Aires Broadband Coherent Transformers

(A New Method to Obtain Coherent Electromagnetic Radiation)

The term "coherence" means consistency and connection between electromagnetic oscillations. Electromagnetic radiation is distributed across time and space, so it is possible to estimate the coherence of oscillations radiated by a source at various points in time at any particular point in space (temporal coherence) or the coherence of oscillations radiated at a particular point in time at various points in space (spatial coherence). These properties lead to the conclusion that energy losses at a point of coherent radiation are minimized.

Coherent radiation is most frequently generated using lasers.

A ***LASER*** *(**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation)* is a device that uses a quantum mechanic effect of induced (stimulated) radiation in order to create a coherent beam of light (Fig. 1).

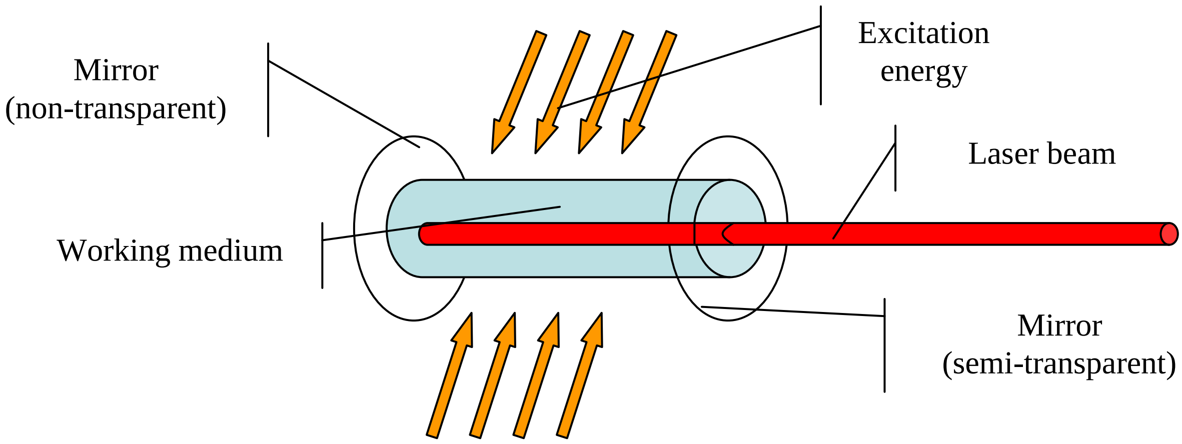

Fig. 1. Laser

A laser beam is coherent radiation. This is evident by the fact that its diameter remains unchanged over a very long distance. An example is given in Fig. 2.

Fig. 2. A laser beam maintains its diameter over a large distance.

A laser emits a monochromatic wave. This means that all of the elemental beams that make up the laser have the same wavelength.

Fig. 3. A soliton wave moving along the channel

There are examples of coherence where the waves do not have the same wavelength, but still behave as an organized group. Known as solitons, these waves were discovered in 1834 by Scottish physicist John Scott Russell. He was the first to describe a sustained wave that does not lose its shape on the surface of a narrow channel (Fig. 3).

Research on optical solitons is actively underway. Their use makes it possible to transfer information virtually losslessly on an optical channel. This technology was the basis for the development of fiber optics with a controllable dispersion, which makes it possible to create solitons whose impulse shape can be maintained indefinitely. Such communication systems have achieved lossless data transmission speeds of 5 Gbps over 15,000 km, 10 Gbps over 11,000 km, 40 Gbps over 700 km and 80 Gbps over 500 km. In order to achieve such results, the fiber's index of refraction is not constant, but has a specific relationship with both the fiber's radius and its length. The magnitude of the dispersion along the length of the optic fiber is changed periodically between negative and positive.

In the examples we will consider (laser, optic fiber), coherence is created due to the properties of the medium. For a laser, this is a gas or a crystalline solid. For an optic fiber, it is a solid.

Another interesting example of obtaining coherent radiation using a novel approach is creating regular structures on the surface of solids. These structures then act as resonators. An example of this approach [1] is the use of SiC wafers with a regular structure in the form of parallel grooves with a width and depth of 0.28 µm and a distance between them (period) of 6.25 µm, to obtain coherent radiation with a peak at a wavelength of 11.36 µm (Fig. 4).

