Effect of different couplings on the relaxation time of a magnetic dimer

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An issue of great interest to the community of magnetism today is the dynamics of coupled magnetic films and their applications in MRAM technology. It has been shown [1] that these structures, and among them the so-called Magnetic Tunnel Junctions (MTJ), provide promising features for efficient magnetic recording. The dynamics of such systems strongly depends on many physical parameters related with the films material properties and, in particular, on the coupling between the magnetic films.

In this work we investigate the effect of exchange (EI) and dipole-dipole (DDI) coupling on the dynamics of a magnetic dimer (MD) composed of two magnetic layers coupled via a nonmagnetic spacer. We use the kinetic theory of Langer to obtain (semi-)analytical expressions [2, 3] for the relaxation time of the MD coupled by either EI or DDI and compare their efficiency in the MD reversal.

Each magnetic layer is modeled by a macroscopic magnetic moment of fixed magnitude and with uniaxial anisotropy pointing in an arbitrary direction with respect to the applied field (Fig. 1). In the case of DDI, three different anisotropy configurations have been studied: longitudinal anisotropy (both easy axes are parallel to the MD bond), transverse anisotropy (both easy axes perpendicular to the MD bond) and mixed anisotropy (one parallel and one perpendicular to the MD bond). In the case of the longitudinal anisotropy the DDI has been compared to EI.

The results are shown in Fig. 2 where the (reduced) relaxation time is plotted as a function of $\sigma=\frac{KV}{k_B T}$, which is the anisotropy-energy (reduced) barrier in the absence of interactions. Here K is the anisotropy constant of the material, taken to be the same for both magnetic layers; V is the volume of the magnetic slabs; T the temperature; and k_B the Boltzman constant. $\tau_0 \sim 10^{-9}$ is the (characteristic) free-diffusion time. In order to compare the effects of these two interactions, which lead to different switching mechanisms, we have considered the switching of the MD from the same initial state into the same final state, the initial state being with both magnetic moments pointing upwards out of plane; the final state being with them pointing downwards out of plane. The switching path followed by the two magnetic moments, which determines the switching mechanism of the MD, depends on the type of coupling and intensity of the latter.

Apart from the fact that the relaxation time obviously increases with σ (or with decreasing temperature) for both EI-MD and DDI-MD, we see that for both coupling regimes there is a critical value σ_c at which the relaxation times corresponding to EI and DDI intersect each other. This means that below σ_c the MD switches faster via one coupling than via the other; the order in which this happens depends on the coupling regime.

In the strong coupling regime it is the DDI that leads to the shortest switching time below σ_c and then the situation reverses beyond σ_c . In this regime the EI energy barrier is constant (owing to saturation) while that of DDI continues to grow. So, below σ_c the prefactor of the relaxation time prevails and the

DDI is more favorable for a fast switching. However, as σ_c is exceeded, the energy barrier prevails over the prefactor and thereby the ever growing DDI energy barrier leads to a longer switching than via EI.

In the WC regime the situation is different since the MD switching operates via the fanning mode (a two-step process) passing through an intermediate state and crosses two saddle points. For EI the ratio of the relaxation rate of the second step to that of the first step implies that for small values of σ (high temperature), namely $\sigma \leq \sigma_c$, the second step is slower than the first. However, in the case of DDI the second step is always faster than the first. Therefore, for small σ the EI leads to a faster switching, whereas above some critical value of σ , or equivalently below some critical temperature, the lower energy barrier of DDI leads to a shorter switching time.

In conclusion, at low temperature, the EI-MD switches faster than DDI-MD in the SC regime, while at high temperature, EI-MD switches faster than DDI-MD in the WC regime.

References

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[3] H. Kachkachi, Europhys. Lett. 62 (2003) 650; J. Molec. Liquids 114 (2004) 113 ; Phys. Rev. B 72 (2005) 134425.

Figures

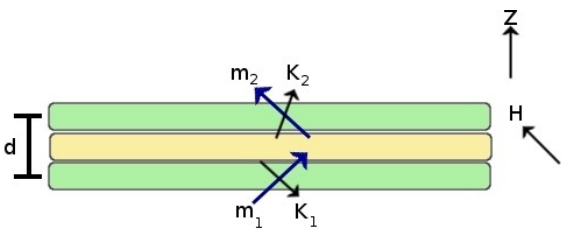

Figure 1: Scheme of an MTJ

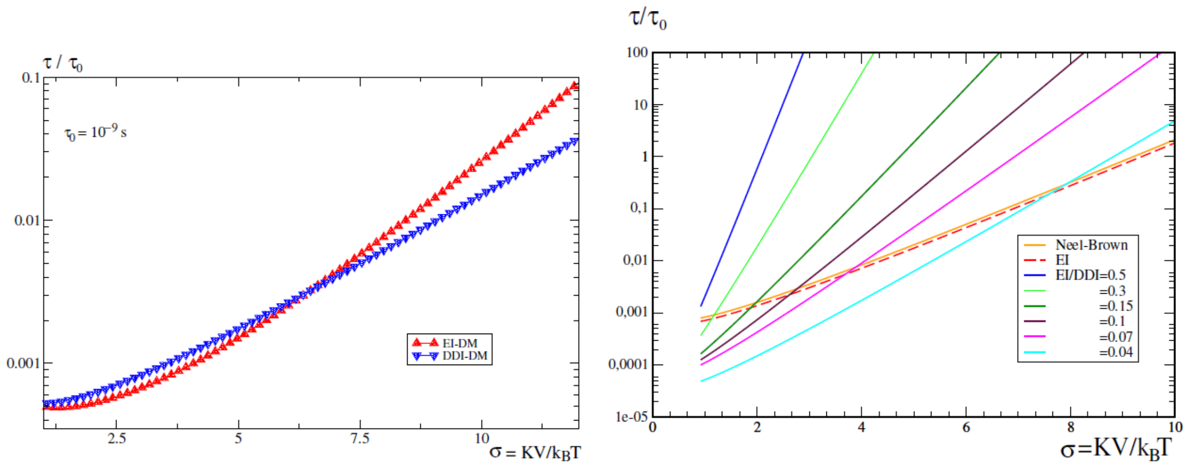

Figure 2: Reduced relaxation time, τ/τ_0 , versus $\sigma = \frac{KV}{k_B T}$ for the EI- and DDI-MD, in the absence of the magnetic field, for weak-coupling regime (left) and strong-coupling regime (right). The Néel-Brown result coincides with EI (j=10)