Sperimagnetic phase transitions in ferrimagnetic amorphous alloy GdFeCo

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Abstract. In our work we consider a model of amorphous ferrimagnetic alloys GdFeCo of "rare earth"-"transition metal" type. Such ferrimagnetic alloys are perspective for ultrafast switching applications [1] and spintronic devices, which is caused by high resonant frequencies in comparison to resonant frequencies of transition metal films and high velocity of domain walls motion induced by spin-polarized current [2]. Like other amorphous compounds, these alloys are characterized by the absence of long-range order of atomic structure, which turns out into microscopic stochastic of magnetic properties causing the sperimagnetic structure (see Fig. 1).

- For calculation of magnetic field and temperature driven phase transitions in amorphous GdFeCo we consider a model of "rare-earth"–"transition metal" amorphous ferrimagnet consisting of two magnetic sublattices — f-sublattice (Gd) and d-sublattice (FeCo).
- We divide a bulk material into *N* macroscopic particles having uniform magnetization and properties. Every particle has uniaxial anisotropy aligned with the axis *Oz*, but has a random value of magnetic anisotropy constant to represent amorphous nature of material.
- External magnetic field is parallel with the axis *Oz*, so the system has the axial symmetry, which allows us to describe magnetic moment vector with only polar angles θ_d and θ_f, neglecting azimutal angles φ_d and φ_f.
- We take into account only d-d and f-d exchange interactions neglecting f-f exchange interaction, which is due to the interaction hierarchy in RE-FM ferrimagnets: $|J_{dd}| > |J_{fd}| > |J_{ff}|$.
- We apply the molecular field theory approximation for the d-sublattice. The molecular field H_m is suggested to be the same for all particles.
- We use the Gibbs distribution function for evaluation of thermodynamic mean values of magnetizations and the free energy.

We consider the Hamiltonian:

$$\hat{H}(\{\theta_d^{(i)}, \theta_f^{(i)}\}) = \sum_i \left[-J_{fd}\cos(\theta_d^{(i)} - \theta_f^{(i)}) - \mu_0\mu_d(H+H_m)\cos\theta_d^{(i)} - \mu_0\mu_f H\cos\theta_f^{(i)} - K_f^{(i)}\cos^2\theta_f^{(i)}\right],$$

where J_{fd} is an exchange constant between f- and d-sublattice, μ_0 is the magnetic constant, μ_d is a magnetic moment of the d-sublattice of a particle, μ_f is a magnetic moment of the f-sublattice of a particle, *H* is a value of external magnetic field oriented along *Oz* axis, H_m is a molecular field for d-sublattice, $K_f^{(i)}$ is a random magnetic anisotropy constant. The Hamiltonian can be represented as a sum of single-particle terms $H(\{\theta_d^{(i)}, \theta_f^{(i)}\})=\sum_i E_i(\theta_d^{(i)}, \theta_f^{(i)})$.

The molecular field Hm is defined as $H_m=\lambda M_d$, where λ is a molecular field coefficient depending on exchange interaction between TM-ions, M_d is a net magnetization of d-sublattice.

The partition function and the free energy:

$$Z = \frac{1}{2^{2N}}\prod_i \iint \exp\left(-\frac{E_i}{k_B T}\right)\sin\theta_d^{(i)}\sin\theta_f^{(i)}d\theta_d^{(i)}d\theta_f^{(i)} \qquad F = -k_B T\log Z$$

Magnetization of d- and f-sublattices:

$$M_{d,f} = \frac{\mu_{d,f}}{NV_0}\sum_i \frac{\iint \exp\left(-\frac{E_i}{k_B T}\right)\cos\theta_{d,f}^{(i)}\sin\theta_d^{(i)}\sin\theta_f^{(i)}d\theta_d^{(i)}d\theta_f^{(i)}}{\iint \exp\left(-\frac{E_i}{k_B T}\right)\sin\theta_d^{(i)}\sin\theta_f^{(i)}d\theta_d^{(i)}d\theta_f^{(i)}}.$$