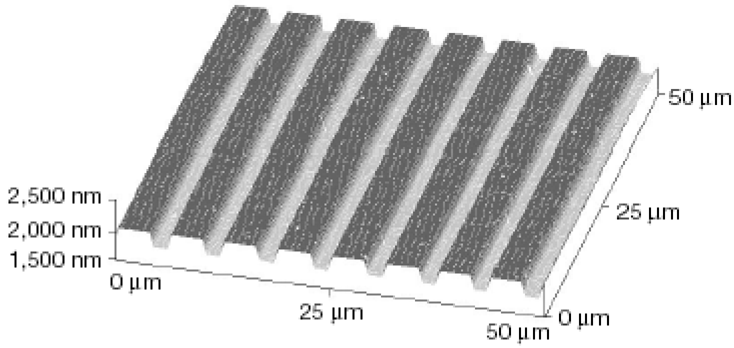

Fig. 4. SiC wafers, which are a source of coherent radiation.

This radiation was virtual monochromatic at a distance of up to 100 µm from the wafer's surface.

Coherence in an extremely narrow range of wavelengths distinguishes the devices described above. Laser developers use a property of the working medium to generate virtually monochromatic radiation. The authors of [1] followed this traditional path in an attempt to create a device whose radiation was close to monochromatic.

It may be interesting to imagine when it would be possible to generate electromagnetic oscillations on not a single frequency, but a wide range of frequencies, while preserving interrelationships between them such that they remain coherent, not only in time, but also in space, like a laser. To do this, we can use, as a foundation, a certain resonator on a planar substrate similar to [1], but with a topographical surface in the form of circles with specific interrelationships.

A device that generates coherent radiation with such properties would find application in a diversity of fields, including for spatial encoding of data, because it can transform incident radiation into a coherent form with properties containing information about the incident radiation.

It is well-known that a surface's properties are associated with a violation, in one direction, of the strict periodicity of the crystal lattice, with a breakdown in the crystal's translational symmetry. Its properties, in general, differ from the crystal's properties in magnitude, and the formation of certain topological features may reveal unexpected opportunities to create solid components of a fundamentally new type.

Meanwhile, a solid's surface properties have used by humans for a long time. Recall mirrors or other such components widely used in optics, such as diffraction gratings, whose base is a regular pattern of lines or circular slits or groves on the surface of a solid. Optics traditionally considers three phenomena: the diffraction, interference, and polarization of light.

Another phenomenon of the interaction of electromagnetic radiation with a substances that yields an effect such as polarization of charges in a conductor or a dielectric, is traditionally studied by solid-state physics

There is yet another field of science and technology related to the use of regular structures - radiophysics and radio technology. The foundation of any antenna is regularly spaced conductive and dielectric devices. Recently, the development of so-called fractal antennas has aroused great interest. These antennas are based on a fractal configuration [2], which significantly improves their characteristics.

A special area of coherent radiation research has to do with creating optical computing devices. There are a large number of ways to record and process optical information, which has been received in coherent light, about any given physical object. The most widespread of them relies on processing an image of the object, based on, for example, a hologram of the object. This method makes it possible to obtain not only the power distribution, but the electromagnetic waves' phases as well. This is the foundation for the creation of devices and methods for image correction, which are essentially optical processors.

So-called self-affine structures on the surface of a semiconducting wafer open unexpected opportunities for use in scientific research and engineering. The authors have researched the behavior of a silicon wafer with a self-affine structure of circular depressions formed on its surface. To do this, a computer model was used. The model was based on the phenomenon of the polarization of the charge carriers as a result of the interaction of the wafer's material with electromagnetic radiation. A shape constructed out of self-similar copies of itself is called a self-affine shape. In [3] a self-affine fractal is defined as a structure that is invariant after simultaneous yet quantitatively different changes in the scale along different spatial axes. The affine transformation of a vector from the origin to point (x_1, y_1), to a vector from point (b_1, b_2) to point (x_2, y_2) in [4] is defined as:

$$x_2 = a_{11}x_1 + a_{12}y_1 + b_1$$
(1) $$y_2 = a_{21}x_1 + a_{22}y_1 + b_2$$

System (1) can be represented as a matrix:

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

and is illustrated by Figure 5:

