Research Project

Femtosecond Nonlinear-Optical Studies of Nanoscale Magnetic Structures

High-density two-dimensional arrays of magnetic nanoparticles and nanowires are producing many new opportunities to study the fundamental physics of magnetism (such as exchange and dipole-dipole interactions) and spin-dependent transport, as well as leading to incredible technological applications. Magnetic properties of nanoscale materials can be dominated by finite-size and surface effects. Finite-size effects are deviations from bulk properties as the spatial dimensions become comparable to fundamental length scales of the properties being studied. Surface effects mainly originate from the surface atoms with reduced coordination numbers and symmetry and broken exchange bonds. Superparamagnetism, reduction/enhancement in magnetization, enhancement in anisotropy, and decrease in Curie temperature are commonly observed in magnetic nanoparticles. They are the consequences of a complex interplay between finite size effects and surface spin disorders. The dynamic magnetization reversal process is also strongly dependent on size: as the nanoparticle size increases from a few nm to a few hundred nm, the reversal mechanisms start from coherent rotation to curling to domain wall motion (superparamagnetism dominates nanoparticles with the smallest sizes). However, it is often difficult to correlate these effects with dimensional parameters and to compare with theoretical calculations, due to large structural inhomogeneities and lack of high spatial resolution data in dynamics.

The innovation of our research is to achieve high spatial and temporal resolution, which will be accomplished using the newly funded *Alpha300S* high transmission nanoscale optical delivery system together with the advanced time-resolved optical spectroscopic techniques. Nanoscale-resolved optical experiments require an optical resolution better than the diffraction limit expressed as $0.61\lambda/(n \cdot \sin\theta)$, where λ is the wavelength, n is the index of refraction and θ is the angle of incidence measured from the normal direction. In order to achieve sub-diffraction-limit resolution, the *Alpha300S* scanning near field optical microscope will be used to deliver or collect light. The system utilizes a STM probe with a tip opening of tens of nanometers (Fig. 1). Light passes through the cantilever sensor and emerges from the tip opening, forming a light source with a dimension about the tip diameter. For the near-filed measurements, we have already been testing some nanoscale optical delivery antennas from *Witec.*

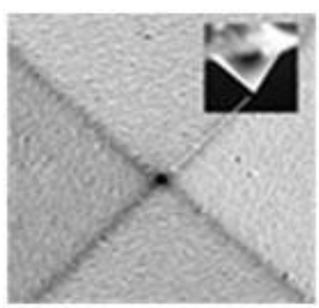

Figure 1 cantilever sensor

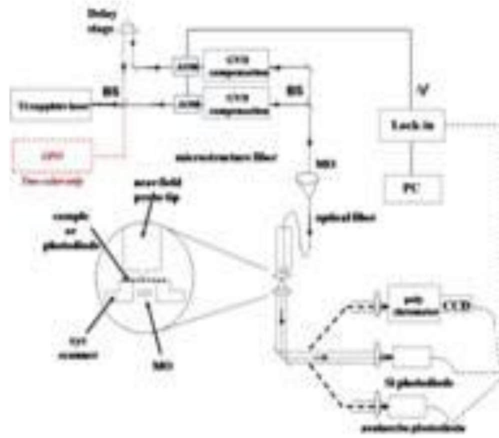

Figure2 Schematic illustrations of the apparatus: MO, microscope objectives; BS, beam splitter.

Research Project

Ultrafast Diagnostics of Dynamical Magnetic Properties in Novel Microwave Films and Devices

One of the major loss mechanisms for metallic magnetic films is eddy current loss. Magnetic/non-magnetic multilayers were shown to be effective in suppressing eddy currents and induce excellent soft magnetic properties with orders of magnitude reduced coercivities, and significantly reduced microwave loss tangents. Compared to the AFM/FM/AFM trilayers and FM/AFM bilayers, trilayers of FM/AFM/FM have their advantages for many microwave applications. In addition to have a higher effective magnetization *Meff* and therefore, a higher flux conduction capability, the FM/AFM/FM structure leads to lower coercivity, which was possibly due to magnetic charge compensation at the magnetic film edges. Most recently, amorphous ferromagnetic materials such as *CoFe* and *CoZrTa* (CZT) have been studied to improve the performance of integrated inductors due to their soft magnetic properties and the ease with which they can be prepared. However, their modest resistivity, FMR, and multiple magnetic resonance feature sometimes found below the FMR frequency pose limits to enhance the properties of the inductors. The multilayer FM/AFM/FM configuration (*e.g. CoFe/PtMn/CoFe* multilayers) could be an effective way for solving the problems.