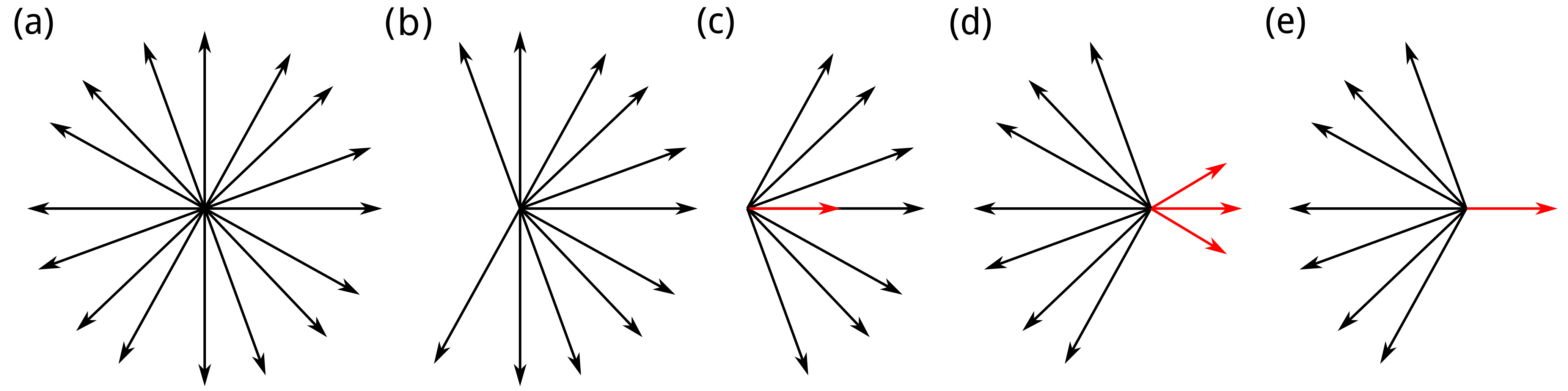

Figure 1 – Possible magnetic structures of magnetic amorphous alloys of RE-TM type: (a) — speromagnetic structure; (b) and (c) — asperomagnetic structure; (d) and (e) — sperimagnetic structure. Black and red arrows in (c), (d) and (e) subfigures represent different sublattices

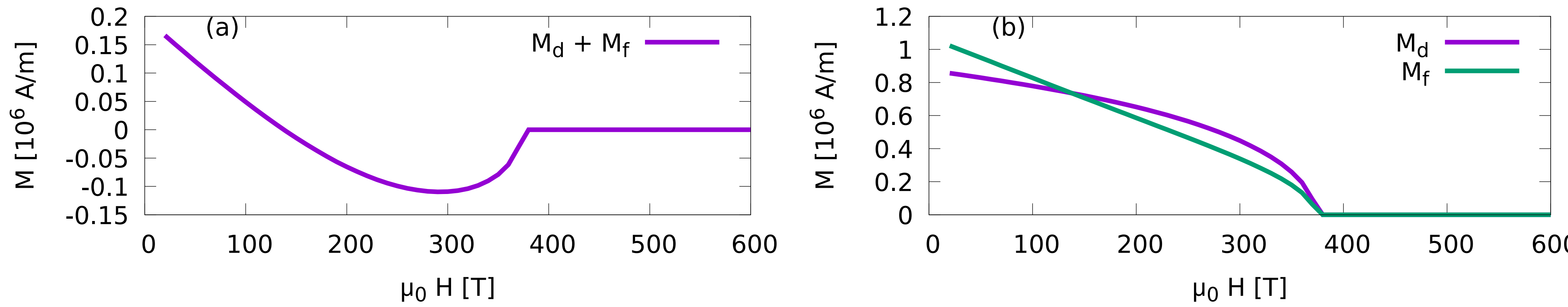

Figure 2 – Temperature dependencies of the net magnetization (a) and d- and f-sublattices magnetizations (b) for *H*=0.

