RK01

Dynamics of successive minor hysteresis loops

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Cumulative growth of successive minor hysteresis loops in Co/Pd multilayers with perpendicular anisotropy was studied in the context of time dependent magnetization reversal dynamics. We show that in disordered ferromagnets, where magnetization reversal involves nucleation, domains' expansion and annihilation, differences between the time dependencies of these processes are responsible for accumulation of nuclei for rapid domain expansion, for the asymmetry of forward and backward magnetization reversals and for the respective cumulative growth of hysteresis loops. Loops stop changing and become macroscopically reproducible when populations of upward and downward nucleation domains balance each other and the respective upward and downward reversal times stabilize.

RK02

Gilbert damping constants of exchange biased NiFe/FeMn bilayers

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The physics of exchange bias effect has been studied intensively for the past decades, however, a few experiments have been reported about the spin dynamics and damping mechanism for the exchange biased systems. Recently, the vector network analyzer ferromagnetic resonance (VNA-FMR) is employed to research the spin dynamics of ferromagnetic thin films with wide range microwave frequencies. In this study, the dynamics magnetic properties of the NiFe/FeMn bilayers is investigated by VNA-FMR with various external static field. The exchange bias is verified by vibrating sample magnetometer and VNA-FMR with varying the thickness of FeMn. Spin dynamics and the Gilbert damping constants of exchange biased NiFe/FeMn bilayers are investigated by the analysis of FMR spectra. The exchange bias field induced asymmetry in the magnetization hysteresis loops. It implies the spin dynamics must be asymmetry for positive and negative field region. We perform VNA-FMR measurement for positive and negative fields. In results, we find that the apparent damping parameters are different in the both field directions in the exchange biased NiFe/FeMn bilayers. Therefore, we conjecture that the exchange bias layer acts differently, depends on the relative direction of the ferromagnetic layer magnetization to the exchange bias field.

RK03

Non-linear susceptibility and influence of the applied magnetic field on ZFC/FC curves

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ZFC/FC curves are widely used to characterize assemblies of magnetic nanoparticles. They reflect the crossover between the blocked and superparamagnetic (SP) regime with increasing temperature. With a low applied field a linear response can be assumed, the shape of the curves is then independent of the applied field H, and a simple theoretical modeling is possible: this allows efficient theoretical fits of experimental curves. We have studied the influence of the applied field magnitude on the ZFC/FC curves shape, both theoretically and experimentally. While the effect of H on the energy barriers has already been discussed, its effect on the response of SP particles has not been considered. However, this non-linearity manifests itself much before the modification of the switching energy distribution. In addition to experimental measurements on a diluted Co nanoparticle assembly, we have simulated ZFC/FC curves for different applied fields, including the third-order susceptibility in the SP response. The later depends on the anisotropy and does not at all correspond to a Langevin function around the blocking temperature. We find that the curves can be significantly affected (in particular the low temperature limit of the FC) for quite low applied fields, which are usually used in experiments.

RK04

On the relation between the magnetoelastic effect and the damping constants of $(Ni\text{-}Fe)_{1-x}M_x$ (M = Ag, Cr, Ga, Au, Pd, and Pt) films

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The dynamics of magnetic thin films have received attention in magnetic device applications such as recording heads, media, and MRAM. Although the dynamics significantly depend on the damping constant α, which determines the strength of damping torque in magnetic thin films, details about their damping mechanism, especially the magnetoelastic effect on damping remain unclear. Herein to clarify the effect of λs on α in $(Ni\text{-}Fe)_{1-x}M_x$ films in detail, we evaluated α and λs in these films. For M= Au, Pd, and Pt, α increases linearly and negative λs increases as x increases. In contrasts, α and positive λs tend to increase almost linearly with x when M=Ag, Cr, and Ga. These results provide clear evidence that α is correlated with λs in (Ni-Fe)-M films. Furthermore, increments of α and the absolute value of λs to x are markedly enhanced in the order of M = Pt, Au, Pd, Cr, Ag, and Ga, suggesting that 5d transition metal dopants are more influential on both α and λs than 3d and 4d transition metal dopants due to the strong spin-orbit interaction of 5d dopants. Consequently, these results demonstrate that a change in magnetostriction energy via transition metal dopants can effectively control α.

