Characterization of Size-Separated Gd_5Si_4 Micro- and Nano- Particles for Self-Regulated Magnetic Hyperthermia

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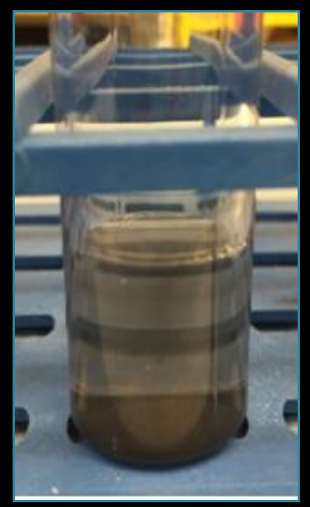
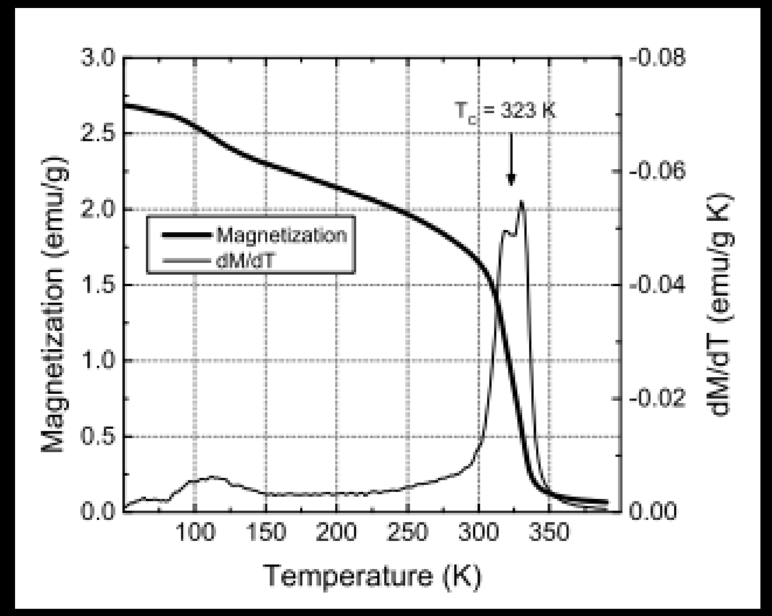
Summary: Gd_5Si_4 is a promising candidate for magnetic hyperthermia because its critical temperature is near the therapeutic range (a magnetic phase transition ~320 – 340K that could be beneficial for preventing overheating) and is tunable (preparation conditions such as milling time and particle size controllable), opening the door for self-regulated hyperthermia while being potentially biocompatible material. We explore size-selected particles to understand differences between larger and smaller nanoparticles to optimize the specific loss power SLP and magnetic transition temperature (Curie temperature) TC[1]

Polydisperse samples:

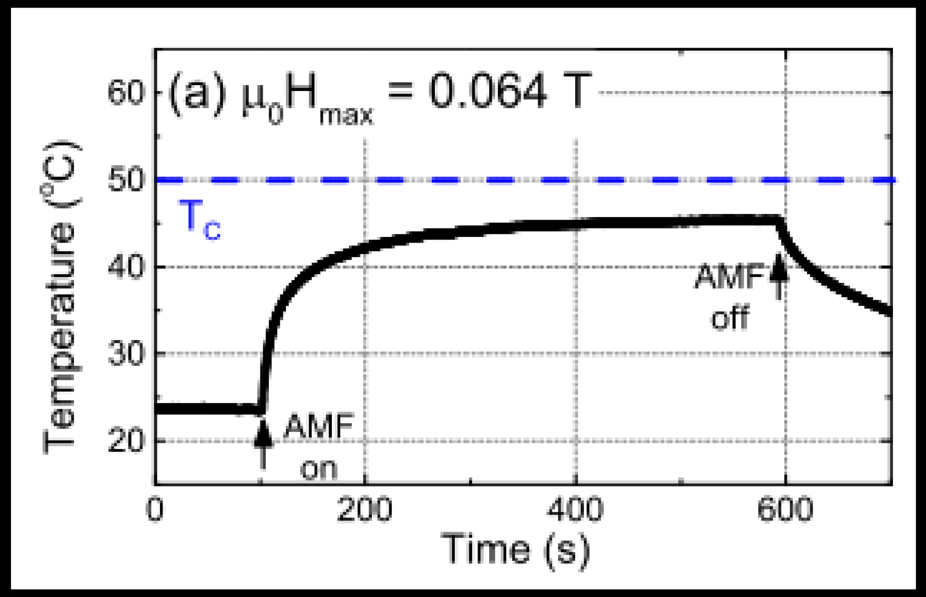
Particles synthesized by ball-milling of bulk Gd_5Si_4 ingot; details are described elsewhere [1]. Data for this section from collective sample of particles ranging in size from µm-nm.

