# DESCRIPTION OF SCANNING PROBE MICROSCOPY IMAGES BY THE USE OF SPECTRAL DENSITY ANALYSIS.

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## ABSTRACT

Method of the numerical description of the nanocrystal surface images in Scanning Probe Microscopy is developed. Digital image is considered as two-dimensional stationary random process. An apparatus of statistical spectral analysis is implemented to determine the character of the order of quantum dots disposition on the crystal surface.

## 1. INTRODUCTION

Scanning Probe Microscopy (SPM) is an effective tool for surface researching and develops intensively in recent time. The experimental results are useful both in fundamental and in applied fields of physics. In particular, it is connected with high precision of this method and with the SPM capability of both surface nanotopography viewing and surface modification in nanosizes.

Surface image processing is an important stage of the SPM experiment. SPM method specific characters are the reason for SPM images peculiarity, in particular,

- SPM images always contain noise of various natures.
- SPM images has periodical character as a consequence of periodical character of atomic and molecular structures.
- SPM images are the convolution of the surface topography and probe topography and require special decoding.

This work is devoted to the building of the scheme of correction and quantitative analysis of the SPM images of nanocristals. The samples of nanocristals were obtained during molecular beam epitaxy as a result of self-organization effects in systems InAs/GaAs.

## 2. DESCRIPTION OF THE METHOD OF TWO-DIMENSINAL SPECTRAL DENSITY ESTIMATION.

A tool for the detecting of the periodical character in the image elements disposition is developed in this work. A method of statistical spectral analysis is implemented here. In this way, digital SPM image is considered as two-dimensional stationary random process. Two-dimensional Fourier transformation F (p,q) of the image T(x,y), mxn pixels is calculated:

$$F(p,q) = \frac{1}{\sqrt{mn}} \sum_{x=1}^{n} \sum_{y=1}^{m} T(x,y) \exp(-i2\pi(\frac{xp}{n} + \frac{yq}{m})) \quad (2.1),$$

where x, y –area coordinates; p, q – area frequencies. F(p,q) is complex variable, which real and imaginary parts are not correlated random variables and each of them can be considered as weighted summa of a great number of random variables. Spectral density of the process is determined as the square of the module of Fourier transformation value:

$$G(p,q) = |F(p,q)|^2 \quad (2.2)$$

So, if we use this method of spectral density estimation, G(p,q) can be considered as random value distributed as chi-square with two degrees of freedom [1][2]. It can be also shown [2], that normalized standard error of this estimation is equal to 1. This precision is not suitable in most applications. One of the methods for decreasing of this error is to fulfill smoothing of calculated spectral density in frequency area. It means that a convolution of the image on study spectral density and of some smooth function, named spectral window, is calculated:

$$G'(p,q) = G(p,q) ** W(p,q) \quad (2.3)$$

This procedure increases the number of degrees of freedom of chi-square distribution, which approximates the spectral density. And it means that the value of normalized standard error decreases. [2]

Parameters of chi-square distribution are calculated by the use of the spectral window W(p,q) parameters and the image size. Periodical character of the image can be determined by detecting spectrum peaks which have statistical significance with the confidence probability, assigned beforehand. 100(1-α)% confidence limits for the spectral density G(p,q) can be calculated as: $\left[\frac{\nu G'(p,q)}{\chi_\nu^2(1-\alpha/2)}, \frac{\nu G'(p,q)}{\chi_\nu^2(\alpha/2)}\right]$. (2.4)

One more problem, which can be solved by Fourier Spectrum analysis, is numerical estimation of the measure of the order in image elements disposition. This parameter can be obtained by the comparing of the Spectrum peaks with Gauss probability distribution function. Disperse of approximating Gauss distribution can be used as the measure of disperse of the value of image elements disposition period.

## 3. APPLICATION TO SPM-IMAGES INVESTIGATION.

A sample of SPM image of the semiconductor surface with quantum dots is shown on Fig. 1.

In the case if the scanned sample has a declination of a rather horizontal plane, or its surface has brightly expressed macrostructure, SPM image contains brightness trend. It is offered to carry out image preprocessing to delete trend, which decreases strongly the effectiveness of spectral analysis of the image. For this the surface, enveloping in relation to researched one, is built. An outcome of a subtraction of an enveloping surface is image reflecting only a thin surface topography, which is she subject of our research.

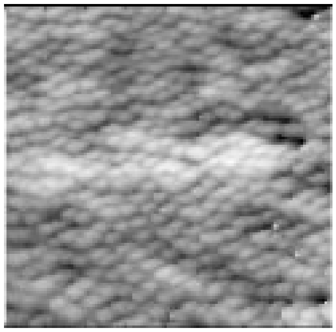

**Figure 1.** Initial SPM image

As the researched surfaces are generated in an outcome of effect of self-organizing, it is important to receive the quantitative information on a character and measure of surface units disposition order.

The procedure of calculations described above is carried out. Two-dimensional smoothed spectral density for the SPM image from figure1 is shown on Fig. 2.

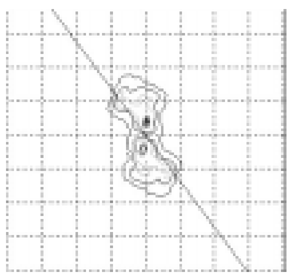

**Figure 2.** Two-dimensional spectral density of SPM image.

The section of this spectral density with 80% confidence limits for the spectrum peaks, calculated by formula (2.4), is shown on the Fig. 3. The normalized width of spectral window W(p,q) is

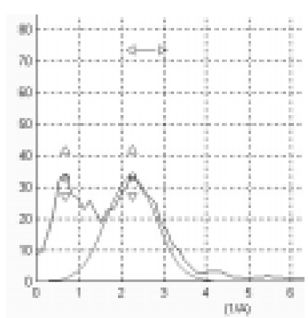

**Figure 3**.Spectrum section.

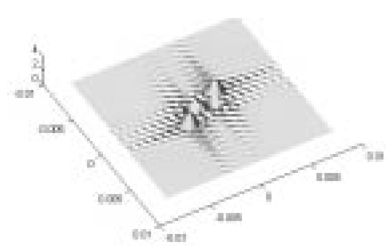

**Figure 4.** Tree-dimensional view of digital filter.

shown by horizontal arrows. Approximating Gauss distribution is also shown. The analysis of this section creates the base for the building of digital filter. Tree-dimensional view of the filter is shown in Fig. 4, and the result of its implementation to the initial SPM image is displayed in Fig. 5.

## 4. SUMMARY.

The tool for the quantitative estimation of the periodical and ordered character of the SPM images is suggested. It is based on the theory of statistical spectral analysis of random processes. This research expands the approach, described for one-dimensional signal processing [1][2], to the image processing. The effectiveness of implementation of the method of statistical spectral analysis in the investigations of semiconductor surfaces with quantum dots is shown. Quantitative estimations of existence of the order in quantum dots disposition

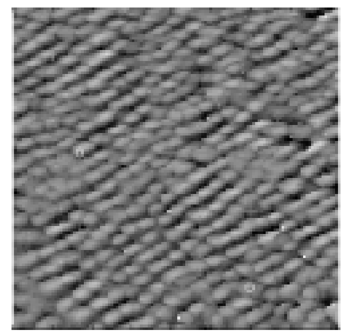

**Figure 5**. The result of digital filtration of SPM image.

on semiconductor surface are obtained. These results can be useful in the designing of new generation of lasers.

## 5. REFERENCES.


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