Sandia National Laboratories

The Role of Particle Size and Volume Fraction in UHF Ferrite Absorbers

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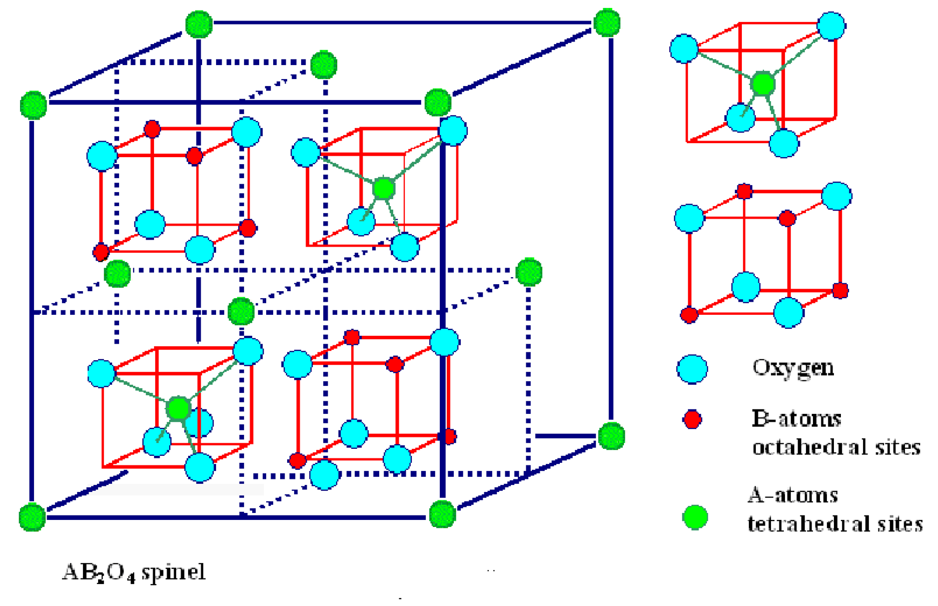
Introduction

As 5 G becomes ubiquitous, the need for thin, lightweight UHF absorbers for EMI mitigations increases. The impact of particles size and volume fraction on complex permittivity, permeability, and EM absorption was investigated in magnetite, NiZn ferrite, and MnZn ferrite in the UHF regime towards optimization of a lossy spinel ferrite loading in hybrid UHF EM absorbers.

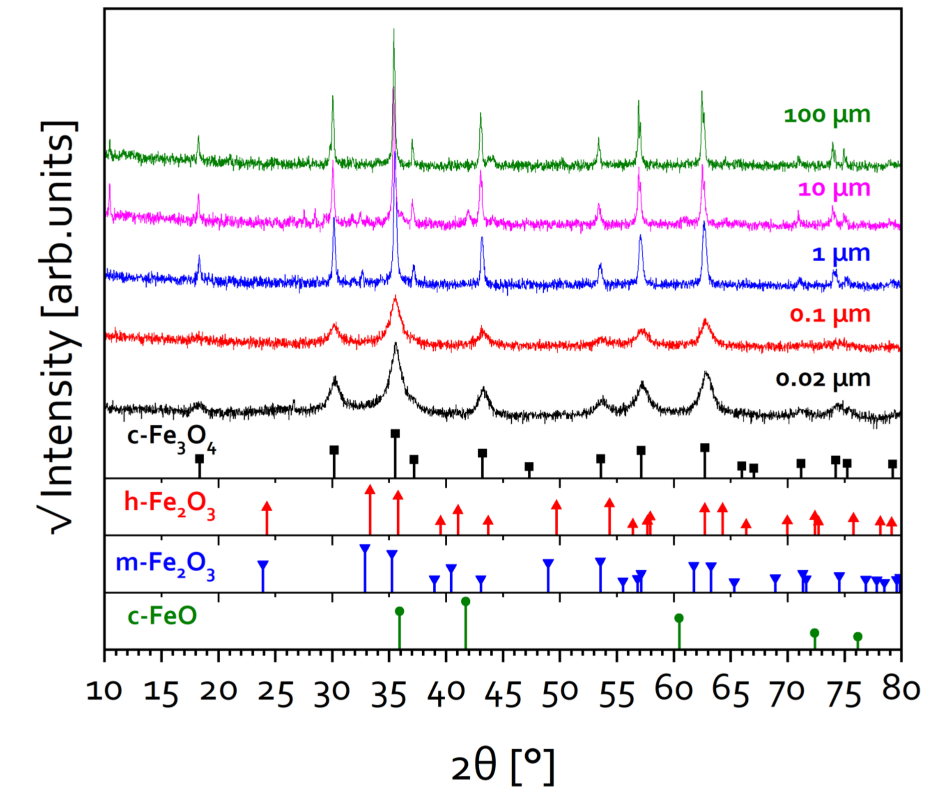
Spinel Structure: Cation location and d-orbital splitting

