Advanced Magnetics for High Frequency Link Converters and an Agile Grid

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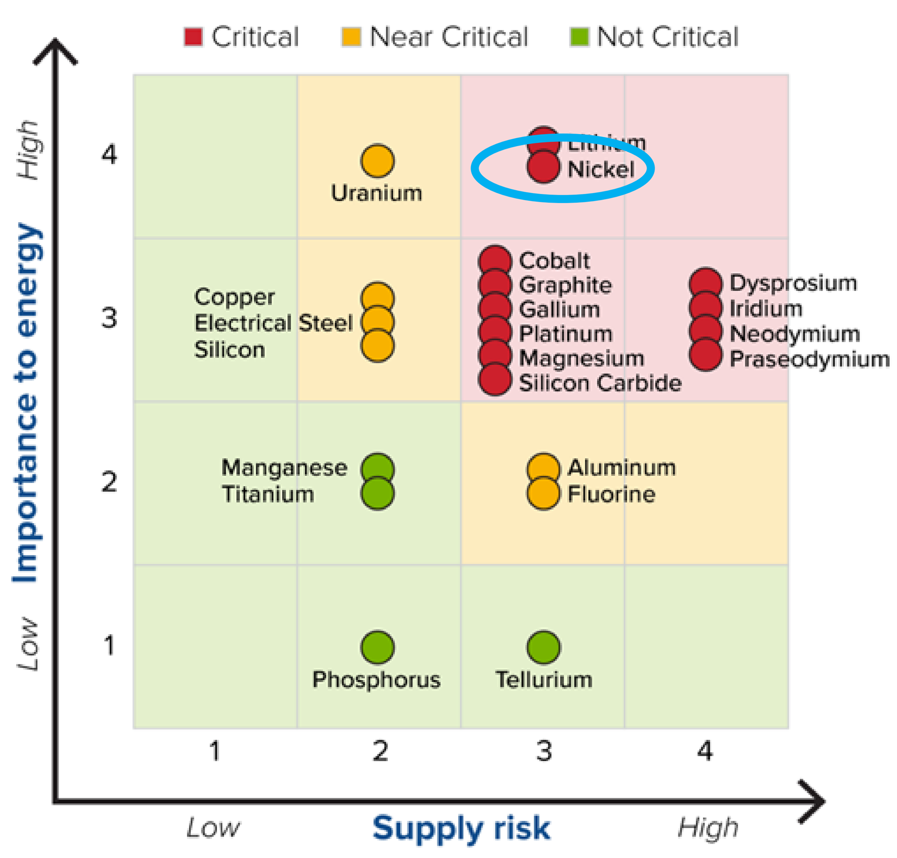
What is the project about?

Advanced magnetic materials will enable power dense and low loss DC links and their implementation in conjunction with energy storage systems. Innovative magnetic core materials suitable for high frequency link converters that can perform without active cooling are being fabricated. The specific material of interest is the soft magnetic material iron nitride (γ'-Fe_4N), which will be optimized for multiple applications. Iron nitride, manufactured into magnetic components for the first time ever, will lead to lighter, smaller, and more affordable magnetic components for energy storage applications, including high frequency support.

Why are we doing this? Elimination of critical material nickel from magnetics



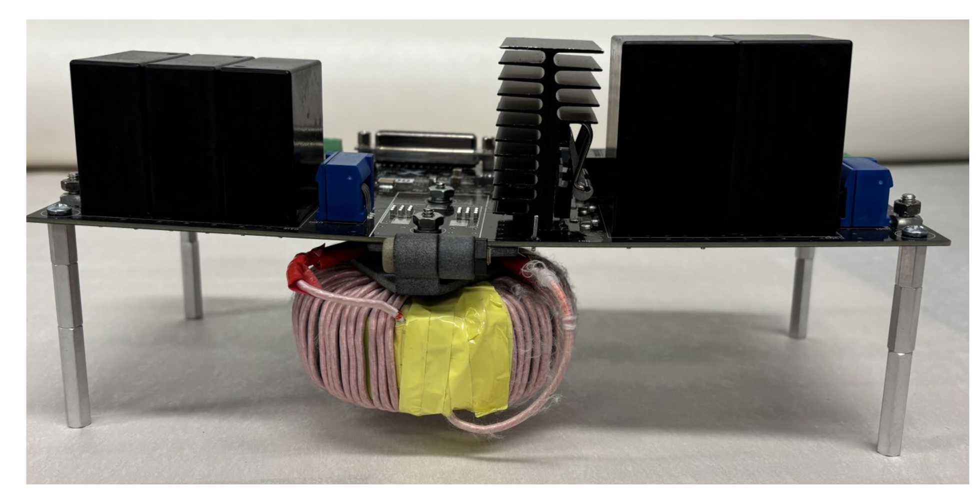
Objectives:

- Develop iron nitride (γ'-Fe_4N) materials with magnetic properties competitive with MPP (molypermalloy powder)
- Develop cost competitive manufacturing methods

Benefits:

- MPP contains 79% nickel
- Fe_4N is free of critical materials
- Lower manufacturing costs
- Potential to apply γ'-Fe_4N in multiple applications
  - Output transformer cores
  - Filter inductors
  - Snubber inductors

Why are we doing this? Achieve high flux density in magnetics operating at high frequency (10 kHz - 1 MHz)



Synchronous buck converter with MPP inductor

- High flux density leads to light & compact electronics
- Current γ'-Fe_4N toroids are competitive in core loss! (see data below)

Other targeted properties

- High permeability
- Low coercivity
- Affordability

FY25 Milestones:

M1: Fabrication of Fe_4N core with O.D. ≥ 4 cm — Complete!
M2: Testing of Fe_4N core in a dual active bridge (DAB) testbed — Underway

Previous Work in the Field

Magnetic Material	J_s (T)	ρ (μΩ·m)	Cost
Nanocrystalline Alloys	1.20	1.15	High
Amorphous Alloys	1.60	1.37	High
Soft Ferrites	0.52	5x10^6	Low
SMCs	~1	0.1-1200	Low
Si steel	1.87	0.5	Low
γ'-Fe_4N	1.89	> 200	Low

- No existing magnetic material meets all requirements
- γ'-Fe_4N can meet all demands of high frequency transformers and inductors
- Note: $J = \mu_0 M$

Methodology

Hypothesis:

- γ'-Fe_4N can meet all requirements of high frequency transformers and inductors

Methods:

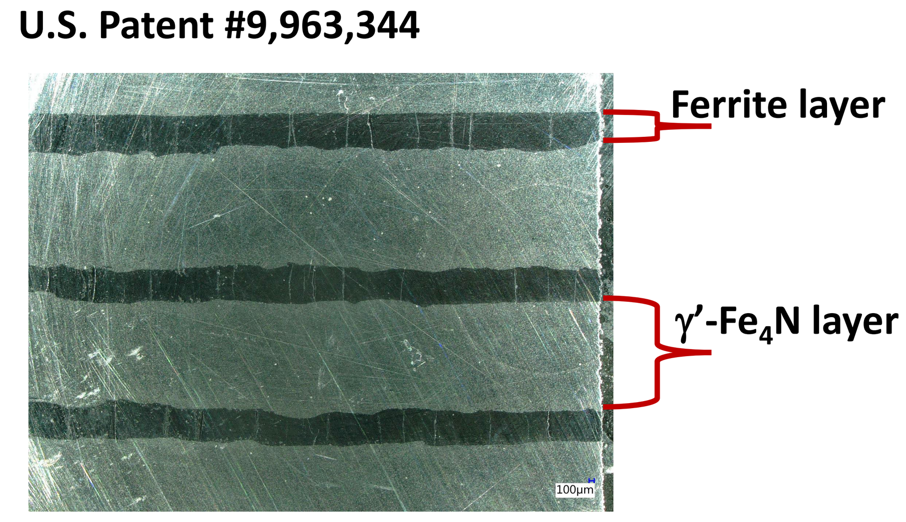
- Develop pathways for high quality γ'-Fe_4N raw powder production
- Fabricate novel iron nitride and iron nitride based composite magnetic cores
- Test new magnetic cores in relevant environments
- Demonstrate improved performance over state of the art

Innovation/Risk:

- γ'-Fe_4N not fabricated as a bulk material or demonstrated in any device prior to this work

