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WAVELET ANALYSIS OF TIME-OF-FLIGHT ION MASS SPECTROMETRY SIGNALS

Key words

Laser deposition, plasma technology, wavelet analysis.

Abstract

The problem of deposition of thin layers on non-layer substrates occupies a special place in modern materials technology. One of the fast-growing methods is laser ablation involving the evaporation of material by the laser pulse, thereby forming a plasma cloud, which is then deposited on the substrate. The basic method of diagnostics of plasma cloud is a mass spectrometer. The paper has presented the physical bases of the operation time of flight mass spectrometer and the theoretical models of signal received from the spectrometer. In the experimental part, the spectrum obtained for Pb_2 lead particles that were then subjected to wavelet analysis is presented, thanks to which we have received additional information about the composition of the plasma cloud and about any other isotopes. The paper is an introduction to further research on the use of wavelet transform in spectroscopic analysis.

Introduction

For several decades, mass spectrometry has been the most important research tool using atomic beams. Its universal characteristics such as high sensitivity and versatility have caused the permanent development of this test method. The aim of the study was to determine the possibility of applying wavelet analysis to study the structure of the plasma cloud released from the target material under the influence of a laser pulse. The research will improve the method of the deposition of thin layers by laser ablation (PLD-Pulsed Laser Deposition).

1. Time of flight spectrometer

The rapid development of mass spectrometry was initiated in 1948 by A.E. Cameron by developing the principles of mass analysis by measuring the time of flight. Mass spectrometry is a standard tool in the study of the physical foundations of the process of PLD.

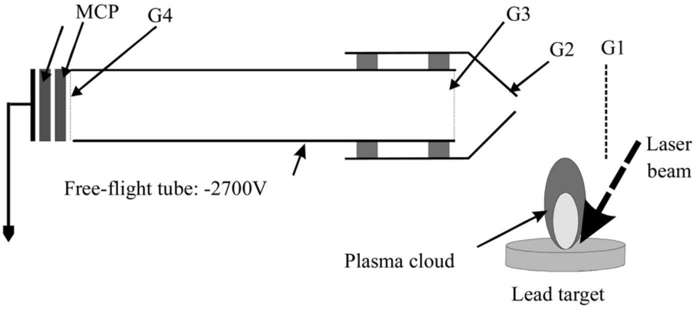

Fig. 1. Scheme of time-of-flight spectrometry

In the experiment there was used a mass spectrometer time of flight of COMSTOCK model TOF-101 and laser $\lambda = 308$ nm, which design is based on the idea of Wiley-McLaren. The negative potentials G2, G3, and G4 grids have enabled the examination of positive ions. The spectrometer has been extended to the inlet aperture in the shape of a cone and an electronic pulse to push ions. This arrangement allowed for the selective examination of the plasma cloud by applying a delay between the laser pulse and the occurrence of the potential of the G2 grid [1]. Ions having the same charge accelerated by the potential difference of G2 and G3 grids receive the same amount of kinetic energy, and the times of flight through the free flight tube are proportional to the square root of the mass. So defined operating conditions of the spectrometer find very good confirmation in the study, e.g., atomic beams. Unfortunately, in the case of plasma research resulting in the ablation of shields of a solid, the velocity distribution of the initial components of the plasma cloud with a large concentration and a multiplicity of possible types of ions seriously interfere with the identification of the spectra. It is necessary in such studies to include precise calibration of the spectrometer and to provide the separator of ions due to their energy.

Scheme spectrometer is shown in Figure 1. Positive ions that are a result of the laser pulse have been released from the target fly into the space between the G1 and G2 grids (the inlet aperture), where, due to the voltage, they are drawn into the spectrometer through the inlet nozzle. There they are accelerated in the region between the G2 and G3 grids. Then they move uniformly in the free flight tube. At the end of the tube is the detector, which is where the micro-channel plate (MCP) is in our experiment.

2. Signal from time of flight spectrometer

A detailed description of the physical basics of mass spectrometry can be found in [1, 2]. The mechanism of film formation by the laser deposition is described in [3]. For comparison, we have used the sputtering of target material mechanisms under the influence of various factors (ions, electrons, photons) [4]. Mathematical foundations of the description of the dynamics of gases in the semi-limited space are in papers [5, 6].