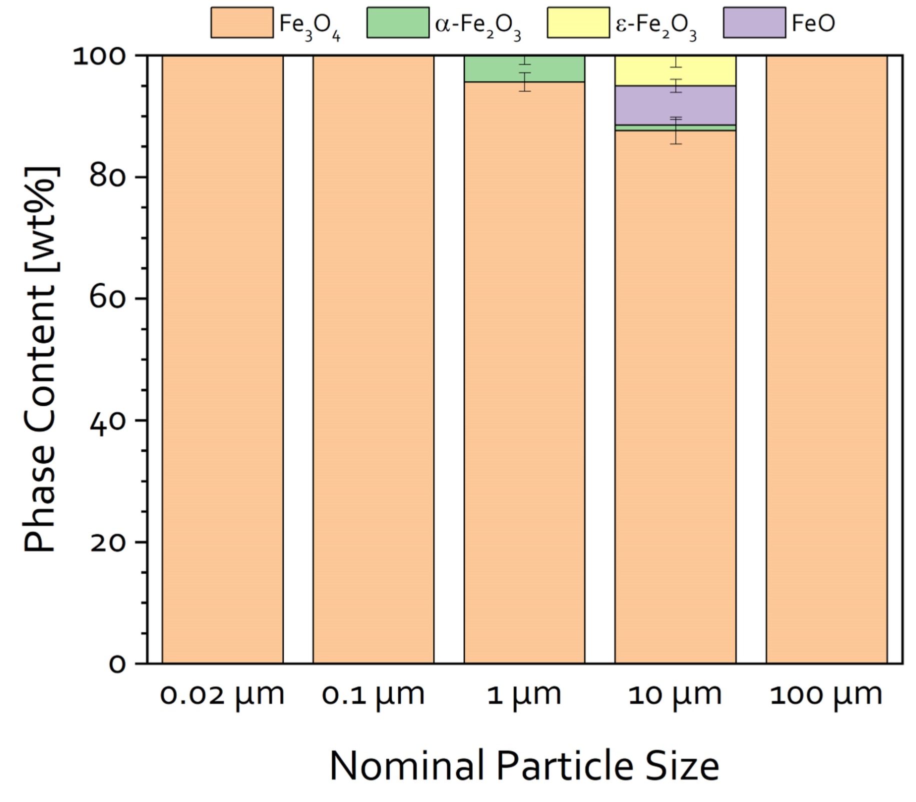


https://www.tf.uni-kiel.de/matwis/amat/def_en/kap_2/basics/b2_1_6.html

Ferrites are useful absorbers as they are insulating and both magnetically and dielectrically lossy. Transition metal cations occupy octahedral and tetrahedral sites within the lattice. The crystal electric field splits the d orbitals; e_g orbitals are higher in energy at octahedral sites, and t_{2g} orbitals are higher in energy at tetrahedral sites.

