A NEW ULTRA-WIDEBAND (10 MHz- 26 GHz) RF MAGNETIC METROLOGY SYSTEM (RFMAG26): COMBINED FMR SPECTROMETER AND PERMEAMETER

Yunpeng Chen[1], Xinjun Wang[2], Huaihao Chen[2], Yuan Gao[1] and Nian X. Sun[1,2]

1) Winchester Technologies LLC, Burlington, USA, chen@winchestertech.org

2) Northeastern University, Boston, USA, n.sun@northeastern.edu

I. INTRODUCTION

Magnetic materials are the necessary components of the magnetic memory and microwave devices. Ferromagnetic resonance and permeability measurements provide a basis for the design and characterization of magnetic materials and the development of new devices. Here, we demonstrated a wideband (10 MHz -26GHz) rf magnetic metrology system that combines FMR spectrometer and permeameter. The system enables the characterization of the complex permeability, FMR linewidth, saturation magnetization, effective anisotropy field, Gilbert damping, inhomogeneous linewidth broadening, and gyromagnetic ratio. The demonstration has been performed on in-plan samples of 30 nm FeGaB and 2 nm NiFe film, and ultra-thin FeCoB/MgO multilayers with perpendicular magnetic anisotropy (PMA). In addition, the permeability measurements do not need expensive vector network analyzer (VNA) and show 40-50 dB higher SNR over the other permeameters.

II. EXPERIMENT AND RESULTS

The proposed rf magnetic metrology system is established from the FMR spectrometer presented in the previous report [7], which uses a microwave source instead of a VNA. The signal detected is proportional to the field derivative of the microwave power. The FMR data are plotted in Fig.1 for the in-plane 30nm FeGaB and 2 nm NiFe films, and a FeCoB/MgO multilayer with PMA. For the in-plane films, the saturation magnetization M_s, anisotropy field H_k can be extracted from the FMR results. The gyromagnetic ratio γ and effective perpendicular field H_{eff} and damping constant α can be extracted for the PMA sample.

The complex permeability is defined as $\mu=\mu'+i\cdot\mu''$, where μ' and μ'' are the real and imaginary part of permeability respectively. The initial permeability can be determined from saturation magnetization and anisotropy field as $\mu'_{initial}=1+4\pi M_s/(H_k+H)$, where H is the external field. The complex permeability as a function of frequency at fixed bias field is determined by frequency-swept measurement. The imaginary permeability versus frequency is obtained by using the integration process as described in Ref [7]. We then calculate the real part of permeability from the imaginary part, using Kramers-Kronig relation. Fig. 2 shows the measured spectrum of complex permeability of a 30 nm FeGaB sample at zero bias field and 2000 Oe bias field. The resonance shifts from 2 GHz to 20 GHz with the increase of bias field and the magnitude of permeability is reduced by the applied field. The permeability results on an ultra-thin 2nm NiFe is presented in Fig. 2(c). The profile of the complex permeability agrees well with the theoretical permeability calculated from Landau–Lifshitz–Gilbert (LLG) equation, which validates the results.

III. PERFORMANCE COMPARISON BETWEEN DIFFERENT METHODS ON PERMEABILITY MEASUREMENTS

A comparison between the reported permeability measurements on magnetic films is summarized in Table I. The new method presented in this study can measure thin-film samples through a much wider frequency bandwidth than any other permeability measurements using microwave transmission line or cavity with vector network analyzer. The measurements on 30 nm FeGAB film show SN ratio of 72 dB, which is the highest sensitivity among all the permeability measurement techniques that we know. In addition, our system is able to detect a 2 nm ultra-thin NiFe film with 28 dB SNR.

IV. CONCLUSION

A new rf magnetic metrology system with the functions of FMR spectrometer and permeameter has been demonstrated with ultra-wide frequency band from 10 MHz up to 26 GHz. The system is capable of characterizing the magnetic properties of the magnetic films with in-plane or perpendicular anisotropy, including complex permeability, FMR linewidth, saturation magnetization, effective anisotropy field, Gilbert damping, inhomogeneous linewidth broadening, and gyromagnetic ratio, through the FMR measurements and analysis. The

Yunpeng Chen
E-mail: chen@winchestertech.org
tel: +1-302-7402998

measurements on permeability have shown much higher SN ratio over the conventional permeameters.