Based on this model, there has been suggested a time distribution signal from the spectrometer in the form of the following:

$$f(t) \propto u^{n-3} t^{-n} \exp\left\{-\beta_K^2 \left[(z-ut)^2 + y^2\right]/t^2\right\} \tag{1}$$

where

z – axis perpendicular to the target
y – axis parallel to the target
t – time
u – initial velocity.

The parameter n is 4 or 5, depending on the type of spectrometer used in the detector.

The β_K factor equation is as follows:

$$\beta_K = \sqrt{\frac{m}{2kT}} \tag{2}$$

where

m – mass of particles
T – temperature of the plasma cloud.

The impact of β_K factor, which is the inverse of the most likely speed, on the distribution function of the signal of the spectrometer is shown in Figure 2.

Knowing the distribution time of flight of the particles, one can determine the velocity and energy distributions according to the following:

$$f(v) = f(t) / \frac{dv}{dt} = \frac{f(t)t^2}{L_{TOF}} \tag{3}$$

$$f(E) = f(t) / \frac{dE}{dt} = \frac{f(t)t^3}{mL_{TOF}{}^2} \tag{4}$$

where L_{TOF} is the length of the free-flight tube in the spectrometer.

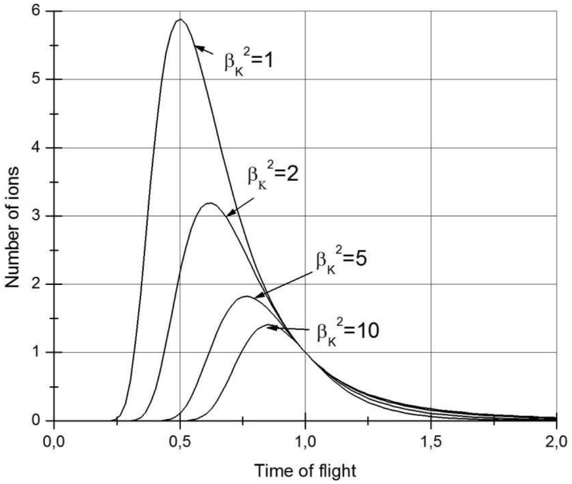

Fig. 2. The changes of the time distribution of the signal for different values of β_K^2 factor according to function (1)

When only the average time of flight of ions is determined, a sufficient approximation is to use a Gaussian function for signal analysis with a mass spectrometer.

3. Results

Figure 3 shows the mass spectrometer signal of a Pb_2 molecule. The Gaussian distribution function has been matched to the signal. The resolution time-of-flight measurement was 2.5ns.

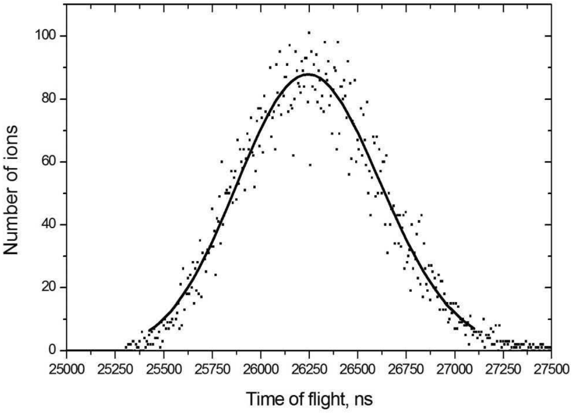

Fig. 3. The signal of Pb_2 particles from the spectrometer

The signal was then subjected to wavelet analysis using Matlab-Toolbox Wavelet to capture the signal discontinuity caused by the different masses of isotope invisible in Figure 3, and the results are presented in Figures 4, 5, 6, and 7. The theoretical basis for wavelet analysis can be found in [9, 10]. The paper presents the results of research using dmey wavelet on four levels of decomposition. The selection of these wavelets resulted from the authors' experience acquired in other studies, which showed that the type of signal should be adjusted to the type of wave. There studies have also been carried out using other wavelets, and the results of the work will be included in subsequent publications. Although the signals are after the decomposition that is a1, a2 etc. are the most interesting, we must bear in mind that noise may also contain interesting information. We have showed the whole decomposition, so that the reader could see the change in the signals and noise, which must be completed at some point because the decomposition has distorted the signal. We have focused only on the signals after purification of the noise where the graphs are just below the signal s. We have found that the best results taking into account signal decomposition are found using a dmey wavelet on the second and third level (Figures 5 and 6), and it provides an analysis of the structure of the plasma cloud. In the reconstructed signals, distinct maxima are visible which we think of as isotopes ^{206}Pb, ^{207}Pb, and ^{208}Pb, which will allow the identification of the components of the cloud.