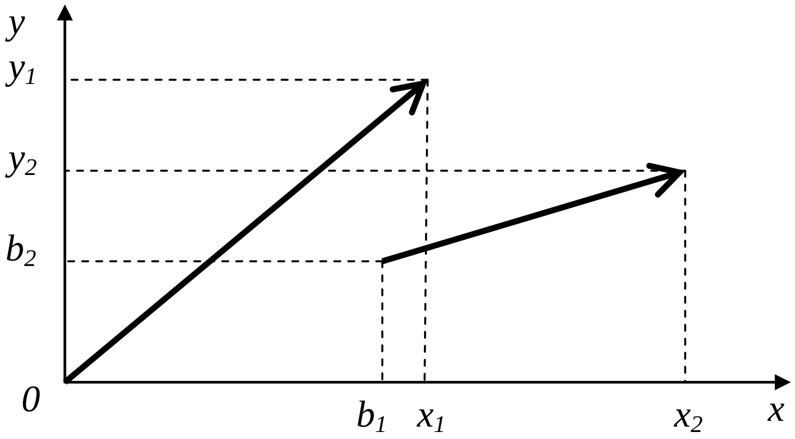

Fig. 5. Affine transformations of a vector

Affine transformations can also define a rotation by angle *a* about the origin

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

and scaling:

(4) $$T_1 = \begin{bmatrix} m\ 0\ 0 \\ 0\ m\ 0 \end{bmatrix}$$, $m>1$ will shift away from the origin,

$m<1$ will shift toward the origin,

Scaling operations applied to all points in any shape will expand or contract its size by a factor of *m*.

The behavior of a silicon wafer, on which a large number of circular grooves have been overlaid using plasma-chemical etching, was studied. The foundation for the affine transformations is a pattern made of circular lines (Fig. 6, 7).

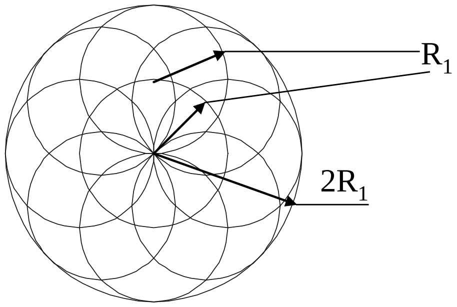

Fig. 6. First stage of creating a self-affine surface

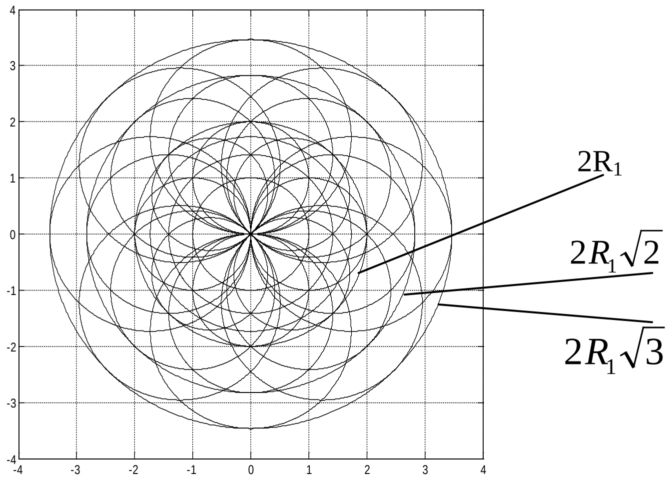

Fig. 7. Second stage (The basis for performing affine transformations)

After performing the transformations, which are a magnification of the points of the shape in Fig. 7 by a scaling factor of $m_1=2^i$ and a rotation by an angle proportional to $m_2=2^j$, and superimposing the result on the original figure yields the shape shown in Fig. 8.

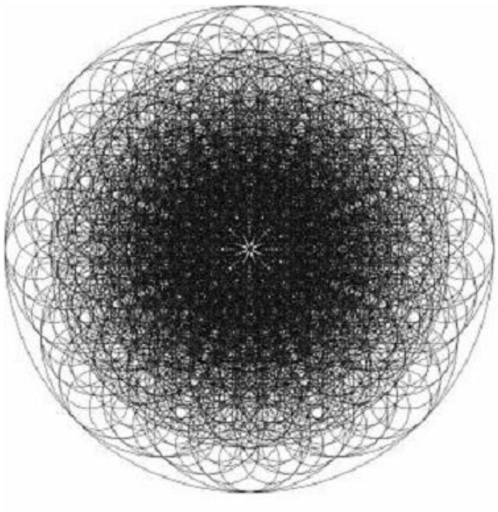

Fig. 8. Result of performing affine transformations

The appearance of this sort of structure on the surface of a silicon wafer is shown in Fig. 9.

