Comparative analysis of application of wavelet analysis for the recognition of element composition nanostructures

I M Tkachenko¹, E R Kozhanova², V V Belyaev¹,³, H. Yazbeck¹

¹RUDN University (Peoples’ Friendship University of Russia), Moscow, Russia
²Yuri Gagarin State Technical University of Saratov, Saratov, Russia
³Moscow Region State University, Very Voloshinoy str., 24, 141014, Mytishi, Russia

E-mail: tkachenko_im@rudn.university

Abstract. The paper presents a technique for applying a wavelet analysis (continuous and discrete wavelet transforms) to analyze the elemental composition of nanostructures in order to identify the chemical composition. The experimental data were obtained by means of a scanning electron microscope. The acquisition, processing and study of spectra were carried out using the author's software product "labpraktikum_osnov_wavelet".

1. Introduction

Presently, in problems related to spectral-temporal analysis of nonstationary and inhomogeneous signals to recognize nonstationarities and local features localized both in the time and frequency domain, the wavelet analysis by means of continuous and discrete wavelet transform is applied. This paper deals with the application of the continuous wavelet transform (CWT) and discrete wavelet transform (DWT) [1] to analyze the elemental composition of nanostructures. The orientation of the mesogen molecules at the interface was considered [2–5].

2. The method of research of structure of nanostructures with application wavelet analysis

One of the tools to gain fundamental knowledge about materials, among them nanostructures, is the scanning electron microscopy that has a variety of advantages as compared to any other methods.

In the course of a R&D work performed with the aid of a ZEISS SIGMA SEM HD scanning electron microscope that allows obtaining images in secondary and reflected electrons as well as applying a set of spectra of the specimen material's characteristic xeroradiography, two solid plates have been examined [6]:

1) the first plate consisting of pure silicon (Si) was a reference specimen;
2) the second plate represents a chemical compound (AlSiO₂) obtained by using lithographic technology.

In the course of experiments, tables of bonding energy (eV) and intensity (pulse/s) values have been obtained, on the basis of which standard panoramic spectra of both plates – that of silicon Si (Fig. 1a) and that of the chemical compound AlSiO₂ – have been plotted (Fig. 1b).
Analysis of the panoramic spectra of the plates under study shows (Fig. 1) that their spectra are nonstationary and non-uniform signals with local features that characterize the presence of a chemical element in nanostructures, therefore the application of wavelet analysis, in the form of continuous and discrete transformations, for the purpose of their recognition is a task relevant. As is known, statistical and stochastic characteristics, as well as the energy spectrum, are used for recognition.

The composition of panoramic spectra obtained (Fig. 1) shows that those spectra feature a total maximum within the range of 300 through 400 eV evidencing the presence of silicon atoms in the compounds (Fig. 2).

The paper [6] offers the technique of applying the wavelet transform to analyze the elemental composition of nanostructures (Fig. 3), which consists of two stages:

Stage 1 - obtaining a panoramic spectra of electron spectroscopy and its wavelet analysis.

Stage 2 - the choice of the site of the panoramic spectra of electron spectroscopy for a more detailed study of the structure and its wavelet analysis. It is worth noting that the second stage can be repeated many times with different parameters determining the dimensions of the part of the panoramic spectra.

The main task is to choose a wavelet transform and wavelet functions, which captures the local feature of the panoramic spectra. To implement the technique offered, the author's software product LABPRAKTIKUM_OSNOV_WAVELET [7], which is written in the MATLAB GUIDE, consisting of several modules has been used to process, examine and analyze the spectra obtained.

3. Comparative analysis of application of wavelet analysis

Initially, the proposed technique was tested using continuous wavelet transform (CWT) with various wavelet functions using the authoring software "LABPRAKTIKUM_OSNOV_WAVELET"
[7], which demonstrates various types of CWT visualization [8]. For recognition of extrema, a wavelet spectrogram with a wavelet function was used wavelet Haar (table 1).

**Table 1.** Results of CWT survey spectra of plates using the fourth module "LABPRAKTIKUM_OSNOV_WAVELET" (wavelet Haar)

| Visualization methods | Wavelet function | Plate No. 1 (reference sample, Si) | Plate No. 2 (AlSiO2 chemical compound) |
|-----------------------|------------------|-----------------------------------|--------------------------------------|
| Wavelet Spectrogram   | Wavelet haar     | ![Wavelet Spectrogram](image1)     | ![Wavelet Spectrogram](image2)       |
|                       | Gauss wavelet 1st order | ![Wavelet Spectrogram](image3) | ![Wavelet Spectrogram](image4) |

The analysis of the obtained wavelet spectrogram obtained in the course of CWT shows information redundancy and clear fixation of the extremum point.

