LLB micromagnetic models for ultrafast magnetisation processes

D Hinzke, U Nowak, O Chubykalo-Fesenko and RW Chantrell

I. Introduction

Micromagnetic simulations are faced with considerable challenges in dealing with magnetisation processes at short timescales and elevated temperatures. Recently we have proposed the use of the Landau-Lifshitz-Bloch (LLB) equation [1] to replace the LLG equation for such cases. The reason is that the LLB equation allows longitudinal fluctuations of the magnetisation in addition to the transverse fluctuations included in the LLG equation. As a result the LLB equation is capable of describing magnetisation processes on the sub-picosecond timescale and at temperatures up to and beyond the Curie temperature. The purpose of the paper is to outline the physics of the LLB equation and to describe an LLB-micromagnetic model and its applications to ultrafast magnetisation processes. The physics of a novel 'linear' reversal mechanism will be discussed in terms of both atomistic and (single spin) LLB models, the latter allowing an estimate of the switching time in the linear reversal mode, which can be in the picosecond regime.

II. The LLB equation

The LLB equation can be written in the form

$$\dot{\mathbf{m}}_{\mathbf{i}} = -\gamma[\mathbf{m}_{\mathbf{i}} \times \mathbf{H}^{\mathbf{i}}_{\text{eff}}] + \frac{\gamma\alpha_{||}}{\mathbf{m}_{\mathbf{i}}^{\mathbf{2}}}\left(\mathbf{m}_{\mathbf{i}} \cdot (\mathbf{H}^{\mathbf{i}}_{\text{eff}} + \zeta^{\mathbf{i}}_{||})\right)\mathbf{m}_{\mathbf{i}} - \frac{\gamma\alpha_{\perp}}{m_i^2}\left[\mathbf{m}_{\mathbf{i}} \times \left[\mathbf{m}_{\mathbf{i}} \times \left(\mathbf{H}^{\mathbf{i}}_{\text{eff}} + \zeta^{\mathbf{i}}_{\perp}\right)\right]\right], \quad (1)$$

The LLB equation is valid for finite temperatures and even above T_c though the damping parameters and effective fields are different below and above T_c. The transverse and longitudinal damping parameters are defined in [2]. The local effective field $\mathbf{H}^{\mathbf{i}}_{\text{eff}}$ contains contributions from the anisotropy, Zeeman and any interaction terms and in addition a field which ensures convergence of the magnetisation magnitude to the saturation value appropriate for a given temperature. The paper will describe in detail both the LLB equation and the micromagnetic formulation into which it is included.

A. Results

Fig. 1 demonstrates the ability of the LLB micromagnetic model to cover all timescales of importance in terms of the longitudinal and transverse relaxation. It shows a calculation of the response of the magnetisation in an optically pumped FMR experiment. This involves the application of a magnetic field at some angle to the plane of the film followed by a low-power pulse from a femtosecond laser. This heats the film and reduces the magnetisation, resulting in a shift of the magnetisation direction to a new equilibrium position. As the sample cools the magnetisation precesses back to the equilibrium position. It can be seen from fig. 1 that the experimentally observed initial fast demagnetisation in the sub-picosecond timescale is reproduced by the LLB equation, as is the longer timescale precessional motion back to equilibrium.

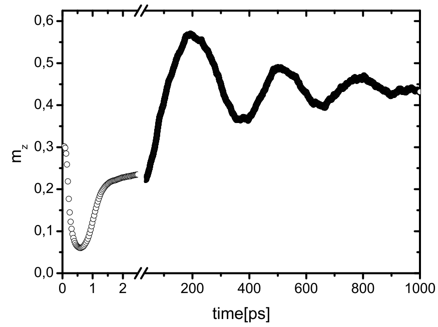

Fig. 1. Modelling of a fast demagnetisation dynamics with low laser fluence in a thin film ($48 \times 48 \times 6$ nm) with periodic boundary conditions and in-plane anisotropy of value $K(T = 0) = 1.3 \cdot 10^5 erg/cm^3$.

We will also present results showing the existence of a novel reversal mode termed 'linear reversal'. Atomistic calculations show that at temperatures close to the Curie temperature the magnetisation reverses via a state of zero magnetisation which involves no precession of the magnetisation. This reversal mechanism is extremely fast since the reversal is governed by the time to reach zero magnetisation. This is determined by the longitudinal relaxation time, which is of the order of hundreds of femtoseconds. The LLB equation also exhibits a linear reversal mode in remarkable agreement with the atomistic calculations. Calculations of the opto-magnetic reversal phenomenon [3] will also be presented. These demonstrate that a likely explanation for the sub-picosecond reversal observed experimentally is the excitation of a linear reversal mode in large field of around 10T arising from the inverse Faraday effect. The implications of this mechanism for ultrafast magnetisation reversal will be discussed.

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References

[1] D. A. Garanin, Phys. Rev. B **55**, 3050 (1997).
[2] N. Kazantseva, D. Hinzke, U. Nowak, R. W. Chantrell, U. Atxitia, and O. Chubykalo-Fesenko Phys. Rev. B **77**, 184428 (2008)
[3] C. D. Stanciu et al., Phys. Rev. Lett. **99**, 047601 (2007).