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MAGNETOSTRICTION CONSTANT OF MULTILAYER Ni-Ag FILMS DETERMINED BY FERROMAGNETIC RESONANCE

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Abstract. – The results of magnetostriction constant $\lambda_A$ of multilayer Ni-Ag films are reported. The measurements have been performed at room temperature using strain modulated ferromagnetic resonance method. The magnetostriction constant $\lambda_A$ depends linearly on the inverse Ni layer thickness. This effect is suggested to be due to the reduced local symmetry in interfaces.

Introduction

Compositionally modulated (CM) structures are of interest from both fundamental and technological points of view. Such structures are obtained by depositing two different metals in alternate sequence, either by sputtering or by evaporation. When one of these bilayers is magnetically ordered interesting magnetic properties are expected for certain thickness of the bilayers. In such system the contribution of the surface (or interface) effects to the bulk properties and it could be easily changed and analysed. The important role of the magnetic surface anisotropy for the magnetic properties of these films has recently been confirmed experimentally for very thin [1] or compositionally modulated [2] films.

Several systems based on Ni, such as, Ni-Cu, Ni-Mn have been studied in the past [3, 4]. The magnetic properties of multilayered Ni-Ag [5, 6] and Ni-C [7] films were recently studied using the ferromagnetic resonance (FMR) and the vibrating sample magnetometer (VSM). In this paper experimental results of the magnetostriction of multilayer Ni-Ag films at room temperature are reported.

Experimental procedure

The multilayer films have been prepared by sequential deposition of two metals in ultra high vacuum using several electron guns. The base pressure was $1 \times 10^{-10}$ Torr changing to about $5 \times 10^{-8}$ Torr during film deposition. Water cooled glass and Si substrates were used. For all the samples the Ag layer was 5 nm thick and the Ni layer thickness was varied from 1.5 to 6.7 nm. The number of bilayers were adjusted to get an effective Ni layer thickness of about 100 nm. One single Ni layer of 100 nm thick was also prepared. More details and some magnetic data have already been published [6].

The magnetostriction of the investigated films was measured using the method of strain modulated ferromagnetic resonance (SMFMR) [8-10]. In the SMFMR method the strain, periodic in time, applied to the sample placed in a cavity, causes a modulation of the ferromagnetic resonance line position. As a consequence of the magnetoelastic coupling, the intensity of the signal obtained after phasesensitive detection is proportional to the strain modulation depth $m_{\sigma}$. Simultaneously the FMR signal ($m_{\sigma}$—magnetic field modulation) is recorded. The magnetostriction constants can be obtained by comparing the intensities of the SMFMR signal ($l_0$) to those of the FMR signal ($l_0$)

$$\Delta H_\sigma = m_{\sigma} = m_0 \left( G_0/G_\sigma \right) / \left( l_0 / l_0 \right), \quad (1)$$

where $G_0$ and $G_\sigma$ are the gains of the amplifier system. The shift $\Delta H_\sigma = H_\sigma - H_0$ could be obtained by evaluating the resonance fields for the stress $\sigma \neq 0$ and $\sigma = 0$ from the ferromagnetic resonance condition:

$$\left( \frac{\omega}{\gamma} \right)^2 = \frac{1}{M^2} \sin^2 \theta \times \left[ \frac{\partial^2 F}{\partial \theta^2} \right] - \left( \frac{\partial^2 F}{\partial \phi^2} \right)^2, \quad (2)$$

$\theta$ being the polar and $\phi$ the azimuthal angle for $M$. The free magnetic potential energy $F$ consists of Zeeman, demagnetizing, anisotropy and magnetoelastic parts. In the presence of an uniaxial stress $\sigma_{kl} = \sigma_{\gamma k \gamma l}$ ($\gamma k$ is the direction cosine of the stress $\sigma$) the magnetoelastic energy has the form

$$F_{\text{ME}} = M_{ijkl} \alpha_i \alpha_j \sigma_{kl}, \quad (3)$$

where $\alpha_i$ denotes the direction cosine of magnetization $M$. For point symmetry $\infty$/mm four independent components $M_{11}, M_{13}, M_{13}$ and $M_{44}$ (in the Voigt notation) are obtained. In a case of an isotropic material the saturation magnetostriction constant $\lambda_s = M_{11}$ and $M_{11}/M_{12} = -2$.

Experimental results

In the experiment, the uniaxial stress is applied in the plane of the film, and the d.c. magnetic field configuration changes from parallel to perpendicular. Under these conditions from $\Delta H_\sigma$ measured as a function of an angle between d.c. magnetic field and the normal to the film, two components $M_{11}$ and $M_{12}$ could be determined. The results for two samples and for nickel thin films are given in table I. The saturated magnetostriction constant $\lambda_s$ was also determined, assuming isotropic character of the magnetoelastic tensor (see Tab. I and Fig. 1). The $\lambda_s$ of the investigated Ni-Ag
Table I. – Magnetostriction constants at room temperature.

<table>
<thead>
<tr>
<th>Thickness of Ni [nm]</th>
<th>$4\pi M_s$ (VSM) [kGs]</th>
<th>$4\pi M_{\text{eff}}$ (FMR) [kGs]</th>
<th>$H_A = 4\pi M_s$ (VSM) $- 4\pi M_{\text{eff}}$ (FMR) [kOe]</th>
<th>$M_{11}/M_{12}$</th>
<th>$\lambda_s \times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>4.640</td>
<td>7.485</td>
<td>$-2.845$</td>
<td>-10</td>
<td>-10</td>
</tr>
<tr>
<td>2.2</td>
<td>4.235</td>
<td>6.870</td>
<td>$-2.635$</td>
<td>-19.5</td>
<td>-19.5</td>
</tr>
<tr>
<td>2.2</td>
<td>4.360</td>
<td>6.850</td>
<td>$-2.490$</td>
<td>-22.5</td>
<td>-22.5</td>
</tr>
<tr>
<td>4.4</td>
<td>4.810</td>
<td>3.695</td>
<td>+1.115</td>
<td>-2.65</td>
<td>-28</td>
</tr>
<tr>
<td>6.7</td>
<td>5.050</td>
<td>4.535</td>
<td>+0.515</td>
<td>-2.64</td>
<td>-29</td>
</tr>
<tr>
<td>105.0</td>
<td>6.100</td>
<td></td>
<td></td>
<td>-2.12</td>
<td>-35</td>
</tr>
</tbody>
</table>

films similarly like for Ni-C [11] linearly depends on the inverse Ni layer thickness

$$\lambda_s = -35.6 \times 10^{-6} + 35.4 \times 10^{-6} \text{ [nm]} (1/t_{\text{Ni}}) \quad (4)$$

where $t_{\text{Ni}}$ is the thickness of nickel layer. This dependence indicates on the importance of surface (or interface) contributions to the bulk properties. The observed effect is mainly due to the reduced local symmetry in surfaces or interfaces.

![Fig. 1. – Magnetostriction constant $\lambda_s$ vs. inverse Ni layer thickness.](image)

**Conclusion**

The room temperature measurement of magnetostriction shows that the magnetostriction constant $\lambda_s$ of the investigated Ni-Ag films linearly depends on the inverse Ni layer thickness but does not change its sign. Our measurements indicate the important role of the interface effects for the magnetic properties of the investigated films.