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ACOUSTIC WAVE VELOCITY IN Ag/Fe NANOLAYERS

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The paper presents the results of acoustic wave velocity investigation in metallic Ag/Fe nanolayers deposited on GaAs substrate. Measurements of velocity were performed using femtosecond technique. Ag/Fe samples were characterized by different thickness of bilayers. On the basis of experimental results of velocities, effective elastic constants c_{11} were evaluated. In the range of bilayers thickness above 80 Å the c_{11} values are in accordance with those calculated from the elastic constants of bulk materials (Rytov model). For lower values of bilayer thickness elastic constants exhibit large decrease. Grimsditch's model was applied to interpret changes of elastic constants dependence for low bilayer thickness. This model contains an additional interlayer treated as the parameter. Comparison the values of theoretical elastic constants obtained by applying of Grimsditch model with those calculated from experiment shows qualitative accordance in the range of small bilayer thickness.

Keywords: metallic nanolayers, effective elastic constants nanolayers.

1. Introduction

In recent years nanolayers are more frequently applied in nanoelectronics. Nanolayers are elements of such devices as: Bragg's mirrors, digital memories of high capability VCSEL lasers etc. The novel physical phenomena, not appearing in the same "bulk" materials are used in these devices. The examples of these phenomena are: phonon frequency gap (stop band), giant magnetoresistance, acoustical localized modes in frequency gaps, elastic anomalies. The elastic anomalies in nanolayes structures demonstrate the marked decrease or increase in the effective elastic constants with decreasing multilayer periodicity. Such anomalies were observed, between others, in Co/Cu, Fe/Cu nanolayers [1, 2].

In this paper we present the results of a study of the elastic properties of the Ag/Fe multilayers. The velocity of longitudinal acoustic wave in these nanolayers was measured. These type of nanolayers possess magnetic properties which were investigated by A. BERGER, R. P. ERICKSON [3] and T. PHALET *et al.* [4]. In the Ag/Fe nanostructure indirect magnetic interaction between ferromagnetic layers (Fe) separated by a non magnetic Ag layer takes place. The base mechanism describing this phenomenon is RKKY exchange interaction [4]. The elastic properties in these nanostructures cause change magnetic properties by magnetoelastic interaction.

2. Measurement results

Acoustic wave velocity in Ag/Fe nanolayers was measured by using picosecond technique. Experimental setup and measurement method were described in our previous paper [5]. Measurements changes of reflection coefficient of light were performed as a function of delay time of probing laser beam relatively to the exciting pulse. In Fig. 1 geometry of structure of the nanolayer samples is shown. Ag/Fe specimens were obtained by molecular beam epitaxy (MBE) method. The sample were prepared on GaAs substrate.

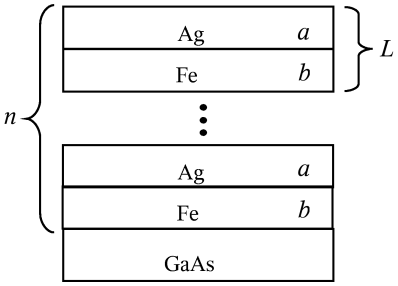

Fig. 1. Geometry of Ag/Fe nanolayer sample.

The ratio of thickness of the Ag sublayer to Fe sublayer for all samples was constant and equal to $(a/b) = 1 : 1.5$. The parameters of nanolayers samples and results of measured velocities of acoustic waves are presented in Table 1. The velocity was measured by echo method. The velocity is expressed in Å/ps because small thickness of layers.

Table 1. Geometrical parameters and results of measured acoustic wave velocity of Ag/Fe nanolayers.

N	10	10	10	15	20	20
a [Å]	55	45	33	27	23	20
b [Å]	80	70	50	40	35	30
nanolayer thickness [Å]	1400	1200	880	1055	1210	1050
V_{eff} [Å/ps] measured	39	37	37.5	35	30	26

3. Theory and interpretation of experimental results

In accordance with RYTOV model [6] in two-component multilayer periodical media acoustic longitudinal wave propagates with effective velocity $V_{\rm eff}$:

$$V_{\rm eff} = \frac{L}{a/V_1 + b/V_2}\,, \tag{1}$$

where V_1 and V_2 – velocities of acoustic longitudinal waves in sublayers, a and b thicknesses of sublayers, L – total bilayer thickness.

Taking into account difference between acoustic impedances Z_1 and Z_2 of both sublayers by introducing parameter ε equal to:

$$\varepsilon = \frac{Z_2 - Z_1}{(Z_1 Z_2)^{0.5}}\,, \tag{2}$$

one can obtain modified formula for effective acoustic wave velocity:

$$V_{\rm eff} = \frac{L}{\sqrt{\left(\dfrac{a}{V_1} + \dfrac{b}{V_2}\right)^2 - \varepsilon^2 \dfrac{a}{V_1}\dfrac{b}{V_2}}}\,. \tag{3}$$

Equation (3) gives no possibility to interpret the measurements results of acoustic wave velocities placed in Table 1. The differences of theoretical values of effective velocities obtained from formula (3) for bilayer thicknesses (L) of measured multilayer samples are not greater than 0.5%. The great changes of effective velocities were observed in experiment for samples with small bilayer thickness. The measured changes were up to 30%.