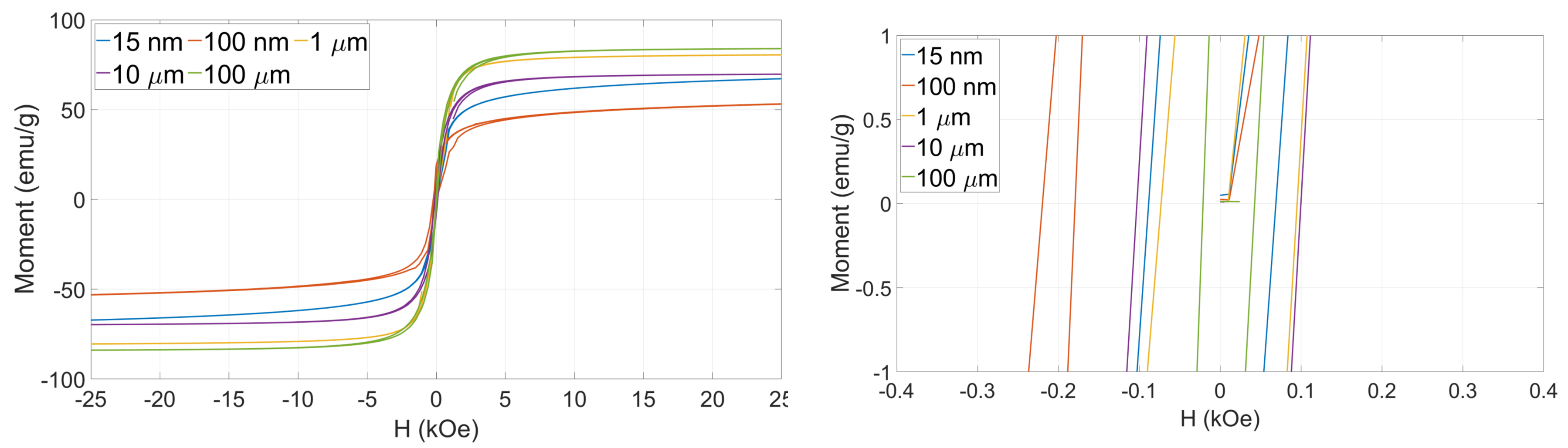
Assessing Phase Purity: x-ray diffraction



