Overcoming the Critical Slowing Down of Magnetization Dynamics

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In order to develop ultrafast and energy efficient storage devices based on magnetic media, it is usually believed that magnetization must undergo a longitudinal dynamics [1,2] as opposed to a precessional one [3,4]. It must then be completely quenched at the sub-picosecond timescale [5] before recovering in the opposite direction. However, when magnetization approaches zero, its dynamics slows down, a phenomenon called Critical Slowing Down (CSD) [6,7] which generally exists when a system is close to a phase transition [8].

In order to explain CSD and explain how it can be avoided in magnetic systems, we introduce a two level mean field model for localized spins [9]. Magnetization dynamics is then understood as transfers of energy and angular momentum, and to each magnetic configuration, one can define a temperature for the spin system even under out of equilibrium conditions. We then show that only angular momentum transfers can lead to magnetization reversal and suppress CSD via two mechanisms referred to as spin heating and spin cooling: the heating and respectively cooling of the magnetic system via exchange of spin with an external bath. These effects are simulated using a s-d model of magnetization dynamics [10], consistent with this framework. Experimentally, we demonstrate the existence of these two mechanisms by monitoring the ultrafast magnetization dynamics of a ferromagnetic [Co/Pt] multilayer when it is subjected to an external spin current emitted by a GdFeCo alloy [11]. We show that magnetization crosses zero in 400 fs and reaches equilibrium in 2 ps. Moreover, using the bipolarity of the source spin current [12], we show that magnetization can be reversed twice consecutively in 650 fs. This shows that one can achieve a complete control of magnetization dynamics at the sub-picosecond timescale, close to the ferromagnetic/paramagnetic phase transition, using ultrashort pulses of spin with tunable polarization[9].

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