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STUDY OF TECHNOLOGICAL PROCESSES OF DETECTORS WITH Si(Li) SEMICONDUCTOR USING COMPUTER-MATHEMATICAL MODELS

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Abstract

The article analyzed the use of semiconductor nuclear radiation detectors, which are of great importance in the field of electronic technologies today. The volt-ampere characteristics of large nuclear radiation eight-band semiconductor coordinate-sensitive detectors were compared using a mathematical model. The values of the volt-ampere characteristics of all the bands of the semiconductor eight-band detectors were compared, and this process was carried out using the MATLAB software package. Mathematical modeling used the method of least squares. The obtained results showed that the proposed equivalent electrical circuit allows to describe the current and voltage values of Si(Li) p-i-n structures with high accuracy. It was found that the largest difference in the ratio of the current strength values in the results obtained by practice and modeling is 0.2358.

Keywords: Computer mathematical model, semiconductor detector, current, voltage, tape, coordinate-sensitive.

Introduction

In recent years, various types of semiconductor devices have been developed that are widely used in electronic equipment. Among them, semiconductor nuclear radiation detectors, which successfully compete with charged particle counters of another type (radioactive radiation charging) have a special place [1]. Semiconductor detectors are used in the production of high-grade pure substances in nuclear power, applied and fundamental scientific research, medicine, agriculture, environmental protection and other fields of national economy [2-3].

Materials and Methods

In this work, the electrophysical characteristics of large-scale nuclear radiation eight-band semiconductor coordinate-sensitive detectors (VAX) were compared using a mathematical model. In this case, the input parameter was represented by voltage, and the output parameter by current.

The research of the mathematical model of the process was based on the conducted experiments. Here, the input parameter is the voltage, and the output parameter is the current of the sample. The construction of the mathematical model of the process was carried out on the basis of the conducted experiments. Table 1 shows the results of the relationship between the obtained current and voltage based on the experimental experience for each of the bands of the eight-band detector.

Table 1

Voltage	**Detector band number**							
	1	2	3	4	5	6	7	8
U (volt)	I (μA)							
10	0,2	0,4	0,2	0,2	0,6	0,3	0,2	0,3
20	0,3	0,5	0,4	0,3	0,8	0,35	0,3	0,5
30	0,4	0,6	0,6	0,34	0,9	0,4	0,4	0,6
40	0,45	0,7	0,7	0,36	1,1	0,48	0,5	0,7
50	0,46	0,8	0,9	0,39	1,25	0,53	0,6	0,8
60	0,48	0,9	1,1	0,43	1,49	0,61	0,7	0,84
70	0,53	1	1,2	0,47	1,62	0,62	0,8	0,9
80	0,68	1,2	1,4	0,52	1,8	0,66	1	1
90	0,71	1,3	1,6	0,56	2	0,71	1,2	1,1
100	0,78	1,4	1,7	0,59	2,1	0,75	1,3	1,2
110	0,8	1,6	2,1	0,63	2,26	0,84	1,7	1,28
120	0,82	1,9	2,4	0,64	2,4	0,86	1,9	1,3
130	0,9	2,1	2,5	0,68	2,6	0,9	2	1,36
140	1,2	2,9	3	0,85	2,9	1,1	2,4	1,6

Results and Discussion

Graphs of the dependence of the output parameter on the input parameter to evaluate the static characteristics of the object under study are presented in Fig. 1. It shows the results obtained for each band of the eight-band coordinate-sensitive detector. As can be seen from the obtained experimental results (Fig. 1), in order for the mathematical model to be closer to the initial process, it should be presented in the form of a quadratic equation. Then, the type of model can be expressed in the form of formula (1) as follows:

$$y = (ax^2 + bx - c) \quad \text{or} \quad \mu = (ax^2 - bx + c) \qquad (1)$$

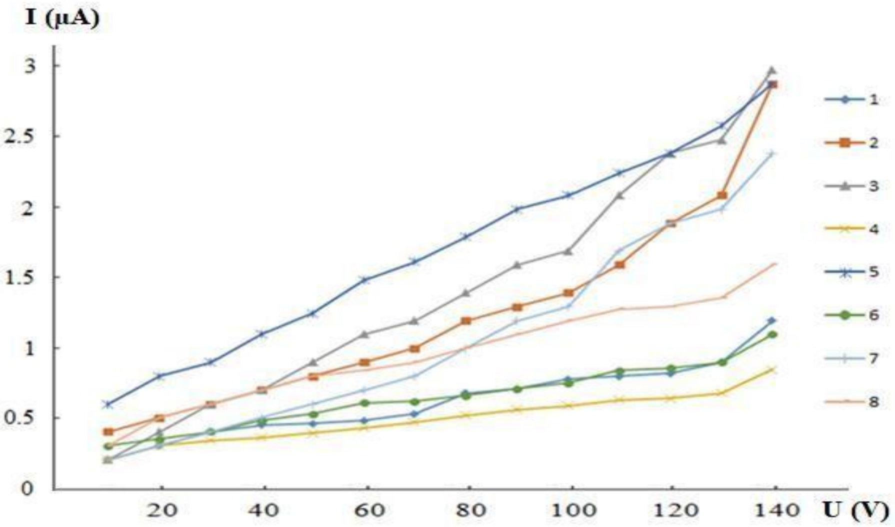

Fig. 1. Volt-ampere characteristics of a semiconductor eight-band coordinate-sensitive detector: 1– 1 band; 2– band 2; 3- band 3; 4– band 4; 5– band 5; 6– band 6; 7– band 7; 8– band 8.

