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THE FOURIER ANALYSIS OF PICOSECOND ACOUSTIC SIGNALS GENERATED BY LASER BEAM IN Au/V NANOLAYERS

M. ALEKSIEJUK, F. REJMUND

Institute of Fundamental Technological Research
Polish Academy of Sciences
Świętokrzyska 21, 00-049 Warszawa, Poland
e-mail: maleks@ippt.gov.pl

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Paper presents the results of study of picosecond acoustic signals generated by femtosecond laser pump pulse in Au/V multilayers. Au/V nanostructures with a period of 36-205Å located on MgO substrate were studied. The dependence of measured changes of the laser light reflectivity from nanostructure surface on different delays of probe beam was examined. Peak frequencies obtained by FFT analysis were interpreted as frequencies of acoustical localized modes. The obtained values of these localized modes are in agreement with numerical results. In the same sample localized modes were excited simultaneously in the first and second frequency forbidden gaps.

Key words: picosecond acoustics, metallic nanolayers, FFT analysis.

1. Introduction

One of the most rapidly developing branches of nanotechnology is nanophononics. Nanophononics considers interaction of acoustic phonons with material on a nanometric scale. This interaction gives many new physical effects which will be the basis of novel nanodevices. The acoustic properties of periodical multilayer nanostructures have been widely studied using Brillouin, Raman scattering and picosecond acoustic methods [1–5].

In the previous our papers ultrasonic picosecond technique was used to study acoustic properties of Au/V nanolayers [6–8]. These papers mainly deal with finding conditions for acoustic localized modes excitation in nanolayer metallic structures. In present paper FFT analysis is used to investigate frequency spectrum of acoustic signals generated by femtosecond pulses of light interaction with metallic monolayer structures.

2. Experimental results

Samples of Au/V multilayers with superlattice period from 36 to 205 Å using a pump-probe laser beam technique were investigated. For excitation of sample femtosecond light pulses generated by Ti: sapphire laser were applied. Delayed probing beam served for measuring sample reaction in time after excitation [6]. The changes of reflectivity coefficient as a function of delay time between pump and probing beam were obtained. For different samples two kinds of responses were observed. First type of answer was characterized with appearance of acoustic echoes while second one contained high frequency oscillations connected to localized acoustic modes. Examples of both types registered dependences are presented on Figs. 1 and 2. The case presented on Fig. 1. was observed in nanolayer samples with bilayer thickness lower than 80 Å. From the value of the delay time of echo it is possible to calculate sound velocity in multilayer structure. For nanolayer with bilayer thickness greater than 80 Å the high frequency oscillations were registered. For intermediary thicknesses, weak echoes signals were registered against the background of high frequency oscillations.

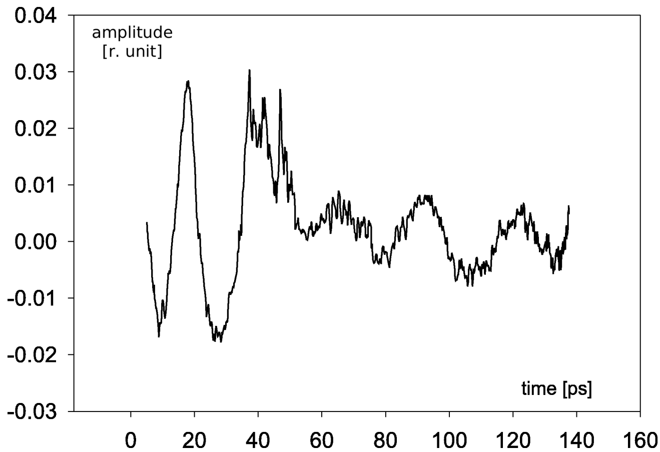

Fig. 1. Dependence of reflectivity coefficient changes versus delay time for 16 Å/21.5 Å Au/V nanolayer.

