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ЭНЕРГОСБЕРЕГАЮЩИЕ НАНОКОМПОЗИТНЫЕ ПОКРЫТИЯ НА ОСНОВЕ МЕДИ

Исследованы спектрально-селективные характеристики металлодиэлектрических нанокомпозитных покрытий на основе меди. Разработан вычислительный алгоритм определения коэффициентов отражения и пропускания нанокомпозитных металлодиэлектрических структур на основе меди в диэлектрических матрицах SiO2. Выполнено численное моделирование их оптических характеристик в спектральном диапазоне от 0,3 до 3 мкм для различных вариантов структур. Обсуждаются возможности практической реализации и применения нанокомпозитных структур на основе меди в качестве энергосберегающих.

Ключевые слова: металлодиэлектрические структуры, спектрально-селективные характеристики, нанокомпозитные покрытия, энергосбережения.

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SYNTHESIS OF NANOELECTRONIC DEVICES WITH PROGRAMMABLE STRUCTURES

The synthesis of reliable programmable nanoelectronic devices based on the technology of quantum automata has been described.While constructing majority circuits of combinational and sequential types the theory of finite automats is using. The order of construction and programming of various types of arithmetic-logic devices has been analyzed.

Keywords: quantum nanodots, majority elements, field programmable gate array.

Introduction. The contradictions between specialization and universatility can be eliminated through the development of field programmable gate array (FPGA), which algorithms of work can be changed at the request of the designer of a particular computer equipment, that is by creating the arithmetic logic circuits with programmable features.

Relevance of research. The development of theory and practice of using a majority principle is an urgent problem at present time, because the performance of nanoelectronic computing systems with programmable structures significantly reduces their cost and greatly simplifies the phase of automated circuit design. One programmable nanocircuit replaces from 30 to 150 integrated circuits with medium scale of integration.

Problem statement. The problem of developing the design principles of the reliable computer technology is very important nowadays. Application of mathematical and circuit analysis along with computer aided design can significantly improve the reliability of designing devices.

Main material. The most promising area of nanoelectronics is creation of multi-functional subsystems when one module combines a large number of logic elements into a single functional unit, intended to implement complex logic functions. These subsystems must satisfy the following basic requirements:
- have a minimum number of external connections;
- have a hardware compatibility;
- use the same type of cells if it is possible;
- have a property extension, that is to have a flexible structure.

To implement systems with variable structure (adaptive system), besides, it needs to be able to programmatically change the technical parameters of the subsystems during or before work. In terms of cheapening of nanoelectronic subsystems and improving the reliability of their work they should be performed on the same type of cells with the same configuration of connections between cells [1].

Programmable nanoelectronic device, which consists of three universal majority elements (UME), duly connected to each other (fig. 1), can be used as such cell to build majority adaptive systems (MAS). Informational (x_3, x_2, x_1, x_0) and control signals (r_2, r_1, r_0) are submitted to the inputs of UME [2].

With the help of FPGA of this type all the functions of two or three arguments can be implemented, including functions of sum, difference, carry and loan, functions of one, two and three memory elements, and some functions of four or five arguments. The feature of FPGA is that its logical possibilities and connections may be changed by the program that allows it to be used for constructing of MAS. The most important functions in majority basis, implemented on the base of FPGA, are shown in table 1.
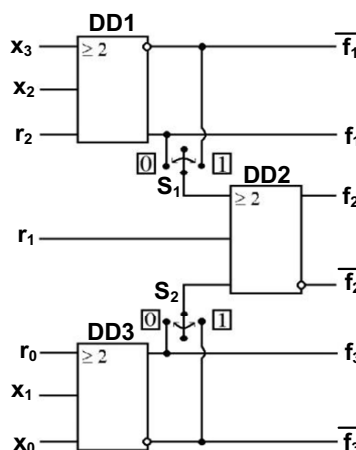
Fig.1. Block diagram of a universal programmable nanoelectronic device

FPGA is a functionally complete unit, because in its composition are functionally complete UME.

