ARCHIVES OF ACOUSTICS
32, 4 (Supplement), 41–46 (2007)

FREQUENCIES OF LOCALIZED ACOUSTIC MODES IN DEPENDENCE ON MUTUAL RELATION OF COMPONENTS OF Au/V NANOLAYERS

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(*received July 15, 2007; accepted October 18, 2007*)

The paper presents the study of frequencies of the acoustic localized modes in metallic Au/V nanolayers. On the basis of Rytov model describing acoustic wave propagation in periodic layered medium and Djafari–Rouhani formula the frequencies of localized modes were numerically calculated. Dependencies of localized modes frequencies were presented graphically as a function of b/L nanolayer parameter (b – thickness of Au sublayer, L – thickness of Au/V bilayer) for first and second phononic stop bands. Obtained experimentally frequencies of localized modes for Au/V nanolayers were compared with calculated values. Accordance between experimental and theoretical results is satisfactory.

Keywords: metallic nanolayers, localized acoustic modes.

1. Introduction

Present-day technologies of nanolayers fabrication enable establishing of their parameters with an unexpected precision. It is possible to obtain nanolayers composed of single atomic layers of various materials. Then, the possibilities producing nanolayers from materials which effective parameters can be respectively assumed open the way to creation of nanomaterials having the new properties not known for bulk materials. These technologies caused appearing and development of the new branches of material science such as the forbidden gap or the wave functions engineering. Nowadays nanostructures are applied as elements of nanophotonic devices. In the nearest future such progress probably will take place in field of nanophononics. In nanolayered materials there are observed the new acoustic phenomena similar to photonic ones. One of them is appearance of the frequency forbidden gap in periodic nanolayer materials.

In this article the study of origin of the localized acoustic modes and their position in frequency forbidden phononic gap in metallic Au/V nanolayer structure are presented.

Experimentally obtained results of localized modes frequencies were compared with those obtained from theoretical calculations in the range of the phononic gaps. The parameters of the phononic gaps were determined using Rytov model of acoustic wave propagation in multilayer periodical structure [1].

2. Results

Rytov model generally describes periodical multilayered continuum medium. Using this model Rytov has derived the dispersion relation i.e. the formula describing frequency of propagating acoustic wave ω as a function of the wave vector q. This dispersion relation contain the material and geometrical parameters of sublayers creating described medium [1, 2]. The dispersion formula is determined by the following expression:

$$\begin{aligned}\cos(qL) \;=\; & \cos\left(\omega\frac{a}{c_1}\right)\cos\left(\omega\frac{b}{c_2}\right) \\ & -\frac{1}{2}\left(\frac{\rho_1 c_1}{\rho_2 c_2}+\frac{\rho_2 c_2}{\rho_1 c_1}\right)\sin\left(\omega\frac{a}{c_1}\right)\sin\left(\omega\frac{b}{c_2}\right),\end{aligned} \tag{1}$$

where a and b are the thicknesses of layers 1 and 2 respectively, L is the repetition period of multilayer – bilayers thicknesess $(L = a + b)$, c_1 and c_2 designates longitudinal or transverse velocities of acoustic waves propagating in sublayer 1 and 2 respectively, in direction normal to the multilayer plane (in considered case – longitudinal wave), ρ_1, ρ_2 are the densities of 1 and 2 sublayer, respectively. The scheme of measured nanostructure is show on Fig. 1. In Fig. 2 the numerically calculated dispersion curve for the longitudinal acoustic wave in the investigated Au/V nanostructure is presented. Two frequency gaps appear in observed frequency region, one at boundary of mini Brillouin zone and second in the center of mini Brilloin zone. The boundaries of mini Brillouin zone are in the range values of wave vector from $-\pi/L$ to π/L.

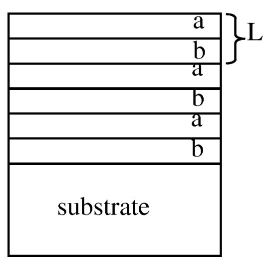

Fig. 1. Geometry of measured Au/V samples.

