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Analysis of morphology changes of heat treated metallization of compound semiconductors by the fast wavelet-transform based on B-Spline

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Heat treatment of metallized compound semiconductors results in generation of Ohmic contacts. The morphology changes of the surface during the thermal treatment can be observed by scanning electron microscope. According to our previous results these patterns show fractal character. The fractal dimension of a self-similar object can be calculated using the toolbox of fast wavelet-transform. A method is presented for analyzing the electron microscopic images of the heat treated samples by a fast wavelet-transform based algorithm using the filter coefficients of the two dimensional B-Spline functions. A connection between the dimension values of the patterns and the temperatures of the heat treating are shown.

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1. Introduction

The heat treatment is an important step of compound semiconductor device technology, the contacts obtain their desired electrical characteristics during this process. The type of the contact changes from Schottky to Ohmic one, the specific contact resistivity and some mechanical properties (such as bondability and adhesion to the substrate) change as well [1]. The surface morphology is typical for the given structure thus it can be used for characterization of processes taking place during the heat treatment. The generated patterns show self-similarities [2], which can be traced by wavelet transform [3-5].

The wavelet transform is a basic method in image processing. According to definition

$$T_{\Psi}[f](b,a) = \frac{1}{\sqrt{a}} \int f(x)\, \Psi\left(\frac{x-b}{a}\right) dx \qquad (1)$$

of the one-dimensional wavelet transform, the wavelet Ψ scans the function *f*, similarly to a generalized window. In formula (1) the function Ψ is the wavelet, the parameters *a* and *b* are the dilation and translation parameters [6-7]. Wavelet transform is closely related to the windowed Fourier transform, it offers the possibility to time-frequency analysis, it gains information of both the local and the global properties of the function. Fast wavelet transform is an effective method for calculating the wavelet transform of a discrete signal using only the filter coefficients of the wavelet Ψ .

If instead of Ψ a function with non zero integral is applied in (1) and the transformed function *f* has self similar property, the result of the integral scales as $\sim a^D$, where *D* is the fractal dimension. Since the integrals of the so called scaling functions or father wavelets are 1, their filter coefficients – which are well known numbers – can be substituted to the fast wavelet transform routine, thus an effective method is presented for calculating integrals of type

$$T_{\phi}[f](b,a) = \frac{1}{\sqrt{a}} \int f(x)\, \phi\left(\frac{x-b}{a}\right) dx. \qquad (2)$$

The simplest father wavelet is the Haar function φ with two non-zero filter coefficients. However, applying the Haar function in fractal dimension calculation do not differ much from the usual box counting algorithm, since the value of $\varphi(x)$ is 1 in the interval [0,1) and zero elsewhere.

2. Transformation with b-splines

The nth B-splines are defined recursively from the Haar function φ according to

$$\varphi^{(n)}(x) = \varphi^{(n-1)}(x) * \varphi(x) \tag{3}$$

where the sign $*$ means convolution. It can be said, that the B-Splines are derived as a power of the Haar-wavelet, where the multiplication is the convolution. In the $n \to \infty$ limit, algorithm (3) results in the Gaussian function.

The filter coefficients of the nth B-spline scaling function are generated from the nth row of the Pascal triangle. In our calculations the third B-Spline is applied, since it is continuous, differentiable (Fig. 1), and has only four non-zero filter coefficients, which results in easy transformation process and high numerical stability.

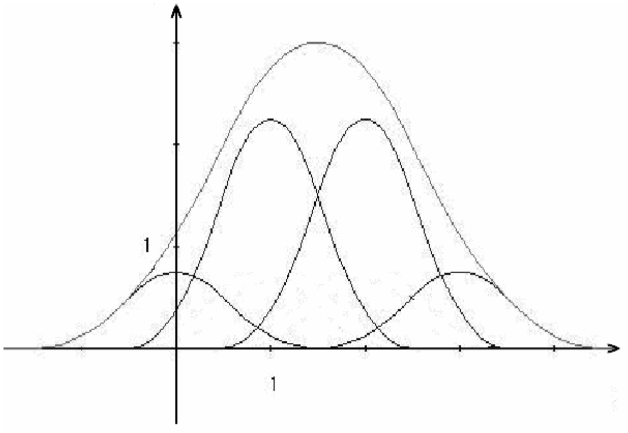

Fig 1. Illustration of the one dimensional construction rule $\varphi^{(3)}(x) = \varphi^{(3)}\left(\frac{x}{2}\right) + 3\cdot\varphi^{(3)}\left(\frac{x-1}{2}\right) + 3\cdot\varphi^{(3)}\left(\frac{x-2}{2}\right) + \varphi^{(3)}\left(\frac{x-3}{2}\right)$ *of the third B-spline.*

The two dimensional modified fast wavelet transform method is given by expression

$$P[k+1,i,j] = \sum_{n,m=0}^{3} c_{nm} \cdot P[k, i+n\cdot 2, j+m\cdot 2] \tag{4}$$

where matrix P is the kth transform of the picture, k is the resolution level, i.e., the dilation coefficient a_k of the kth transformation step fulfills $a_{k+1}=a_k/2$ in the two dimensional version of formula (2), i, j, m and n are the translation indices, and the coefficients are

$$c_{mn} = \frac{1}{16}\cdot\begin{bmatrix} 1 & 3 & 3 & 1 \\ 3 & 9 & 9 & 3 \\ 3 & 9 & 9 & 3 \\ 1 & 3 & 3 & 1 \end{bmatrix}. \tag{5}$$

As an illustration, the third two dimensional B-spline is plotted in Fig. 2.

