COHERENT EMISSION OF ELECTROMAGNETIC RADIATION FROM THE SURFACE OF SEMICONDUCTOR PLATE WITH THE SELF-AFFINE RELIEF

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Abstract

Regular structures on the surface of materials give to them uncommonly properties. In [1] is described the plate from the semiconductor material with the regular relief in the form of grooves, thermal radiation from which is coherent.
Uncommonly can narrative itself relief with the self-similar properties. In the work are examined the results of the study of the behavior of such relief.

Keywords: surface electromagnetic wave, semiconductor.

Keywords: surface, magnetron spraying electromagnetic wave, semiconductor, thin metallic film, fractal nano-surface.

1 Introduction

Progress of nano-technologies and the study of the new principles of the construction of electronic and optics, places the problem of developing of the physical models, which adequately describe their work. The promising possibilities present the regular structures, which were formed on the surface of semiconductor material.
It is known that the special surface properties are connected with the disturbance in one of the directions of a strict periodicity of crystal lattice, with the break of the translational symmetry of crystal. Its properties are differed from the properties of crystal in the volume and formation on the surface of some topological special features can reveal the unexpected possibilities for creating fundamentally new type solid-state elements.
The properties of solid surface are used by humanity very long ago, it is worthwhile to recall about the mirrors, or about such elements, widely used in optics as the diffraction gratings, basis of which is regular structure from the annular or linear slots or the grooves on the solid surface. Optics traditionally examines three phenomena: diffraction, interference and light polarization.
Another phenomenon of interaction of electromagnetic radiation with the substance, which leads to this effect, as the polarization of charges in the semiconductor or the dielectric is studied traditionally by solid state physics. There is one additional division of science and technology, connected with the application of regular structures – radiophysics and radio engineering. The basis of any antenna are the regularly located in the space conducting and dielectric devices. Recently great interest causes the development of the so-called fractal antennas, basis of which is the fractal configuration, which substantially improves the characteristics of antenna.
The unexpected possibilities for the use in scientific studies and technology offer the so-called self-affine structures on the surface of semiconductor plate.

2. Formulation of the problem

Self-affine is the figure, built from its affine copies. In [2] self-affine fractal is defined as structure invariant after a simultaneous, but quantitatively different change of the scale along the different directions in the space.
The affine transformation of vector from the origin of coordinates into the point from coordinates (x_1, y_1), into the vector from the point from coordinates

(b_1, b_2) into the point with the coordinates (x_2, y_2) into [3] is defined as:

$$(1) \quad \begin{cases} x_2 = a_{11}x_1 + a_{12}y_1 + b_1 \\ y_2 = a_{21}x_1 + a_{22}y_1 + b_2 \end{cases}$$

System (1) can be represented in the form of the matrix:

$$(2) \quad T = \begin{bmatrix} a_{11} & a_{12} & b_1 \\ a_{21} & a_{22} & b_2 \end{bmatrix}$$

and to illustrate by figure 1:

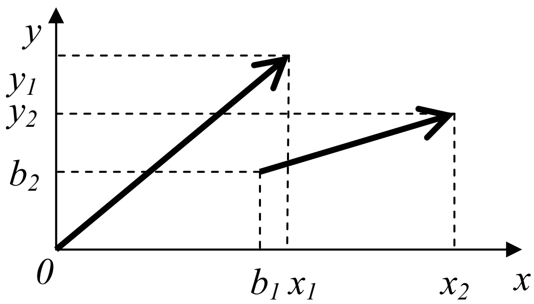

Fig. 1. Affine transformations of the vector

Also by affine transformations it is possible to assign the operation of turning to angle of α relative to the origin of the coordinates

$$(3) \quad T = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \end{bmatrix}$$

and the scaling:

$$(4) \quad T_1 = \begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \end{bmatrix}$$ with $m>1$ occurs the removal from the origin of coordinates, with $m<1$ occurs the drawing near at the origin.

The operation of the scaling above all points of what either figure, leads to an increase or the decrease of its sizes in m of times.

3. Experiments

Behavior of silicic plate, to which by the method of plasma-chemical etching was substituted the figure from a large quantity of grooves of annular form, was investigated. Figure from the ring circuits is basis for fulfilling the affine transformations (Fig. 2,3).

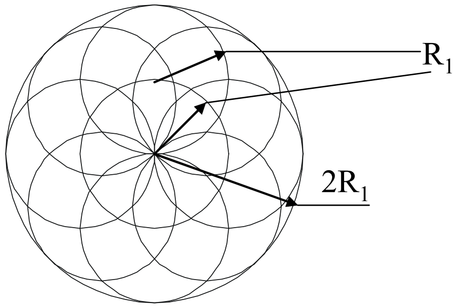

Fig. 2. First stage of the construction of the self-affine surface.