Synthesis of majority systems on the base of FPGA is recommended to do according to the following order:

1. The bolean functions, which are specified or obtained, are presented in majority basis.

2. The minimization of obtained majority function is performed.

3. The row, which is equivalent to the minimum form of the majority function, is sought in table 1.

4. A block diagram of the given subsystem is created, considering the opportunities of UME and specified number of inputs.

The functioning of the systems on quantum cellular automata (QCA) is based on the interaction of Coulomb forces of quantum dots for performing logic functions. They are designed to reduce the use of transistors and to solve the problems of density and connection of devices. The cellular automata consists of grouped quantum dots, connected with tunnel junctions and capacitors. Quantum

dots are regions of low potential, which are surrounded by a ring of high potential. There are several methods of their formation, but the most common ones is metallization. In cellular automata four quantum dots are placed in the corners of a square. Each automata contains two electrons, which are placed diagonally, because of the action of Coulomb repulsion forces, in opposite corners (fig. 2). Two possible location of these electrons are marked as polarization of cells $P = -1$ and $P = +1$ [1].

Table 1

Examples of the most important functions that can be implemented on FPGA

| №	r_2	r_1	r_0	f_1	f_2	f_3	Numb. of output func.
1	0	0	0	$maj(x_3,x_2,0)$	$maj(x_3x_2,x_1x_0,0)$	$maj(x_1,x_0,0)$	24
2	0	0	1	$maj(x_3,x_2,0)$	$maj(x_3x_2,x_1 \vee x_0,0)$	$maj(x_1,x_0,1)$	24
3	0	1	0	$maj(x_3,x_2,0)$	$maj(x_3x_2,x_1x_0,1)$	$maj(x_1,x_0,0)$	24
4	0	1	1	$maj(x_3,x_2,0)$	$maj(x_3x_2,x_1 \vee x_0,1)$	$maj(x_1,x_0,1)$	24
5	1	0	0	$maj(x_3,x_2,1)$	$maj(x_3 \vee x_2,x_1x_0,0)$	$maj(x_1,x_0,0)$	24
6	1	0	1	$maj(x_3,x_2,1)$	$maj(x_3 \vee x_2, x_1 \vee x_0,0)$	$maj(x_1,x_0,1)$	24
7	1	1	0	$maj(x_3,x_2,1)$	$maj(x_3 \vee x_2,x_1x_0,1)$	$maj(x_1,x_0,0)$	24
8	1	1	1	$maj(x_3,x_2,1)$	$maj(x_3 \vee x_2, x_1 \vee x_0,1)$	$maj(x_1,x_0,1)$	24
9	0	0	x_4	$maj(x_3,x_2,0)$	$maj(x_3x_2,maj(x_1,x_0,x_4),0)$	$maj(x_1,x_0,x_4)$	44
10	0	x_4	0	$maj(x_3,x_2,0)$	$maj(x_3x_2,x_1x_0,x_4)$	$maj(x_1,x_0,0)$	40
11	0	x_4	x_5	$maj(x_3,x_2,0)$	$maj(x_3x_2,maj(x_1,x_0,x_5),x_4)$	$maj(x_1,x_0,x_5)$	76
12	x_4	0	0	$maj(x_3,x_2,x_4)$	$maj(maj(x_3,x_2,x_4),x_1x_0,0)$	$maj(x_1,x_0,0)$	44
13	x_4	0	x_5	$maj(x_3,x_2,x_4)$	$maj(maj(x_3,x_2,x_4),maj(x_1,x_0,x_5),0)$	$maj(x_1,x_0,x_5)$	48
14	x_4	x_5	0	$maj(x_3,x_2,x_4)$	$maj(maj(x_3,x_2,x_4),x_1x_0,x_5)$	$maj(x_1,x_0,0)$	76
15	x_4	x_5	x_6	$maj(x_3,x_2,x_4)$	$maj(maj(x_3,x_2,x_4),maj(x_1,x_0,x_6),x_5)$	$maj(x_1,x_0,x_6)$	80
16	1	f_2	0	$maj(x_3,x_2,1)$	$maj(x_3 \vee x_2,x_1x_0,f_2)$	$maj(x_1,x_0,0)$	Trigger with control inputs
17	f_1	0	f_3	$maj(x_3,x_2,f_1)$	$maj(maj(x_3,x_2,f_1),maj(x_1,x_0,f_3),0)$	$maj(x_1,x_0,f_3)$	Two triggers
18	f_1	f_2	f_3	$maj(x_3,x_2,f_1)$	$maj(maj(x_3,x_2,f_1),maj(x_1,x_0,f_3),f_2)$	$maj(x_1,x_0,f_3)$	Three triggers
19	f_2	f_2	$\overline{f_2}$	$maj(x_3,x_2,f_2)$	$maj(maj(x_3,x_2,f_2),maj(x_1,x_0,\overline{f_2}),f_2)$	$maj(x_1,x_0,\overline{f_2})$	Accum. adder
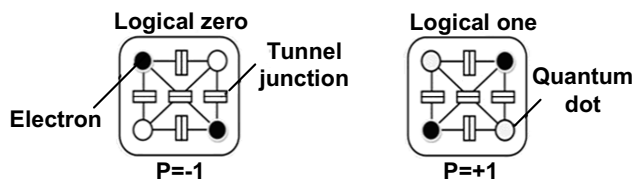
Fig. 2. Quantum cells in states of logical zero and logical one