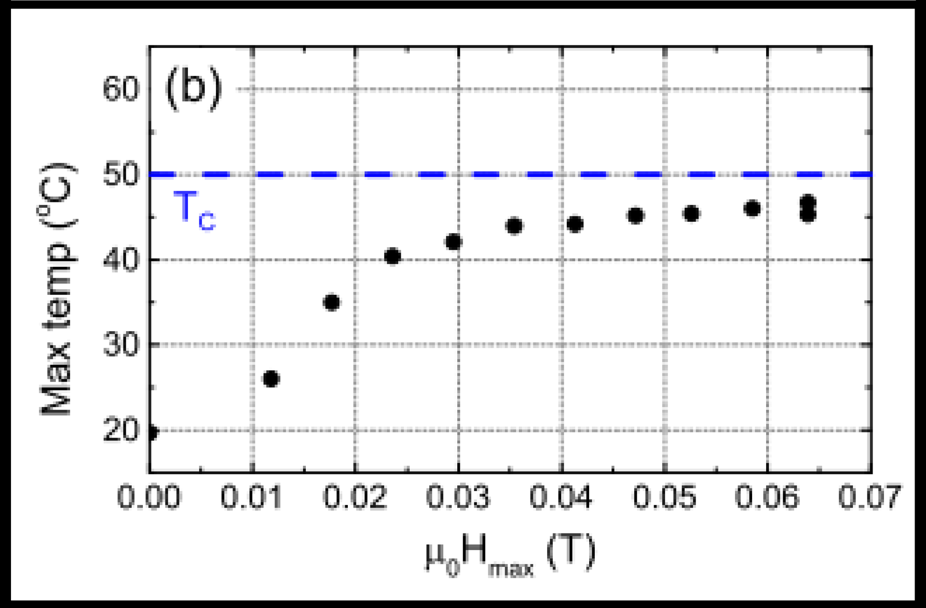


10 nm Gd_5Si_4 Micro and Nano-particles in H_2O, from Virginia Commonwealth University.



Magnetization *(M)* (thick line) and *dM/dt* (thin line) as a function of temperature *(T)* at a magnetic field of 0.01 T[1]