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RK05

Ultrafast magnetization dynamics of ferromagnetic systems induced by mid infrared laser pulses

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The aim of the present study is to show how the ultrafast demagnetization and the subsequent rapid re-magnetization occur when exciting a ferromagnetic material with low energy infrared pulses. We have used mid-infrared femtosecond laser pulses (λ= [3-10 μm]) to excite CoPt3, Ni and Co ferromagnetic thin films. The magneto-optical response is then probed in the visible (λ = 798nm). Our results show that even though only intraband transitions occur, the demagnetization process and its subsequent relaxation to the lattice and to the environment are still the dominant processes involved in the magnetization dynamics. We also show that the material band structure is important to interpret the thermalization dynamics of the spins that occur before the heating of the lattice. For specific experimental configurations, we show that it is possible to induce a motion of precession of the magnetization around the effective magnetic field and observe it while it is damped. The magnetization dynamics induced at 6.5 μm in nickel shows an oscillatory behaviour with a period of 2 ps. We attribute this result to the excitation of a two-magnons mode on the NiO by an acoustic mode generated in nickel.

RK06

Ferromagnetic resonance of bilayer CoFeB/NiFeSiB thin film

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Spin transfer torque magnetic random access memory (STT-MRAM) is one of the candidates for next generation random access memory. For practical application, the device should have high thermal stability and low critical current density. They have strong correlation with saturation magnetization (Ms) and damping constant (α) so that we need to determine Ms and α. To study the damping mechanism of the thin films, we have performed ferromagnetic resonance (FMR) experiments through vector network analyzer with bilayer thin films of CoFeB(10-x nm)/NiFeSiB(x nm) (x=0,1,2,….,10). We have fitted the FMR data with Lorentz function to get the information of resonance frequency and line width. From these two fitting parameters, we could get Ms and α by Kittel formula and Full Width at Half Maximum. As increasing x values, the Ms tends to increase, whereas the α suddenly decrease and then saturate. This implies that the added NiFeSiB layer in CoFeB plays a role to prevent the spins align along the field direction.

RK07

Observation of non-kittel ferromagnetic resonance in Co/Cu multilayer system

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In this research, we study the ferromagnetic resonance behavior (FMR) of Co/Cu multilayer system. The samples stacking Ta (5nm) / [Co (4nm) / Cu (t)]*10 / Ta (5nm) with t = 0.5 ? 6 nm were prepared by dc magnetron sputtering in a multitarget sputtering chamber at room temperature and 1 mTorr of pure Ar-pressure. The magnetoresistance (MR) was measured by the standard four point measurement with current in plane (CIP) configuration using Quantum Design Physical Properties Measurement System (PPMS). The magnetic hysteresis loops were recorded using a Vibrating Sample Magnetometer (VSM). FMR responses were measured at microwave frequencies by means of a Vector Network Analyzer (VNA) equipped with a low pass filter circuit. Clear FMR responses were recorded for all samples, however, the noise increased for samples with thicker spacer. Then resonance frequencies (fr) acquired from FMR responses. Theoretically, this FMR should follow Kittel frequency given by: $fr=(\gamma/2\pi)\sqrt{H(H+4\pi M)}$. However, our results shows that the resonace linewidth and the deviation of resonance frequency from kittel behavior will increases as the spacer thickness increased. This behavior is the result of RKKY interaction evident by the increased GMR and will be dicussed within the manuscript.

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RK08

Neighboring layer dependence of ultrafast thermo-magnetic property in GdFeCo films

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Femtosecond pulsed laser light allow excitation of magnetic systems much shorter than the time scale of thermal diffusion represented by conventional Fourier's law. In this time scale, heating and demagnetization phenomena arise via strongly non-equilibrium non-adiabatic way, and cannot be explained by conventional equilibrium thermo dynamics description[1]. In this study, we investigated the neighboring layer dependence of ultrashort laser-induced thermal/magnetic response in layered GdFeCo films by all-optical pump-probe method. Simultaneously, change of normalized reflectivity was measured for monitoring the time evolution of electron temperature Te. We designed layered structures as same 20 nm thick GdFeCo with different neighboring layers (conductive AlTi and insulating SiN). We found two characteristic time region from magnetic behavior: (A) rapid step-like demagnetization and (B) following recovering process with precessional motion. The time scale of (A) is conformed as within picoseconds range (time constant ~100 fs) independently with film structure, which is much shorter than ferromagnetic resonance (period ~0.1 ns at 10 GHz) and hundreds fs delayed with respect to the increase of Te. Following regime (B), film structural dependency of precessional magnetic motion was appeared. The difference of precession frequency and damping properties indicate the different time evolution of lattice temperature in magnetic layer.

