Magnetic Properties over Several Length Scales:
Micro-magnetic Modeling and Effective Medium Theory

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We combine micro-magnetic modeling with effective medium theory to predict the bulk properties of magnetic composites, in particular those of ferrite particles in a non-magnetic matrix. We verify our model using published measured data[1] of ferrite-composite materials.

The micro-magnetic calculations use a public domain (ITL/NIST) model, the Object Oriented MicroMagnetic Framework (OOMMF)[2]. This provides a framework for solving the Landau-Lifshitz-Gilbert equation, while determining the effective field by minimizing the micro-magnetic energy. We use the micro-magnetic model to predict detailed domain structures for various materials (nano and micron scale) and fields. The different features of the domain structures lead to a complicated dynamic susceptibility. We investigate the influence of size, shape, magnetic history, and intrinsic properties on the dynamic susceptibility (for example, the effect of changing the anisotropy constant, Ku, is shown in Figs. 3 and 4.). We expand and compare this to past efforts[3], which focus on striped systems.

In this research, the single particle magnetic susceptibility is used in a Bruggeman effective medium equation to predict bulk permeability. We assume a system of ellipsoidal ferromagnetic inclusions, randomly distributed in a magnetically neutral host material. The average permeability of the inclusions is determined from the previously described microscale models or by measured data; and includes the effects of disorder in the orientation of the anisotropic inclusions. The macroscopic effective medium permeability is studied as a function of inclusion volume fraction and is compared to experiment for verification. Our calculation predicts a shift in the resonance frequency of a saturated body as a function of inclusion fill fraction, in agreement with experiment and without requiring a magnetic field reciprocity factor[4].

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[2] M.J. Donahue and D.G. Porter, "OOMMF User's Guide, Version 1.0", Interagency Report NISTIR 6376.
[3] O. Gérardin et al., J. Appl. Phys. **89**, 7012 (2001); O. Gérardin et al., J. Appl. Phys. **88**, 5899 (2000); Vukadinovic et al., Phys. Rev. Lett **85**, 2817 (2000).
[4] J. L. Mattei et al., J. Appl. Phys. **87**, 4975 (2000).

Topic area: Multiscale Modeling of Materials

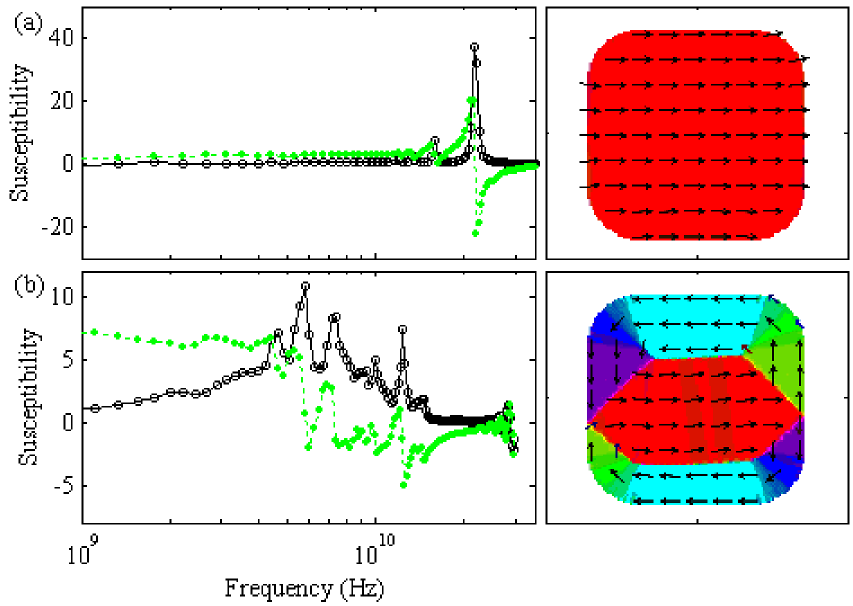

Figure 1. Susceptibility (real: green closed circles; imaginary: black open circles) of a 10x10 micron ferrite inclusion with (a) a dc field and a time dependent field perpendicular to one another within the plane of the particle and (b) no applied dc field and a time dependent field perpendicular to the direction of the largest domain.

