Temperature Dependence of Magnetization Damping in Heusler Alloy Films

J. Dubowik, M. Załęski, H. Głowiński

Institute of Molecular Physics, Polish Academy of Sciences, M. Smoluchowskiego 17, 60-179 Poznań, Poland

AND I. Gościańska

Department of Physics, A. Mickiewicz University, Umultowska 85, 61-614 Poznań, Poland

The Gilbert damping for Co_2CrAl ($Co_2Cr_{0.3}Fe_{0.7}Al$) and Ni_2MnSn Heusler alloy films was investigated as a function of temperature. The best films reveals the Gilbert damping nearly independent of temperature. Magnetic relaxation in Co_2CrAl is strongly influenced by magnetic inhomogeneities due to phase separation. The best Ni_2MnSn epitaxial films have comparable Gilbert damping α of 6×10^{-3} as half-metallic $Co_2Cr_{0.3}Fe_{0.7}Al$ films with $\alpha = 3 \times 10^{-3}$.

PACS numbers: 76.50.+g, 75.70.Ak, 75.78.Jp

1. Introduction

It has been recently shown, both theoretically [1] and experimentally [2, 3], that the Gilbert damping constant α in half-metallic (HM) Co-based full Heusler alloys (HA) is low. Magnetization damping is directly related to viscous-damping-like term in the Landau–Lifshitz–Gilbert equation $(\alpha/M)(\boldsymbol{M} \times \mathrm{d}\boldsymbol{M}/\mathrm{d}t)/M$ and described by the ferromagnetic resonance (FMR) linewidth ΔH (peak-to-peak of the first derivative of the FMR absorption) $\Delta H = 2/\sqrt{3}\alpha(\omega/\gamma)$, where ω is the angular frequency of microwaves and γ is the gyromagnetic ratio. In the case of thin ferromagnetic films there are various extrinsic and intrinsic contributions to the linewidth and, in fact, the measured ΔH in the perpendicular configuration (i.e. with the field applied perpendicular to the film plane) is believed to be given exactly by the Gilbert damping [4]. If no additional line broadening comes from magnetic inhomogeneities (such as local resonances) in the parallel configuration extrinsic damping due to two-magnon scattering plays an important role [4].

The Gilbert damping constant α in some HM HA films can be as low as 0.003 in $Co_2Fe_{0.4}Mn_{0.6}Si$ [2] or even 0.001 in Co_2FeAl [3] which gives the relaxation frequency $G = \alpha\gamma M_S$ of 50 and 20 MHz, respectively. This makes HA attractive for low damping materials for future spintronic applications [1]. However little is known on temperature dependence of magnetization damping in HA films. A theoretically predicted dependence for the damping constant on the electrical resistivity of HA reveals minimum as a function of temperature due to resistivity-like and conductivity-like contributions [1].

In this contribution we present temperature dependence of FMR linewidth of Co_2CrAl (and $Co_2Cr_{0.3}Fe_{0.7}Al$, too) and compare it to that of Ni_2MnSn HA films in order to find the influence of half-metallicity. Co_2CrAl is theoretically predicted half-metal HA with a band-gap in the minority spin band of 0.8 eV [5]. Ni_2MnSn reveals no HM properties (i.e. it has no band-gap [6]) but both HA have almost the same Curie temperature of 320 K and 330–350 K, respectively.

2. Experimental details and discussion

The Co_2CrAl films were prepared by using magnetron sputtering system ($p_{base} < 2 \times 10^{-8}$ Torr) onto Si (100) oxidized substrates. Ni_2MnSn films were prepared by either flash evaporation method (polycrystalline films) or by sputtering onto MgO (100) substrates at 300–350 °C in order to achieve proper structural ordering. The crystalline ordering of Co_2CrAl and Ni_2MnSn films was B2 and $L2_1$, respectively, as confirmed by X-ray diffraction (XRD) and transmission electron microscopy (TEM). Thickness of the film varied between 12 and 180 nm. Ferromagnetic resonance was measured with a standard X-band spectrometer (9.2 GHz) in a temperature range between 130 K (4.2 for Co_2CrAl) and 350 K. Since quantitative measurements of the actual site ordering by XRD is difficult, we measured the effective magnetization of the samples to compare it with the magnetization of the best ordered bulk samples. Extrapolated to 0 K was 440 G (2.4 μ_B/f.u.) and 637 G (3.6 μ_B/f.u.) for Co_2CrAl and Ni_2MnSn, respectively. These results are 10–20% lower than that reported for the best ordered bulk samples (3 and 4 μ_B/f.u.) [7, 8]. The Gilbert damping α was determined from ΔH measured at the perpendicular configuration. By independent measurements of ΔH as a