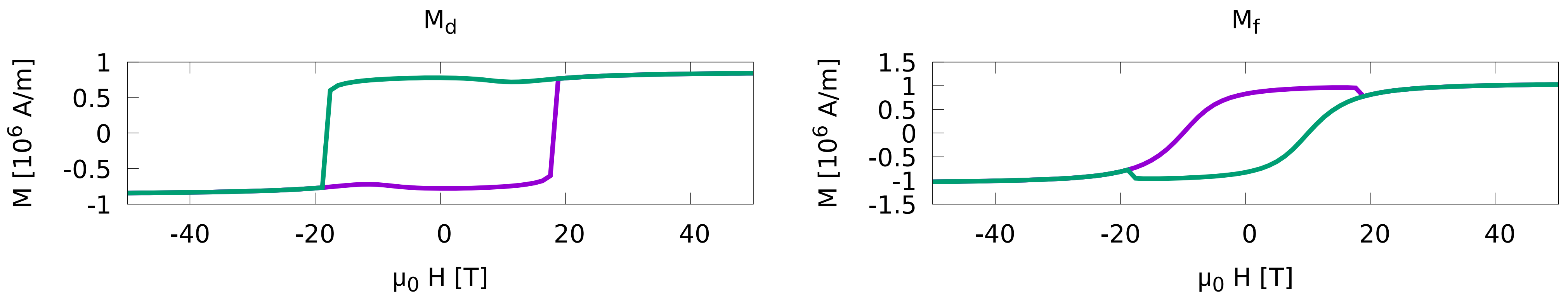

Figure 3 – Hysteresis loops of magnetizations for d- and f-sublattices for *T*=100 K.

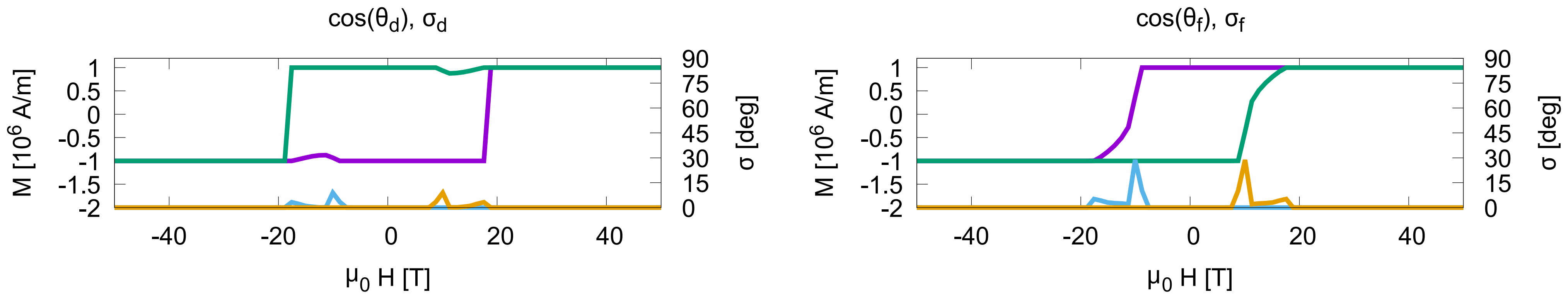

Figure 4 – Hysteresis loops of cosines (left axis scales) for mean θ_d and θ_f angles, which correspond to a minimal energy for the Hamiltonian, and standard deviation from the mean angles (right axis scale and bottom curves) σ_d and σ_f, which non-zero values point to appearance of stochastic sperimagnetic structure.

Conclusion. Taking the approach of stochastic anisotropy model [3] we revealed the presence of sperimagnetic structures in magnetic field regions where the canted phase takes place ($|\theta_d - \theta_f| < \pi$), which shifts critical field values and widens the canted phase field regions.

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