# Ultrafast Demagnetization Rates in Two-Component Magnetic Materials

**O. Chubykalo-Fesenko[1,§], U. Atxitia[2,3], P. Nieves[2], J. Barker[1] and R.W. Chantrell[1]**

[1]Instituto de Ciencia de Materiales de Madrid, CSIC, Cantoblanco, c. Sor Juana Ines de la Cruz, 3, Madrid, 28440, Spain

[2]University of York, UK

[3] Departamento de Física de Materiales, UPV/EHU, San Sebastian,

[§] oksana@icmm.csic.es

**Abstract** The recently derived Landau-Lifshitz-Bloch equation of motion for two-component magnetic systems, including ferri- ferro- and antiferromagnets, provides a framework to analyze species dependent ultra fast demagnetization rates. In agreement with reported experimental observations, we show that Gd sublattice demagnetizes slower then FeCo in GdFeCo. However, we predict that at high initial temperatures Gd should be faster than Fe, providing the possibility to control the polarity of the transient antiferromagnetic state. Our results indicate that typically Fe should be slower than Ni in FeNi. The situation is opposite if Fe is 4 times stronger coupled to the electronic system than Ni.

The element-specific synchrotron measurements, using X-ray circular magnetic dichroism, have opened the possibility to evaluate separately the ultra fast demagnetization rates in multi-component magnetic alloys. Prominent examples are measurements in GdFeCo [1], where it was established that Gd sub-lattice is much slower than Fe. Differently, in NiFe the two sub-lattices have similar demagnetization rates and the debate on which is faster is still going on [2-4]. It has been proposed that the ratio between the magnetic moment and the Curie temperature, $\mu/TC$, is a good figure of merit to establish the ultrafast demagnetization rates of materials [5]. Following this ratio, any rare earth material is clearly at least 3-5 times slower than any transition metal. At the same time, recently it has been established that a typical "fast" transition metal Ni can become "slow" approaching the Curie temperature [6]. Thus, the question what is the relative demagnetization speed in each metal comprising a multi-component ferromagnet is not trivial.

The Landau-Lifshitz-Bloch (LLB) equation, recently derived for a two-component system [7], can help to elucidate this question. For pure longitudinal processes (when the sublattices magnetizations remain parallel) we write the LLB



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equation for each sublattice ν and for the reduced magnetization $\vec{m}_\nu = \vec{M}_\nu / M(T=0)$ in the form:

$$\frac{d\vec{m}_\nu}{dt} = -\gamma_\nu \alpha_\nu^{||} \left[ \frac{\Gamma_{\nu\nu}}{2} \left( \frac{m_\nu^2}{m_{e,\nu}^2} - 1 \right) - \frac{\Gamma_{\nu\kappa}}{2} \left( \frac{m_\kappa^2}{m_{e,\kappa}^2} - 1 \right) \right] \vec{m}_\nu$$

Here $\gamma_\nu$ is the gyromagnetic ratio and $m_{e,\kappa}$are the equilibrium magnetization values. The longitudinal damping and the rate parameters are evaluated in the mean-field approximation. Namely,

$$\alpha_\nu^{||} \cong \frac{2\lambda_\nu k_B T m_{e,\nu}}{J_{0,\nu} m_{e,\nu} + |J_{0,\nu\kappa}| m_{e,\kappa}},$$

where $\lambda_\nu$ is the parameter representing the atomistic coupling to the heat bath (proportional to the scattering rate), $k_B$ is the Boltzmann constant, $T$ is the temperature, $J_{0,\nu} = z_\nu J_\nu$, $J_{0,\nu\kappa} = z_{\nu\kappa} J_{\nu\kappa}$, $J_\nu$ is the intra-sublattice exchange parameter and $z_\nu$ is the average number of the neighbors of the same species, $J_{\nu\kappa}$ is the inter-sublattice exchange parameters and $z_{\nu\kappa}$ is the average number of neighbors of the opposite species. The temperature-dependent rate parameters are expressed in terms of the longitudinal susceptibilities $\chi_\nu^{||} = (\partial m_\nu / \partial H)_{H \to 0}$ as:

$$\Gamma_{\nu\nu} = \frac{1}{\chi_\nu^{||}} \left( 1 + \frac{|J_{0,\nu\kappa}|}{\mu_\nu} \chi_\kappa^{||} \right), \quad \Gamma_{\nu\kappa} = \frac{|J_{0,\nu\kappa}|}{\mu_\nu} \frac{m_{e,\kappa}}{m_{e,\nu}}$$