The pump-probe differential magnetic Kerr (DMK) experiments in *CoFe/PtMn/CoFe trilayers* were performed at ~ 77 K in the Voigt geometry using a Ti-sapphire laser that provided ~ 70 fs pulses of central wavelength 780 nm at the repetition rate of 82 MHz. The pump pulses induce coherent magnetic precessions modifying the reflection of the probe pulses that follow behind. Time-domain DMK measurements give the pump-induced shift of the polarization angle of the reflected probe field as a function of the time delay between the two pulses. The FMR measurements were carried out at X-band (~ 9.74 GHz) using a Bruker electron paramagnetic resonance (EPR) spectrometer. The experimental results are summarized in Fig. 1 (a) and (b). Fig. 1 (a) shows DMK data for a 200-Å-thick *CoFe* trilayer sample after subtracting an exponentially decaying background. The oscillations are assigned to the precession of the magnetization around ***M0***. The PI used linear prediction methods to fit the time-domain data and, as shown in the inset of Fig. 1 (a), the Fourier transform of the fit reveals three modes, which are assigned to *SD*, *SE*, and *S*0. While *SE* and *S*0 refer to the surface and bulk exchange-dominated spin wave modes, the observation of *SD*, the non-homogeneous dipole mode is due to the finite penetration depth of the pump pulses. The three modes were observed in the DMK spectra of all the samples and show little dependence of thickness of the samples. The frequencies of the modes are plotted as a function of the applied magnetic field in Fig. 1 (b), together with FMR results for the 200-Å sample.

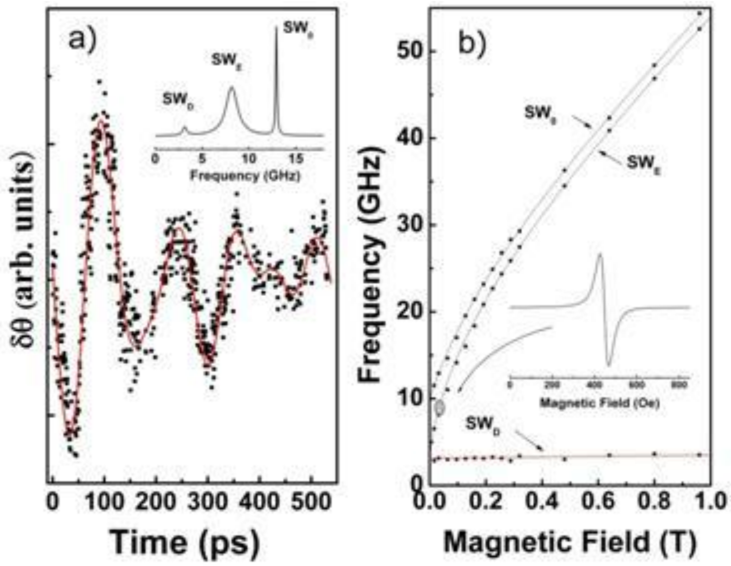

Fig. 1(a) Voigt-geometry DMK data for the 20-nm CoFe/PtMn/CoFe film (solid square) at H0 = 320 Oe. The red curve is the linear prediction fit. The inset shows the Fourier transform of the fit. (b) Measured magnetic-field dependence of the precession mode frequencies. The inset is the FMR spectrum and the solid lines show the fits.

"Magnetic anisotropy and spin wave relaxation in CoFe/PtMn/CoFe trilayer films", Y. H. Ren, C. Wu, G. Yu, C. Pettiford, and N. X. Sun, (submitted to Phys. Rev. B, 2009.)

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"Ferromagnetic resonance studies of surface and bulk spin-wave modes in CoFe/PtMn/CoFe multilayer films", Cheng Wu, Steven Greenbaum, Carl Pettiford, Nian X Sun, Yuhang Ren J. App. Phys. 103. 07B525 (2008).