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The contributions of intrinsic damping and two magnon scattering on the ferromagnetic resonance linewidth in $[Fe_{65}Co_{35}/SiO_2]_n$ multilayer films

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ABSTRACT

In order to investigate microwave damping mechanisms of ferromagnetic films with a structure of [ferromagnetic (FM)/non-magnetic insulator (NMI)]$_n$, a serial of $[Fe_{65}Co_{35}/SiO_2]_n$ multilayer films was prepared by a magnetron sputtering method on the glass substrate. As-prepared films show excellent soft magnetic properties with tiny coercivities along the easy and hard axis respectively, and remarkable in-plane unixial anisotropies were observed too. The microwave properties were characterized by the ferromagnetic resonance (FMR) and a broadband permeameter. The corresponding theoretical fitting was conducted based on the Landau–Lifshitz–Gilbert (LLG) and two magnon scattering (TMS) theory. Fitting results show the TMS linewidth has a value of 36 times bigger than Landau–Lifshitz intrinsic linewidth, which gives a quantitative and explicit physical picture of microwave damping mechanisms in $[Fe_{65}Co_{35}/SiO_2]_n$ multilayer films and may be important for the understanding of damping in [FM/NMI]$_n$ multilayer films.

1. Introduction

In recent years, there has been an extensive research on microwave properties of ferromagnetic thin films to satisfy many requirements of advances in the wireless technology such as WiFi networks, real-time mobile communication in GHz frequency band [1]. Ferromagnetic thin films attract more interest of researchers because of their combined properties of the high saturation magnetization, controllable in-plane anisotropy field, high permeability in GHz range, high electrical resistivity for reducing the eddy current loss and other interesting physical phenomena [2,3]. Compared to usual single-layer nano-granular films whose magnetic grains are separated in the insulating amorphous phase, multilayer films with a microstructure of [magnetic metal/insulator]$_n$ could be more effective and convenient to obtain higher resistivity for high frequency applications meanwhile maintaining their soft magnetic properties [4]. For these purposes, it is important to get a better understanding of the damping mechanism of ferromagnetic multilayer films.

Up to now, there are lots of published theoretical and experimental results on the microwave damping mechanism of magnetic materials [5–13]. More attentions have been paid to the damping in the single-layer nano-granular magnetic film [10,11], magnetic alloy film [14] and the multilayer film with a structure of [ferromagnetic (FM)/non-magnetic metal (NMM)]$_n$ [12,13]. However, the damping mechanism of multilayer films with the structure of [ferromagnetic (FM)/non-magnetic insulator (NMI)]$_n$ has been less considered recently. Obviously, the damping mechanism in [FM/NMI]$_n$ multilayer films is more complicated and will be more interesting for the understanding of the spin dynamics in ferromagnetic films. It will give a theoretical guidance to prepare all kinds of magnetic films for high-frequency microwave absorption applications.

In the present work, multilayer films of $[Fe_{65}Co_{35}/SiO_2]_n$ were prepared by the magnetron sputtering. Microwave properties of some typical samples were determined by the ferromagnetic resonance (FMR) and a broadband permeameter. Especially, we focus on damping origins of those multilayer films. The dependences of the FMR field H_{RES} and FMR linewidth ΔH_{RES} on the polar angle θ of the external field, measured from the FMR, have been successfully fitted based on the Landau–Lifshitz–Gilbert (LLG) equation and two-magnon scattering (TMS) theory. From fitting results, a quantitative relationship between the Landau–Lifshitz (L–L) intrinsic and TMS extrinsic damping has been obtained.

2. Experiments

A serial of $[Fe_{65}Co_{35}/SiO_2]_n$ multilayer films was prepared by a magnetron sputtering method on the glass substrates. Before sputtering, a 10 nm Ta buffer layer was first deposited on the substrate. Two separate targets, $Fe_{65}Co_{35}$ and SiO_2, were set to sputter alternately with the same power of 40 W. The thickness of all the

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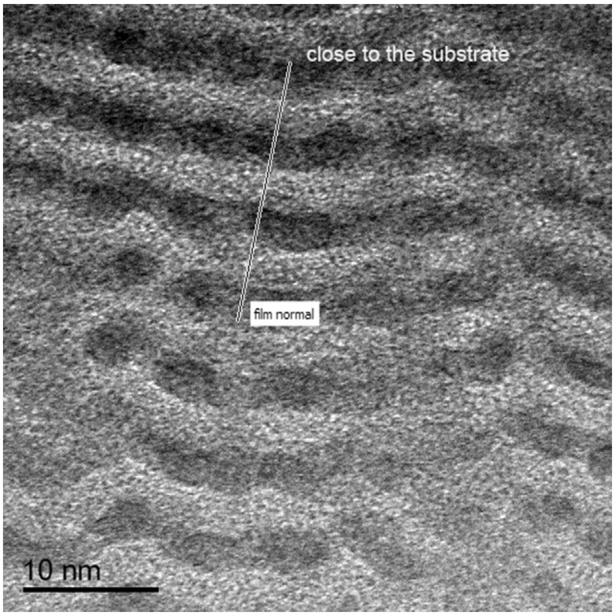

Fig. 1. The bright-field HRTEM images of the cross-section for the sample S1.

layers was controlled by the time of the substrate staying on each target. During sputtering, an in-plane external static magnetic field of about 150 mT was applied to induce a uniaxial magnetic anisotropy. The static magnetic properties were measured using a vibrating sample magnetometer (VSM). The microstructure of the films was determined by the high resolution transmission electronic microscopy (HRTEM). Microwave magnetic properties were characterized by the FMR measurement using a shorted waveguide at 9.78 GHz. The permeability spectra were measured by a broadband one-port microstrip permeameter in combination with the Agilent network analyzer from 200 MHz to 9 GHz [15]. All measurements were carried out at room temperature.