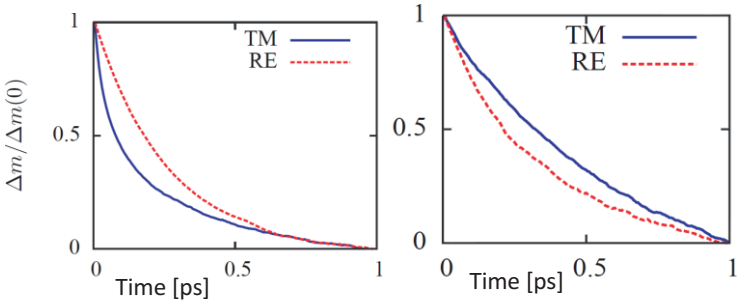


**Fig. 1.** Atomistic simulations of longitudinal relaxation in disordered GdFeCo ferrimagnet with 25% of Gd under a heat pulse with initial temperature 300 K and final temperature $0.75T_C$=600 K (left) and $0.975T_C$=780 K (right). The demagnetization curves are normalized to the value at 2ps. The parameters of GdFeCo are taken from Ref.[9].

The longitudinal relaxation rates can be evaluated as the eigenvalues of the two coupled linearized LLB equations. This indicates that one cannot attribute a one-exponential decay to each of the sublattices. Nevertheless, for FeCoGd the analysis of the demagnetization rates shows that for temperatures not close to $T_C$,

$\Gamma_{FeCo,Gd} \sim \Gamma_{Gd,FeCo} < \Gamma_{Gd,Gd} \ll \Gamma_{FeCo,FeCo}$ and FeCo and Gd sublattices can be practically described by one eigenvalue. In this temperature region Gd is much slower than FeCo. Close to $T_C$, however, the situation surprisingly changes and our model predicts that Gd becomes faster than FeCo. To confirm these predictions, we present the corresponding atomistic simulations in Fig.1. One of the consequences of the change of relaxation rates is the possibility to observe the "inverted" transient ferromagnetic state at high temperatures [8], i.e. directed towards Fe instead of Gd.

As for the relaxation in NiFe, our results show that since the two-sublattices Fe and Ni are strongly coupled, one cannot characterize their individual ultra fast dynamics in terms of one-exponential behavior. Nevertheless, following the common experimental practice, we fit the magnetization relaxation curves to one exponential decay. Fig.2 presents the ratio between Ni and Fe demagnetization times as a function of their coupling to the bath parameters and the pulse temperature. Because Fe and Ni are similar transition metals, one can expect similar coupling to the bath parameters for both in their alloy. This indicates that in normal situation Ni is faster than Fe. However if one assumes that Fe is 4 times stronger coupled to the electronic system, as also discussed in Ref.[4], the situation is opposite.

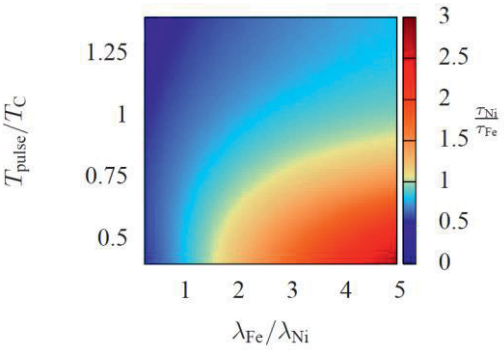


**Fig. 2.** The ration between Ni and Fe relaxation times in FeNi alloy, obtained from the LLB-based simulations, as a function of the ratio of the coupling to the bath parameters and the maximum pulse temperature.

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