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The Role of Particle Size and Volume Fraction in Fe_3O_4 Ferrite Microwave Absorbers

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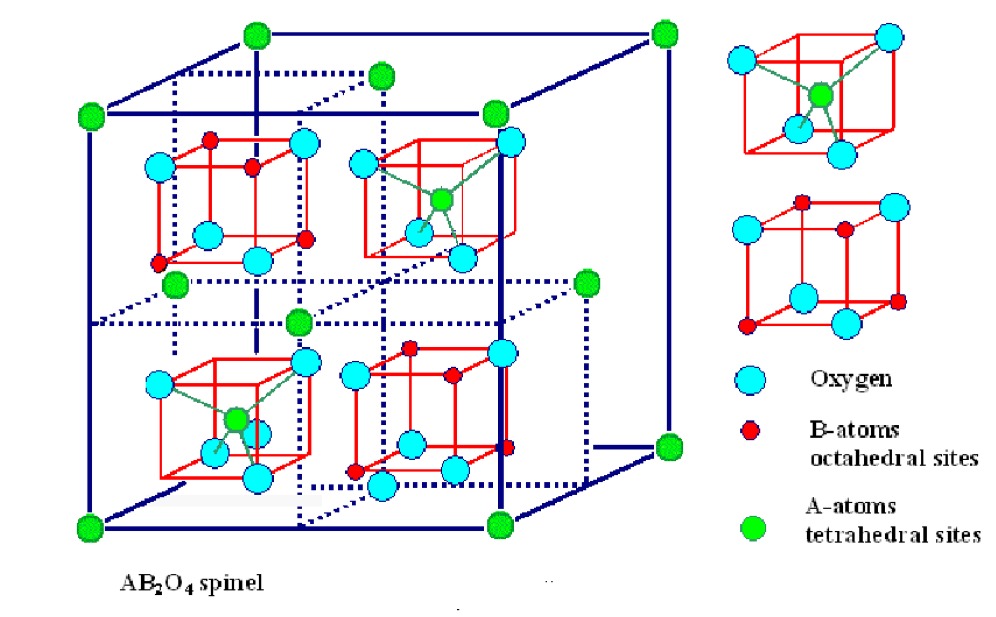
Introduction

The impact of particles size and volume fraction on complex permittivity, permeability, and EM absorption was investigated in magnetite towards optimization of lossy spinel ferrite (e.g., MnZn, NiZn, etc.) loading in hybrid EM absorbers.

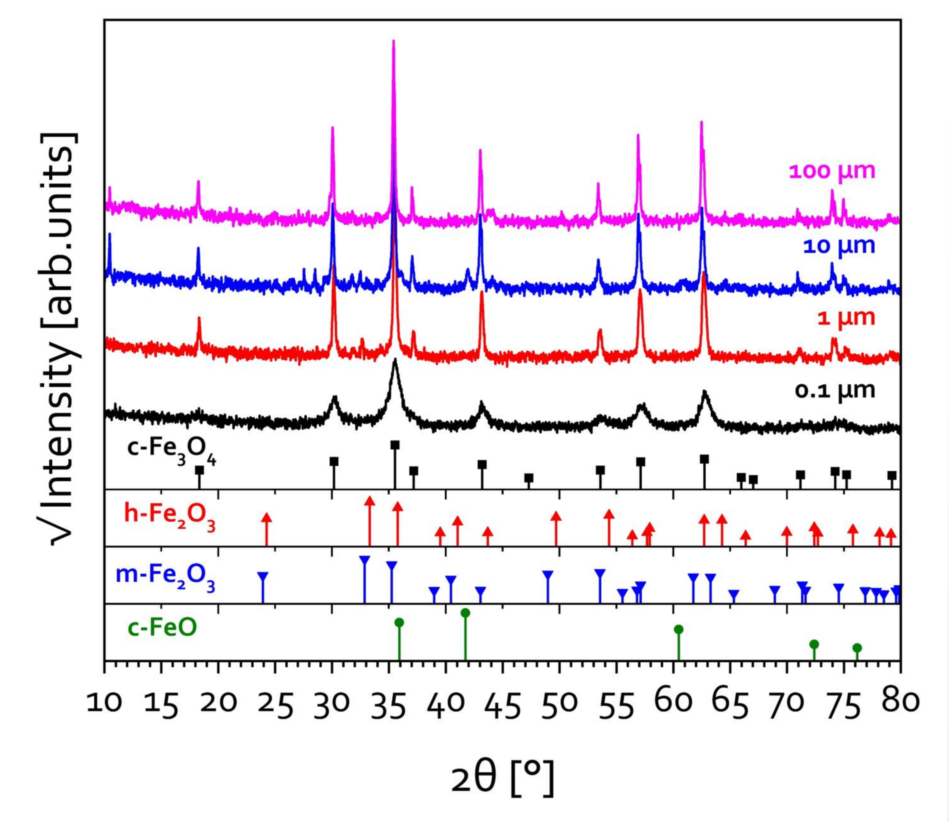
Spinel Structure: Cation location and d-orbital splitting