In mathematical modeling, there are many ways to describe an object using a regression equation, one of which is the least squares method. According to this method, the mathematical model of the computer is represented by a regression equation, where the sum of the squared differences between the values obtained in modeling and the values obtained in experiments must be zero, that is:

$$\Sigma(Y_{Eks} - Y_{His})^2 \rightarrow \min \quad \text{ёки} \quad \Sigma\,(\mu_{Eks-}\mu_{His})^2 \rightarrow \min \qquad (2)$$

where, Y_{Eks} — is the experimental value obtained as a result of measurements (in this case, current); Y_{His} — is the theoretical calculated value.

Comparing (1) and (2), we get:

$$\Sigma(\mu_{Eks} - (ax^2 - bx + c))^2 \qquad (3)$$

In equation (3), the value of the coefficients a, b and c is unknown. To find the value of these coefficients, it is necessary to implement the mandatory condition of the method of least squares.

Using the method of least squares, it is possible to calculate the values of the unknown coefficients a, b and c from the expression (1). After that, we calculate the derivative of the above function by the coefficients a, b and c and set it to zero.

If expression (4) is denoted by Φ, then we get:

$$\Phi = \Sigma(\mu_{Eks} - (ax^2 - bx + c))^2 \qquad (4)$$

$$\begin{cases} \dfrac{\partial \Phi}{\partial a} = 0 \\ \dfrac{\partial \Phi}{\partial b} = 0 \\ \dfrac{\partial \Phi}{\partial c} = 0 \end{cases} \qquad (5)$$

To approximate the mathematical model to the experimental process, it can be expressed as a quadratic equation. We express expression (5) by expression (4), resulting in a system of equations with three unknowns, namely:

$$\begin{cases} \Sigma(\mu_{Eks}T^2 = a\Sigma\, T^4 + b\Sigma\, T^3 \; + c\,\Sigma\, T^2 \\ \Sigma(\mu_{Eks}T = a\Sigma T^3 + b\Sigma\, T^2 \; + c\Sigma\, T \\ \Sigma(\mu_{Eks} = a\Sigma\, T^2 + b\,\Sigma\, T + cN \end{cases} \quad (6)$$

where N - is the number of performed experiments (based on the above, N = 15).

by calculating the system of equations (6) and comparing them, we obtain the results of the mathematical modeling experiment (Fig. 1).

In order to measure VAX through mathematical modeling, it is necessary to create mathematical expressions of the technological process. The output parameter (y) of this technological process changes depending on the input parameter (x), that is, there is a functional relationship between them in the form of y=f(x) [2]. If it is not possible to express it through certain laws of mathematical expression, then the method of experimental statistical modeling can be used. For this, an experiment is conducted. By changing the value of the input parameter (x), we get the value of the output parameter (y).

These values are expressed in a coordinate system, the points obtained from the experiment are connected and a regression curve is formed. A regression curve can take different forms. For example, in a straight line, parabola or other forms. The equation is chosen depending on the type of regression curve (for example, the equation of a straight line through the origin y=k(x).

The coefficient of this equation is determined by the least square method. Based on this method, it is necessary to do the following:

$$\sum_{i=1}^{n}(y_{yi} \;- y_{xi})^2 \to \min \qquad (7)$$

where n is the number of experiments, y_{yi} - the experimental value of the output parameter corresponding to the input parameter x_i , y_{xi} - the calculated value of the output parameter corresponding to the input parameter x.

In this case, the deviation of the calculated experimental point should be minimal. If the slope
of the regression curve is closer to the line passing through the origin, then it can be expressed by an equation of the form y=kx.

We compare this equation with (7) and get:

$$\Phi = \sum_{i=1}^{n}(y_{yi} - kx_i)^2 \to \min \qquad (8)$$

According to the condition of the function analysis method according to the classical formula:

$$\frac{\partial\phi}{\partial k} = 0 \qquad (9)$$

Conditions for the extremum of this function, i.e:

$$\sum_{i=1}^{n} 2(y_{yi} - kx_i)x_i = 0 \qquad (10)$$

k - is the coefficient of the equation, which after mathematical simplification is expressed as:

$$K = \frac{\sum_{i=1}^{n} y_{yi} * x_i}{\sum_{i=1}^{n} x_i^2} \qquad (11)$$

To calculate the coefficient k, the following sums should be calculated:

$$\sum_{i=1}^{n} y_{yi} \cdot x_i\,; \quad \sum_{i=1}^{n} x_i^2 \qquad (12)$$

Fig. 2 shows the comparison of the experimental VAX of the nuclear radiation large-scale semiconductor coordinate sensitive detector with the VAX obtained by the proposed modeling.