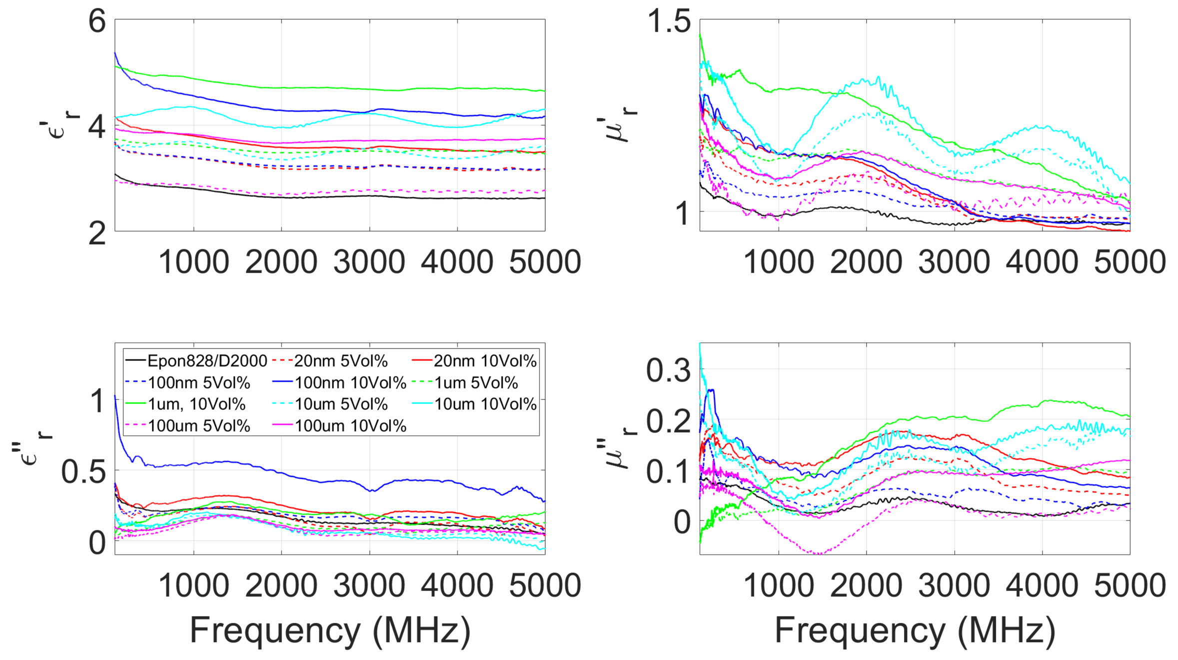


Results

Magnetite powder saturation magnetization and coercivity



Magnetite, $Ni_{0.5}Zn_{0.5}$, and $Mn_{0.7}Zn_{0.3}$ Ferrite: μ_r and ϵ_r



Snoek's Law

$$f = \frac{\gamma M_s}{3\pi\chi}$$

$$\mu = \frac{\mu_i D}{\mu_i \delta + D} \quad [1]$$

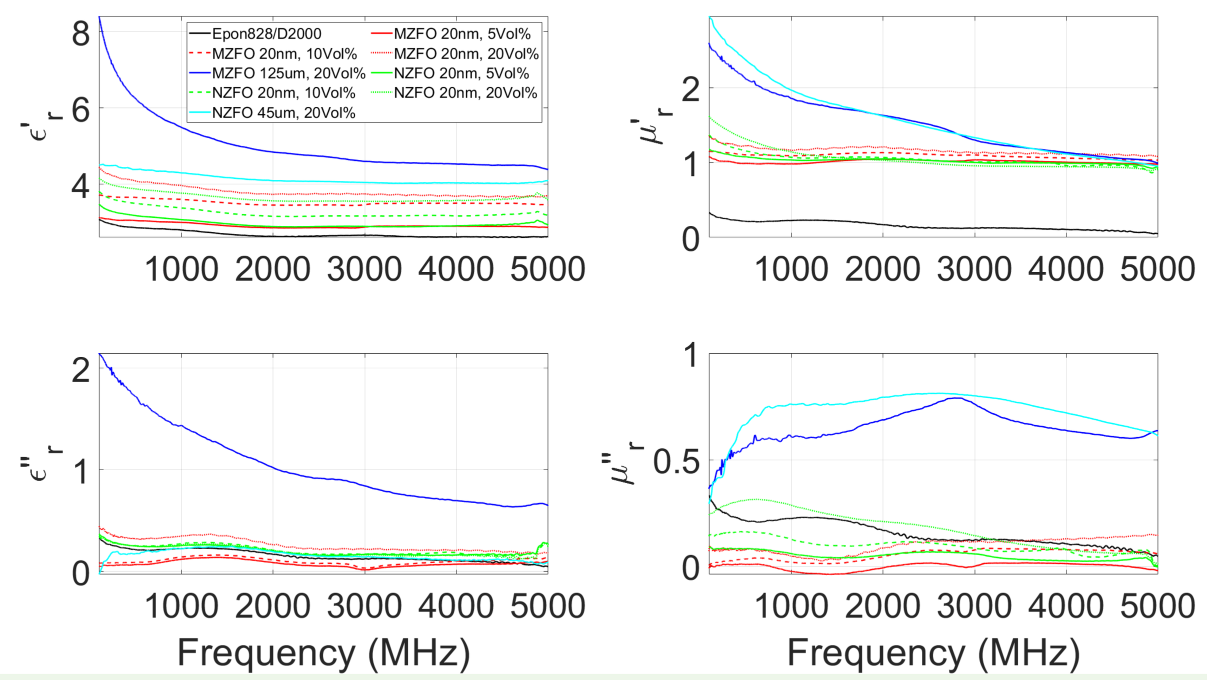
Magnetic permeability increases with grain size while resonance, f, decreases. μ_i is the complex permeability of a single crystal, and δ is the grain boundary thickness.

