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Shape effect in FMR of Ni-Co-Mn-In layers obtained by pulsed laser deposition

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Abstract. We have studied thin layers of $Ni_{50-x}Co_xMn_{50-y}In_y$ alloys on (001) Si substrate obtained by pulsed laser deposition method (PLD) using YAG Nd^{3+} laser operating at second harmonic. The target was bulk $Ni_{50-x}Co_xMn_{50-y}In_y$ (x = 5, y = 14.5) alloy prepared by induction melting of pure elements under argon atmosphere. Magnetic properties were investigated on Bruker X band EPR spectrometer (9.36 GHz) at room temperature. The magnetic resonance spectrum consists of non-symmetric lines with resonance field within wide field range (2500-4800 Gs) depending on the orientation of the static field in the plane perpendicular to the layer. Calculated spectroscopic splitting factor g = 2.09.

1 Introduction

The alloys system $Ni_{50-x}Co_xMn_{25+y}Z_{25-y}$ (Z = Sn, In, Ga, etc.), is Co-doped off-stoichiometric version of better-known Ni_2MnZ full Heusler alloys [1]. Addition of Co caused important changes in magnetism and structure [2].

The Ni_2MnZ and Ni_2CoMnZ Heusler alloys undergo martensitic phase transition (MPT) upon changing temperature and they are examples of ferromagnetic shape memory alloys [3-6]. The Ni_2MnGa undergo MPT in stoichiometric form, while Ni_2MnZ (Z = Sn, In, Ge, Sb.) exhibit MPT only in the off-stoichiometric composition [6]. Additionally, the NiMnIn based Heusler alloys in a narrow temperature range could undergo magnetically induced phase transition: from a weak-magnetic martensite to a ferromagnetic austenite [3, 7].

The advantageous properties of Heusler films have initiated study of this group of material [8, 9]. In addition the thin film technology is promising for application in nanodevices (see at [1] chapter 5). In this research, we registered ferromagnetic resonance (FMR) spectra of a NiCoMnIn layers which were prepared on Si substrate by using pulsed laser deposition method.

2 Sample preparation and experimental techniques

The NiCoMnIn films were deposited on silicon substrates by pulsed laser deposition (PLD). The off-stoichiometric bulk $Ni_{45}Co_5Mn_{35.5}In_{14.5}$ was made by arc melting [10] and was used as a target. Films were grown in PREVAC PLD system using the YAG: Nd^{3+} laser with the 532 nm (II harmonics) wavelength, 6 ns pulse time, 10 Hz repetition rate and fluence F in the range of 16 J/cm^2. The laser beam was focused on the target using a quartz lens with focal distance of 600 mm. The growth temperature T_s was 300 K. The deposition of the layers was carried out at 10^{-7} mbar vacuum.

The FMR measurements were performed on Bruker ELEXSYS E580 spectrometer using the X-band (9.36 GHz). Angular dependence was registered with the use of uniaxial goniometer at room temperature. The samples for these measurements were fixed in the microwave cavity in such a way that applied static field was perpendicular to rotating sample (Fig. 1). The *xyz* coordinate system in Fig. 1 is the system connected with a sample. The *z* is a rotation axis. The spectra were recorded as a function of angle with a 4 degrees step.

3 Results and discussion

The addition of Co and change of composition influence on the martensitic transformation and Curie temperature. [10-12]. In the $Ni_{50-x}Co_xMn_{25+y}In_{25-y}$ alloys with the 5 at.% of Co (x = 5) a T_C^A (Curie temperature in austenite phase) temperature was shifted to 343 K [10]. Therefore at the room temperature we could registered ferromagnetic resonance.

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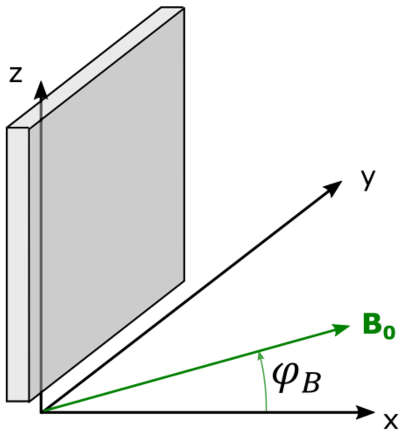

Fig. 1. Schematic orientation of film with respect to static field $\mathbf{B_0}$.

FMR spectra of the investigated sample at room temperature are shown in Fig. 2 for different angle φ_B between normal to the plane (x axis) and external field $\mathbf{B_0}$ (see Fig. 1). The spectra contain a broad and asymmetrical line of the Dyson shape [13, 14].

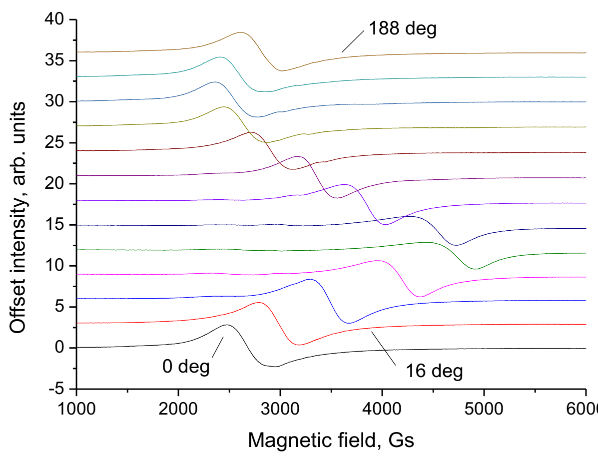

Fig. 2. The angular dependence of the FMR spectra of a film at room temperature. The spectra have been shifted vertically for better visibility.

