Micromagnetic study of response of arrays of superparamagnetic nanoparticles to high-frequency field at finite temperatures

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The magnetic response of composites of magnetic nanoparticles (MNPs) embedded in dielectric matrices to high-frequency (0.1÷1.0 GHz) field is investigated with regard to their application as core materials for microconverters of power. The advantage of the nanocomposite core is reduced conductivity, thus, the suppression of the eddy-current loss. However, the idea has been developed for superferromagnetic materials [1], hopes for ultimate reduction of loos at high frequencies are accompanied by superparamagnetic cores which are composites of highly-separated MNPs, in spite of their relatively low permeability [2]. Both thermal fluctuations and magnetostatic interactions play crucial role in dynamics of superparamagnets and they have to be included into any realistic model. For small MNPs, magnetization fluctuations are huge at room temperature and driving regular oscillations of the magnetization require use of strong alternating field, beyond applicability of linear response description, which motivates numerical approach. Additionally, macrospin approximation for MNPs can be questionable at high frequencies and our micromagnetic simulations include intra-particle dynamics. Applying periodic boundary conditions, we test 3D arrays of high-magnetization MNPs of single magnetic anisotropy axis ($Fe_{65}Co_{35}$) and of cubic anisotropy (Fe), as well as MNPs of lower magnetization (Fe_3O_4) in terms of the amplitude of the magnetic response function, susceptibility and, plotting dynamical magnetization-field curves, we conclude about hysteresis and residual losses. Influence of the interparticle distance on the strength of magnetic response is discussed. Interplay between strong crystalline anisotropy (a high blocking temperature) and dipole-dipole interactions of MNPs is especially intense for arrays of Magnetite nanoparticles, making the dynamical magnetic response of the nanocomposite at room temperature very sensitive to the particle diameter.

References:

[1] K. Brzuszek and A. Janutka, J. Magn. Magn. Mat. 543, 168608 (2022)
[2] M. Kin, H. Kura and T. Ogawa, AIP Advances 6, 125013 (2016)