Ultrafast Demagnetization and Precession Damping Times in Rare Earth Doped Cobalt Films

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Abstract: We show that the ultrafast demagnetization (τ_M) and precession damping (η_M) times of rare-earth-doped Cobalt films have different physical origins. η_M is due to impurity induced spin scattering while τ_M is attributed to spin-orbit interaction

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Investigating the mechanisms which are responsible for the laser induced ultrafast magnetization dynamics in ferromagnetic metals is a pre-requisite for designing future devices working at terahertz frequencies [1-10]. Two key parameters in that respect are the demagnetizing time τ_M and the precession damping time η [1,3,4,6,7]. In this work we study how τ_M and η are modified in ferromagnetic Co doped with rare-earth metal impurities. To understand the physical processes involved we investigate τ_M and η as a function of the laser density of absorbed energy E_0 and of the impurity concentration c_{RE}. The two relaxation times do not follow the same behaviour upon varying each parameter. It leads us to propose two different mechanisms to explain the demagnetization and damping of precession. The spin-orbit is predominant for the demagnetization process, affecting τ_M, while the scattering with magnetic impurities and defects is most important for the damping of the precession η.

The investigated magnetic films were sputtered at an Ar pressure of 5 mTorr at room temperature over substrates of glass and silicium, by co-sputtering a Co target with rare-earth targets (Tb, Ho, Sm and Dy). The time-resolved magneto-optical measurements were done with 48 fs laser pulses (center wavelength 800 nm) delivered at 5 kHz by an amplified Ti:sapphire oscillator in a setup similar to that used in Ref. [1].

Figure 1a displays the time-resolved magneto-optical polar Kerr rotation signal, which represents the magnetization M(t), together with its transmission T(t), which represents the charge dynamics, for a Tb doped Co film, $Co_{89.5}Tb_{10.5}$. The relative differential quantities ($\Delta M/M$ and $\Delta T/T$) are plotted.

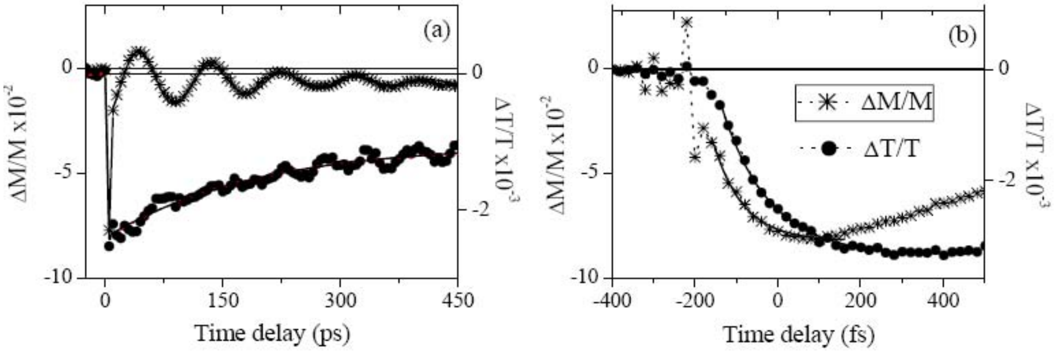

Fig. 1 : Polar Kerr dynamics and differential transmission measured for a $Co_{89.5}Tb_{10.5}$ film for "short" and "long" delay times.

The electronic charge and magnetization dynamics with their distinctive features are measured for long delays, until 450 ps as shown in Figure 1(a). The damped oscillations for $\Delta M/M$ correspond to the projection of the magnetization precession on the polar axis with a corresponding damping $\eta = 149$ ps in that case, while the dynamics of the charges recover their initial equilibrium sate within 185 ps. The initial ultrafast dynamics until 500 fs is shown in Figure 1(b) leading to a demagnetization time $\tau_M = 71 \pm 5$ fs for $Co_{89.5}Tb_{10.5}$.

The influence of the absorbed laser energy density (E_0) on the magnetization dynamics of a rare-earth doped Co film is to increase the damping time η which indicate that there is less "friction" on the precession of the magnetization. For example, the relaxation time η changes for $Co_{93.9}$ $Tb_{6.1}$ from $2.15x10^{-10}$ s to $2.95x10^{-10}$ when increasing E_0 by a factor 3. These results are due to the variation of the magnetization modulus with increasing spin temperature when E_0 increases. We name "torque damping" this mechanism of precession damping which can be explained simply as follows. According to a three bath modelling of the charges, spins and lattice dynamics, an increase of laser intensity manifests by an increasing lattice temperature, which is in quasi equilibrium with the electrons and spins after a few picoseconds [2]. Such increase of temperature reduces the modulus of the magnetization according to the Curie-Weiss law. As a result the friction decreases since it is proportional to M x (dM/dt) in the modified Landau-Lifshitz-Gilbert equation, providing we take into account the changes of the magnetization modulus [2]:

$$\frac{d\vec{M}}{dt} = -\gamma(\vec{M} \times \vec{H}) + (\frac{\alpha}{M}) \cdot \vec{M} \times \frac{d\vec{M}}{dt}). \qquad (1)$$

In Figure 2a and 2b we summarize the results of respectively the demagnetization time τ_M and precession damping time η for several rare-earth doped Co samples. We note that in general the demagnetization τ_M is not significantly affected by the doping concentration and type of impurities. This is a strong indication that the disorder and the mechanism of spins scattering by impurities plays a minor role during the initial stage of the demagnetization dynamics. We rather attribute it to the spin-orbit interaction as recently shown theoretically [10]. In contrast, figure 2b) shows that the precession damping η is strongly affected by the doping concentration, as has been reported before by Bailey et.al in the case of permalloy thin films [9].

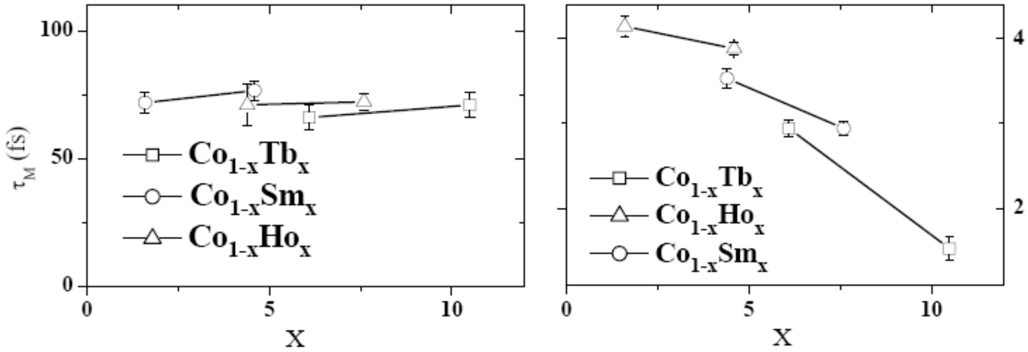

Fig. 2: τ_M and η as a function of $x=c_{RE}$ concentration for Co films doped with Sm, Tb and Ho.

In conclusion, using ultrafast magneto-optics we have measured the ultrafast demagnetization time τ_M and damping time η of the precession in rare-earth doped Co films. We report that τ_M of rare-earth doped Co films is not affected by the doping concentration. It shows the minor role played by disorder and impurity scattering in the initial magnetization dynamics which we attribute to the spin-orbit interaction. In contrast, η is strongly affected by the doping concentration. In addition, the investigations of the precession damping as a function of the absorbed laser energy shows that η increases when we increase the laser pump power. This effect, named "torque damping" is attributed to the reduction of magnetization modulus as the temperature of the system increases.

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