In table. 1 $x_6, x_5, x_4, x_3, x_2, x_1, x_0$ – input informational signals, represented either in direct or inverse code; r_2, r_1, r_0 – control signals; f_3, f_2, f_1 – output signals.

Let us synthesize the function of logical adding of four arguments, using aided design system QCADesigner [3]:

$$f_2 = maj(x_3 \vee x_2, x_1 \vee x_0, 0),\tag{1}$$

which corresponds to the majority equivalent in the sixth row in table. 1.

Functions of logical addition of two of the four arguments are formed on two additional outputs of FPGA:

$$f_1 = x_3 \vee x_2 = maj(x_3,x_2,1),\tag{2}$$

$$f_3 = x_1 \vee x_0 = maj(x_1,x_0,1).\tag{3}$$

Simulation results. To program the functions (1), (2) and (3) keys S_1 and S_2 in block diagram of FPGA (fig. 1.) must be set in the state 0, and the programmable inputs must be set in the polarizations $+P = 1$ for $r_2 = r_0 = 1$, and polarizations $-P = -1$ for $r_0 = 0$ [2].

The fig. 3, a shows a block diagram of FPGA, which is built on the working field of QCA Designer [3]. It consists of 55 quantum cells, which have size 18x18 nm, with 4 quantum dots about 5 nm in diameterand 20 nm distance between their centers. The total size of FPGA is (198x218) nm. It has four informational inputs x_3, x_2, x_1 and x_0, three programmable inputs with polarizations $+P = 1$ and $-P = -1$, and three pairs of complementary outputs f_1, f_2 and f_3.

The results of computer-aided design of FPGA time characteristics are shown on fig. 3, b. Positive pulses correspond to positive polarizations $+P = 1$, and negative – negative polarizations $-P = 0$. The corresponding truth table of FPGA for this programming mode is shown in table 2.