Volume Fraction

$$V_F = \frac{D^3}{(D+\delta)^3} \quad [2]$$

$$\mu = \frac{\mu_i}{\mu_i\left(V_F^{-\frac{1}{3}} - 1\right) + 1}$$

Complex permeability increases with increasing volume fraction for a given frequency, independent of particle size.



[1] Johnson, M. T., and E. G. Visser. "A coherent model for the complex permeability in polycrystalline ferrites." *IEEE transactions on magnetics* 26.5 (1990): 1987-1989.
[2] Han, Ki Chul, et al. "Dispersion characteristics of the complex permeability-permittivity of Ni-Zn ferrite-epoxy composites." Journal of materials science 30 (1995): 3567-3570.

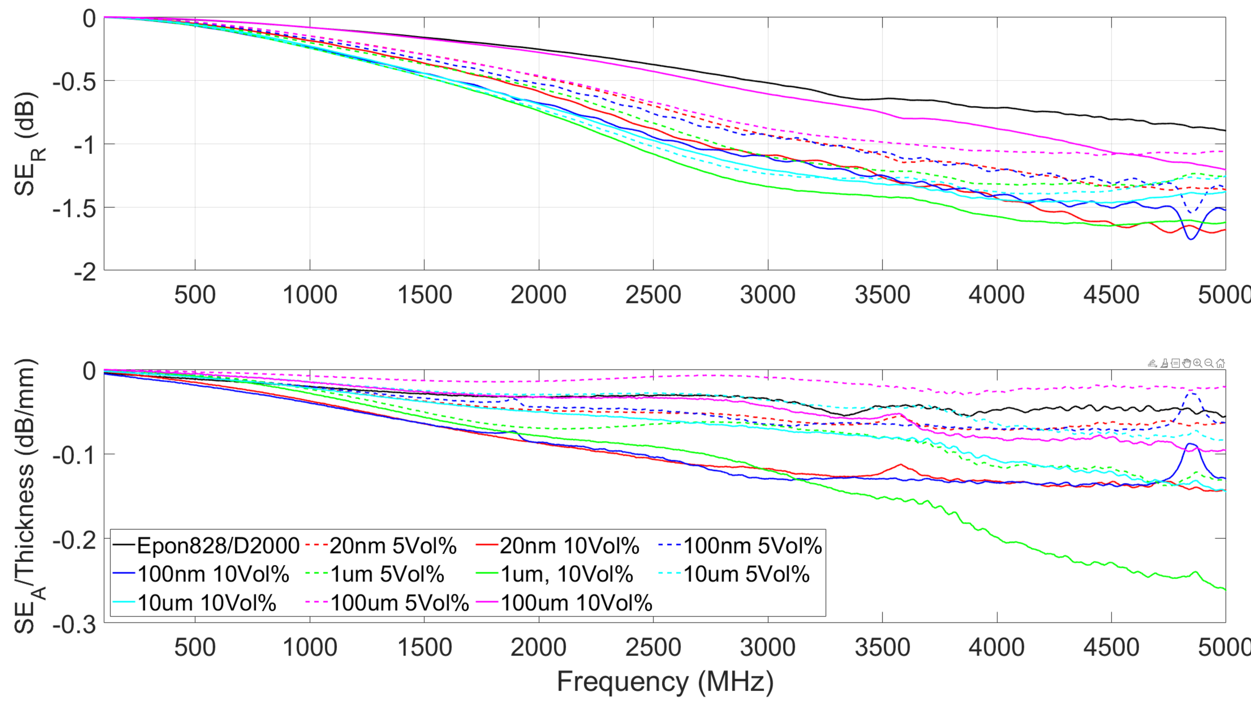
Magnetite, $Ni_{0.5}Zn_{0.5}$, and $Mn_{0.7}Zn_{0.3}$ Ferrite: Shielding Effectiveness