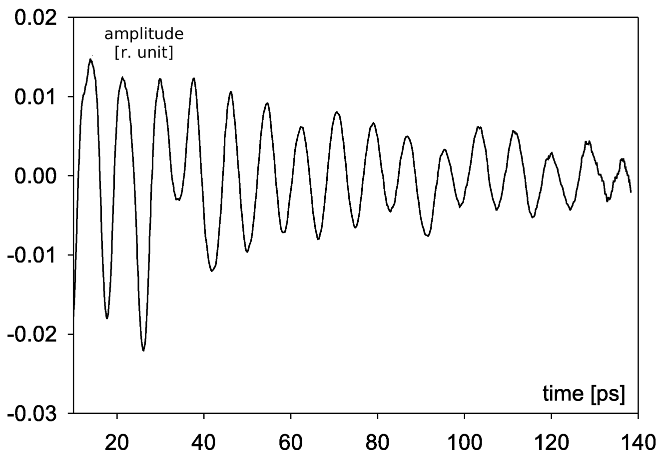

Fig. 2. Dependence of reflectivity coefficient changes versus delay time for 80 Å/91 Å Au/V nanolayer.

In case of high frequency oscillations the value of frequency may be obtained by using regression method. It can be realised by fitting experimental curve to dependence described by mathematical formula. The formula used in the regression method has form:

$$f(t) = a\exp\left(-\frac{t}{d}\right)\sin\left(2\pi\frac{t}{b}+c\right). \tag{1}$$

In Fig. 3 the both curves (experimental and fitted) for Au/V nanolayer (80 Å/91 Å) are shown. Values of calculated constants and standard deviation for this case are presented in Table 1.

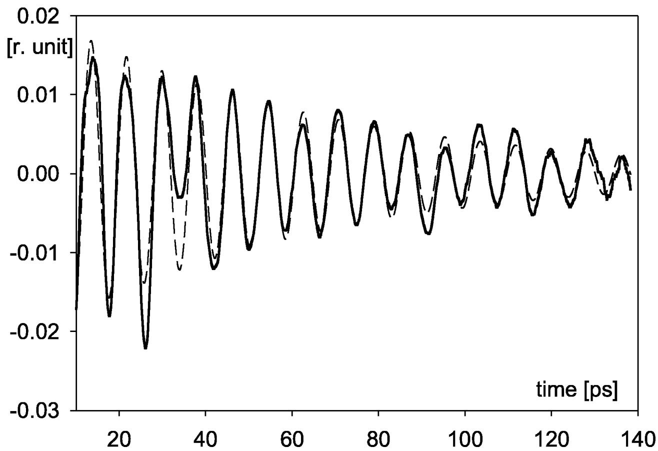

Fig. 3. Experimental dependence and fitted curve for 80 Å/91 Å Au/V nanolayer.

Table 1. Nonlinear regression coefficient values of fitting curve in Fig. 3.

	coefficient value	standard deviation
a	0.0208	0.0004
b	8.1745	0.0045
c	3.7306	0.0199
d	63.7903	1.6534

The frequency obtained as a result of fitting process is equal to 122.3 GHz.

3. Fourier analysis and discussion

The frequencies appearing on figures showing the dependences of the reflectivity coefficient of light on time can be received also by Fourier analysis method (FFT). Two examples of FFT analysis for Au/V nanolayer are presented in Figs. 4 and 5. These dependences were obtained for two different time intervals (at the beginning and the end of the measured time range). In FFT analysis 256 points were used. In Figs. 4 and 5 two peaks at the frequencies 120 GHz and 220 GHz are appearing in first and second frequency gaps, respectively. The proportions of these amplitudes for both figures confirm that the amplitude of localized mode generated in second frequency gap is evidently greater than the one in first frequency gap. All measured multilayers with observed localized modes show similar FFT transforms for registered acoustical high frequency signals.