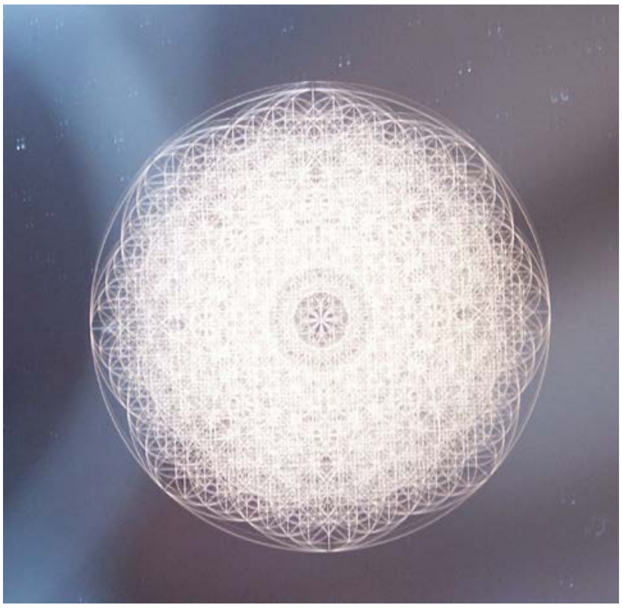

Fig. 9. Appearance of a self-affine structure
on the surface of a silicon wafer

Modeling

Two-dimensional and three-dimensional models were studied with modeling.

Moreover, the following considerations served as the foundation for building the mathematical model.

The rings on the surface of the silicon wafer (Fig. 3-6) are grooves roughly 1.3 µm deep and 1 µm wide. The minimum distance between the "grooves" is 1 µm. The wafer's outer diameter was 6 mm. When interacting with the conductor, an electric field causes charges to shift and concentrates changes in the "grooves" relative to adjacent areas (Fig. 10).

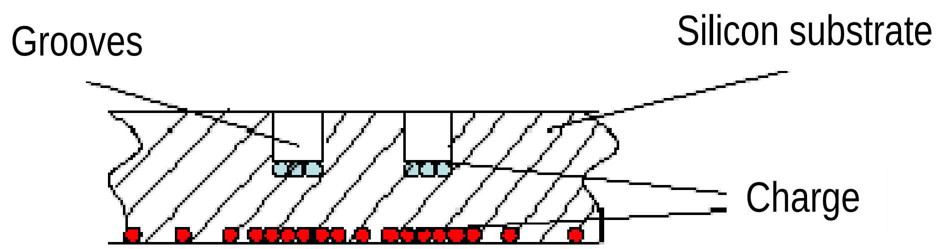

Fig. 10. Distribution of charges across the thickness of the wafer

Therefore, during modeling, it was assumed that the medium's charges would be concentrated more in the "grooves" than in other areas. When the potential reaches some critical value φ_{kr}, there is a discharge along the shortest distance between the grooves (Fig. 11).

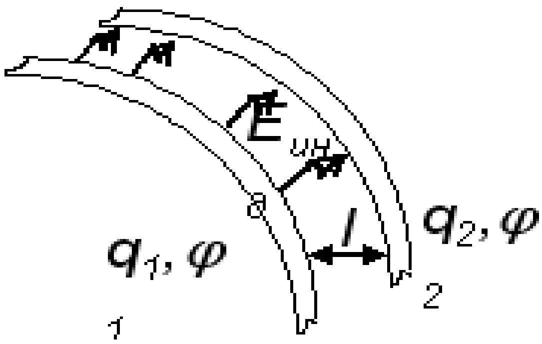

Fig. 11. Discharge between adjacent grooves

a. *Two-dimensional model*

In the mathematical model looks like this:

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

where *D* and *a* are coefficients, *E* is the electric field's strength, *x* and *y* are coordinates, *and* *t* is time. The discharge criteria is implemented as follows: if $|E| > E_{\kappa p}$, then $E = 0$.

Modeling has shown that, regardless of the conditions on the edge of the surface, after time t_{stable}, a stable, soliton-like distribution of the electric field's strength across the resonator's surface is achieved.

The results of the calculations for the two-dimensional model (5) are given in Fig. 12. The red color corresponds to maximum field intensity, while violet corresponds to minimum intensity.

