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# Ferromagnetic resonance of Heusler $Ni_2MnGa$ thin films

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**Abstract**

$Ni_2MnGa$ films, deposited on mica and glass substrates, were studied by ferromagnetic resonance (FMR) technology. The temperature-dependent resonance field was measured and a martensitic phase transformation (MT) was found between 310 and 340 K, exhibiting an abnormality on the curve. The easy axis is found to be in the film plane. The line width increases as a whole with decreasing temperature, which is discussed in terms of the motional narrowing mechanism. The resonance field was also measured as a function of orientation and the results were fitted, exhibiting a good consistence.

**Keywords** : ferromagnetic resonance, $Ni_2MnGa$, resonance field, resonance linewidth

## 1. Introduction

While more and more efforts are put on the ferromagnetic-shape-memory effect (FSME) of $Ni_2MnGa$ [1-3], some other attention should be paid on the magnetic anisotropy, which plays some roles on the FSME and supplies some detailed information on the magnetic properties. Ferromagnetic resonance (FMR) is a useful method to get some information on the magnetic anisotropy. For a given microwave with a certain frequency, FMR happens and the microwave is absorbed when orthogonally applied filed makes the magnetic moment of the ferromagnetic sample precess at the same frequency. FMR has been widely used to measure the parameters of magnetic anisotropy as well as the value of magnetization [4-5]. Shanina *et al.* [6] used FMR signal to study the magnetic anisotropy of non-stoichiometric $Ni_2MnGa$ together with the FSME and fine details of the magnetic structure. In this work, we report some FMR results of nearly stoichiometric $Ni_2MnGa$ films deposited onto mica and glass substrates as a function of temperature and orientation of the applied filed.

## 2. Experiment

In a vacuum better than $5 \times 10^{-5}$ Pa, $Ni_2MnGa$ films, with the actual composition of $Ni_{0.463}Mn_{0.247}Ga_{0.260}$ and a thickness of about 160 nm, were prepared by flash evaporation onto glass and mica substrates, heated up to 720 K in order to get ordered structure. The FMR spectra were measured using an electron paramagnetic resonance (EPR) spectrometer operating at 9.08 GHz, and an external magnetic field ranging from 0 to 1.5 T. The resonance field and line width of the films were measured for both the in-plane and out-of-plane configurations from 75 to 400 K. The sample orientation was controlled by a goniometer to measure the angular dependence of the resonance field.

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## 3. Results and discussion

The resonance conditions for a tetragonal symmetry are simply expressed for perpendicular and parallel configurations [5].

$$\frac{\omega}{\gamma} = H_{r\perp} - \left[4\pi M \frac{2(K_2 + K_{4\perp})}{M}\right] \quad (1)$$

$$\left(\frac{\omega}{\gamma}\right)^2 = \left(H_{r//} - \frac{2K_4}{M}\right)\left[H_{r//} + \left(4\pi M \frac{2(K_2 + K_{4//})}{M}\right)\right] \quad (2)$$

where $\omega$ is the resonance frequency, and $\gamma$ is the gyromagnetic ratio, which equals to $\mu_B g/\hbar$, $\mu_B$ is the Borh magneton and $g$ the spectroscopic splitting factor. $M$ is the magnetization, and $H_r$ the resonance field. $K_2$ and $K_4$ are the second- and fourth-order anisotropic constants, respectively. According to the resonance conditions, one knows that the out-of-plane resonance field has a similar tendency while the in-plane one has an opposite tendency with magnetization $4\pi M$.

The resonance filed $H_r$, obtained in the in-plane and out-of-plane configurations for the $Ni_2MnGa$ films on glass and mica, is shown in Figure 1 as a function of temperature from 400 K to 75 K. One can find, by comparing the values of $H_r$ of the film at the same temperature, that the in-plane $H_r$ is smaller than that obtained in the out-of-plane orientation. This means that the magnetically easy axis lies in the film plane, which was confirmed by the hysteresis-loop measurements. An obvious kink between 310 and 340 K can be observed in the curves of the film on mica, indicating a phase transition from austenite to martensite upon cooling. That the value of $H_r$ becomes smaller when the film undergoes an austenite→ martensite phase transformation can be ascribed to the induced magnetic moment of the martensite is smaller than that of the austenite [7-8]. But for the films on glass, only a small kink can be observed. This may indicate that the substrates might have some effects, and the actual reason is under study.