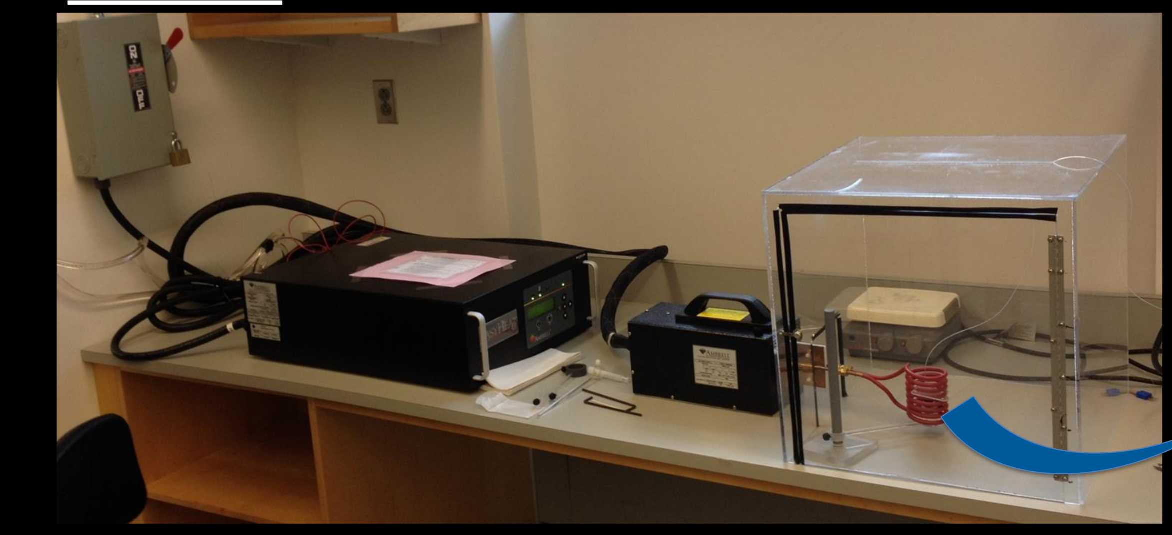




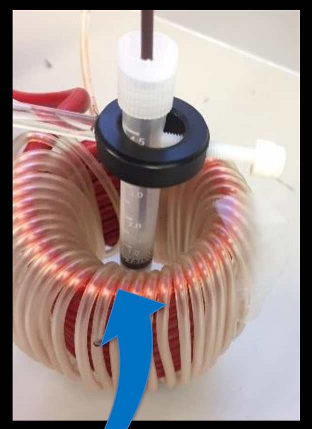
(a)Heating curve for 0.0326 g of particles with PEG in 250 µL of H2O in a container with a conical bottom, in an applied AMF with peak field amplitude of 0.064 T and frequency of 213 kHz[1]

(b) Maximum temperature reached for this sample as a function of applied field amplitude, showing that the maximum temperature reached is 47 ◦C, close to the Curie temperature of the sample[1]