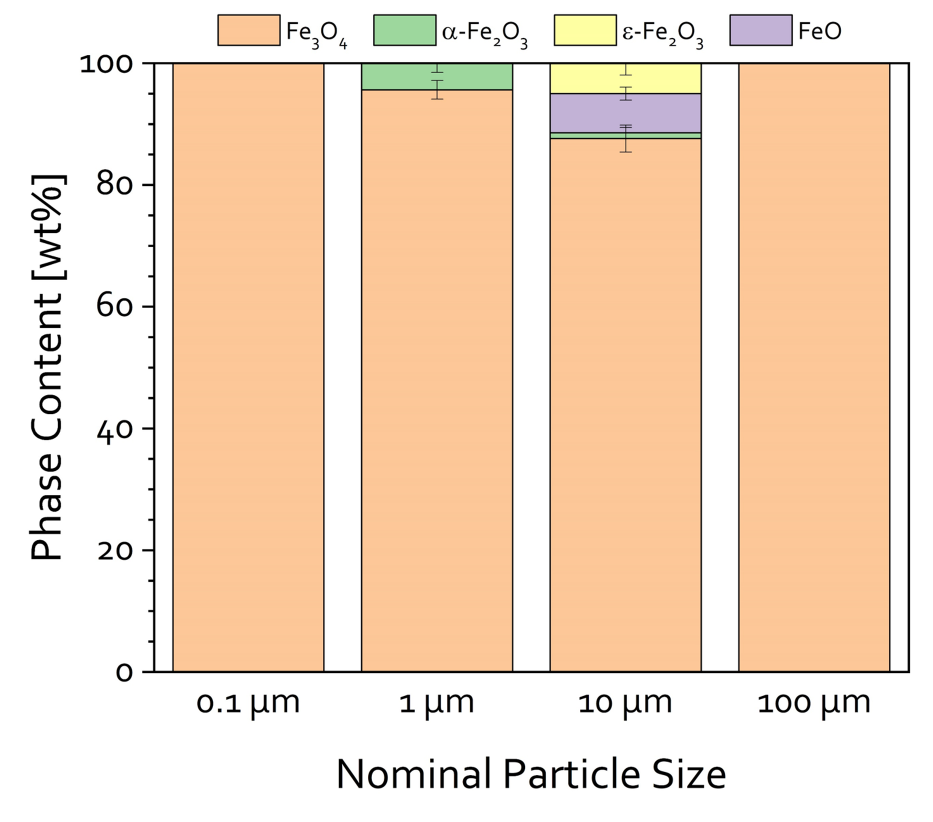


https://www.tf.uni-kiel.de/matwis/amat/def_en/kap_2/basics/b2_1_6.html

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



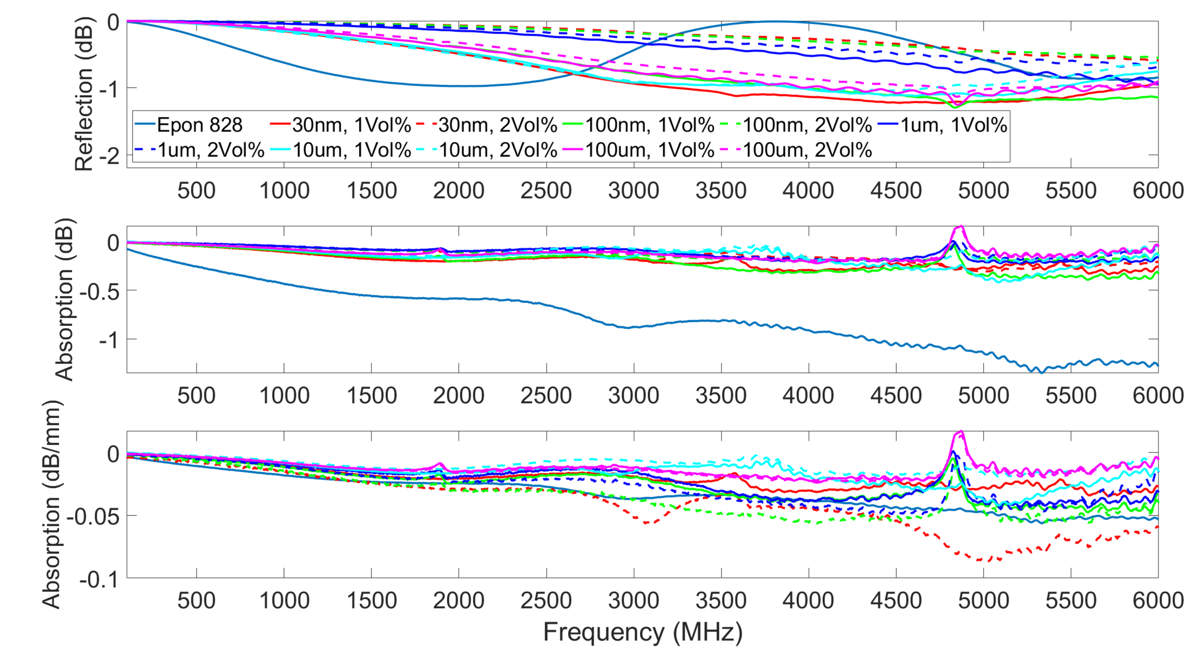


Results

Complex Permittivity, Permeability, and Shielding Effectiveness

Particle Size (µm)	Volume Fraction (%)	Sample Length (mm)	Particle Size (µm)	Volume Fraction (%)	Sample Length (mm)
0.03	1	9.64	1	5	9.31
0.03	2	3.53	1	10	7.22
0.03	5	8.38	10	1	9.94
0.03	10	8.31	10	2	11.2
0.1	1	8.24	10	5	9.39
0.1	2	3.64	10	10	8.71
0.1	5	8.95	100	1	9.32
0.1	10	8.94	100	2	8.86
1	1	5.17	100	5	10.31
1	2	4.14	100	10	5.08

*Epon 828 / D2000 sample length = 24.0 mm



Shielding Effectiveness

$$R = |s_{11}|^2$$
$$T = |s_{21}|^2$$

$$SE_A = 20log_{10}\left(\frac{T}{1-R}\right)$$
$$SE_R = 20log_{10}(1-R)$$

Matching Thickness

Reflection is minimized when:

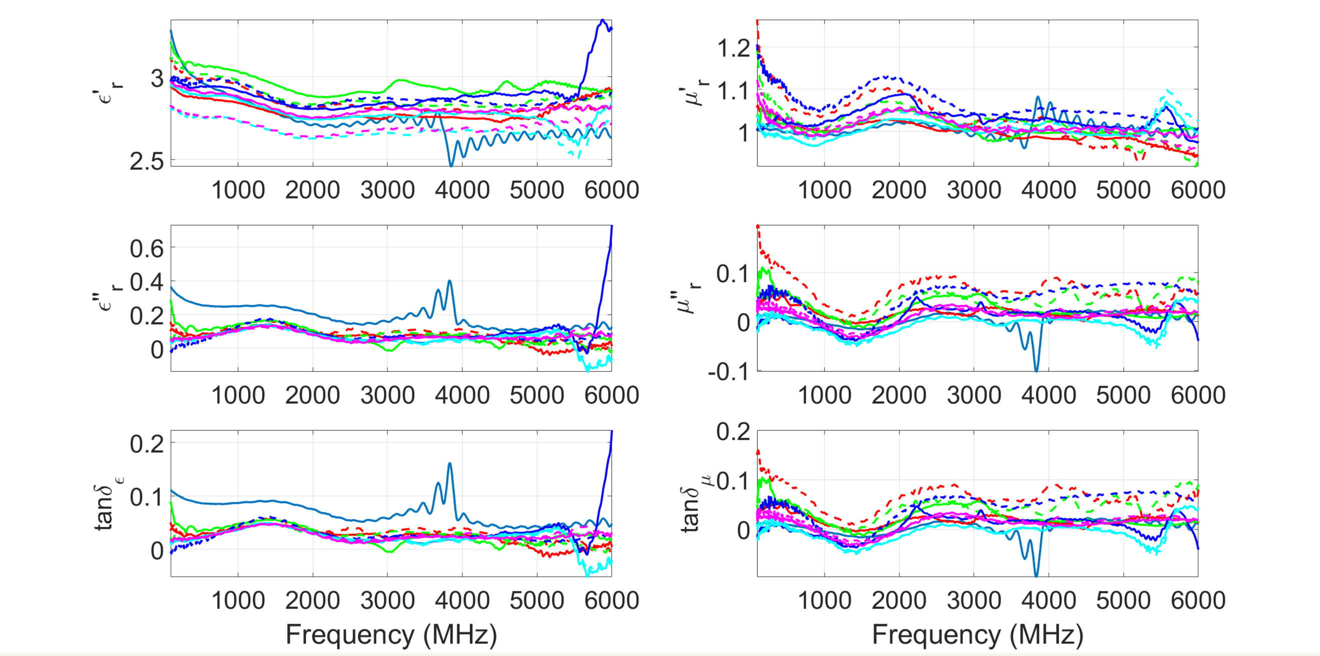
$$t_m = \frac{nc}{4f\sqrt{|\mu_r||\epsilon_r|}}$$

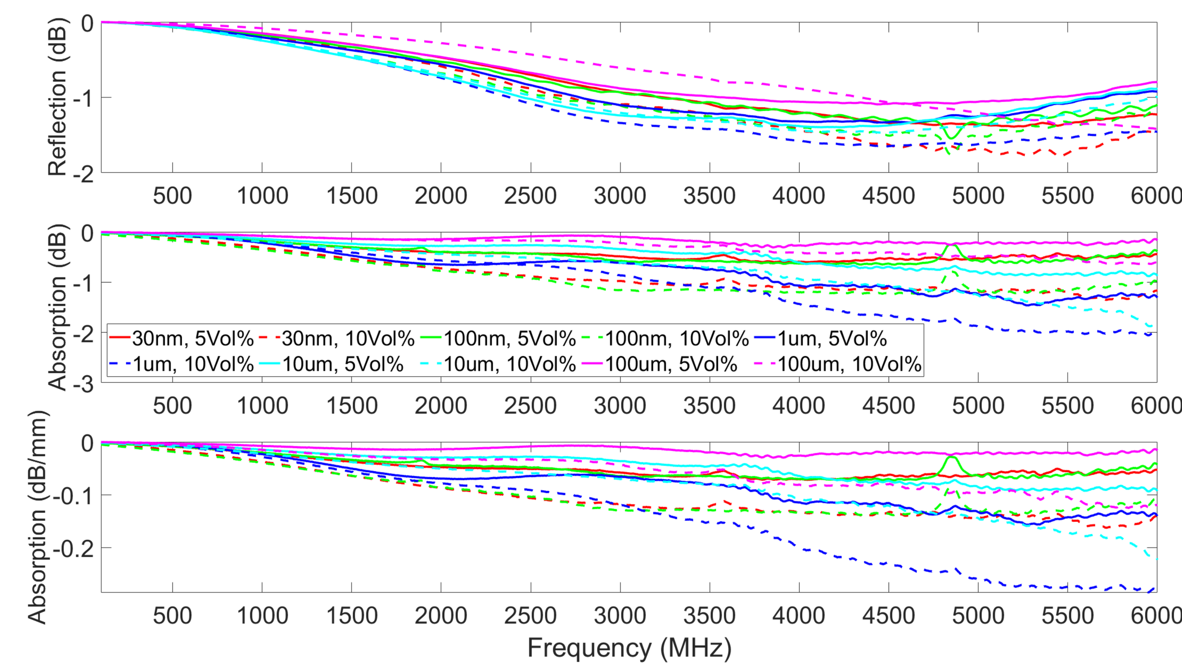
n = odd integer (short)