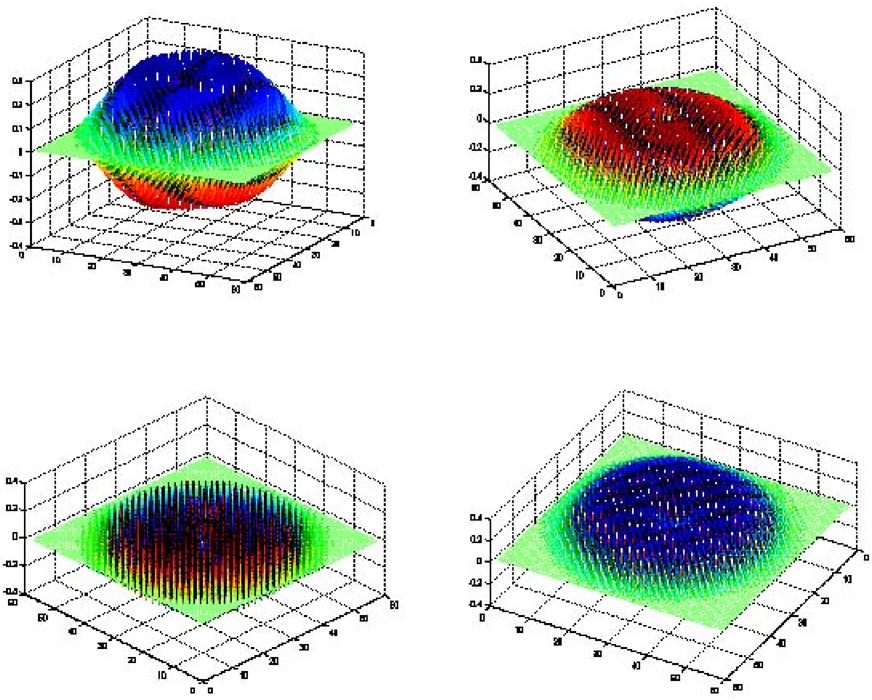

Fig. 12. Distribution of the intensity of *E* across the wafer's surface under the specified conditions; various projections.

Below, for comparison, we present the result of an experiment on a prototype, in which the surface of a silicon wafer (Fig. 9) was illuminated using a powerful (250 W) halogen lamp (Fig. 13).

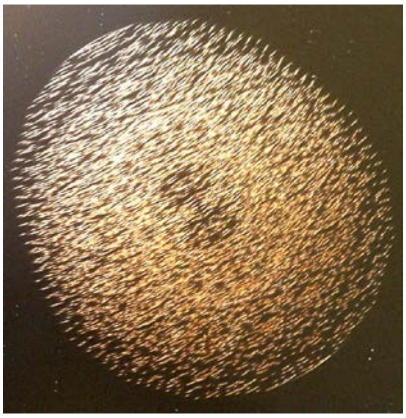

Fig. 13. Result of an experiment on a prototype, in which the surface of the wafer was illuminated using a powerful (250 W) halogen lamp.

Fig. 13 shows a luminous "scaly" dome, similar to the results of the computational experiment in Fig. 12.

b. *Three-dimensional model*

We investigated a three-dimensional model:

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

Technically, this model only differs from the two-dimensional model by the presence of a third spatial coordinate *z*. However, this makes it possible to create a more complete representation of the interaction of the silicon wafer with the self-affine topological surface, with radiation, and obtain the spatial distribution of intensity *E*. The resonator's surface lies in plane *x0y* with the origin at the center of the resonator. The *z*-axis is orthogonal to this plane (Fig. 14).

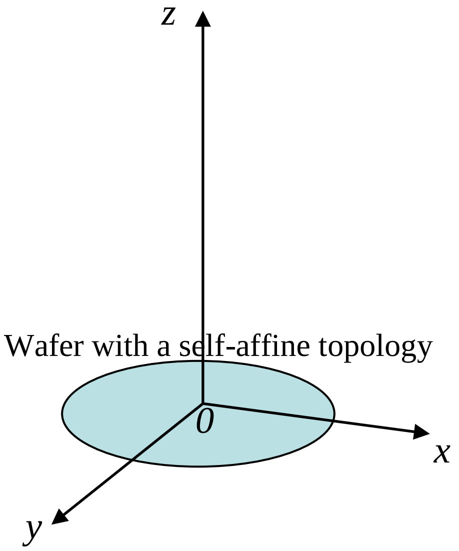

Fig. 14. Orientation of the wafer relative to the coordinate system

The next figure (Fig. 15) presents the results of modeling using a three-dimensional non-stationary model (6). The upper left figure is time 1 (computer time). The middle left figure is time 2. The lower left figure is time 3. The upper right figure is time 4. The middle right figure is time 5, and the lower right figure is time 6. The red color corresponds to maximum intensity, while violet corresponds to minimum values.