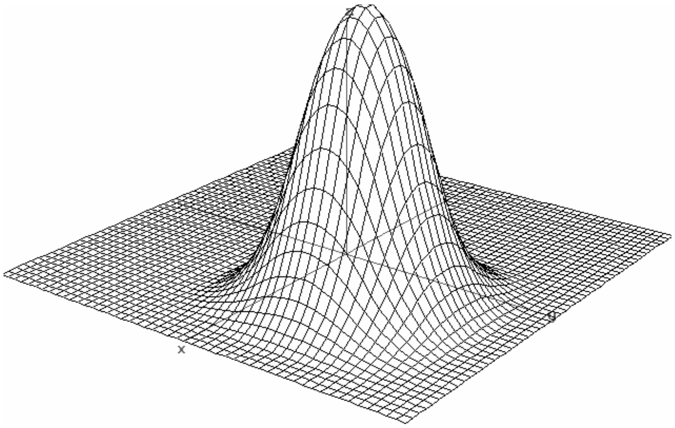

Fig. 2. Graph of the two variable form of the 3. B-Spline.

In case of self similar patterns the two dimensional version of transform (2) with B-spline $\varphi^{(3)}(x,y)$ scales as

$$\langle | T_{\varphi^{(3)}}(\mathbf{b},a) | \rangle_{\mathbf{b}} \sim a^{D} \tag{6}$$

where **b** is the two dimensional translation parameter, and the results of the transformation with a given dilation parameter *a* are averaged according to **b**.

3. Results and discussion

The fractal behavior of the self similar patterns on the surface of metallized semiconductors and the appearance of the ohmic-contact can be closely connected. Au/pd thin films on gaas compound semiconductors substrates show very interesting morphology changes during the heat treatment, clusters called trapeze-like patterns appear, which can be observed in the first part of fig 3. Formula (6) is applied for determining the fractal dimension of the system. The average of the B-spline transform of the picture is plotted versus the dilation parameter *a* in the second part of Fig. 3 on log-log scale. The fractal dimension is the average slope of the line, in case of the trapeze-like pattern *D*=1.62. This value well characterizes the existence of the Ohmic-contact.

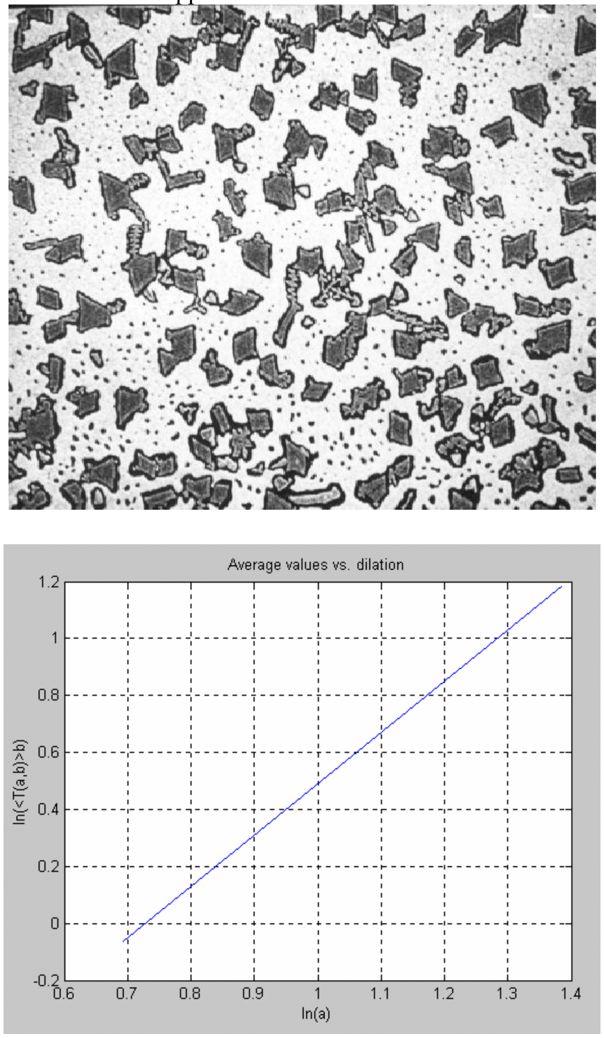

Fig 3. The trapeze-like pattern on the surface of Au/Pd/GaAs and the log-log plot of its B-spline transform by means of the dilation parameter.

4. Conclusion

We have presented a new method for calculating fractal dimension, which unites the simplicity of the fast wavelet transform and the good quality of the gaussian windowed fourier transform. Formulae of the fast wavelet transform are applied with b-spline “synthesis father wavelet” filter coefficients, which are determined by the elements of the pascal-triangle. The two dimensional form of this b-spline transform keeps the self-similarity of the analyzed pattern. The heat treated metallized compound semiconductors show trapeze-like morphology on their surfaces and they can be characterized by their fractal dimension. The qualification of these patterns is important for understanding the processes taken place during the thermal treatment and for developing a method for calculation the resistances of the contacts.

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