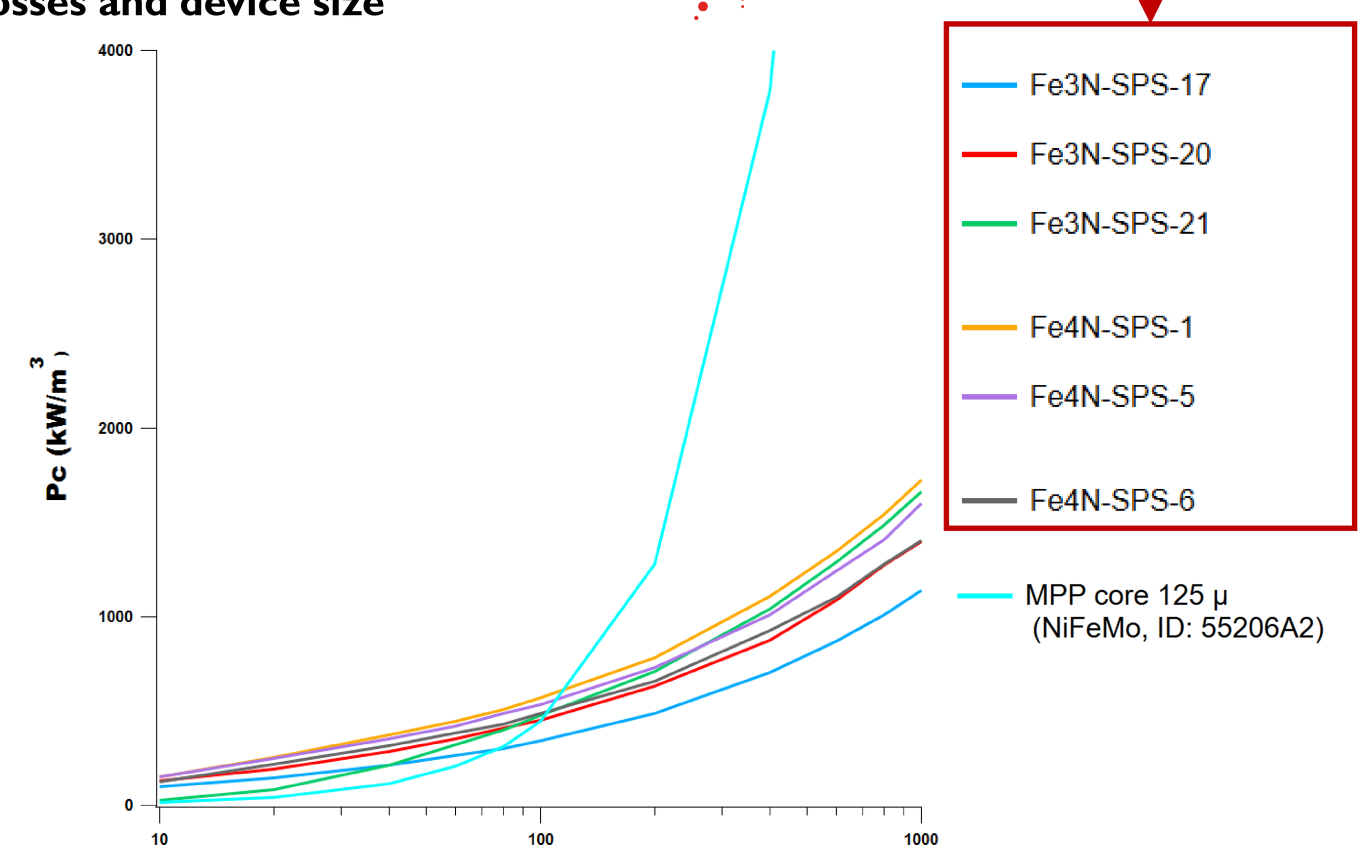
What have we done (Results)? Spark Plasma Sintered (SPSed) iron nitride cores