function of magnetization angle from the film normal at room temperature we checked that when the magnetization is inclined to the film plane the linewidth increases by about 100–200 Oe in accordance with two-magnon scattering picture [4].

Figure 1 shows temperature dependence of $\Delta H^\perp$ and $\Delta H^\parallel$ of two Ni_2MnSn films measured at perpendicular and parallel configurations, respectively. For the polycrystalline film (full dots and squares), it is seen that for both configurations ΔH is nearly independent of temperature in the range of 250–300 K (just below the Curie temperature of 330–350 K) and monotonically increases as temperature is lowered to 100 K. However the difference between $\Delta H^\perp$ and $\Delta H^\parallel$ increases substantially with decreasing temperature. For the epitaxial film (open circles and squares) the trend is generally the same but ΔH for both configurations is much lower, especially for the perpendicular configuration. In order to give evidence for two-magnon scattering we additionally investigated the FMR linewidth of the epitaxial film as a function of the angle between magnetization and the normal (not shown) and checked that $\Delta H^\perp$ is mainly given by the intrinsic Gilbert damping with $\Delta H^\perp$ as low as 20 Oe at 250 K. The Gilbert damping coefficient α is of 0.006.
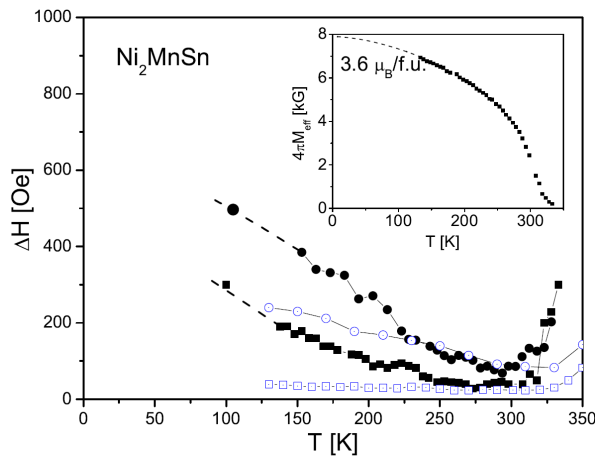

Fig. 1. Temperature dependence of FMR linewidth of Ni_2MnSn films measured at perpendicular (full and open squares) and parallel (full and open circles) configurations. Inset shows temperature dependence of the effective magnetization.

Figure 2 shows the temperature dependence of $\Delta H^\perp$ and $\Delta H^\parallel$ of Co_2CrAl film. $\Delta H^\perp$ decreases with decreasing temperature and attains minimal value of 108 Oe at 140 K and then unexpectedly grows up to 3700 Oe at 4 K. $\Delta H^\parallel$ changes in a similar way but broadening in the linewidth onsets at temperatures lower than 200 K. We interpret such a behavior as due to strong magnetic inhomogeneities of polycrystalline Co_2CrAl with $B2$ structure. Indeed, in a temperature region of 100–250 K we observed clear resolved spin wave spectra (SWR) that however display separation independent of mode number. This implies a depth-dependent magnetization profile in-