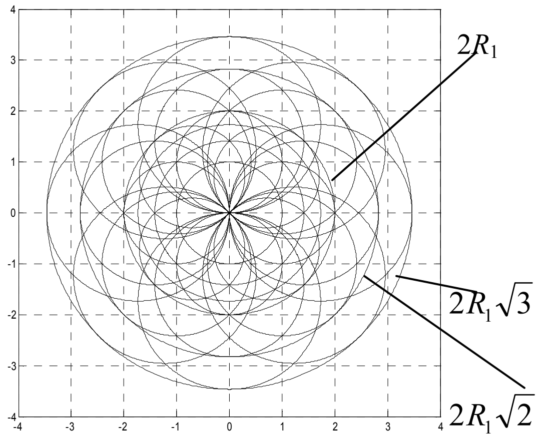

Fig. 3. Second stage (basis for fulfilling the affine transformations)

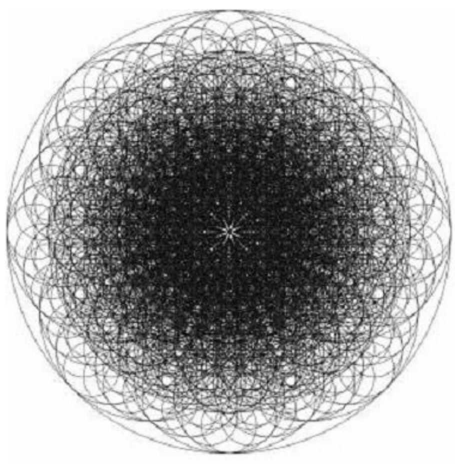

Fig. 4. Result of fulfilling the affine transformations

After the fulfillment of the transformations, which are the multiplication of the points of the figure Fig. 3 by the scale factor of $m_1=2^i$ and the turnings to

. the angle proportional to coefficient of $m_2=2^j$ and of imposition on the initial figure, can be obtained the figure, represented in Fig. 4. The exterior view of this structure on the surface of silicic plate is represented in Fig. 5.

With the simulation two-dimensional and three-dimensional nonstationary models were investigated. In this case as basis for constructing the mathematical model the following considerations served: rings on the surface of silicic

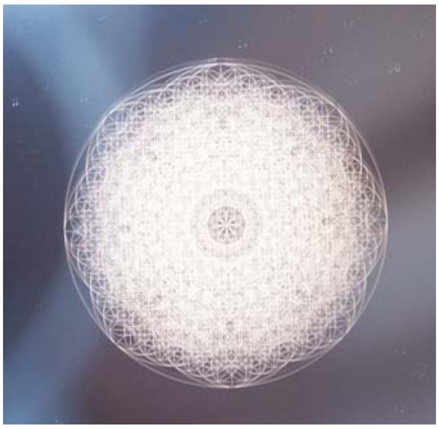

Fig. 5. The exterior view of the self-affine structure on the surface of the silicic plate

plate (Fig.4,5) are grooves with depth about 1,3 μm, with the width of 1 μm the minimum distance between the "grooves" composes value 1 μm the outside diameter of plate it composed the value of 6 mm. Electric field with interaction with the semiconductor, is caused the phenomenon of the displacement of charges and, the increased, with respect to the adjacent regions, concentration of charges in the region of "grooves" (Fig. 6).

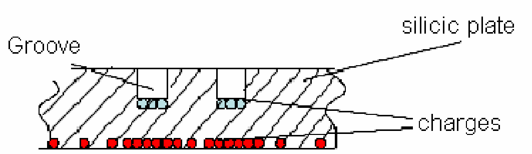

Fig. 6. Charge distribution along the thickness of the plate

Therefore with the simulation it was assumed that the concentration of charge carriers in the "grooves" is higher than in the surrounding regions. With the reaching by the potential of some critical value φ_c appears the breakdown on the shortest distance between the grooves (Fig. 7).

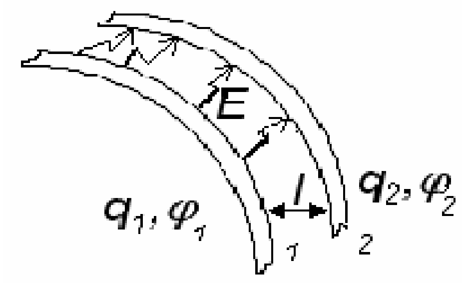

Fig. 7. Breakdown between the adjacent grooves.

a. Two-dimensional model

Mathematical model for the present case takes the form:

$$(5)\ \frac{\partial E}{\partial t} = D\left(\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2}\right) - aE$$

where D and a are coefficients, E is tension of electric field, x and y are coordinate, t is the time. Breakdown condition realized as follows: if $|E| > E_c$, then $E = 0$.

Simulation showed that independent of boundary conditions of surface, after some time t_s, is established the steady and soliton-like distribution of the tension of electric field over the surface of resonator. The results of calculations for two-dimensional model (5) are given in Fig. 8. Red color corresponds to the maximum values of tension, the violet color is for the minimum.