With the change of polarization of the inputs r_2, r_1, r_0 and set the keys S_1 and S_2 in different positions FPGA with seven inputs (fig. 1) can be programmed for 192 logical functions of two and four inputs combinational circuits.
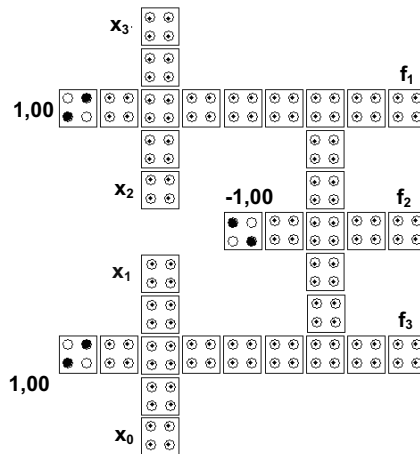
a)
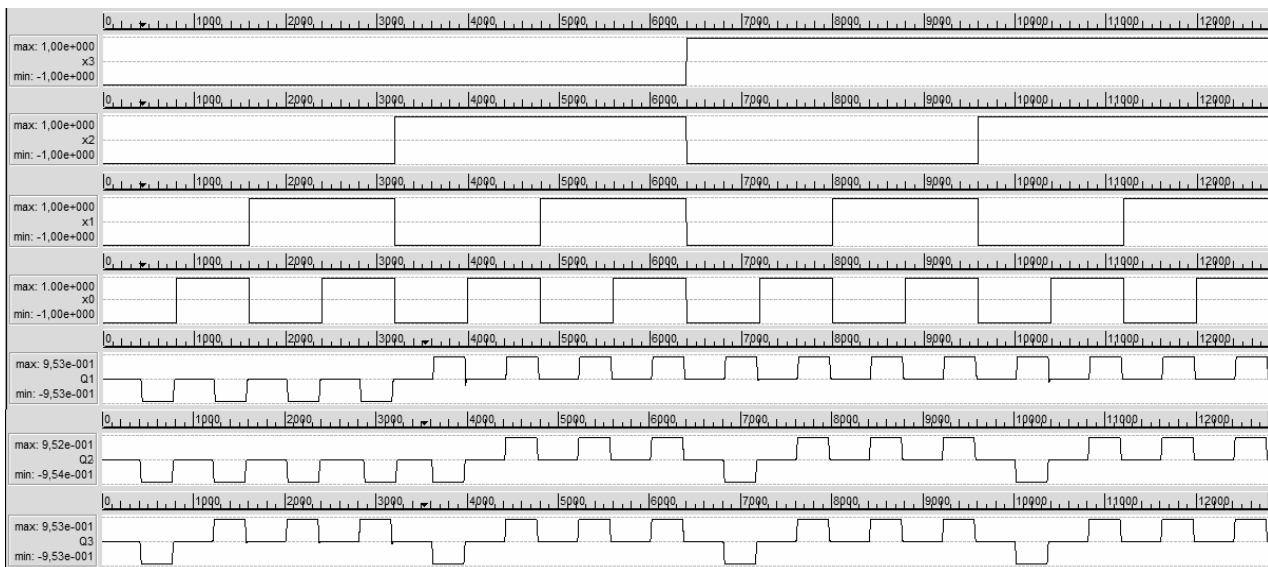
b)

**Fig. 3. Computer-aided design of combinational FPGA on QCA**

Table **2**

Truth table of functions $maj(x_3\ x_2, x_1\ x_0, 0)$

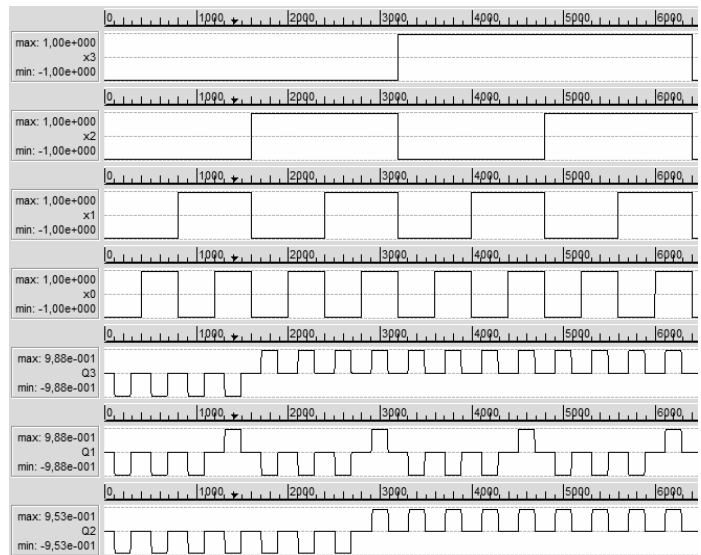| x_3	x_2	x_1	x_0	f_1	f_2	f_3
0	0	0	0	0	0	0
0	0	0	1	0	0	1
0	0	1	0	0	0	1
0	0	1	1	0	0	1
0	1	0	0	1	0	0
0	1	0	1	1	1	1
0	1	1	0	1	1	1
0	1	1	1	1	1	1
1	0	0	0	1	0	0
1	0	0	1	1	1	1
1	0	1	0	1	1	1
1	0	1	1	1	1	1
1	1	0	0	1	0	0
1	1	0	1	1	1	1
1	1	1	0	1	1	1
1	1	1	1	1	1	1

With the change of polarization of the inputs r_2, r_1, r_0 and set the keys S_1 and S_2 in different positions FPGA with seven inputs (fig. 1) can be programmed for 192 logical functions of two and four inputs combinational circuits.