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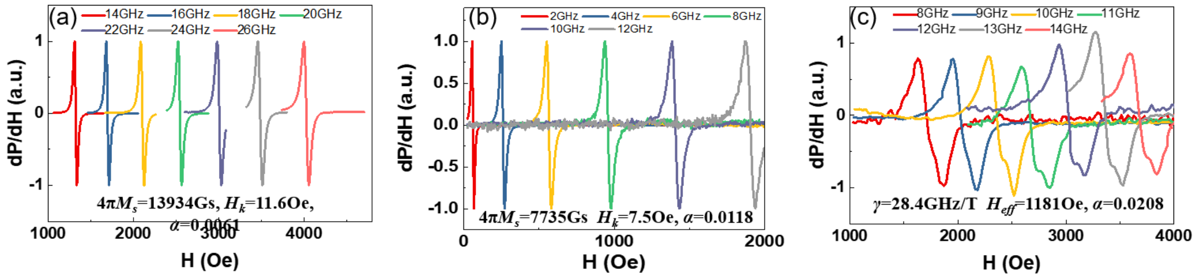

Fig. 1 The measured FMR spectrum of in-plane films, (a) 30nm FeGaB and (b) 2nm NiFe, and (c) perpendicular film of 2nm MgO/1nm FeCoB/0.3nm Ta/ 1nm FeCoB/2nm MgO.

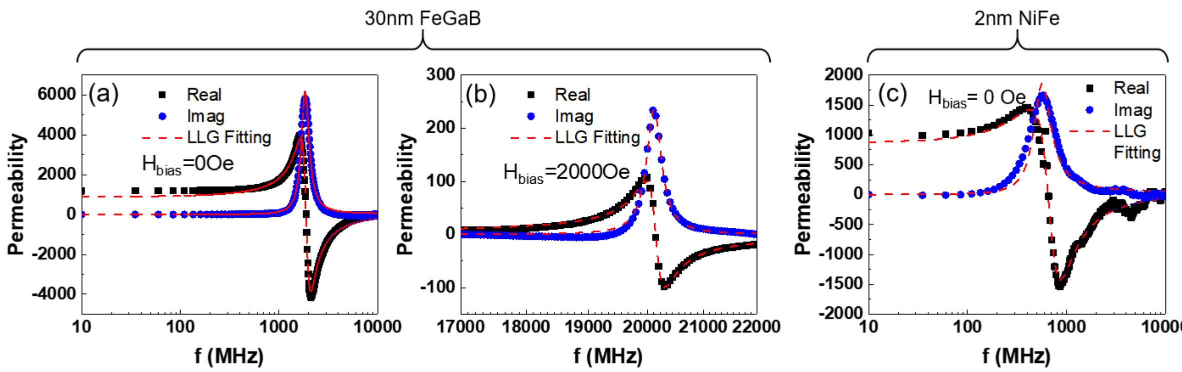

Fig. 3 The measured complex permeability spectrum of 30nm FeGaB at (a) zero bias field and (b) 2000Oe bias field, and (c) 2nm NiFe at zero bias field. The dashed lines are the theoretical permeability from LLG equation.

TABLE I
S/N RATIO AND BANDWIDTH OF DIFFERENT PERMEABILITY MEASUREMENT METHODS ON VARIOUS MAGNETIC FILMS

Sample under Test	BANDWIDTH	Estimated SNR	
700nm NiZn Ferrite	45MHz-10GHz	13dB	Ref [1]
100nm FeGaB	500MHz-3GHz	27db	Ref [2]
100nm FeCoN	1MHz-1.2GHz	30dB	Ref [3]
100nm NiFe	100MHz-6GHz	14dB	Ref [4]
100nm NiFe	500MHz-6GHz	16dB	Ref [5]
200nm CoNbZr	1MHz-9GHz	27dB	Ref [6]
30nm FeGaB	10MHz-26GHz	72dB	This study
2nm NiFe	10MHz-26GHz	28dB	This study