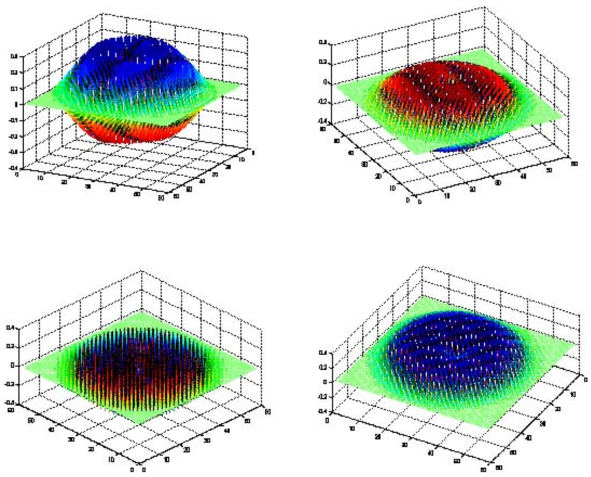

Fig. 8. Result of the simulation of distribution of tension of the electrical field on the surface with the two-dimensional model (5). Steady-state regime, different projections.

It is below, for the comparison, is given the result of full-scale experiment, with the illumination of the surface of silicic plate (Fig. 6) with the aid of the powerful (250 *W*) halogen lamp (Fig. 9).

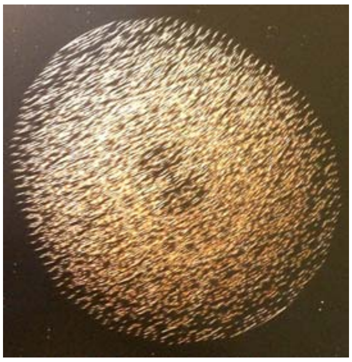

Fig. 9. Result of full-scale experiment, with the illumination of the surface of the plate with the aid of the powerful (250 W) halogen lamp.

In Fig. 9 is visible the light "scaly" cupola, similar to the results of simulation in Fig. 8.

b. Three-dimensional model

It was examined the model:

$$(6)\quad \frac{\partial E}{\partial t} = D\left(\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial z^2}\right) - aE$$

From two-dimensional this model is formally differed only in terms of the presence of the third space coordinate z however, this makes it possible to compose more complete idea about interaction of silicic plate with the self-affine surface relief with the emission, to obtain the spatial distribution of tension E. The surface of resonator lies on plane $x0y$, the origin of coordinates in the center of resonator, z axis is perpendicular to the origin of coordinates (fig 10.).

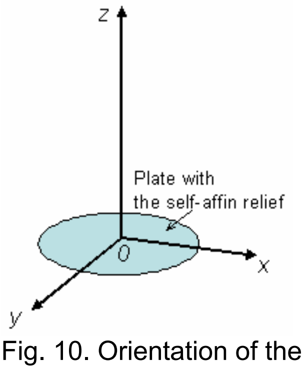

Fig. 10. Orientation of the plate relative to the coordinate system

The following figure (Fig. 11) presents the results of simulation on three-dimensional nonstationary model (6). Left upper figure is for moment of time 1 (computer time). Left average figure is for moment of time 2. Left lower figure is for moment of time 3. Right upper figure is for moment of time 4. Right average figure is for moment of time 5, and right lower figure is for moment of time 6. Red color corresponds to the maximum values of tension, violet - minimum. In the figures the dynamics of the development of wave along z axis, perpendicular to the surface of plate is well visible (Fig. 10). Plate is located to the left and occupies the position, whose boundaries are noted in the left average figure (fig.10) by two lines. With the diameter of silicic plate 6 *mm*, the wavelength along z axis composes value of approximately 1,1 *mm*. incident to the plate radiation it is white noise.

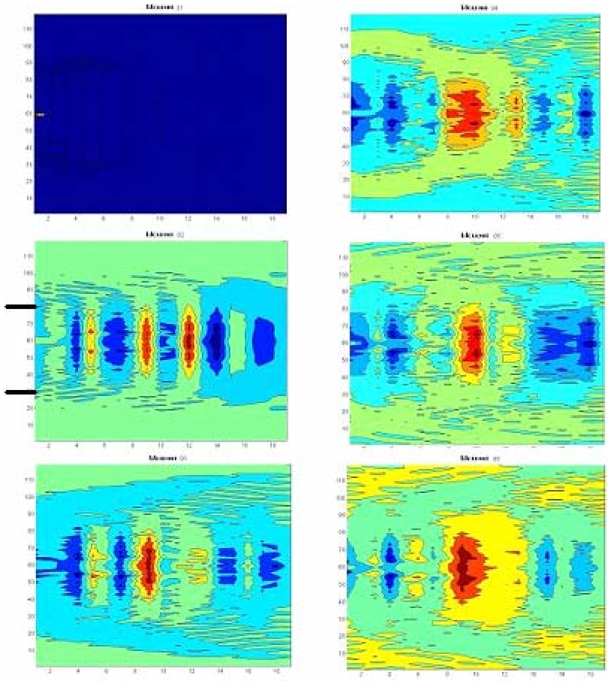

Fig. 11. Dynamics of the change in the tension E above the plate.

Conclusions

The experiments showed, that the semiconductor plate with the self-affine relief of surface function as the converter of incident to it radiation into the coherent form.

The motion of electric charges over the surface of plate leads to the formation of the standing soliton-like surface waves, which possess coherent properties. The length of these waves is determined by the relief of surface.

References

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