Now lets synthesize the circuit for the 16th raw of the table 1, which consists of two majority elements with separate inputs x_3, x_2 and x_1, x_0. Direct outputs f_1 and f_3 of these majority elements are combined into RS-triggers, covered with feedback f_2 (fig. 1). On fig. 4, a built this sequential nanoelectronic circuit in the form of QCA Designer, and the results of time simulation are shown on fig. 4, b. It has a size (350x240) nm and consists of 48 quantum dot automatas.

The results of computer-aided design of FPGA time characteristics are shown on fig. 3, b. Positive pulses correspond to positive polarizations +P=1, and negative – negative polarizations -P=0. The corresponding truth table of FPGA for this programming mode is shown in table. 2.
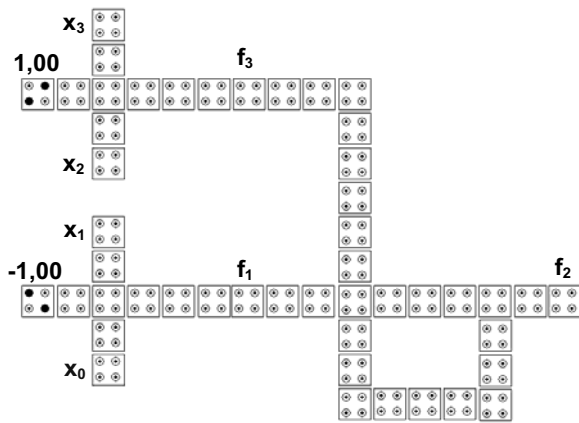
a)　　　　　　　　　　　　　　　　　　　b)

Fig. 4. Computer-aided design of sequential FPGA on QA

Verification table of FPGA states are given in table 3.

Table 3

Truth table of functions maj(maj(x_3,x_2,1),maj(x_1,x_0,0),f_2)

x_3	x_2	x_1	x_0	f_1	f_2	f_3
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	0	1	0	0	0	0
0	0	1	1	0	0	1
0	1	0	0	1	0	0
0	1	0	1	1	0	0
0	1	1	0	1	0	0
0	1	1	1	1	1	1
1	0	0	0	1	1	0
1	0	0	1	1	1	0
1	0	1	0	1	1	0
1	0	1	1	1	1	1
1	1	0	0	1	1	0
1	1	0	1	1	1	0
1	1	1	0	1	1	0
1	1	1	1	1	1	1

Conclusions. In the nearest ten years semiconductor components of big integrated circuits will achieve quantum technological limitations and will not meet the increasing performance requirements of computer technology. Therefore, new nanotechnologies are developing so actively, that would provide significantly higher performance. One of such developments is the quantum cellular automata and created on its basis systems with programmable structures. As shown above, such devices will provide realization of full system of logic functions for both combinational and sequential arithmetical and logical computing devices.

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СИНТЕЗ ПРОГРАМОВАНИХ НАНОЕЛЕКТРОННИХ ПРИСТРОЇВ

Описаний синтез надійних програмованих наноелектронних пристроїв на базі технології квантових автоматів. При побудові мажоритарних схем комбінаційного та послідовностного типів використовується теорія кінцевих автоматів. Проаналізовано порядок побудови та програмування різних типів арифметико-логічних пристроїв.
Ключові слова: квантові автомати; мажоритарні елементи; логічні елементи, програмовані користувачем.

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СИНТЕЗ ПРОГРАММИРУЕМЫХ НАНОЭЛЕКТРОННЫХ УСТРОЙСТВ

Описан синтез надежных программируемых наноэлектронных устройств на базе технологии квантовых автоматов. При построении мажоритарных схем комбинационного и последовательностного типов используется теория конечных автоматов. Проанализированы порядок построения и программирования различных типов арифметико-логических устройств.
Ключевые слова: квантовые автоматы; мажоритарные элементы; логические элементы, программируемые пользователем.