The line width $\triangle H_{pp}$, defined as the peak-to-peak

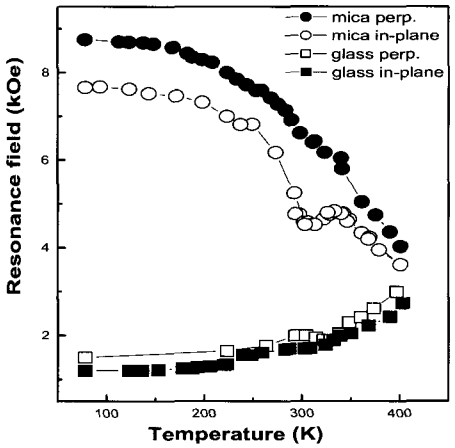


Fig. 1. Resonance field measured as a function of temperature.

width on the derivative of the absorption spectrum, is a measure of the relaxation rate of the magnetization. $\triangle H_{pp}$ is mainly caused by the intrinsic (or Gilbert) damping of the magnetization and by the magnetic inhomogeneities. The results are displayed in Fig. 2. The abrupt increase just below 340 K for the film on mica in the out-of-plane configuration can be mainly attributed to the large inhomogeneity and the resulting two magnon-scattering loss during the austenite→ martensite phase transformation [9]. Despite this abnormality, the $\triangle H_{pp}$ becomes broader as a whole when the temperature decreases. This can be explained by the motional-narrowing effect if one keeps in mind that the magnetic dipolar interaction (intrinsic damping) is the predominant cause of line broadening. It is considered that the line width decreases owing to the rapid relative motion of atoms [10]. Thus, $\triangle H_{pp}$ can be expressed as:

$$\Delta H_{pp} = k(\Delta H)_0^2 \tau \quad (3)$$

where $(\Delta H)_0$ is the line width in the rigid lattice, $k$ proportional coefficient, and (the average time for an atom to remain in one site of the rigid lattice. The

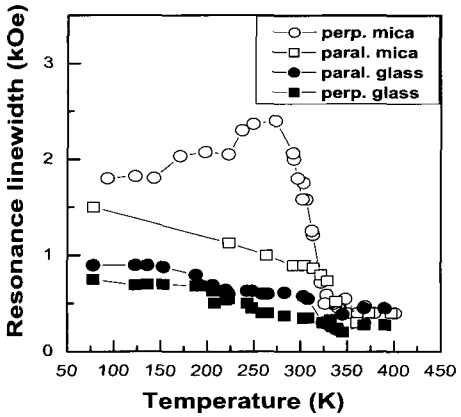


Fig. 2. Temperature-dependent resonance linewidth.

slower the relative motion of atoms, the larger the value of $\tau$, as the temperature decreases. Therefore, the corresponding line width increases with the decreasing temperature, as shown in Fig. 2.

The resonance field Hr was measured as a function of angle when the applied field rotated from perpendicular to parallel direction to the film plane. The results are shown for films on mica and on glass in Figs. 3(a) and 3(b), respectively. The results were fitted following the methods in Ref [4] and one can see the fitted Hr shows a good consistence. Larger anisotropy can be found at 78 K, indicating larger structural asymmetry at lower temperature. It can be seen that the substrate has some effects on the magnetic properties. The smaller values of $H_r$ in the in-plane direction than those in the out-of-plane direction confirm the in-plane easy axis.

## 4. Conclusions

The resonance field of $Ni_2MnGa$ films deposited on mica and glass is angular-, temperature-dependent. The substrates also affect the value of the resonance field. The easy axis lies in the film plane. An austenite→ martensite phase transformation was found in the temperature range of 310 - 340 K upon cooling. The resonance line width increased as a whole with decr-

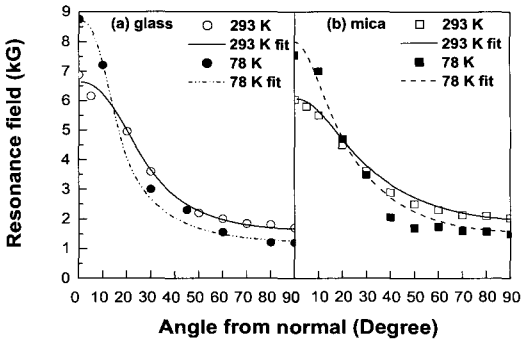


Fig. 3. Angle-dependent resonance field.

easing temperature, which can be explained by the intrinsic damping owing to the motional-narrowing mechanism. The abrupt increase is ascribed to the large inhomogeneity during martensitic transformation.

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