3. Results and discussions

Fig. 1 displays the bright-field HRTEM images of the cross-section for the sample named S1 with a structure of $[Fe_{65}Co_{35}/SiO_2]_{20}$. It can be seen that the sequential deposition of FeCo and SiO_2 layers produces a nanogranular multilayer structure appearing as most of FeCo planes isolated by amorphous SiO_2 layers. The thicknesses for FeCo and SiO_2 layers are respectively about 2.5 nm and 2.1 nm. This structure differs from conventional nanogranular magnetic films, and presents more magnetic inhomogeneities.

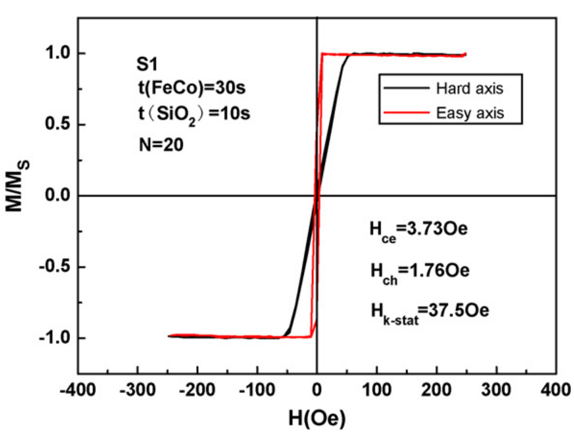

Fig. 2. The magnetization curves of the sample S1 measured by VSM with easy axis coercive force (H_{ce}) equal to 3.73 Oe, hard axis coercive force equal to 1.76 Oe, and static uniaxial anisotropy ($H_{k\text{-}stat}$) field equal to 37.5 Oe.

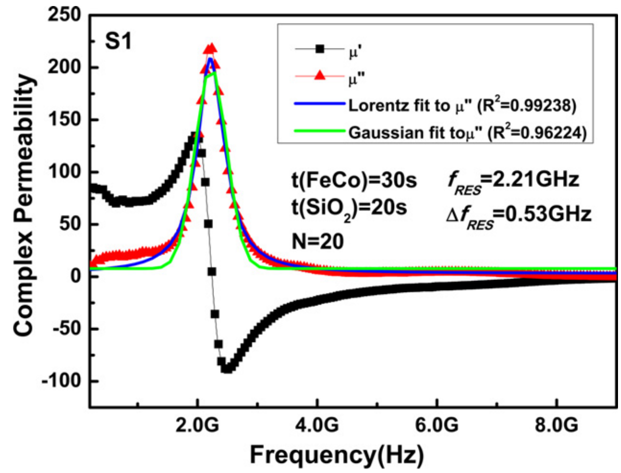

Fig. 3. The frequency-dependent permeability of sample S1 measured by a broadband one-port microstrip permeameter without an external field parallel to the easy axis. The inset in the right corner is the schematic of permeameter. The natural resonance frequency (f_{RES}) equal to 2.21 GHz, the resonance linewidth (Δf_{RES}) equal to 0.53 GHz.

Fig. 2 shows magnetization curves for the sample S1. The coercivities H_{ce} and H_{ch}, respectively along the easy and hard axis, are 3.73 Oe and 1.76 Oe. The static in-plane anisotropy field $H_{k\text{-}stat}$ is about 37.5 Oe, which is calculated by the integration of reduced magnetization between the easy axis and hard axis loops [16]. These soft magnetic properties can be attributed to the exchange interaction among magnetic grains in the same layer and the interlayer exchange coupling which exists between adjacent magnetic FeCo layers across the nonmagnetic SiO_2 interlayers. According to the assumption in Refs. [17,18], if thin enough, the SiO_2 interlayer will be not continuous but contain a lot of pinholes, through which the two FeCo films will be in contact. The magnetization in the adjacent FeCo layers will be forced to align parallel. Consequently, the local magneto-anisotropies of magnetic grains and the demagnetization effects will be averaged out over an increasing number of magnetic grains, such that an in-plane uniaxial anisotropy can be induced by an external field during the sputtering process. It should be mentioned that the presence of pin-hole will reduce the resistivity of films, but it is necessary for multilayer films and granular films to perform magnetic exchange interaction. They can still achieve higher resistivity than pure metal films.

In order to investigate microwave properties of the $[Fe_{65}Co_{35}/SiO_2]_n$ multilayer films, we observed the permeability spectra of the sample S1. Fig. 3 shows the frequency-dependent permeability of the sample S1, which was measured using a broadband one-port microstrip permeameter without an external field parallel to the easy axis of the sample. First, the permeability spectra have a legible resonance peak at 2.21 GHz with a full-width at half-maximum (FWHM) about 0.53 GHz, and this resonance is not in a relaxation type but a resonance type, which indicates that the spin precession along the easy axis in the film almost keeps in an uniform mode. Second, the regression parameter R^2 from the Lorentz fit is more close to 1 than that from the Gaussian fit. It is reasonable to say that the line shape of the permeability spectra is more likely a Lorentzian, which implies that the contribution to the damping linewidth mainly comes from the two-magnon scattering and intrinsic damping [19].

Fig. 4 shows the imaginary part of complex permeability of the sample S1 measured with different external fields. The external field H_b was applied along the easy axis and in the plane of the sample. Some parameters obtained from Fig. 4 are plotted in Fig. 5 for comparison, including the resonance frequency f_{RES} and the frequency linewidth Δf_{RES}. It can be seen that the resonance