Then, the proposed technique was tested using a discrete wavelet transform (DWT) with various wavelet functions, decomposing the signal into approximating and detailing coefficients by levels with a Haar wavelet (Fig. 3) [9].

![Figure 3](image5)  
**Figure 3.** Detailing factors of three levels in fiberboard (Haar wavelet) silicon Si (a) and chemical compound AlSiO2 (b) with a range from 0 to 2000 eV
A visual comparison of the obtained wavelet coefficients in fiberboard is time-consuming, therefore, to compare the obtained detailing coefficients, statistical characteristics, energy spectrum and stochastic characteristics of the wavelet transform results are used, including for DWT [8, 9].

In article [9-10] statistical characteristics were obtained: arithmetic average, variance and mean square deviation of detail coefficients. The analysis showed that dispersion has the greatest diagnostic significance of recognition.

We will conduct a comparative analysis of the CWT and DWT for recognizing the elemental spectrum of nanostructures (Table 2), which shows that the discrete wavelet transform (DWT) is the most informative. This type of wavelet analysis allows not only to find the points of extremum, but to recognize the signal.

Table 2. Comparative analysis of the survey spectra of plates using CWT and DWT for recognition of the elemental spectrum of nanostructures

| №  | Criterion comparisons | CWT          | DWT            |
|----|------------------------|--------------|----------------|
| 1  | Type of visualization | Wavelet Spectrogram | Graphs of detail coefficients |
| 2  | Feature                | Determination of extremum points and inflection points. | Statistical and stochastic characteristics as well as the energy spectrum are used for analysis and recognition. |
| 3  | Disadvantage           | Information redundancy; difficulty in obtaining numerical characteristics (except for the maximum and minimum, points of inflection) | - |

4. Conclusion

Subsequently, it is planned to create software that implements hardboard for conducting experiments in order to recognize the elemental composition of nanostructures based on data from a scanning electron microscope. Using wavelet analysis, it is planned to conduct research and analysis of the functioning of a multielectrode semiconductor optical amplifier with quantum dots.

5. Acknowledgement

The paper is prepared under partial support of Russian Foundation for Basic Researches (RFBR) (project No. 19-07-00602_a).

References

[1] Zakharov A A, Kozhanova E R, Tkachenko I M. Comparative Characteristics of Application of Classical Fourier Transform and Continuous Wavelet Transform For Signal Analysis: Study Guide for students in Specialty Electronic Instruments and Devices (210105.65), Majors Electronics and Nanoelectronics (Bachelors – 21010062, Masters - 2110068). Ministry of Education and Science of the Russian Federation, Yuri Gagarin State Technical University of Saratov, Saratov. 2012. 132 p.

[2] Chausov D N 2018 Journal of Physics: Conference Series 996 012019 DOI 10.1088/1742-6596/996/1/012019

[3] Dadivanyan A K, Belyaev V V, Chausov D N, Stepanov A A, Smirnov A G, Tsybin A G, Osipov M A 2015 Molecular Crystals and Liquid Crystals 611 (1) 117. DOI 10.1080/15421406.2015.1030196

[4] Dadivanyan A K, Noah O V, Pashinina Y M, Belyaev V V, Chigrinov V G, Chausov D N 2012 Molecular Crystals and Liquid Crystals 560 108 DOI 10.1080/15421406.2012.663185

[5] Dadivanyan A K, Chausov D N, Belyaev V V, Pashinina Yu M, Noa O V, Chigrinov V G 2012 Journal of Experimental and Theoretical Physics 142 (6) 1253 DOI
10.1134/S1063776112110027

[6] Tkachenko I M, Kozhanova E R 2017 *Mathematical Methods in Engineering and Technology. ММТТ-30* 12 (3-2) 40.

[7] Kozhanova E R, Zakharov A A, Tkachenko I M labpraktikum_osnov_wavelet: Certificate of State Registration of Computer Software No 2011611250 dated February 07, 2011.

[8] Tkachenko I M, Kozhanova E R 2018 *Scientific and Technical Bulletin of the Volga region* 11 261.

[9] Kozhanova E R, Tkachenko I M 2018 *International Conference on Actual Problems of Electron Devices Engineering, APEDE 2018*. DOI:10.1109/APEDE.2018.8542352

[10] Chausov D N, Kurilov A D, Belyaev V V, Kumar S 2018 *Opto-Electronics Review* 26 (1) 44. DOI 10.1016/j.opelre.2017.12.001.