Permalloy Production for 3D-Printed Magnets

Vincent Lan – vlan@umd.edu

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Introduction

Inductors are common components in many electronic devices which stabilize current and store energy in the form of a magnetic field that are used in power supplies, transformers, and electro-magnets. The energy storage capabilities of an inductor can be enhanced by providing the inductor with a magnetic core. While most other electronic components can be printed, there are currently no methods to additively manufacture inductor core. Thus, the manufacturing of inductor cores require specialized machinery which can be costly, bulky, and wasteful. This project focuses on the optimizing the production of permalloy nanoparticles for additively manufactured inductor cores to streamline the manufacturing process for electronics.

Permalloy (Ni20Fe80) is a desirable material with low magnetic coercivity, meaning it generates a relatively low amount of heat when subjected to alternating magnetic fields. In high power applications, magnetic fields can alternate over a billion times per second so low magnetic coercivity materials drastically decrease heat build up during device operation. Since electronics are sensitive, the build up of heat can prevent a device from functioning properly.

Permalloy synthesis via a wet chemical method is simple but only produces approximately 0.5 g with the method described by Qin et al. (2009). Scale-up of the reaction may not follow a linear process so material quality issues can arise if conditions such as heat uniformity are not kept consistent.

Methods

Permalloy Synthesis

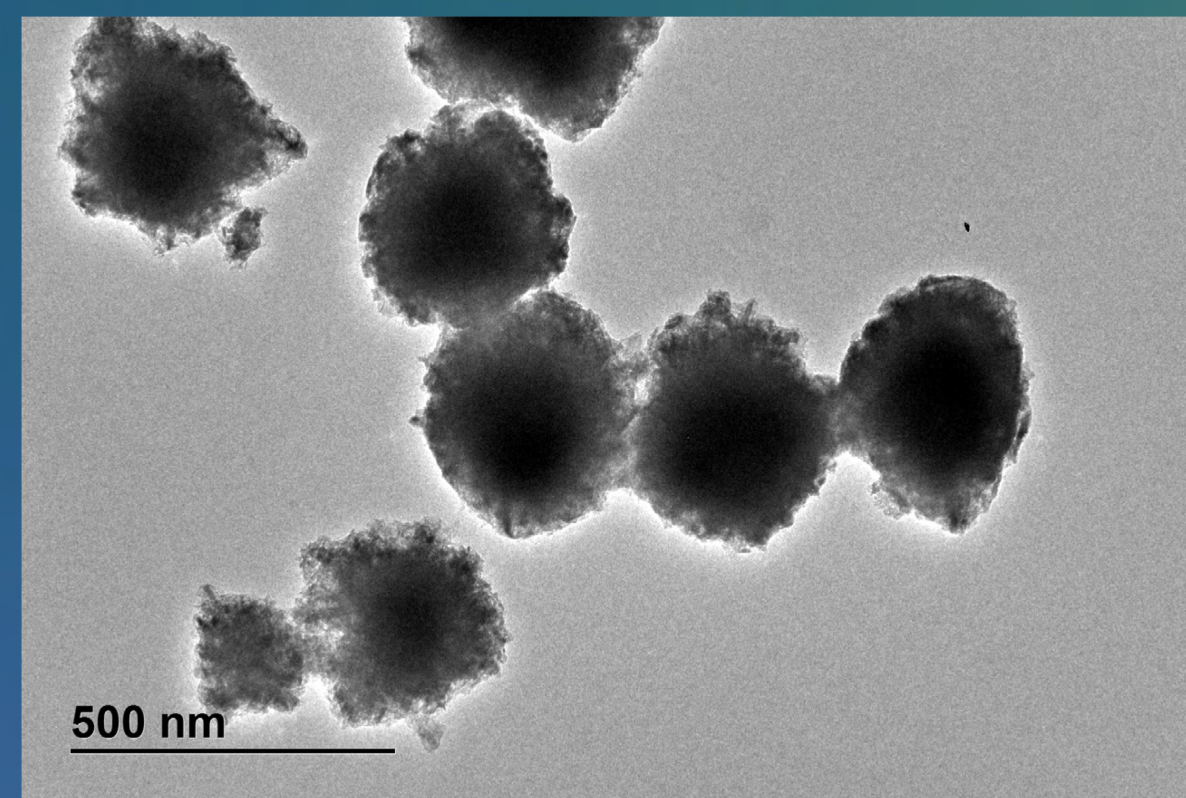
0.1M $FeCl_2$, 0.1M $NiCl_2$ and 2M NaOH were dissolved into propylene glycol at 80°C by mechanical stirring, and then heated to 180°C for 2 hours. To clean the nanoparticles of excess polymer, a combination of equal parts acetone, ethanol, and water was added to the solution. The solution was placed in an ultrasonic bath and placed under a magnet for magnetic phase separation, both for 15 minutes. The wash steps were repeated until the resultant liquid phase from magnetic separation was transparent.

