Modeling of electrical conductivity of labyrinth bimetallic nanofilms

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Abstract. In the framework of this paper, the results of experimental studies on the production of thin labyrinth bimetallic films, as well as measurement of ampere characteristics from volts, are presented. In addition, the simulation of their electrically conductive properties is done.

Introduction
Today granular labyrinth metal films conquer a wide range of applications in various applications of nano- and microelectronics, which I associate with the uniqueness of their structure and the electrical and optical properties they exhibit.

A team of authors of this article do experimental studies on the production of such nanofilms using the laser-plasma sputtering method. In the process of carrying out the work, a mathematical model has emerged that describes the electrically conductive properties of bimetallic labyrinth films obtained by us, which, as a first approximation, will allow us to calibrate our experimental method for obtaining nanofilms with preassigned electrically conductive properties.

Description of the results of experiments on obtaining labyrinth nanofilms and measuring their volt ampere characteristics
The initial colloidal systems were prepared by laser ablation in water [1] under the action of continuous laser radiation on a target of silver and gold immersed in deionized water [2].

The deposition of cluster films was realized according to the experimental scheme described in [3]. The structure of the deposited films was investigated using an atomic force microscope (Fig. 1).
Fig. 1. AFM images of bimetallic nanostructures. The power of laser radiation is 2.5 W. Scanning speed 1.2 mm / s, the number of passes 25. (a); 0.6 mm / s, the number of passes 18 (b) 0.3 mm / s, the number of passes 14 (c).

The volt-ampere characteristics were measured using a four-probe circuit with a linear arrangement of contacts [4].

Figure 2 shows the current-voltage characteristics of the films shown in Fig. 1. In the investigated range of stresses, they turned out to be linear.

![V-A characteristics](image)

Fig. 2. Volt-ampere characteristics of bimetallic films shown in Fig. 1.

**Description of the model of electrically conductive properties of labyrinth nanofilms**

The algorithm for modeling the electrically conductive properties of labyrinth metal nanofilms consists of several steps:

**Step 1**

Generating a random labyrinth by shrew method.

Denote 0 as a passage and 2 as a wall, the visited cell is denoted -2, unvisited -1. The initial conditions are a two-dimensional array filled with -1. The dimension of the array is any number. We assume that the upper left corner of the wall has coordinates (1; 1) and it is visited. The coordinates of
the "shrew" are always even, it moves, respectively, only by jumping long into two elements of the array.

1. Randomly choose the landing point of the "shrew" - generate random non-zero coordinates. The landing point is assigned a value of 1.
2. Randomly choose one of the directions - top, bottom, left, right.
3. If after a jump in the chosen direction we find ourselves in the outer wall or in the aisle, then return to the previous point. Otherwise, we jump in the indicated direction. Assign a value of 1 to the cage into which they landed and through which they jumped.
4. If after landing we can not make a jump (getting into a dead end), then we randomly generate coordinates. Otherwise - go to the second paragraph.
5. Repeat the above step until the indicated coordinates have a pass.

Step 2

The construction of the path from point A to point B, which will be the conductivity path and the calculation of its length.

To find the conduction path, we use the wave algorithm (the Lee algorithm). It allows you to build a path between two elements in any labyrinth.

The wave propagates in the 4 directions from the initial element (Fig. 3 a). The element into which the wave has come forms the front of the wave. In the figures, numbers indicate the wavefront numbers.

Each element of the first wave front is the source of the secondary wave (Fig. 3 b). Elements of the second wave front generate a wave of the third front, and so on. The process continues until the end element is reached.

The second step is the construction of the track itself. Its construction is carried out in accordance with the following rules:

1. Movement in the construction of the route is carried out in accordance with the selected priorities.
2. When moving from a finite element to an initial one, the wavefront number (track coordinates) should decrease.

![Figure 3. Direction of wave propagation a) primary wave b) secondary wave](image)

Priorities of the direction of movement are chosen at the development stage. Depending on how these priorities are set, different paths are obtained, but the path length in any case remains the same.

Fig. 4 shows an example of constructing a trace using the wave algorithm. Red color indicates busy elements. Gray color is the trace after the action of the algorithm. A is the starting point, B is the final point. Priorities of movement to the left, right, right, up, down. The construction of the route is from the initial point to the final one. Priority directions are indicated by arrows. [6]
Step 3
Calculation of the volt ampere characteristic of the conduction path. The calculation is carried out according to Ohm's law for the circuit section \( I = \frac{U}{R} \), where U is the voltage. R is calculated by the classical formula \( R = \frac{l}{\rho S} \), where \( \rho \) is the electrical resistivity of the material, \( l \) is the length of the conductor track calculated by the percolation model, and \( S \) is the area of its cross section.

**Results of modeling the electrically conductive properties of labyrinth bimetallic nanofilms**
According to the above algorithm, a random labyrinth was constructed as a model of the film surface, the electrical conductivity was calculated for a bimetallic labyrinth film Ag / Au. The design area was chosen as 50 * 50 op.ed. The calculated grid consisted of 2500 cells. The ratio of gold and silver particles was chosen to be 50:50. In Fig. 5 shows a random labyrinth and the electricity path.
We calculate the volt ampere characteristic. Following the above algorithm, we find the relative path length from the point, which is: \( \text{LAB} = 483 \) rel. units, and the path length in absolute units is \( \text{Labs}_1 = \text{Ind} \times \text{LAB} = 483 \mu\text{m} \), where \( \text{Ind} \) is the integral absolute value of one cell equal to 100 nm. Since the particles are uniformly distributed and their ratios are the same, the resistance of the path \( R = 1.0626 \times 10^6 \) Ohm is the sum of the resistances of a part of silver \( R_s = 0.386 \times 10^6 \) Ohm and gold \( R_g = 0.5 \times 10^6 \) Ohm. When applying a constant voltage equal to 0.05 V, we obtain an electricity strength of \( 5.64 \times 10^{-9} \) A.

Volt ampere characteristics at a voltage variation from 0.05 to 1 V are shown in Fig. 6.
Fig. 6. Volt Ampere characteristics for path AB

Also, a comparison was made of the electrical properties of a bimetallic film with monometallic silver and gold films, the calculations for which were carried out in a similar way.

Calculations showed that the best design conductivity of a silver film, and a bimetallic film has an electrical conductivity better than that of gold, but worse than that of silver. It was also found that when the ratio of the concentrations of gold and silver components of the conductivity path is varied, the current-voltage characteristic of a bimetallic labyrinth film approaches the current-voltage characteristic of gold, and with an increase in the concentration of gold granules and the current-voltage characteristic of silver with an increase in the proportion of silver granules, respectively. Thus, it becomes possible to model the electrically conductive properties of bimetallic films with predefined properties.

Conclusion
The proposed method for obtaining granular labyrinth metal films, using laser deposition from colloidal solutions, has proved to be simple and affordable. On the other hand, using it, it becomes possible to create systems with non-ordinary electrical properties: to combine various metals in a single nanostructured ensemble of particles. The obtained current-voltage characteristics made it possible in the first approximation to simulate the conductivity of the obtained bimetallic films under various conditions.

As a result of the calculations performed, it became possible to calibrate the concentration of our method for obtaining labyrinth bimetallic films with preassigned electrically conductive properties.

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