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RK09

Magnetization dynamics in perpendicular magnetic anisotropy CoFeB/MgO system

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We study the ultrafast magnetization dynamics of perpendicularly magnetized MgO/CoFeB/Ta and Ta/CoFeB/MgO stack structures which gains wide attention from a viewpoint of perpendicular magnetic tunnel junctions. An all-optical time-resolved magneto-optical Kerr effect measurement reveals that effective Gilbert damping α stays unchanged at ~0.02 in high external field regardless of pump fluence, but it declines drastically with the increase of pump fluence in weak external field. This can be explained by the enlarged apparent relaxation time due to slow remagnetization. Genuine damping tends to attract the precessing magnetization vector towards the effective equilibrium axis, while the tip of the reduced magnetization vector after pump pulse heating recovers growing away from the effective axis. These two competing contributions determine the apparent relaxation time. In a weak field regime, slow recovery of the magnetization vector results in the increased relaxation time and low effective Gilbert damping. We believe that low Gilbert damping found in CoFeB/MgO structure will be expected to reduce the critical current for current-induced magnetization switching.

RK10

Composition dependence of the gilbert damping constant for co-based heusler alloy

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Spin polarized current attracts much attention to operate the magnetic memory devices. To reduce the spin current density, the materials with small Gilbert damping are needed. Recently, it is reported that the Gilbert damping constant of Co-based Heusler alloy known as half-metallic ferromagnet is less than 0.01[1], although the Gilbert damping factor of Co-based Heusler alloy are closely related to crystalline structure and concentration ratio. In this study, to understand the damping mechanism in high-quality L_21-type Co-based Heusler alloy we measured ferromagnetic resonance (FMR) and estimated the Gilbert damping factor. 25 nm thick $L2_1$-type $Co_{2-x}Fe_xSi$ (x=0, 1, 1.5) films for which degree of crystalline order were found to be about 70%[2] were grown on Si(111) substrates. The saturation magnetization of $Co_{2-x}Fe_xSi$ with x=0, 1, 1.5 are 1106, 1023 and 980 emu/cm^3, respectively. SiO_2 insulating layer and coplanar waveguides (CPW) which consists of Ti (5 nm)/Au (60 nm) were prepared. Following that, FMR was measured using a vector network analyzer. The results show the Gilbert damping constant inversely proportional to saturation magnetization. Considering the electron density of state from the ab initio calculation, the broadening of FMR spectra is considered to be related to the electron density of state.

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RK11

Detection of picosecond magnetization dynamics of 50 nm magnetic dots down to the single nanodot regime

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We present the detection of the picosecond dynamics in arrays of 50 nm permalloy dots down to the single nanodot regime by an all-optical time-resolved magneto-optical Kerr effect microscope. The inter-dot separation (S) varies from 200 to 50 nm and simulated magnetostatic fields shows a transition from magetostatically isolated to strongly coupled regime as S decreases. Consequently, we observe a single precessional mode for S down to 75 nm, whose frequency increases with the decrease in S. At the smallest separation S = 50 nm, we observe a mode splitting. The simulated mode profile reveals that the dynamics of a single 50 nm dot is dominated by the edge mode. In sparsely packed arrays we primarily observe the isolated dynamics of the constituent dots in phase. For S = 50 nm, we observe an additional backward volume magnetostatic mode of the array. The damping is minimum for S = 200 nm but increases linearly with the decrease in S as a result of the dynamic dephasing of the precession of the weakly interacting dots. At S = 50 nm, the dephasing due to the superposition of two resonant modes results in a sudden increase in the apparent damping.

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RK12

Femtosecond demagnetization in Ni: Electron-phonon spin flip scattering from first principles

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The femtosecond demagnetization discovered in 1996 [1] represents a critical test of magnetization dynamics theories and may lead to many interesting applications. It is still far from being understood on a microscopic level. Electron-phonon spin-flip scattering in Ni was suggested to be the microscopic explanation of its femtosecond laser-induced demagnetization [2]. We have calculated the spin-flip Eliashberg function [3] based on ab initio electron-phonon coupling matrix elements, which allows us to obtain the spin-flip probability with much higher accuracy. We extend this method also to the regime of non-equilibrated electron distributions relevant for ultrafast processes. We have found that the spin-flip probability depends strongly on electron energy. We consider two cases for system excited by a laser: thermalized very hot electron distributions, as well as highly non-equilibrium electron distributions that are expected to be present immediately after the fs laser excitation. Employing this approach we compute the electron-phonon SF rates. We find that the demagnetization rate is very low for any thermalized electron distribution as compared to non-equilibrium distributions present within first femtoseconds following the pump laser [3]. This is due to the density of states and the specific energy-dependence of SF probability.

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