行政院國家科學委員會專題研究計畫期中精簡報告

新穎鐵磁/非補償面配向多鐵複合奈米結構薄膜之製作與磁電效應之研究

Fabrication and magnetoelectric effect of novel ferromagnet/uncompensated aligned multiferroics nanostructured composite thin films

計畫類別：■ 個別型計畫　□ 整合型計畫
計畫編號：NSC 98-2112-M-029-001-MY3
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執行單位：東海大學物理系

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行政院國家科學委員會專題研究計畫成果報告

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摘要

本計畫由今年 2 月執行迄今除了正在架設高真空濺鍍系統外，亦研究了不同膜厚 NiFe 薄膜(30-50 nm)於不同熱處理溫度(100-700 ^{o}C)下之鐵磁共振效應。此實驗發現了阻尼係數隨著熱處理溫度而提高，在低溫熱處理的部分其提高之因可能源於双磁子散射，而低溫熱處理部分可能為電子散射。

關鍵詞：NiFe, 鐵磁共振

Abstract

Since this project was started from Feb. 2009, in addition to building high vacuum sputtering system, we also studied ferromagnetic resonance (FMR) of NiFe thin films with various thicknesses(30-50 nm), annealed at different heat treatment temperature (100-700 ^{o}C). In this study, a damping enhancement was found in the films with different thickness of 30, 40, and 50 nm annealed at high and low temperatures. The enhancement for the high-temperature annealed films is suggested to be resulted from the two-magnon scattering; for those low-temperature-annealed films, the damping may be related to the electron scattering.

Keywords: NiFe, FMR.

Background

Spin dynamics has received a great deal of attention due to the rapid development of various spintronic devices. Permalloy thin film is widely used in the devices especially in sensors for the ultra-fast magnetic switching due to its very low magnetocrystalline anisotropy. Therefore, many efforts have been made to investigate the spin dynamics of the NiFe films.

In the ferromagnetic resonance (FMR) studies, it has been found that the Gilbert damping (described by the Gilbert damping factor α) of a sputtered NiFe film is 1~2 order in magnitude larger than that of a film grown by molecular beam epitaxy (MBE). The theories have been developed to interpret this significant enhancement in magnetic relaxation by defect scattering. Experiments of defect control have also supported the validity of the theory. However, the approaches that most of the studies have been used to control the defect are adjustment of film thickness and alter the interface or surface morphology. Only few studies concerning effect of dislocation for epitaxial NiFe films were reported.

The sputter deposited films are poly-crystalline and contain various high density planar defects, such as grain boundaries, twin boundaries, anti-phase boundaries, and stacking faults, etc. These planar defects may have an influence on the spin dynamics of the thin films. However, relative study is not done yet. In this study, we focus on the effect of inner defect on magnetic damping in sputter deposited NiFe thin films with with various thicknesses(30-50 nm), annealed at different heat treatment temperature (100-700 ^{o}C).

Experimental

We investigated the magnetic damping by using vector network analyzer (VNA) with flip-chip technique. The Gilbert damping coefficient was extract from the field scanning spectrum of ferromagnetic resonance (FMR) as a parameter to describe magnetic damping behavior.

To conduct the experiment, we first have to establish a probe station for microwave measurements. The work is summarized as follows.

1. Design and fabrication of the coplanar wave guide.

The FMR measurement is performed with different external magnetic field which aligns the magnetic moment of the thin films samples in the direction that microwave is conducted. In order to fulfill this geometry, a 90°-coplanar wave guide is necessary. We designed one as shown in Fig. 1. The computer simulation of the frequency dependence of response indicates a flat background at region from 0 to 23 GHz as shown in Fig. 2.

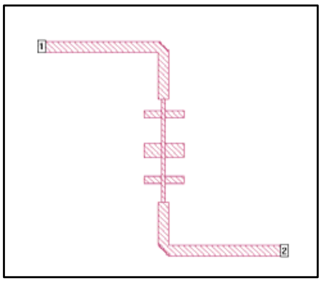

Fig. 1 The coplanar wave guide.

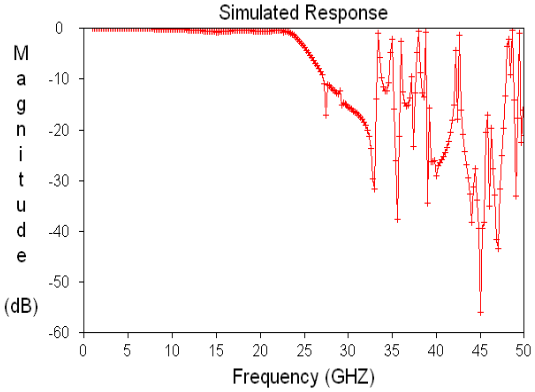

Fig. 2 The simulated response of the wave guide.

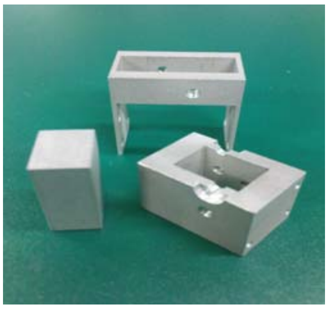

Fig. 3 Sample stage.