The surface exitation of medium described above can generate the elastic wave which propagates inside the structure in direction normal to the surface or nonpropagating vibration in the region close to surface in form of the acoustic localized mode [2, 3].

Acoustic localized modes were observed by author in Au/V nanolayer [3]. The theoretical formula of the localized mode frequency firstly was obtained by DJAFARI–ROUHANI [4]. The dependence of the localized mode frequency on the parameters of capping layer was considered by author in [5].

In the case of the uniform two component nanostructure the localized frequency mode is described by the following equation:

$$p \tan\left(\omega \frac{a}{c_1}\right) + \tan\left(\omega \frac{b}{c_2}\right) = 0, \tag{2}$$

where p denotes ratio of acoustic impedances of both materials creating nanostructure.

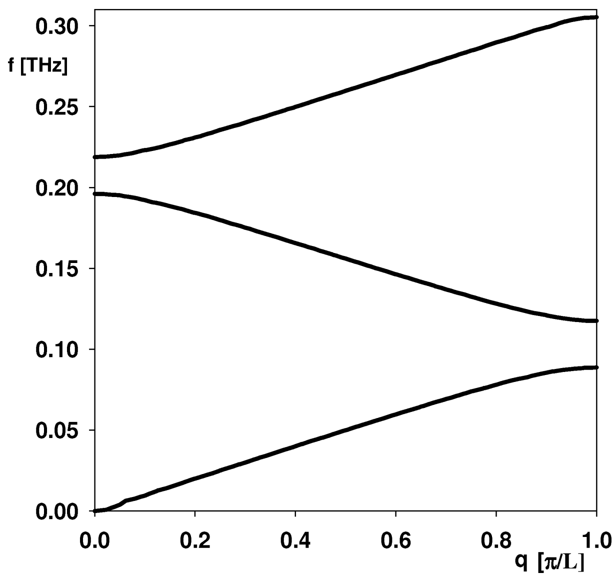

Fig. 2. Dispersion curve for longitudinal acoustic waves in Au/V (96 Å/109 Å) nanolayer.

On base the formulas (1) and (2) the dependences of frequencies of the localized modes as a function of the parameter b/L were calculated for studied Au/V nanolayers. In Figs. 3 and 4 the positions of the acoustic localized modes in the first and the second forbidden frequency gaps (continuous green line) for Au/V nanostructure are presented. The boundaries of the phononic gaps were marked as dotted lines The bilayer thickness for this nanostructure is equal to $L = 205$ Å and in Figs. 3 and 4 also are placed the measured values of the localized mode frequences for Au/V nanolayers (opened squares) for which the thicknesses of sublayers made from gold and vanadium were equal to 96 Å and 109 Å, respectively. The sublayer thicknesses were measured by the low angle X-ray refractometry method.

An interesting result is the relative change of location of the localized mode frequency in the range of the phononic gap. While the value of b/L increase the localized

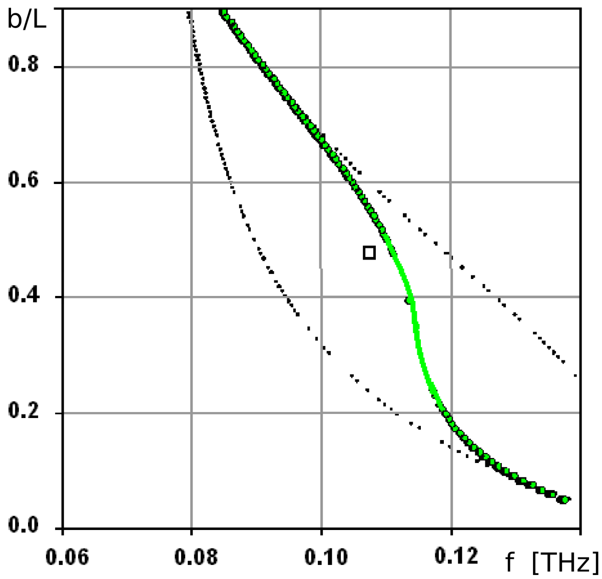

Fig. 3. Frequency dependence of acoustic localized mode on b/L parameter in first frequency gap for Au/V nanolayer of the bilayer thickness equal to 205 Å. The green solid line describes the theoretical values of the localized acoustic mode frequency. The open square denotes the measured frequency of the localized mode for Au/V (96 Å/109 Å) nanolayer.