Method



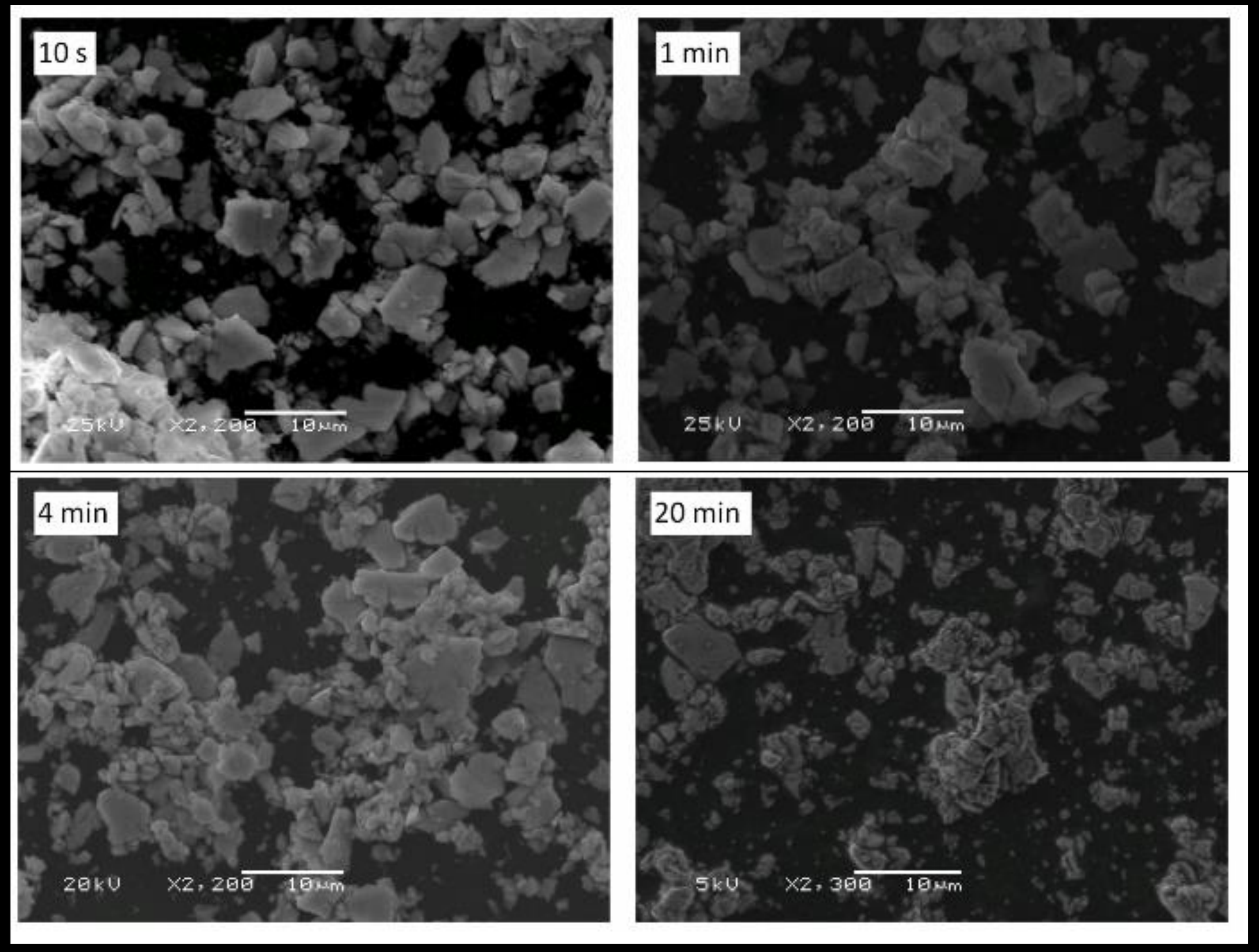
AMF generator (EasyHeat) setup with test magnetic field coil



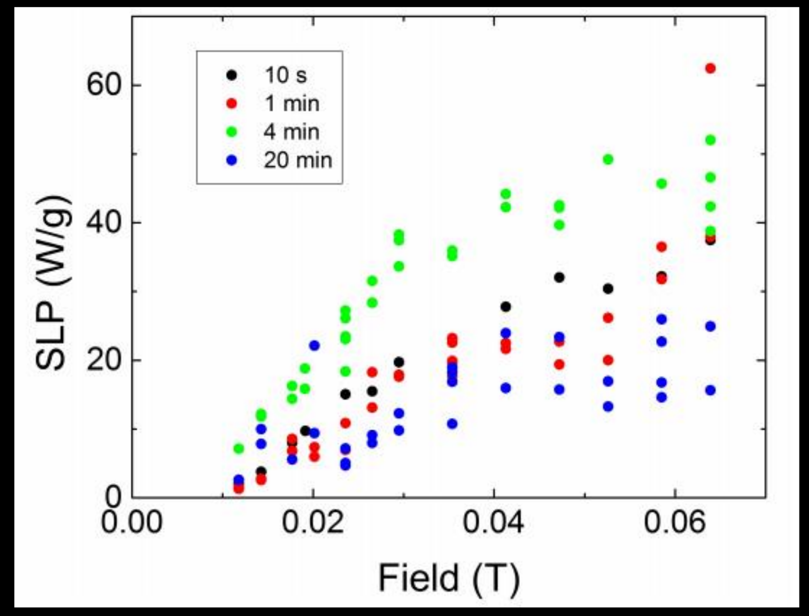
Use of fiber optic temperature sensor to measure Gd5Si4 particles sample subjected to AMF

Size-separated samples:

After ball-milling, the particles were suspended in ethanol and were separated by their sedimentation time, longer sedimentation time leading to smaller average size.



