors' properties varied, the quantitative values of the variations in the information parameters of the system's elements were registered. What is more, according to the last item on the plan of the experiment, the ANN's operation with the corresponding variations in the information parameters of the synapses was emulated.

The quantitative dependences shown in tables 1 and 2 will make it possible to obtain the limits of tolerance on a variation in the elements' parameters, and the qualitative dependences will help define the mechanisms impacting the physical properties of the elements for the purpose of optimizing the system's technical indices.

The methodology aimed to study the information parameters of memristors replicates the one used before, and it also consists of two phases split into five identical procedures (Table 3).

Table 3 – The results of the experimental research into the information parameters of memristors

The change in input voltage	Changing the information parameter of the synapse	Errors of functioning the system (SSE criterion)
0 %	0 %	1.42·10-15
1 %	0.3 %	2.12·10-15
2 %	0.8 %	9.31·10-15
3 %	1.2 %	3.82·10-14
4 %	1.5 %	5.47·10-14
5 %	1.9 %	4.13·10-13
6 %	2.8 %	3.40·10-12
7 %	3.2 %	6.45·10-12
8 %	3.9 %	1.30·10-11
9 %	8.6 %	2.28·10-8
10 %	14.2 %	2.61·10-4

Table 3 shows the results of a variation of the physical and information parameters of memristors caused by a variation in the input voltage.

III. CONCLUSIONS

This article contains an experimental research defining a correlation between the physical and information parameters integrated into a computation system of nanoscale electronic elements, and it has defined an effect of the variation of these parameters on the system's reliability indices.

The obtained results demonstrate that the analyzed physical phenomena and processes in the nanoscale elements, which carry information in a neural network computation system, define the reliability index for this system since geometrical parameters impact their information parameters defining the system's operation accuracy.

The undertaken study serves as a practical basis when solving the problem of analysis and synthesis of the tolerance limits on the physical and information parameters of nanoscale electronic elements. This helps ensure the specified reliability indices and the operation accuracy of the designed neural network computation components of telecommunication systems.

ACKNOWLEGMENTS

The reported study was funded by RFBR, according to the research project No. 16-37-60061 mol_a_dk.

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THE STUDY OF CONTRIBUTION OF THERMIONIC AND TUNNEL COMPONENTS IN HETEROSTRUCTURES WITH A SINGLE QUANTUM WELL InGaAs/GaAs BY ADMITTANCE METHODS

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I. INTRODUCTION

Quantum-dimensional structures are characterized by discrete energy spectrum and at specific conditions may reveal another quantum-mechanical effect namely, tunnel effect. The admittance method is the most prime and efficient research technique, both for bulk semiconductors and heterostructures with quantum well (QW) [1, 2, 5, 7]. It is known that in doped heterostructures due to redistribution of charge carriers the bottom of conduction band (or the top of valence band) are bent, forming additional barriers, close to triangular in form. In [4] the detailed theoretical and experimental studying of processes of capture and emission of charge carriers in heterostructures with QW is presented. It is shown that in heterostructures containing QW there are the competing mechanisms of emission of charge carriers: thermionic emission and tunneling, which make the different contribution to total conductance at different temperatures.

In this work the isotype -type heterojunctions with elastically strained single quantum well (SQW) $In_xGa_{1-x}As$/GaAs grown by MOCVD were investigated [1, 2]. The thickness of the active layer of samples were 6.0…9.5 nm. The parameters and quality of structures were controlled by HRXRD, local cathodoluminescence, etc. Measurements were taken in the temperature range from 10 to 375 K, voltage range of ±40 V, and the frequency range of test signal was 20 Hz – 2 MHz. The experiments on series of samples with SQW $In_xGa_{1-x}As$/GaAs (x=0.065 … 0.29) were carried out. It was found that at small content of In in solid solution it is not possible to notice the features in conductance spectra, related to the tunnel emission, because the small value of band discontinuity gives the response which cannot be registered even at low temperatures.

II. EXPERIMENTAL RESULTS AND DISCUSSION

The best qualitative characteristics are obtained for structure x=0.29 (end of pseudomorphous growth). Results are presented by the integrate figure 1, where in the center the characteristics CV-GV are located, and in the taken-out drawings – the temperature spectra of conductance in the reference points of the CV-curve; at the plateau, in adjacent to the plateau regions, and far from it. It is noticeable that at low temperatures the delay effects begin to play an important role, and at temperatures close to RT the SQW manages to relax at frequencies of the test signal (the quasi-static mode of measurements is implemented). The conductance-voltage (GV) characteristics of structure clearly demonstrate the complex, resonance mechanism of formation of the active conductance for the structure with SQW. The strong modification is experienced by temperature spectra of conductance of the structure depending of the reverse bias. Peaks are the most clearly expressed at the reverse bias -2.3 V that corresponds to the part of CV characteristic adjoining the plateau from the small biases. This area is responsible for the beginning of intensive thermionic emission of charge carriers from quantization levels with the electric field penetrating into the QW. The temperature shift of the maximum of conductance on frequency confirms the thermally activation nature of studied process. The observed phenomenon has resonance character and exists in a narrow voltage range, about 0.5 V.