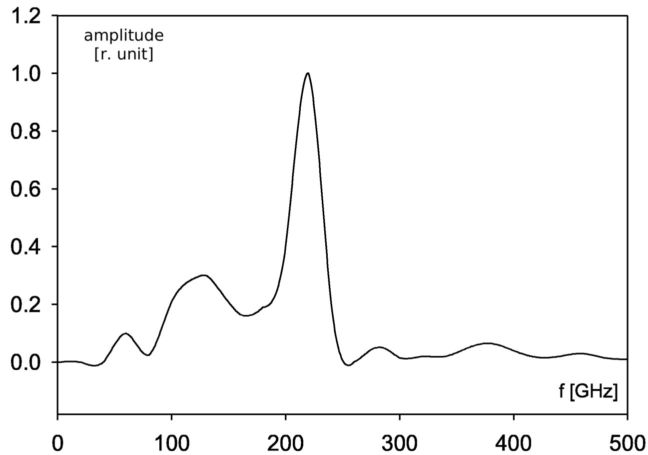

Fig. 4. FFT spectrum of reflectivity changes for 80 Å/91 Å Au/V nanolayer (beginning of time scale).

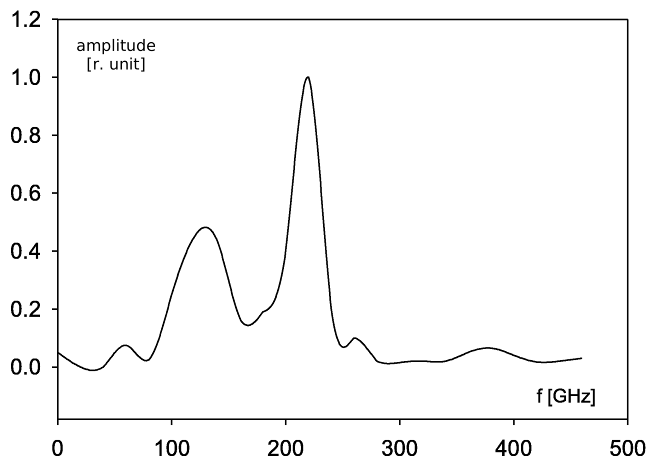

Fig. 5. FFT spectrum of reflectivity changes for 80 Å/91 Å Au/V nanolayer (end of time scale).

The FFT analysis was also made for echo signals. The result of such FFT analysis for selected Au/V nanolayer is shown in Fig. 6. The maximum of frequency for third acoustic echo is 25 GHz. This means that acoustic pulses generated in nanolayer structure by laser impact have frequency of order tens GHz.

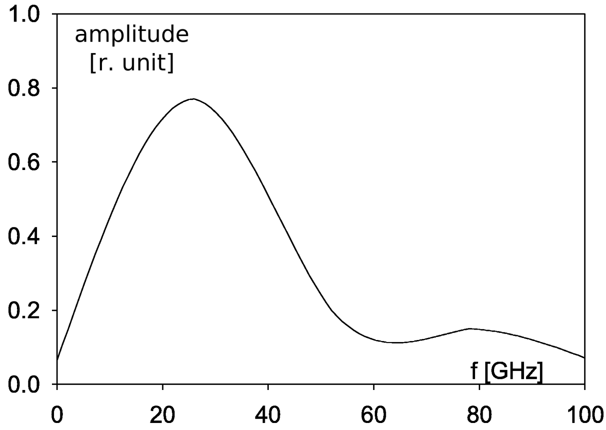

Fig. 6. FFT spectrum of reflectivity changes (third echo) for 16 Å/21.5 Å Au/V nanolayer.

4. Conclusion

The FTT analysis used to study spectrum of high frequency oscillation signals generated by laser pulses allowed to extract two frequencies connected to localized modes. In considered Au/V nanolayers these two acoustic modes appear simultaneously in first and second frequency gaps. The amplitude ratios of frequency peaks in FFT spectrum for different regions of signals show that attenuation of localized mode in second gap is greater.

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