The asymmetry FMR line suggested that investigated sample is conductive and line shape is connected with skin effect. The FMR spectra of $Ni_{50-x}Co_xMn_{50-y}In_y$ film were fitted by using derivative of Dyson function:

$$P(B) = \frac{\Delta B+\alpha(B-B_{res})}{4(B-B_{res})^2+\Delta B^2} + \frac{\Delta B+\alpha(B+B_{res})}{4(B+B_{res})^2+\Delta B^2} \qquad (1)$$

where B_{res} is the resonance field, ΔB is the linewidth and α is the parameter of asymmetry which describes the absorption and dispersion ratio [14]. The examples of fitting are presented in Fig 3.

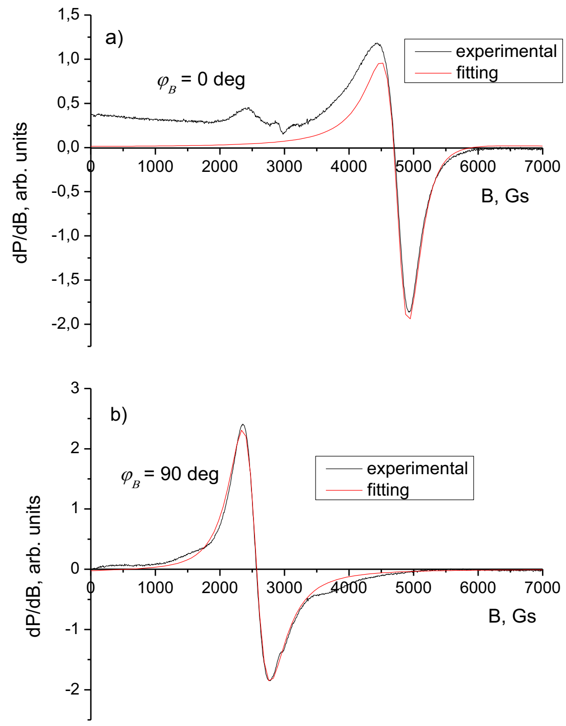

Fig. 3. The FMR signals of the NiCoMnIn film for φ_B = 0 deg and 90 deg.

It could be seen that the line shape depends on the angle between applied static field and the film (Fig. 1). The careful study of obtained spectra reveals overlapping signals. The analysis of FMR parameters was done in this paper for the strongest asymmetric line, whereas the complexity of spectrum will be investigated elsewhere. The parameters of fitted lines are collected in table 1.

Table 1. The fitting parameter of the EPR signals for φ_B = 0 and 90 deg.

φ_B [deg]	B_{res} [Gs]	ΔB [Gs]	asymmetry parameter
0	2534	697	-1,39
90	4803	731	0,38

The ferromagnetic resonance field is described by Landau-Lifshitz equation (LL equation)

$$\dot{\mathbf{M}} = -\gamma(\mathbf{M}\times\mathbf{B}) - \alpha\frac{\gamma}{\mathbf{M}}[\mathbf{M}\times(\mathbf{M}\times\mathbf{B})] \qquad (2)$$

where $\mathbf{M}$ is magnetization vector, $\mathbf{B}$ is the effective magnetic field, γ is the gyromagnetic ratio and α is Gilbert damping parameter associated with a relaxation mechanisms of vector $\mathbf{M}$.

In the case of a ferromagnetic resonance of a flat plane with external magnetic field B_0 perpendicular or parallel to the plane the solution of LL equation reduced to two Kittel equation [16]:

$$\frac{\omega}{\gamma} = [B_{\parallel}(B_{\parallel} + \mu_0 M)]^{1/2} \quad (3)$$

$$\frac{\omega}{\gamma} = B_{\perp} + \mu_0 M \quad (4)$$

where $B_0 = B_{\parallel}$ is a resonance field in plane case and $B_0 = B_{\perp}$ corresponds to of plane case. Taking into account that $\gamma = \frac{g\mu_B}{\hbar}$, these two equations could be written as:

$$\hbar\omega = g\mu_B[B_{\parallel}(B_{\parallel} + \mu_0 M)]^{1/2} \quad (5)$$

$$\hbar\omega = g\mu_B(B_{\perp} + \mu_0 M) \quad (6)$$

Comparing right sites of equations (3) and (4) we obtain the equation

$$x^2 - (B_{\parallel} + 2B_{\perp})x + B_{\perp}^2 - B_{\parallel}^2 = 0 \quad (7)$$

where $x \equiv \mu_0 M$.

Inserting to (7) experimental values $B_{\parallel} = 2534$ Gs and $B_{\perp} = 4803$ Gs given by fitting curves (see Tab. 1), the equation is reduced to

$$x^2 - (2534 + 2 \cdot 4803)x + 4803^2 - 2534^2 = 0 \, (7)$$

From the set of eq. (5) and (6) the g-factor and effective saturation magnetization $\mu_0 M$ could be calculated. The solution are: $g = 2.09$ and $\mu_0 M = 1576$ Gs. The value of g-factor is similar to g-factor $g = 2.01$ listed by Kittel (see Table I [17]) for Heusler alloys.

3 Conclusion

The layers of $Ni_{50-x}Co_xMn_{50-y}In_y$ have been grown on (100) Si substrate by PLD method. Angular dependence of FMR spectra was registered at room temperature. The obtained FMR spectra were fitted by Dyson function. The experimental FMR lines exhibited a strong angular dependence and shape anisotropy with resonance field changed from 2600 Gs (for parallel geometry) until 4800 Gs (for perpendicular geometry). Calculation of g-factor (g = 2.09) provides a typical value for Heusler alloys [17].

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