First ever bulk γ'-Fe_4N!
U.S. Patent #9,963,344



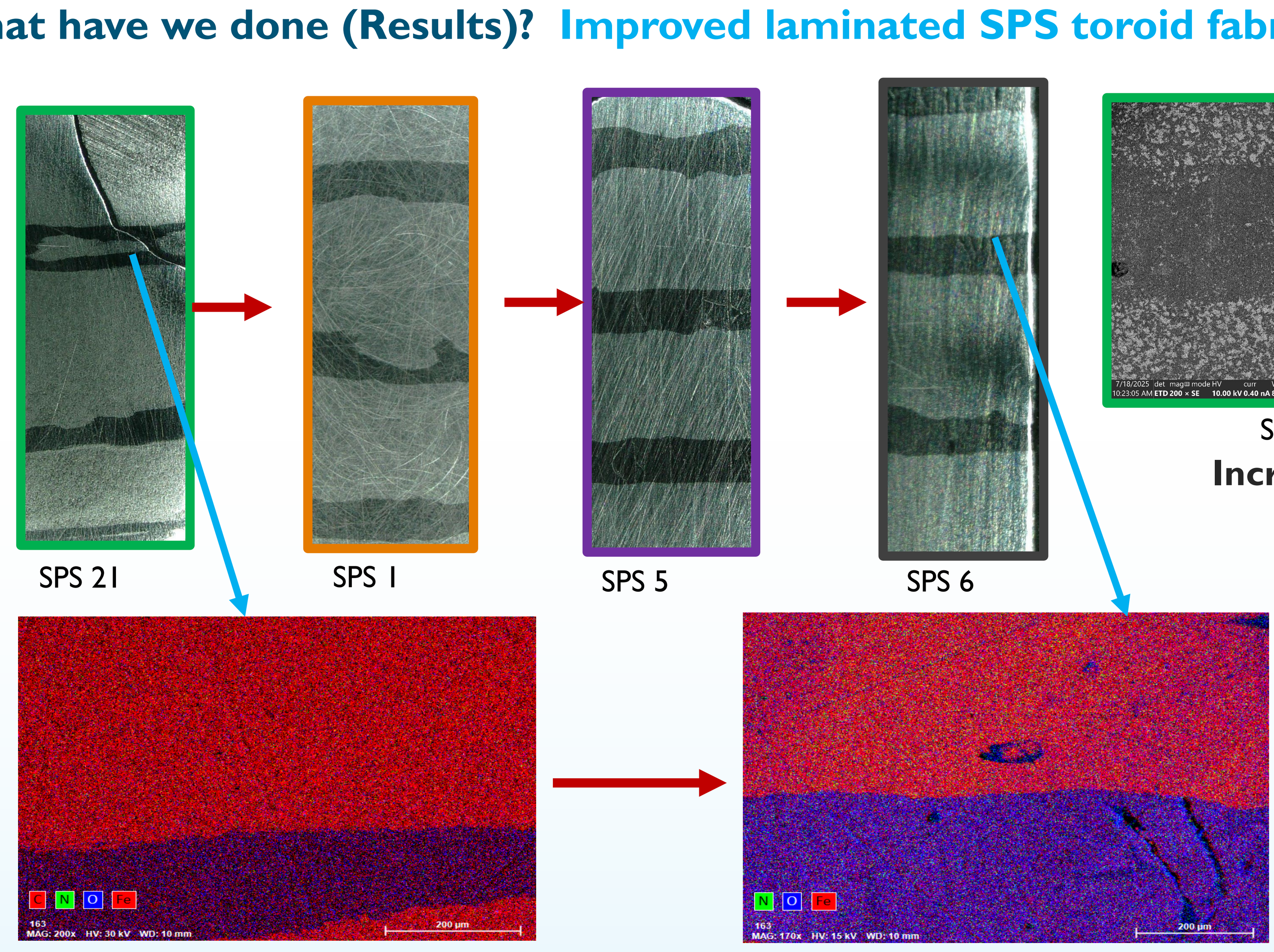
Laminated structure to reduce eddy current losses and device size