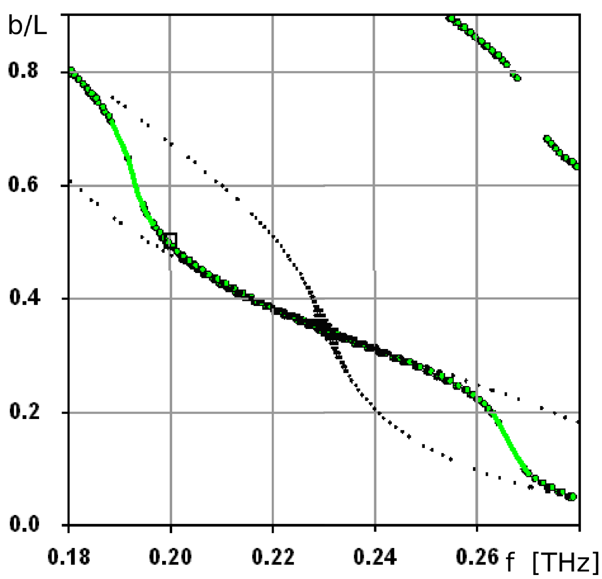

Fig. 4. Frequency dependence of acoustic localized mode on b/L parameter in second frequency gap for Au/V nanolayer of the bilayer thickness equal to 205 Å. The green solid line describes the theoretical values of the localized acoustic mode frequency. The open square denotes the measured frequency of the localized mode for Au/V (96 Å/109 Å) nanolayer.

mode frequency is displaced from the lower edge of gap to the upper one in the case first phononic gap. For the second gap there is an additional effect – crossing the edges of the gap for the some value of b/L parameter.

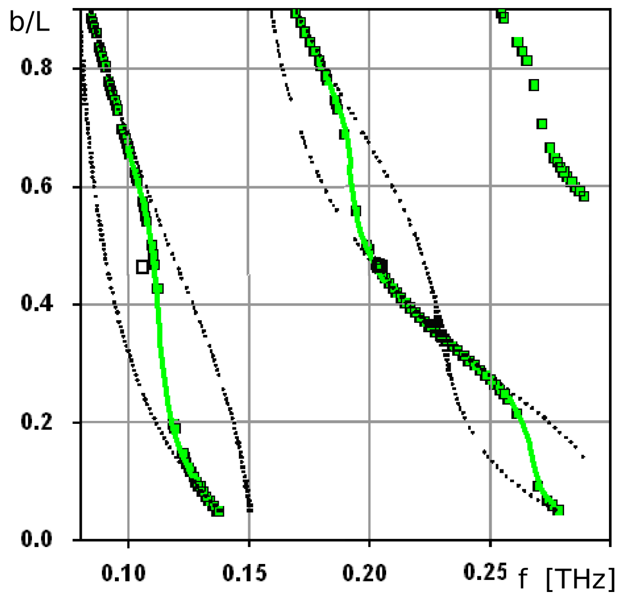

Fig. 5. Frequency dependence of acoustic localized mode on b/L parameter in both frequency gap for Au/V nanolayer of the bilayer thickness equal to 205 Å. The green solid lines describe the theoretical values of the localized acoustic modes frequencies. The open squares denote the measured frequency of the localized mode for Au/V (96 Å/109 Å) nanolayer.

In Fig. 5 the dependences of the localized modes frequencies in the both phononic gaps for Au/V nanolayers are shown.

3. Conclusions

The performed numerical calculations showed interesting dependences for the location of the forbidden phononic gap and the localized mode frequencies in the range of gap on mutual ratio of nanolayer components described by parameter b/L.

The localized mode frequency is moving from the lower edge of gap to the upper one during changes of parameter b/L. For the second gap crossing the edges of the gap appears. There were also obtained experimentally the frequencies of the localized acoustic mode for Au/V nanolayer structure composed of bilayers with thickness L equal to 205 Å. Experimental values of the localized mode frequency are in accordance with the result of numerical calculations.

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