Conclusions

The paper presents the results of preliminary research on a cloud of plasma using wavelet analysis. The studies have confirmed the effectiveness of the use of wavelet transform as a tool to eliminate “noise.” They confirmed the need for a good selection of the type of wavelet, and they demonstrate the high efficiency of this method on the second and third level of decomposition. The results indicate that this diagnostic method will provide further information on the isotopic composition of the plasma cloud.

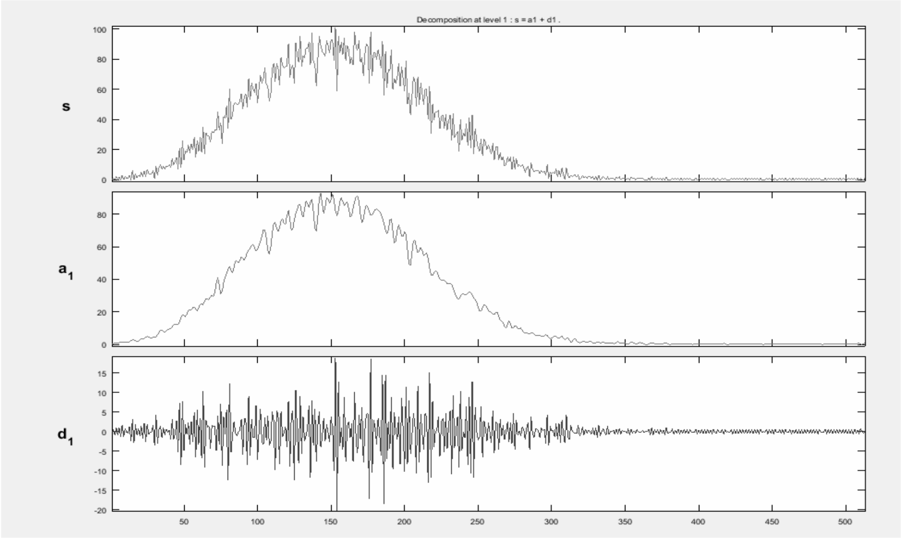

Fig. 4. Wavelet analysis of the signal on the first level of the decomposition

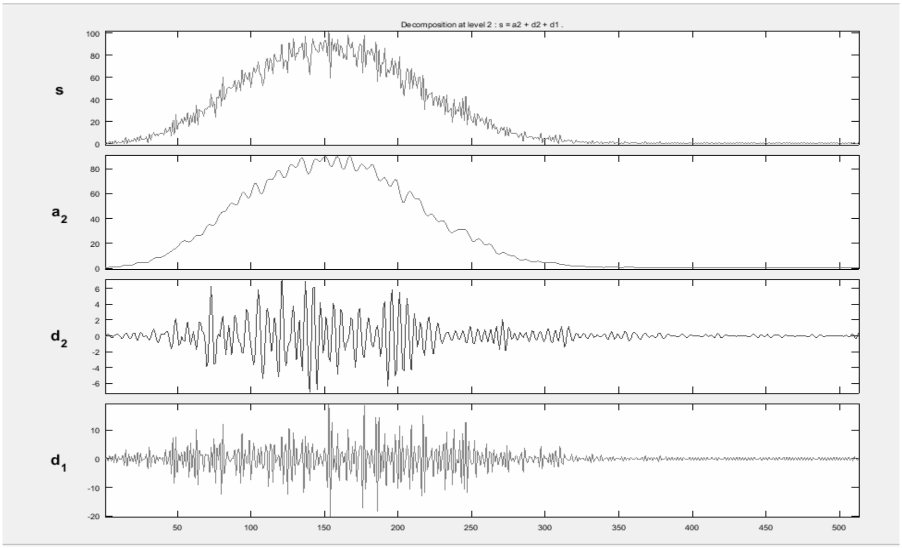

Fig. 5. Wavelet analysis of the signal on the second level of the decomposition

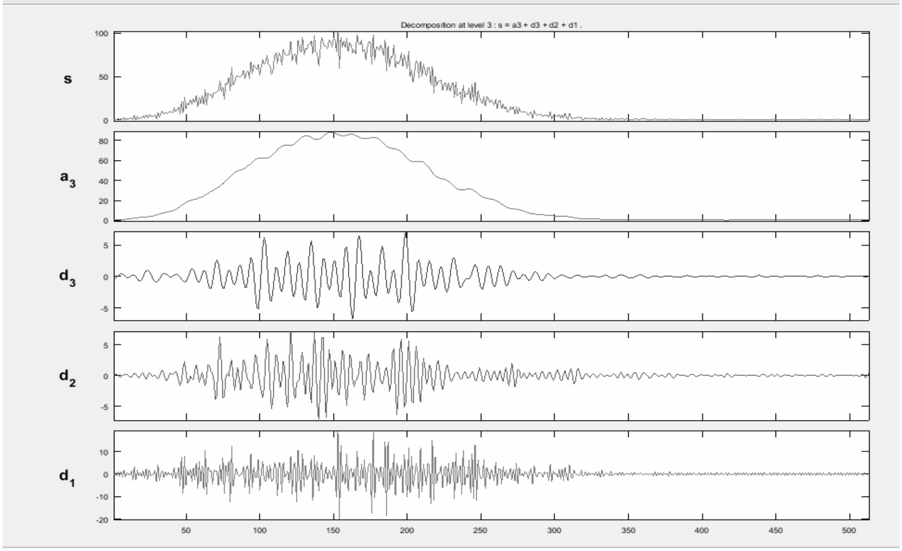

Fig. 6. Wavelet analysis of the signal on the third level of the decomposition

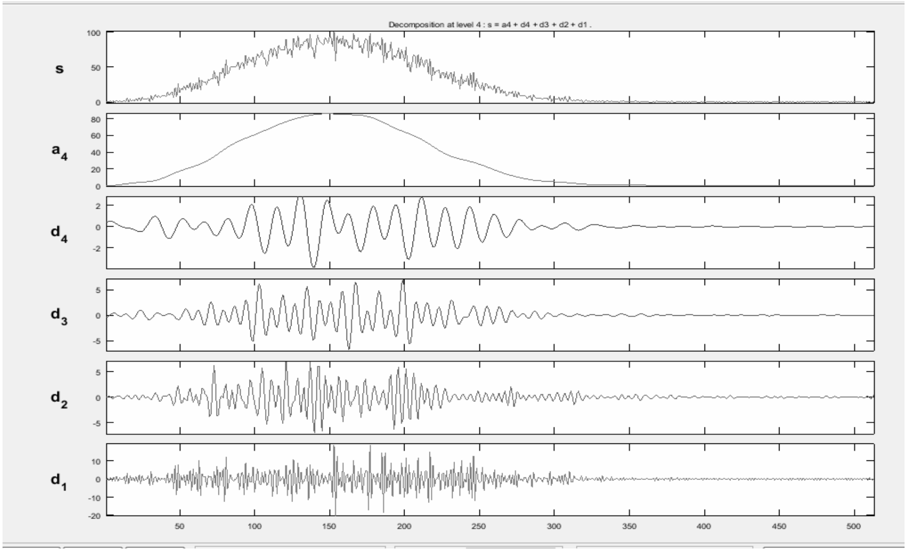

Fig. 7. Wavelet analysis of the signal on the fourth level of the decomposition

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Analiza falkowa sygnałów otrzymywanych w spektrometrze czasu przelotu

Słowa kluczowe

Laserowe osadzanie, technologia plazmowa, analiza falkowa.

Streszczenie

We współczesnej technologii materiałowej szczególne miejsce zajmuje zagadnienie osadzania cienkich warstw na innych niż warstwa podłożach. Jedną z szybko rozwijających się metod jest ablacja laserowa polegająca na odparowaniu impulsem lasera materiału, w wyniku czego powstaje obłok plazmy, który jest następnie osadzany na podłożu. Podstawową metodą diagnostyki obłoku plazmy jest spektrometr masowy. W pracy przedstawiono podstawy fizyczne działania spektrometru masowego czasu przelotu oraz teoretyczne modele sygnału otrzymywanego ze spektrometru. W części doświadczalnej zaprezentowano widmo otrzymane dla cząsteczki ołowiu Pb_2, które następnie poddano analizie falkowej, dzięki czemu otrzymano dodatkowe informacje o składzie obłoku plazmy. Praca jest wstępem do dalszych badań nad zastosowaniem transformaty falkowej w analizie spektroskopowej.