2. Preparation of the coplanar wave guide.

After finishing the design, we made a photo mask to pattern the wave guide onto GaAs (100) wafers for the thin film deposition. The wave guide is made of Cu by radio frequency (RF) magnetron sputtering at room temperature. The base pressure is better than 2×10^{-7} torr, and argon working pressure is fixed at 10 mtorr. A gold layer of 10 nm was caped on the Cu layer to prevent from oxidation. The optimized thickness of Cu for wave guide is 1.5 μm.

3. Design and Build the sample stage.

To conduct microwave from VNA to coplanar wave guide, a sample stage to connect two K-connectors and glass beed and to place and ground the wave guide is necessary. We built a sample stage with an adjustable bottom part to mount the wave guide wafer as shown in Fig. 3.

4. Set up the measurement system.

After preparation of various parts, we assemble the measurement system as shown in Fig. 4. The wave guide is mounted on the sample stage and connected with glassbeeds using indium. The electromagnet is arranged in the perpendicular direction to the two K-connectors and a Hall probe is placed at center of the two poles of the electromagnet. The frequency dependence of signal response is shown in Fig. 5. It shows a flat background with intensity below 10 dB as frequency less than 10 GHz. The result is quite different to the computer simulation probably due to the imperfections generated by the deposition process. We therefore confine our FMR measurements to the frequency below 10 GHz.

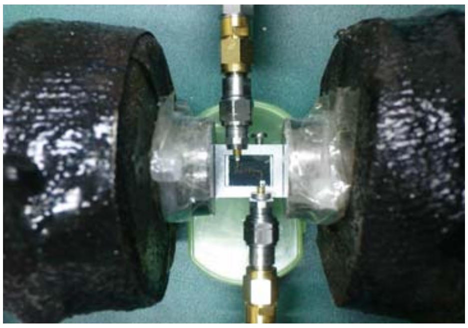

Fig. 4 FMR measurement system.

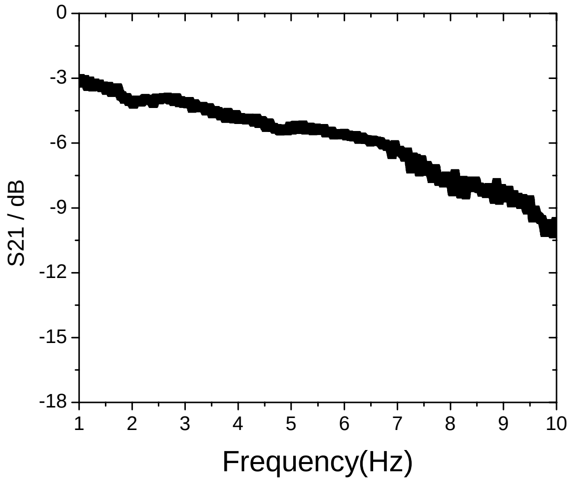

Fig. 5 Frequency dependence of signal response of the wave guide.

5. Sample preparation

After the setting up the probe station, we then prepare the samples. Ni-Fe thin films were fabricated by RF magnetron sputtering. Corning 1737 glass was selected as substrates because its absorption for the microwave is limited, improving the data quality. The thin films were deposited at room temperature. Post annealing was then applied from 100 to 700°C for 30 minutes. The grain growth and the defects elimination induced by the annealing are the means to control the various planar defects. Microstructure and X-ray diffraction will be used to study the density of the planar defects.

Current results

Figure 6 shows the frequency domain FMR spectrum for the NiFe thin films with 50 nm in thickness annealed at 100, 200, 300, and 400°C; 30 nm in thickness annealed at 200°C; and relation between resonance frequency and external field, respectively. Sharp absorption peaks are obtained and the dependence of external magnetic field on FMR frequency is in good agreement with Kittel equation

$$f_{\mathrm{Kittel}}(H_{\mathrm{ext}}) = \frac{|\gamma|}{2\pi}\mu_0\sqrt{(H_{\mathrm{ext}}+H_k)(H_{\mathrm{ext}}+H_k+M_S)}.$$

Linewidth of the absorption peaks were measured directly from the FMR spectrums. The results were summarized in Fig. 7. Linewidth of FMR peak is proportional to Gilbert damping coefficient α. Dependence of linewidth on annealing temperature indicates FMR peaks becomes broadened for higher annealing temperature, revealing damping enhancement. Consistent results were obtained in thin films with different thickness of 30, 40, and 50 nm. The broadening effect for FMR peak with the increasing of external field is also found.

Models, including two-magnon scattering, electron scatting, and spin pumping and sinking effect, have been proposed to explain the damping enhancement duo to extrinsic contribution. Two-magnon scattering describes the energy dissipation resulted from the degeneration of spin precession from uniform mode (wave factor $q = 0$) to spin wave mode ($q \neq 0$). The degeneration may be originated from the structural imperfections such as surface morphology, interfaces, dislocations, etc. as reported experimentally. Another explanation for extrinsic damping enhancement is electron scattering mainly by surface and defects. The Gilbert damping coefficient has been found to be proportional to electric resistance. Spin pumping and sinking induced enhancement in spin relaxation have been predicted in the multilayer films.