To give explanation of these changes GRIMSDITCH model was applied [7]. This model is generalization of Rytov model. M. Grimsditch introduced additionally the virtual interface layer as a free parameter to fit experimental results. This approach was used by G. CARLOTTI *et al*. for the Co/Cu multilayers to estimate the effective $c_{44}^{\rm ef}$ elastic constant from bulk values [1]. The formula given by Grimsditch describing effective elastic constants expresses as follows:

$$\frac{L}{c_{11}^{\rm ef}} = \frac{a}{c_{11}^{\rm Au}} + \frac{b}{c_{11}^{\rm Fe}} + 2\frac{d_{\rm int}}{c_{11}^{\rm int}}\,, \tag{4}$$

where $c_{11}^{\rm ef}$ is the effective elastic constant of multilayer, $c_{11}^{\rm Au}$ is the bulk value of the elastic constant for gold, $c_{11}^{\rm Fe}$ is the bulk value of the elastic constant for iron, $c_{11}^{\rm int}$ is the interlayer elastic constant and $d_{\rm int}$ thickness of interface layer treated as the parameters of the model.

Using this model we obtained theoretical dependence of the effective elastic constant $c_{11}^{\rm ef}$ on bilayer thickness for Ag/Fe nanolayers. The theoretical and measured values of the elastic constant c_{11} are presented in Fig. 2. Taking $c_{11}^{\rm Ag}$ and $c_{11}^{\rm Fe}$ fixed to the values calculated for the bulk elastic constants and $c_{11}^{\rm int}$ and $d_{\rm int}$ as free parameters we obtained following the best-fit parameters equal to $c_{11}^{\rm int} = 30$ GPa and $d_{\rm int} = 5$ Å.

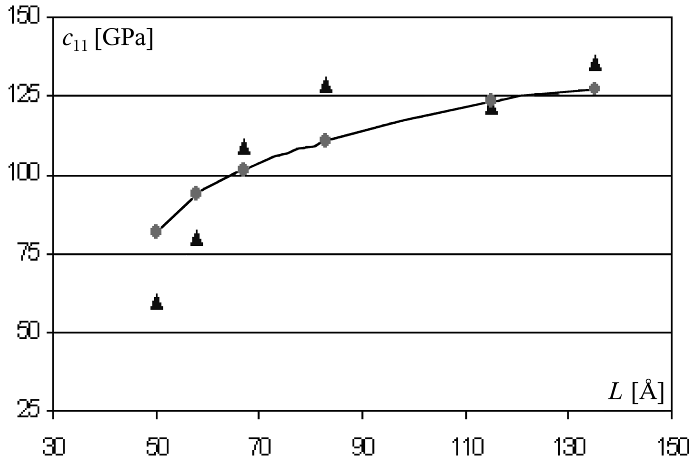

Fig. 2. Dependence of the elastic constant c_{11} on the thickness of bilayers L for Ag/Fe nanolayers. Triangles denote the results obtained experimentally, the circles illustrate theoretical values obtained from Grimsditch model (best-fit).

From experimental dependence in Fig. 2 outcome those in the range of bilayer thickness greater than 90 Å the elastic constant c_{11} does not depend on the bilayer thickness. In the range of the smaller thicknesses (under 90 Å) we observed considerable decrease of the elastic constant values (softening effect). The experimental changes in this range are greater than those calculated in Grimsditch's model. There are known two physical interpretations of the elastic constants change in multilayers for small thickness of bilayer. The first one connects the elastic constants changes with anomalies' of Fermi surface caused by periodicity of nanolayer [8]. The second one attributes the elastic anomalies to strains at the multilayer interfaces [9, 10]. Such strains can bring about structural phase transitions. Particularly, the multilayer containing iron sublayers are susceptible to occurrence of structural phase transitions. The great changes of the elastic constant c_{11} observed in presented investigation indicate that this mechanism is deciding in case Au/Fe nanolayers.

4. Conclusions

The dependences of the elastic constants on the bilayer thickness calculated from experiment for Ag/Fe nanolayer are in qualitative accordance with results obtained in the frame of Grimsditch's model. By using this model the values of the elastic constant and the thickness of additional interlayer were calculated. These parameters characterize quality of the multilayer interface. The results of investigation Ag/Fe nanolayers indicate that elastic anomalies in the range of the small bilayer thickness are probably caused by structural phase transitions in iron sublayer.

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