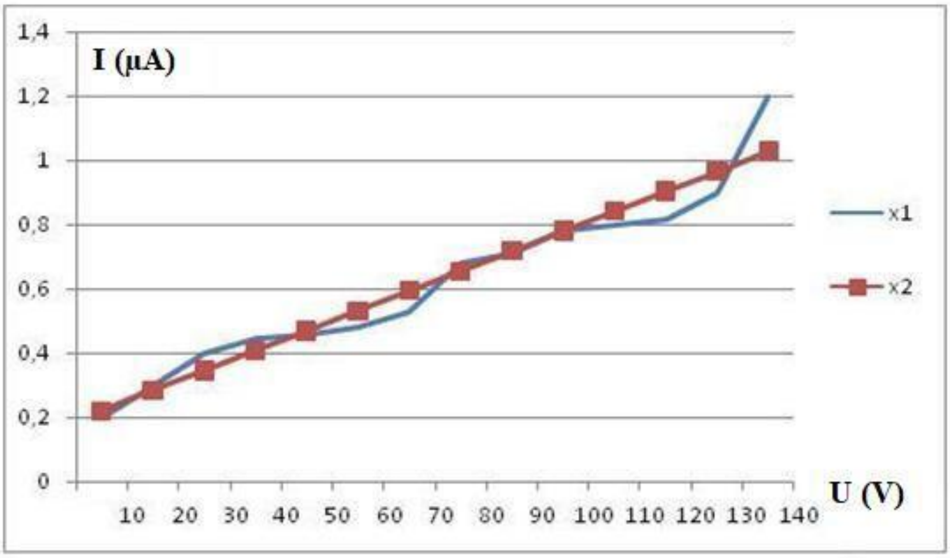

Fig. 2. The volt-ampere characteristics obtained by practical –1 and modeling –2 of a semiconductor coordinate-sensitive detector

The volt-ampere characteristics of all the bands of the semiconductor eight-band detector were compared and MATLAB software was used in this process. A VAX graph for only one band of the detector was then plotted and modeled. MATLAB software capabilities were used to design and calculate VAX for modeling. The results of mathematical modeling show that the proposed equivalent electrical circuit allows to describe current and voltage characteristics for Si(Li) p-i-n structures with a high degree of accuracy. In this case, it was found that the maximum difference in the mutual ratio of current strength values in practical and modeling results is 0.2358 (Fig. 3). This means that the calculation of the dimensions of large-scale semiconductor nuclear radiation coordinate sensitive detectors by mathematical modeling gave good results, that is, the specified task was performed with a relatively small error [4-5].

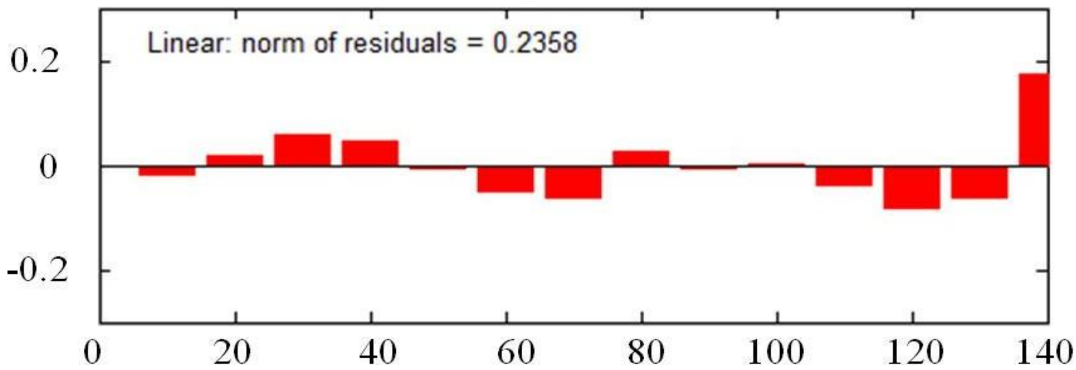

Fig. 3. Differences between experimental results and mathematical modeling results

Conclusion

Thus, the volt-ampere characteristics of the developed nuclear radiation large-scale semiconductor silicon coordinate-sensitive detectors were studied. A VAX graph was created based on modeling using MATLAB software for 1 band of this detector and compared with the experimental VAX graph. In this case, it was found that the biggest difference between practical and modeling results in terms of mutual ratios of current strength values is 0.2358.

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