In this work, the studied sample is single layer NiFe thin films, the possible mechanism for the damping enhancement are two-magnon scattering and electron scattering. If the magnetic damping of a sample is enhanced by two-magnon scattering, according to the theoretical prediction and reported experimental results, the initial slop of dependence of FMR linewidth on frequency will be significantly larger than that of the sample without damping enhancement. As can be clearly seen in Fig. 7, for the samples with three different thickness, large initial slope or value can only be found in the high temperature annealed thin films. Damping enhancement for the films deposited at room temperature did not produce a larger slope in frequency dependence. This result suggests that the enhanced magnetic damping at different annealing temperature region may originate from different mechanism.

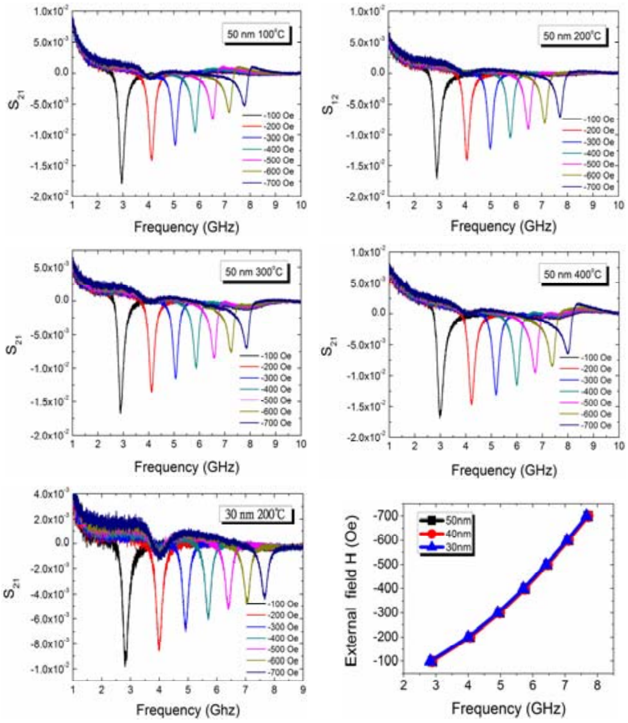

Fig. 6 FMR spectrum for NiFe thin films with different thickness annealed at 100, 200, 300, and 400˚C; and dependence of FMR frequency on external field.

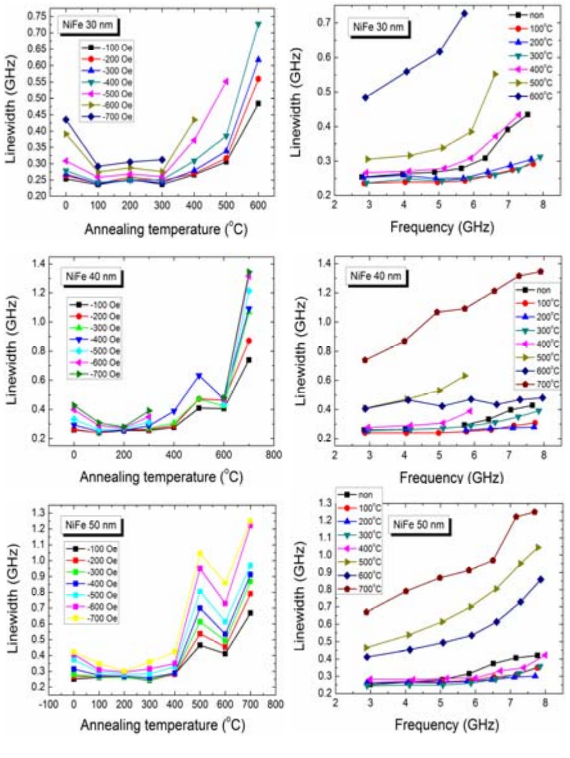

Fig. 7 FMR spectrum for NiFe thin films with different thickness annealed at 100, 200, 300, and 400˚C. And dependence of FMR frequency on external field.

Findings

1. A damping enhancement was found in the films with different thickness of 30, 40, and 50 nm annealed at high and low temperatures.
2. The dependence of linewidth on frequency indicates that enhancement in damping at different annealing temperature region may have different physical origin. The enhancement in the high-temperature annealed films is suggested to be resulted from the two-magnon scattering; for those low-temperature-annealed films, the damping may be related to the electron scattering. However, further study is necessary.

Future works

1. the magnetic damping of ferromagnetic layer thin films.

(i) Reproduce and refine the annealing process.

(ii) Clarify the mechanism for the damping enhancement in the two regions of annealing temperature.

(iii) Perform the measurement of resistance to understand the role of electron scattering.

(iv) Study the annealing effect on surface morphology and defect density by AFM, XRD, SEM, and TEM.

2. Fabrication of uncompensated aligned $BiFeO_3$ thin films with the peroskite structure, and investigation of the influence of intrinsic and extrinsic contributions on the physical characterizations of $BiFeO_3$ thin films.

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