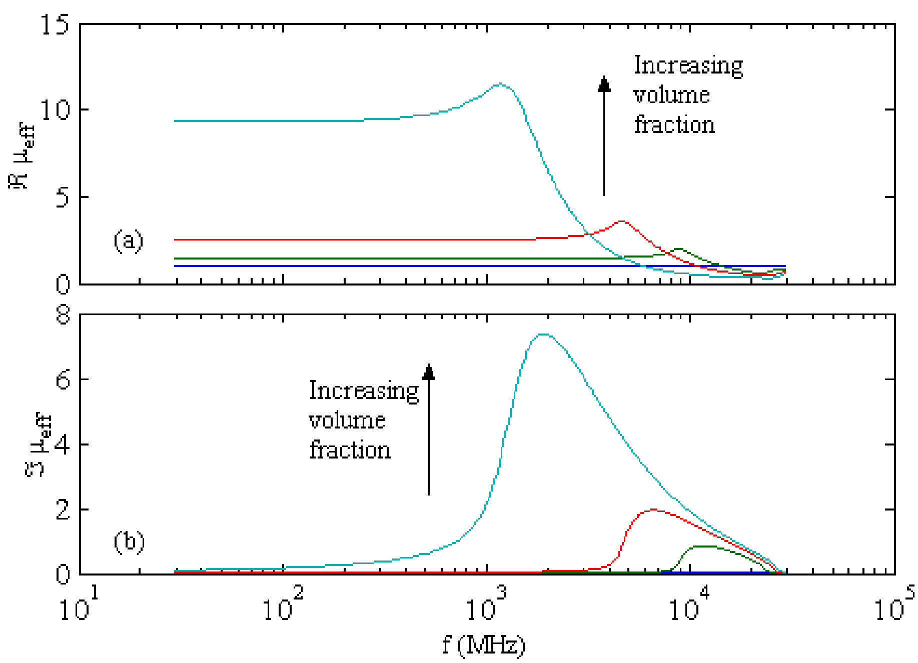

Figure 2. Effective permeability as a function of frequency for various inclusion volume fractions.

Figure 3 The domain structure of a 20 µm x 10 µm x 2 µm flake as a function of anisotropy constant. As the

