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Theory of Generation Linewidth in Spin-torque Nano-sized Auto-oscillators

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The passage of a spin-polarized current through a magnetic multilayer can lead to novel dynamical effects [1], such as self-sustained magnetization precession with frequencies in the GHz range. This effect is important due to the potential applications in tunable nano-scale radio-frequency auto-oscillators. One of the unsolved problems in this field is the problem of the origin of spectral linewidth in these auto-oscillators. In the previous work [2] we have shown that the phase noise in determining the spectral properties of spin-torque auto-oscillators far above the generation threshold, but neglected the *nonlinear frequency shift* in the spin-torque effect. This shift in the frequency occurs due to the increase of the precession amplitude *happening with the increase of the bias direct current. In the present work, we extend our earlier stochastic* spin-wave picture [2] to include the effects of this nonlinear frequency shift.

It has been shown previously, that the inclusion of the spin-torque in the standard spin-wave theory results in a nonlinear oscillator equation for the complex amplitude c(t) of the excited spin wave [3, 4]

$$dc/dt = -i(\omega_0 + N|c|^2)c - \Gamma_0(1+Q|c|^2)c + \sigma I(1-|c|^2)c + f(t)\,, \qquad (1)$$

where ω_0 is the linear frequency of the excited spin wave mode, N is the nonlinear frequency shift coefficient, Γ_0 is the linear relaxation rate, $Q \sim 1$ is the dimensionless parameter describing the increase ofdamping with the increase of the spin wave power $|c|^2$, σ is the efficiency parameter is defined in [3], I is the charge current passing through the magnetic layer, and f(t) *describes the influence of thermal noise. The function $f(t)$ is a stochastic Gaussian process with the correlator* $\langle f(t) f^*(t')\rangle = 2\Gamma_0 n_T \delta(t - t')$, where $n_T = \langle |c|^2 \rangle_I = 0$ is the spin wave power in the state of thermal equilibrium (i.e., at $I \approx 0$).

In substantially supercritical regime ($\zeta = \sigma I/\Gamma_0 > 1.2$) the main contribution to the linewidth of generation comes from the phase fluctuations of the spin wave amplitude $c(t)$. Analyzing Eq. (1) in this regime, we derived the following expression for the linewidth of the spin-torque-induced auto-oscillations:

$$\Delta\omega = \Gamma_0\left(\frac{n_T}{n_0}\right)\left[1+\left(\frac{N}{\Gamma_0(\zeta+Q)}\right)^2\right], \qquad (2)$$

where $n_0 = (\zeta - 1)/(\zeta + Q)$ is the mean power of the auto-oscillation. Equation (2) clearly shows that the equilibrium relaxation rate of the excited mode Γ_0 determines the overall scale of the possible linewidth variations. Then, Eq.(2) demonstrates that the linewidth $\Delta\omega$ is proportional to the noise level n_T/n_0, which is determined by the ratio of the population of thermal spin waves n_T to the population of driven spin waves n_0. Finally, Eq.(2) shows that the nonlinear frequency shift parameter N gives a measure of the contribution of the amplitude fluctuations to the phase noise far above the generation threshold.

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FA06

Effective Anisotropies and Energy Barriers of Magnetic Nanoparticles with Néel's Surface Anisotropy.

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Magnetic nanoparticles with Néel surface anisotropy, different internal structures, surface arrangements and elongation are modelled as many-spin systems with the help of the Lagrangian multiplier technique [1]. The results suggest that the energy of many-spin nanoparticles cut from cubic lattices, can be represented by an effective one-spin potential containing uniaxial and cubic anisotropies. It is shown that the values and signs of the corresponding constants depend strongly on the particle's surface arrangement, internal structure and elongation. Particles cut from a simple cubic lattice have the opposite sign of the effective cubic term as compared to particles cut from the face-centered cubic lattice. Several remarkable phenomena are observed in nanoparticles with relatively strong surface effects: (i) In elongated particles the surface effects can change the *sign of the uniaxial anisotropy. (ii) In particles with cubic core anisotropy, they induce an effective uniaxial anisotropy.*

We also evaluate energy barriesr DE of many-spin particles as a function of the strength of the surface anisotropy and the particle size. The energy barriers larger than the core anisotropy value have been calculated for spherical and truncated octahedral particles with very large surface anisotropy (K_s 100 Kc, where K_s is the Néel surface anisotropy constant and Kc is the core anisotropy value). This confirms a well-known fact that the surface anisotropy contributes to the enhancement of the particle's magnetization thermal stability. The results are analyzed with the help of the effective one-spin potential, which *allows us to assess the consistency of the widely used formula* $\Delta E/V = K\infty + 6K_s/D$ *[2]*, where $K\infty$ is presumably the value of the core anisotropy constant and K_s is some phenomenological constant related with surface anisotropy K_s. We show that the energy barriers of many-spin particles may consistent with this formula only in elongated particles for which the surface contribution to the effective uniaxial anisotropy scales with the surface and is linear in the constant of the Néel surface anisotropy.

Even then the $K\infty$ value may be renormalized by the surface anisotropy. Finally, we try to fit numerical results for multi-spin particles for some of the prevously experimentally reported data on Co particles [3] with positive and negative surface anisotropy constants. The obtained Ks values for K_s>0 are much larger than those obtained experimentally by fitting to the expression $\Delta E/V \approx K\infty + 6K_s/D$.

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