Characterization

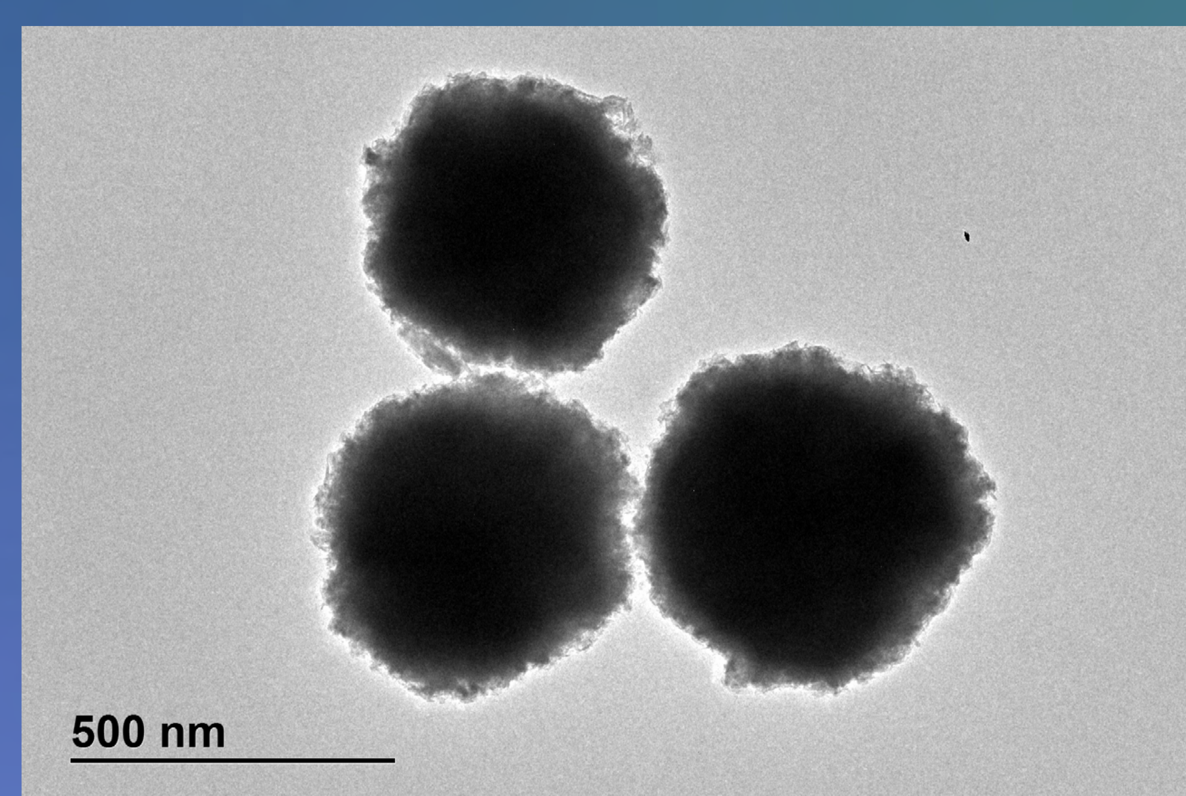
Size distribution was calculated via ImageJ software analysis on Transmission Electron Microscopy (TEM) images. Magnetic properties were calculated via Vibrating Sample Magnetometry (VSM).