calnano

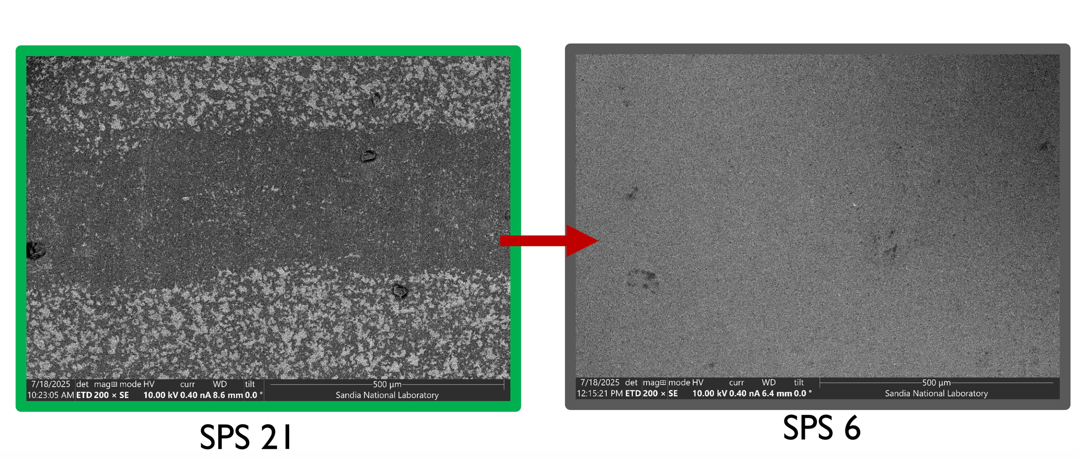


Improved material quality and microstructure to decrease core loss

What have we done (Results)? Improved laminated SPS toroid fabrication

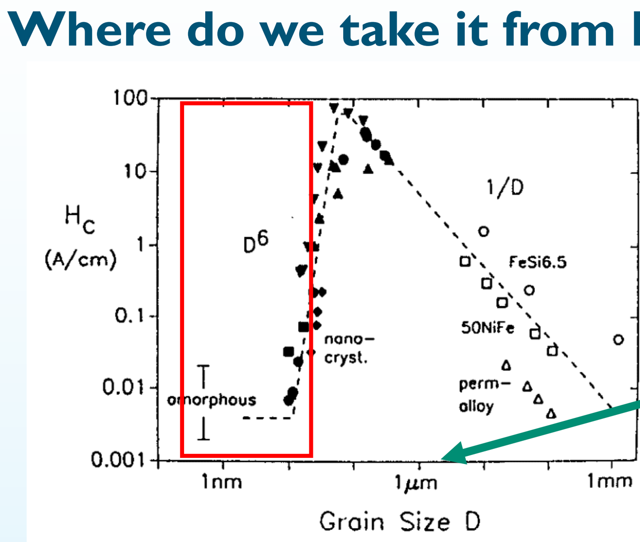


Continuous improvement in layer precision and definition

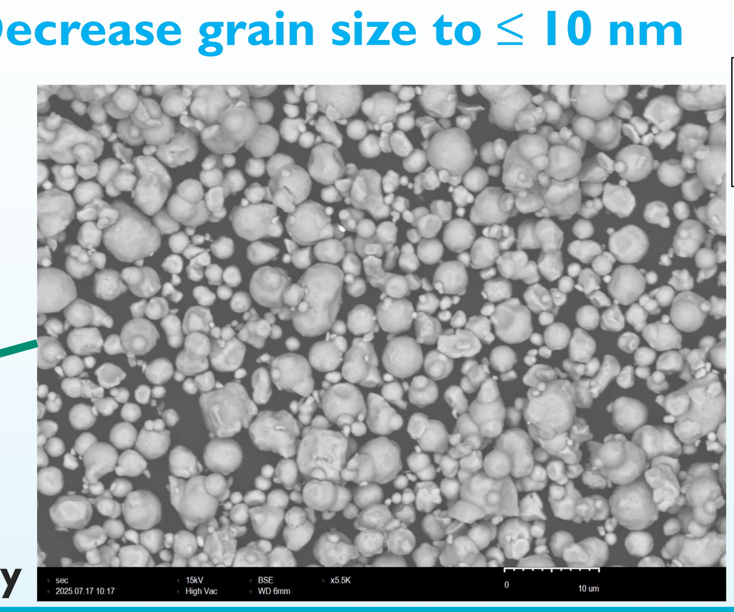


Increased density and well defined layers

Where do we take it from here? Decrease grain size to ≤ 10 nm



Decreasing grain size decreases coercivity



Currently in the 10 micron range

Next steps:

- Optimize milling conditions for smallest particle size
- Filter particles for consistent size

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