The change in the development of the wave along the z-axis, which is orthogonal to the wafer's surface (Fig. 14), can be seen clearly in the figures. The wafer is located on the left and occupies the position whose borders are denoted in the middle left figure (Fig. 15) by two bars. Given a silicon wafer with a diameter of 6 mm, the wavelength along the z-axis is approximately 1.1 mm. The radiation incident upon the wafer was white noise.

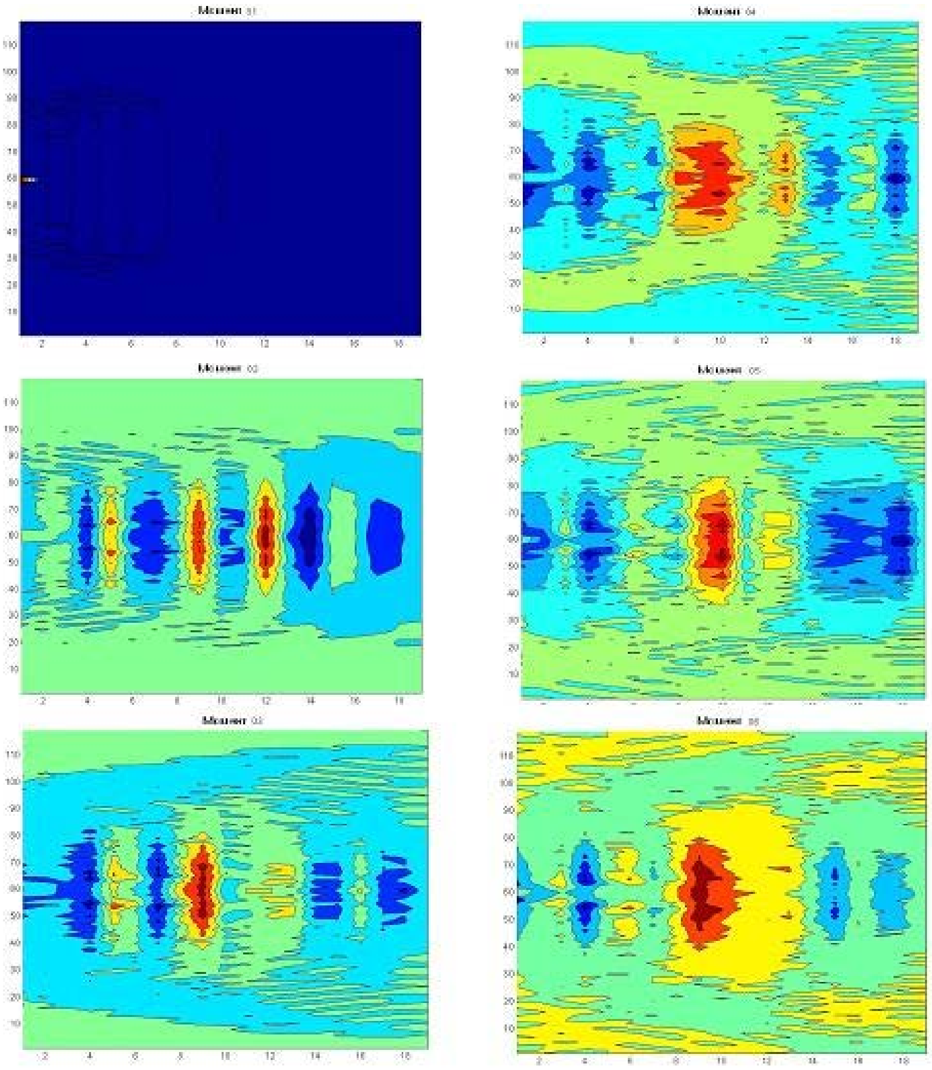

Fig. 15. Change in the intensity of the field over the wafer

Thus, the silicon wafer with the self-affine topography on its surface transforms incident radiation into a coherent form, even if the radiation is white noise.

Conclusions

- Our experiments have demonstrated that a semiconducting wafer with a self-affine topography on its surface transforms a broad spectrum of incident radiation into a coherent form. It redistributes the incident radiation in terms of its wavelength as well as its phase, in accordance with its topography. Its use opens fundamentally new opportunities to create diverse devices for application in the aforementioned areas of science and technology:
- sources of coherent radiation;
- computing devices;
- broadband resonators with distribution of energy through a space that is self-similar and carries information about the amplitude, wavelength, and phase of incident radiation.

These devices will find application in various areas of human activities.

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