Citations

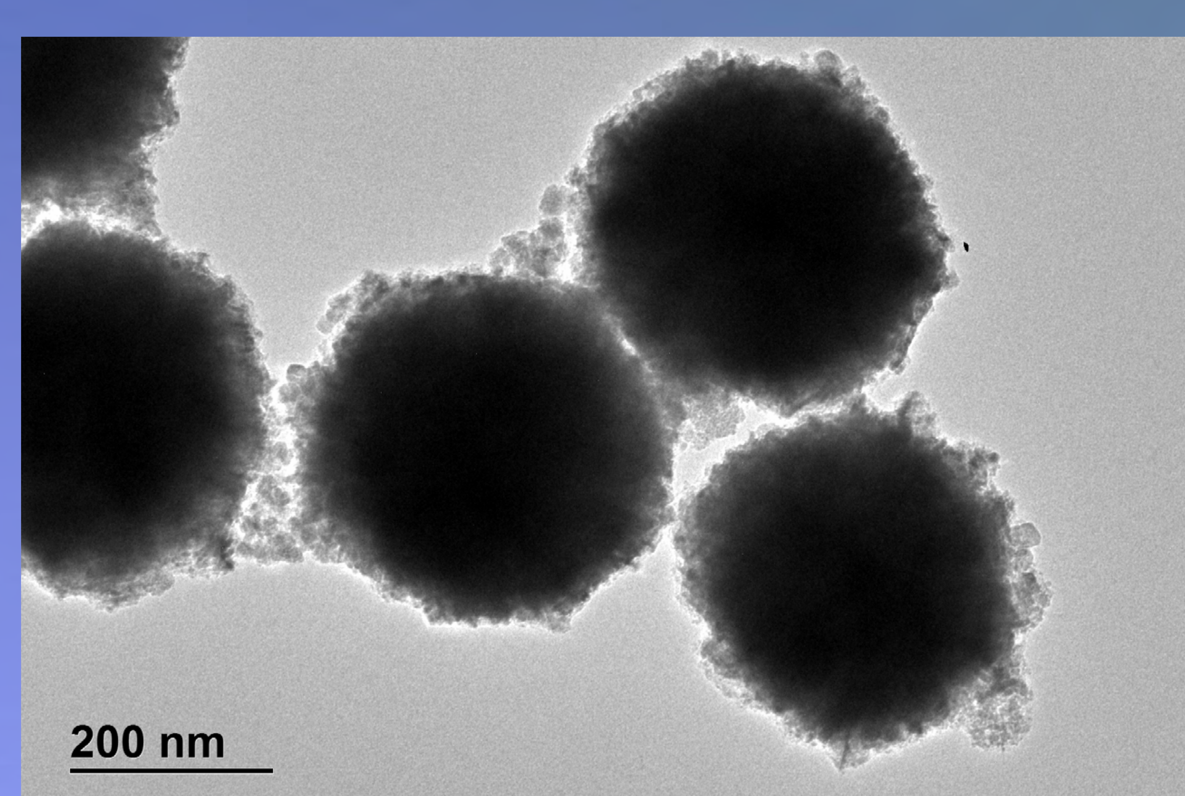
Qin, G., Pei, W., Ren, Y., Shimada, Y., Endo, Y., Yamaguchi, M., . . . Kitakami, O. (2009). Ni80Fe20 permalloy nanoparticles: Wet chemical preparation, size control and their dynamic permeability characteristics when composited with Fe micron particles. *Journal of Magnetism and Magnetic Materials, 321*(24), 4057-4062. doi:10.1016/j.jmmm.2009.08.004



TEM image of "3/28/21 Single" taken by Rebecca Fedderwitz.



TEM image of "3/12/21 Double" taken by Rebecca Fedderwitz.



TEM image of "4/7/21 Quad" taken by Rebecca Fedderwitz.

Sample	Average Size (nm)	Coercivity (Oe)	Permeability
3/1/21 Single	532	85.7	7.2
3/28/21 Single	409	N/A	N/A
2/19/21 Double	325	157.3	6.2
3/12/21 Double	419	108.6	5.7
4/2/21 Quad	519	N/A	N/A
4/7/21 Quad	331	N/A	N/A

Results & Discussion

Over the course of this investigation, multiple parameters have been modified to reduce the number of variables associated with the synthesis including systematically cleaning glassware, streamlining the particle washing process, and implementing a two-bath system to eliminate ramp rate.

Permalloy synthesis at all quantities largely produced spherical particles, with some oblong shapes being present. Doubled syntheses appear to have the smallest size variance while quadrupled syntheses appear to have the largest size variance. Single quantity synthesis is notable having large particle sizes.

Linearly scaled-up permalloy syntheses appears to have resulted in particles with similar magnetic properties to those synthesized at normal conditions; however, more VSM characterization needs to be conducted.

There are some sources of error and limitations associated with this study. Size distribution via ImageJ analysis of TEM images is not a perfect method as it prone to human error. Furthermore, this method represents a small sample of the synthesized mass as opposed to other methods that incorporate the entire sample such as dynamic light scattering. It is also possible that smaller particles may have been washed out along with the supernatant fluid, but this has yet to be confirmed.

Compared to the particles originally synthesized by Qin et al. (2009), the particles synthesized in this investigation fall outside of their recorded size distribution and exhibit different magnetic properties.

Conclusion

The results from this investigation indicate scale-up of the wet chemical method is feasible. Syntheses with multiplied quantities produced particles akin to those synthesized under original parameters. A mechanism for size and property control should be considered as the produced samples varied greatly. Qin et at. (2009) used a nucleating agent to control size and properties.

Future studies would focus on developing permalloy into an ink suitable for 3D printing, including research on colloidal stability, particle loading optimization, and rheology selection. Machine-based image analysis should also be considered to provide accurate results for TEM size distribution.

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