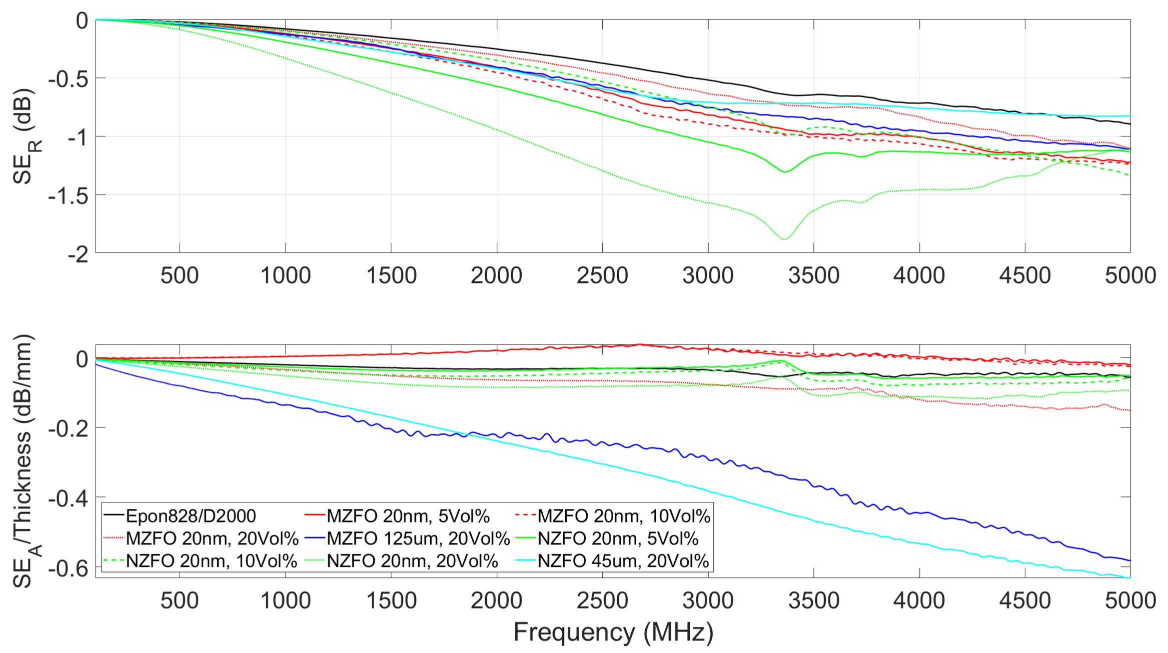
Impedance Mismatch

Reflection is minimized when impedance mismatch is minimized:

$$Z = \sqrt{\frac{|\mu_r|}{|\epsilon_r|}} Z_0$$

$$\Gamma = \left|\frac{Z - Z_0}{Z + Z_0}\right|$$





Matching Thickness

For a given impedance, reflection is minimized when:

$$t_m = \frac{nc}{4f\sqrt{|\mu_r||\epsilon_r|}}$$

n = odd integer (short)
- i.e. metallic backing

n = even integer (open)
- i.e. waveguide

Conclusion

In ferrites generally, real and imaginary permittivity decreases with increasing particle size. That trend maybe absent due to difference in annealing time, where increased annealing time decreases point defects and increased grain size. Conversely, permeability increases with increasing particle size outside the superparamagnetic regime; this is evident in our results. Consequently, we conclude that a combined microparticle loading of NZFO and MZFO, with their relative volume fractions determined by impedance matching, will yield the greatest absorption in the UHF regime.

Acknowledgements

I would like to thank Logan Robinett, Tim Donnelly, Dale Huber, and Ray Martinez for assisting in the measurements for this work.