SEM images of four size-separated samples[2]



Specific loss power (SLP) of the four size-separated samples

Samples with the largest particle sizes (10 s and 1 min) have similar SLP while the sample with the smallest particle size (20 min) has slightly lower SLP. The 4 min sample has the highest SLP, indicating that the particles in this sample may be near optimal size or microstructure for hyperthermia[2]

Conclusion

The differing SLPs are most likely related to the process and duration of ball-milling, and not the particle size. Likely because separation times are on similar order of magnitude. The 4 min sample microstructure has highest SLP, suggesting optimal for magnetic hyperthermia.

Future Work

We plan to add functionality for dynamic hysteresis loop measurements to the apparatus, requiring additional detection coils which must be carefully placed and calibrated. Also allowing us to correlate heating results with the underlying magnetization of the particles by comparing magnetic and calorimetric SLP.

Magnetic determination of SAR (SLP) the equations power volume density P_{vd} and *SAR* are obtained from:

$$P_{vd} = f \cdot \oint_T \mathbf{M_t} \cdot \mathbf{dH_t}$$

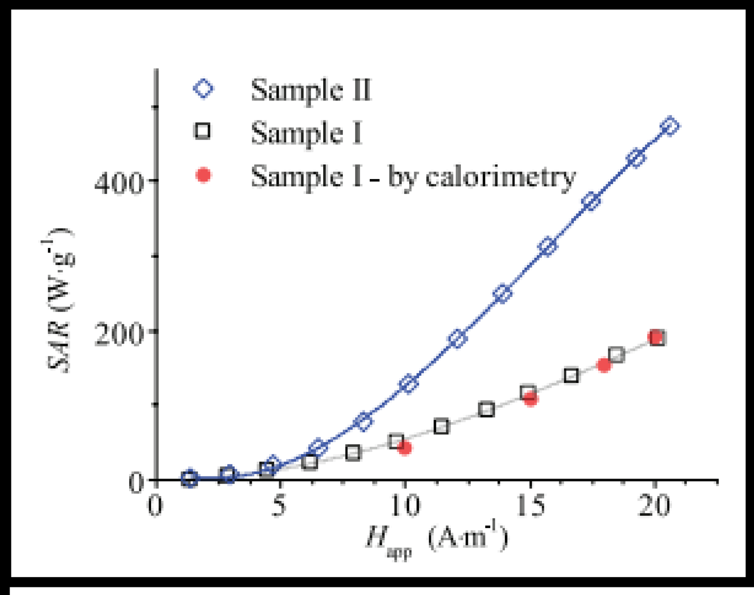
$$SAR = \frac{f}{c} \cdot \oint_T \mathbf{M_t} \cdot \mathbf{dH_t}$$

Where $\mathbf{M_t}$ is instantaneous magnetization at time t, $\mathbf{H_t}$ is field intensity at time t, *f* the frequency, *T* the period and c is the nanoparticle weight concentration in the dispersing medium of volume V_d.[3]

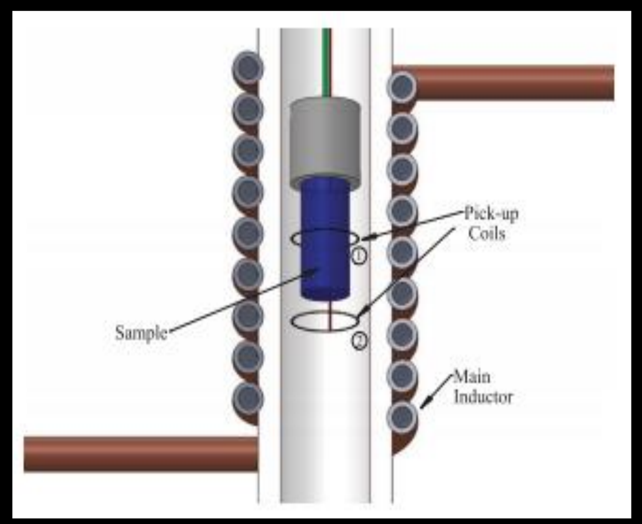
Motivation

Magnetic measurements will help both confirm and explain the results we have found calorimetrically, and offer info about magnetic behavior of the system[4].

