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Extrinsic contribution to Gilbert damping in sputtered NiFe films by ferromagnetic resonance

Bijoy K. Kuanr*, R.E. Camley, Z. Celinski

Physics Department, University of Colorado at Colorado Springs, 1420 Austin Bluffs Parkway, Colorado Springs, CO 80933-7150, USA

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Abstract

We quantitatively determine the intrinsic and extrinsic contribution to frequency (Δf_{res}) and field (ΔH) linewidths using Network Analyzer ferromagnetic resonance (NA-FMR) (using two different excitation cells) and conventional ferromagnetic resonance (FMR) techniques in sputtered thin permalloy (NiFe) films. There are some common features in these two FMR measurements, which allow us to get important information on damping mechanisms and structural magnetic qualities. The NA-FMR data show an increase in frequency linewidth (Δf_{res}) as magnetic field (H) increases. A distinct change in the slope of this increase is noted for a field above 200 Oe. To explain this result, we consider available theories including the "two-magnon" model, and the "local-resonance" model. From a fitting of Δf_{res} versus H data to the Arias-Mills' two-magnon model results, we obtain the Gilbert damping parameters. The frequency variation of conventional FMR linewidth (ΔH) data also yields an effective value for the Gilbert damping ($\alpha_{\mathrm{eff}} = 0.0128$), in good agreement with the data from the Network Analyzer data (0.013 ± 0.004). In addition to the theoretical analysis presented in this paper, we compare our experimental results from RF-excitation cell to the commonly used co-planer waveguide technique.

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1. Introduction

Magnetic thin films and multilayers have been the subject of great interest due to their fundamental differences in magnetic and electronic properties from their bulk counterparts. The thin film properties are greatly influenced by the presence of interfaces. The recent spintronic and magnetoelectronic devices operating in the microwave frequency range are based on the unique properties of thin magnetic films. Therefore, it is important to understand the relaxation [1–4] of magnetization, which is governed by spin

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*Corresponding author. Fax: +1 719 262 3013.
E-mail address: bkuanr@uccs.edu (B.K. Kuanr).

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interactions, and the quality and structure of the interfaces. One of the major issues in the magnetic-data-storage industry is the data-transfer rate. Frequencies for writing and reading are now almost in the microwave region, which raises the question, "How fast can magnetic materials switch?" The answer is determined in part by the relaxation mechanisms in the magnetic film.

The measurement of the resonance linewidth is one of the main techniques used to investigate relaxation mechanisms in a ferromagnetic film. The origin of ferromagnetic resonance (FMR) linewidth in ultrathin films is of considerable interest due to the fact that its relaxation time falls in the nanosecond time regime, which is useful for the high-density magnetic recording employing fast magnetization reversal processes. The recent experimental [2,3] and theoretical [5–8] studies show that FMR linewidth consists of intrinsic and extrinsic contributions. The extrinsic part to linewidth was explained by various theories including the defect-induced two-magnon model, the local resonance model [5–8], etc.

In this paper, we present results for the frequency dependence of the FMR field linewidth from conventional FMR and the magnetic field dependence of frequency linewidth from Network-Analyzer-based FMR techniques. Our studies allowed us to determine the Gilbert parameters from the linewidth data.

2. Experiment

Polycrystalline permalloy films of various thicknesses (20–50 nm) were grown on Si substrates by magnetron sputtering with a background pressure better than 10^{-7} mbar. First a 5 nm thick Ti seed layer was grown for good adhesion to the Si substrate. The permalloy deposition rate was maintained at 0.1 nm/s. The permalloy layer was covered by a 5 nm thick Cu layer to prevent oxidation. The samples were characterized by X-ray diffraction (XRD). From the full-width at half-maximum of the XRD peak, the average grain size (X) of the sample was found [9] to be $\sim 80\,\text{Å}$. The grain size of the sample is important to determine the exact theory applicable to the model calculation for the relaxation processes. The coercivity (H_C) and uniaxial anisotropy of the permalloy film measured from magneto optic Kerr effect (MOKE) hysteresis loop measurements are 6 and 8 Oe, respectively.

The Network-Analyzer FMR (NA-FMR) measurements were done with a Vector Network Analyzer (HP model 8510C). We have used two different RF excitation systems to determine the complex **S**-parameters. In the first method, the film was placed across a coaxial receptacle to produce an electric short circuit between the center ($d_1 = 0.135\,\text{cm}$) and outer ($d_2 = 0.4\,\text{cm}$) conductors of the $50\,\Omega$ transmission line, as used earlier [10]. Calibration is accomplished through the open-short-load method. In the second method we used a Cascade microprobe station along with a silver (Ag; $1\,\mu\text{m}$) co-planer waveguide (CPW). The sample was mounted on top of the CPW structure (with center conductor $w = 50\,\mu\text{m}$ and length $L = 6.6\,\text{mm}$) by employing the flip-chip technique. We characterized the Ag-CPW transmission lines at frequencies from 0.5 to 20 GHz using the NIST Multical software for through-short-line (TSL) calibration process.

The effects of the connections as well as the substrate were subtracted from the measured **S**-parameter data in both the techniques. A fixed magnetic field, H ($>H_C$) was applied in the film plane parallel to the easy axis (EA), while the driving frequency f ($=\omega/2\pi$) was swept. In this configuration the microwave magnetic field ($\mathbf{h}_{\mathrm{RF}}$) component aligned perpendicular to the EA of the permalloy causes the magnetization to precess. Using the coaxial receptacle a simple transmission line approach [10] was used to extract the real (μ') and the imaginary (μ'') components of permeability (μ) from the measured **S**-parameters. However, it is not clear that the contribution from currents within the film is correctly accounted for in this method. The NA-FMR measurements for the CPW geometry are more complex [11,12]. For example due to the non-uniformity of RF magnetic field ($\mathbf{h}_{\mathrm{RF}}$), there is a possibility of the excitation of spin-wave with finite wave-vector ($\mathbf{k}_{\parallel}$) due to the fact that the sample is large compared to the dimensions of the CPW [12]. We have also used 10 and 24 GHz FMR systems to

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