Optimal switching of a nanomagnet assisted by a microwave field

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Magnetic recording is a key technology in the field of high density information storage. In order to increase thermal stability, small nanoparticles with a high anisotropy may be used. However, high fields are then needed to reverse the magnetization but these are difficult to achieve in current devices. In 2003 Thirion et al. [1] showed that the combination of a constant applied field (DC field), well below the switching field, with a microwave (MW) field pulse can reverse the magnetization of a nanoparticle. Further studies on single domain magnetic nanoelements [2] proved that the effect is stronger if the frequency of the MW field matches the ferromagnetic resonance frequency of the nanoelements. Numerical simulations [3] confirm that chirped MW fields are more efficient than monofrequency fields.

The aim of this work is to find the optimal MW field triggering the switching of a nanoparticle under specified constraints. We consider a single-domain nanoparticle, modelled by a macroscopic magnetic moment (macrospin). The shape of the MW field is then sought by minimizing the absorbed energy, following the trajectory of the macrospin, which is a solution of the damped Landau-Lifshitz equation. The boundary conditions are a given initial state and a specified target state that is supposed to be reached after switching. This boundary value problem is reformulated by defining a cost functional that is then minimized using the Lagrange parameter technique [4]. The problem is then solved numerically using the conjugate gradient algorithm coupled to a simulated annealing scheme.

The calculation is carried out for a nanoparticle with a uniaxial anisotropy in an oblique DC magnetic field and a linearly polarized MW field. According to our results, the optimal MW field is modulated both in amplitude and in frequency (see Fig. 1). Its role is to drive the magnetization from the metastable equilibrium position towards the saddle point, then damping induces the relaxation to the stable equilibrium position. A small magnitude of the MW field is sufficient to induce a substantial reduction of the switching field. For the pumping to be efficient, the MW field frequency must match the proper precession frequency of the magnetization, which equals the ferromagnetic resonance frequency at the early stage of the switching process.

The MW field is optimized for various intensities and orientations of the DC field. The switching field curve (Stoner-Wohlfarth astroid) in presence of a given MW field is then computed. The results are in qualitative agreement with experiments on isolated nanoclusters [1] and on single-domain magnetic elements [2]. The effect of damping is also investigated. The strong dependency of the optimal MW field and the switching curve on the damping parameter provides a means of probing experimentally the latter in nanoclusters.

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References

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Figures

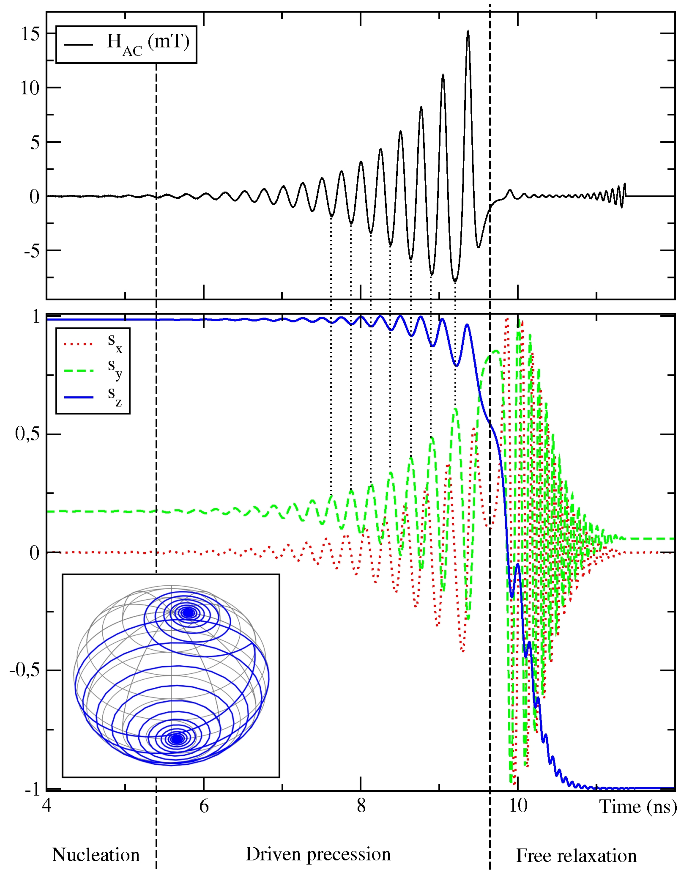

Figure 1: Optimized MW field (upper panel) and the corresponding spin trajectories (lower panel). The DC field is applied in the yz plane making an angle of 170° with respect to the easy axis (z axis), and its magnitude is 150 mT. The inset is a 3D plot of the spin trajectory on the unit sphere.