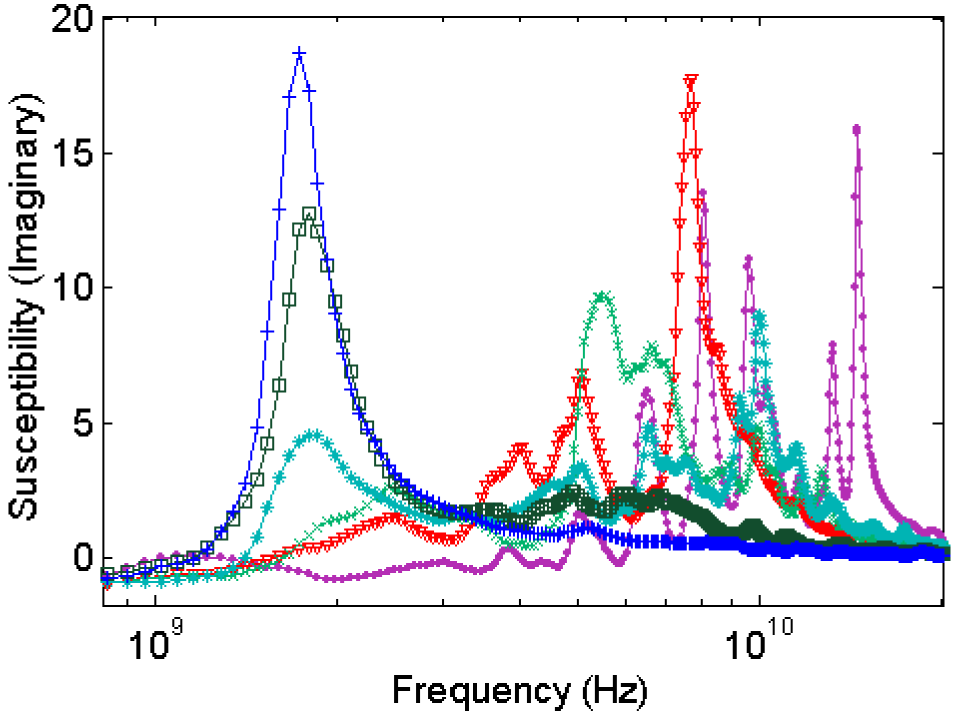

Figure 4 The imaginary susceptibility of a 20 μm x 10 μm x 2 μm flake as a function of anisotropy constant, K_u. The resonant peak decreases in frequency when K_u becomes large. Key: •: K_u = 148 J/m^3; ∇: K_u = 400 J/m^3; x: K_u = 800 J/m^3; *: K_u = 1600 J/m^3; : K_u = 3200 J/m^3; +: K_u = 6400 J/m^3.

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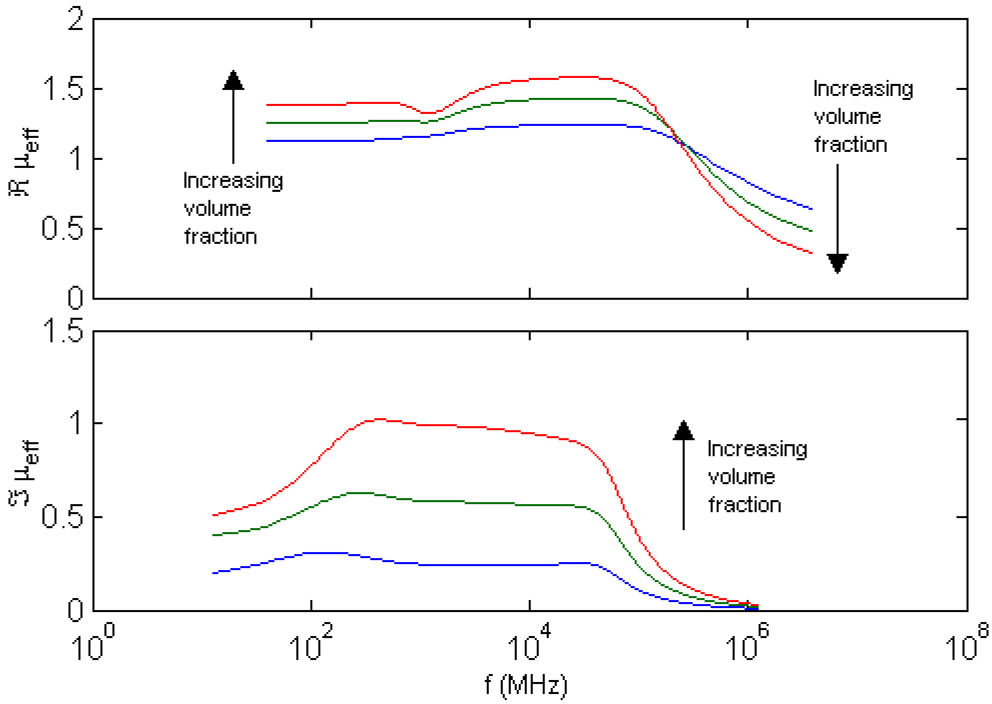

Figure 5 Effective permeability as a function of frequency for a distribution of ferrite flakes of random shapes and orientations in a magnetically neutral medium. The volume fraction refers to the total volume of ferrite flakes; data for volume fractions of 10%, 20%, and 30% are shown in the figure.

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