side the film in accordance to the Portis model of volume inhomogeneity [9]. We interpret the strong broadening in ΔH and SWR as resulting from inclusion of CoCr phase in our Co_2CrAl film. Presumably Co–Cr antisite disorder favors formation of CoCr phase with 20–25 at.% of Cr that becomes ferromagnetic at $T < 100$ K [10] and results in line broadening. Therefore, magnetization relaxation at low temperature is not intrinsic. If for Co_2CrAl $\Delta H^\perp$ value of about 100 Oe is assumed to be solely due to the Gilbert damping, $\alpha = 3 \times 10^{-2}$ ($G = 240$ MHz) is substantially higher than that in the best HM HA [2].
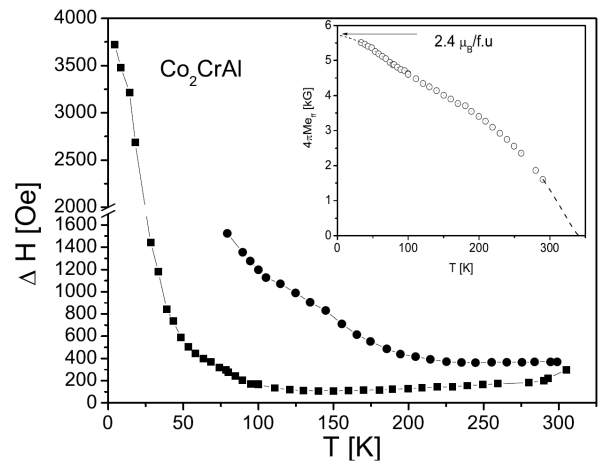

Fig. 2. Temperature dependence of FMR linewidth of Co_2CrAl film measured at perpendicular (squares) and parallel (circles) configurations. Inset shows temperature dependence of the effective magnetization.
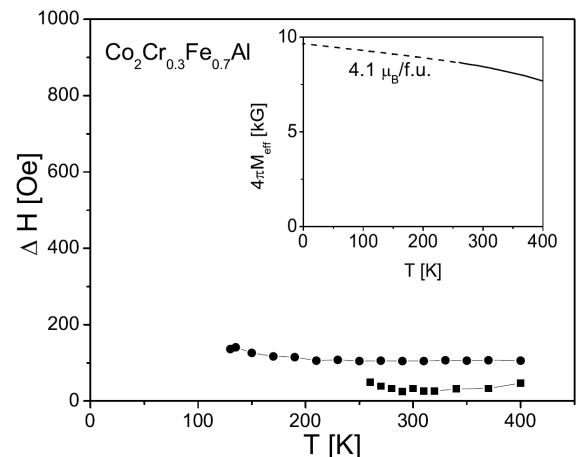

Fig. 3. Temperature dependence of FMR linewidth of $Co_2Cr_{0.3}Fe_{0.7}Al$ film measured at perpendicular (squares) and parallel (circles) configurations. Inset shows temperature dependence of the effective magnetization.

Some Fe containing $Co_2Cr_xFe_{1-x}Al$ HA are considered as HM with a high spin polarization [5]. Therefore we find it worthwhile to compare temperature de-

pendence of $Co_2Cr_{0.3}Fe_{0.7}Al$ film with that of Co_2CrAl. Figure 3 shows a temperature dependence of $\Delta H^{\parallel}$ and $\Delta H^{\perp}$. Since the available field in our electromagnet was too low to observe FMR in perpendicular configuration at $T < 250$ K, $\Delta H^{\perp}$ is shown in a relatively narrow temperature region of 250–400 K. One can see that ΔH for both configurations is nearly independent of temperature with a small increase at the lowest temperatures. The lowest value of $\Delta H^{\perp}$ of 24 Oe at 300 K is comparable with that of the best HM HA [2]. The respective value of α is of 3×10^{-3} ($G = 50$ MHz). These results show that the best ordered $Co_2Cr_xFe_{1-x}Al$ HA belong to a class of materials with a low Gilbert damping.

3. Conclusions

In summary, we investigated temperature dependences of FMR linewidth and confirmed almost temperature independent Gilbert damping constant α from $\Delta H^{\perp}$ vs. T. The values of α for the best Ni_2MnSn and $Co_2Cr_{0.3}Fe_{0.7}Al$ films were small (of 6×10^{-3} and 3×10^{-3}, respectively) and comparable to that of epitaxial $Co_2Fe_xMn_{1-x}Si$ [2]. Since Ni_2MnSn is not half-metal, our results indicate that the Gilbert damping is mainly determined by density of states of d-band in accordance with theoretical calculations [11].

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