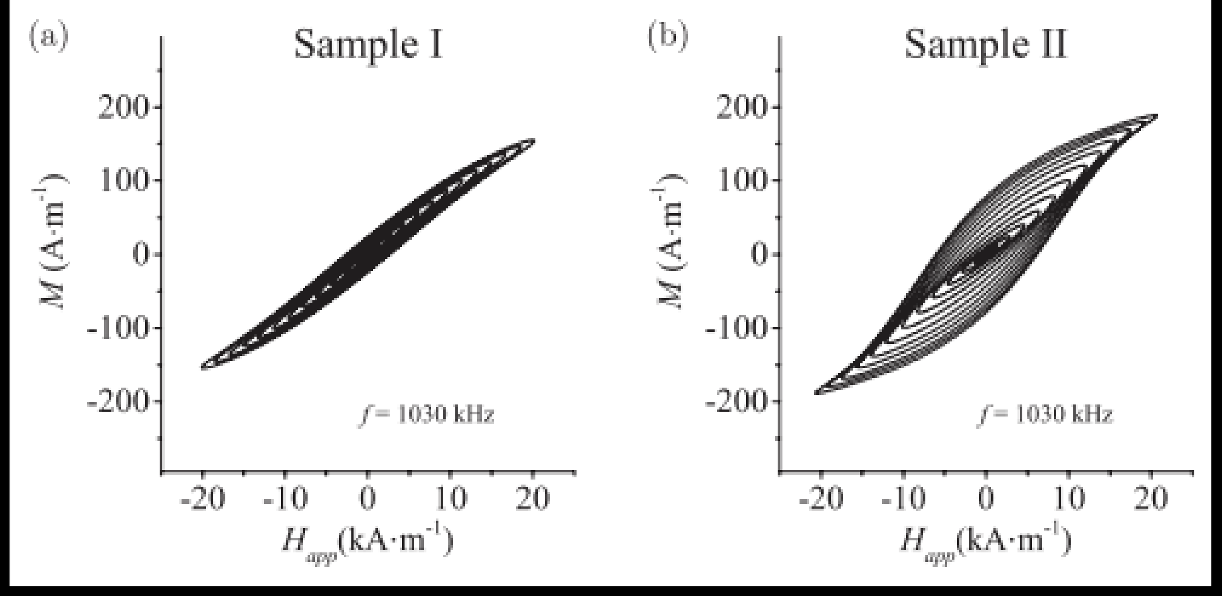
Figures from reference [4]



SAR (SLP) for each sample at different field intensities



Schematic of pick-up coils



Hysteresis loops of sample at same frequency and different field intensities

Reference:

[1] Z. Boekelheide, Z. A. Hussein, et all, "Gd5Si4 micro- and nano-particles for self-regulated magnetic hyperthermia," IEEE Trans. Mag, Accepted 2017.

[2] Z.A.Hussein, Z.Boekelheide, et all. "Particle size dependence of the specific loss power of Gd5Si4 micro- and nano-particles for self-regulating magnetic hyperthermia," submitted abstract for conference 2017.

[3] E Garaio, et all. "A wide-frequency range AC magnetometer to measure the specific absorption rate in nanoparticles for magnetic hyperthermia," Journal of Magnetism and Magnetic Materials. Vol 368 p. 432-437, 2014.

[4] E Garaio, et all. "A multifrequency electromagnetic applicator with an integrated AC magnetometer for magnetic hyperthermia experiments," Meas. Sci. Technol. Vol 25, p.115702, 2014.

Acknowledgements:

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