- i.e. metallic backing

n = even integer (open)

- i.e. waveguide





Landau & Lifshits

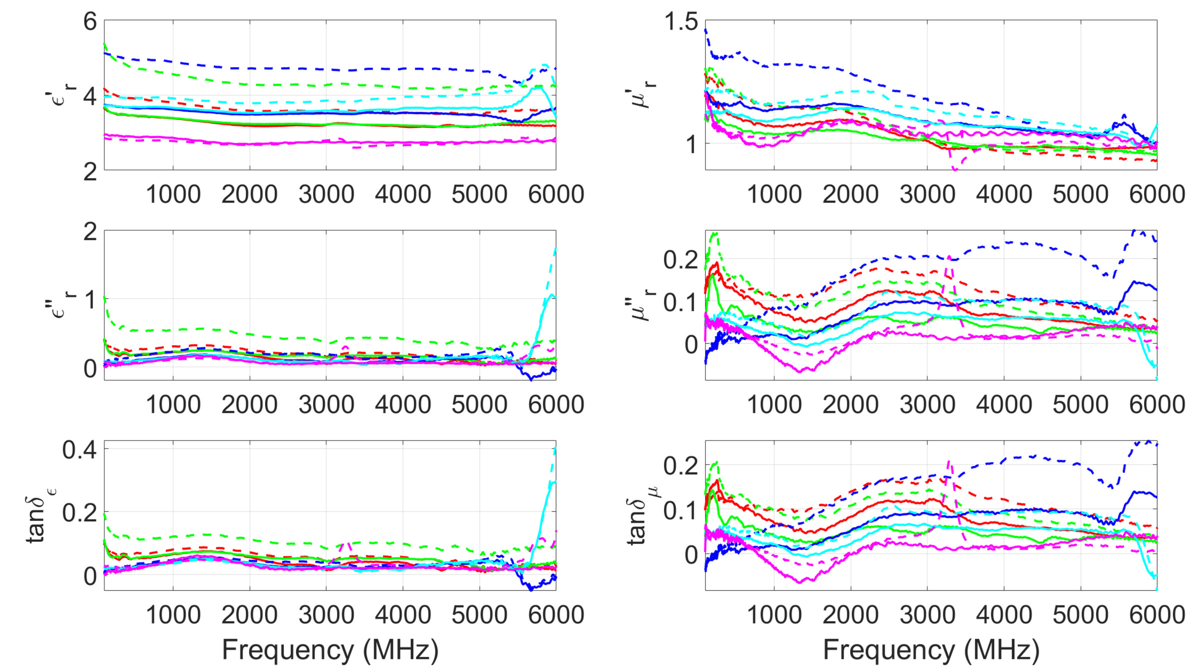
$$\chi \propto \frac{s^2}{\omega d}\sqrt{\frac{\alpha}{\beta}}$$

Domain size, d, decreases with decreasing crystal size. Magnetic permeability, $\mu = \chi + 1$, decreases with frequency, ω, and increases as the crystal becomes smaller.

Snoek's Law

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

The frequency, f, at which Bloch wall losses are greatest is directly proportional to the saturation magnetization, M_s, and inversely proportional to the magnetic susceptibility, χ.



Conclusion

Our results are consistent with the permittivity and permeability values reported by Chigna *et al.* (2020). The trend for increasing real permeability with decreasing particle size was observed, with the notable exception of the 10 µm samples, which may be due to less agglomeration in these samples. The broad peaks in the imaginary permeability are consistent with Kolev *et al.* (2006), although the increased frequency shift with decreasing particle size was not observed, again likely due to agglomeration in the samples with 30 and 100 nm particles.

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