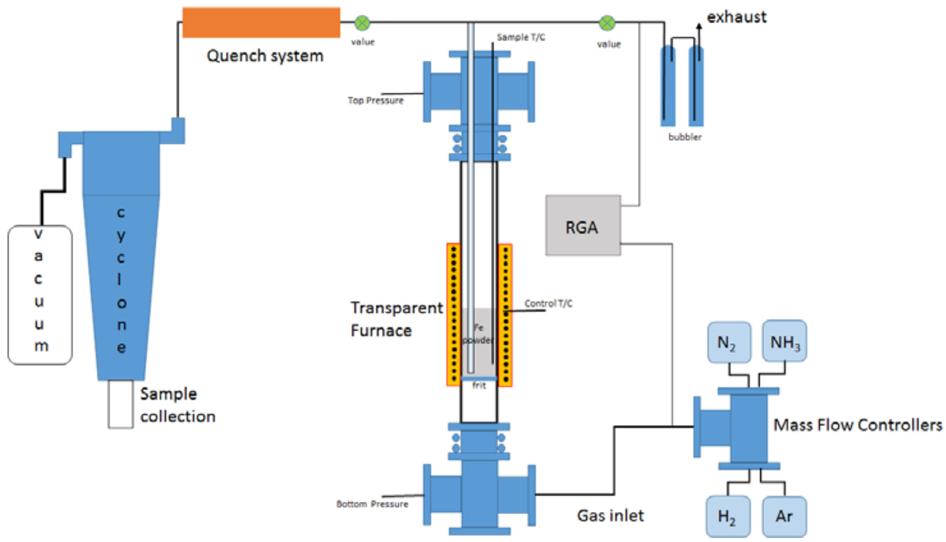
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Advanced Manufacturing of Alpha Double Prime Iron Nitride: An Innovative Rare Earth Element Free Ultra-High Performance Permanent Magnet for Clean Energy Applications

Permanent magnet (PM) driven processes are used extensively in residential, commercial, and industrial applications. In addition, the wind industry uses PMs in electricity generators; and magnetic refrigeration is an emerging application area. PMs usually contain rare-earth elements (REEs). However, there is increasing concern regarding the future availability of REEs, which are predominantly supplied by China, especially if significant growth emerges in REE-based applications. Therefore, there is significant interest in developing alternative REE-free materials for clean energy and energy efficiency applications.

This project will develop an advanced prototype fluidized bed reactor (FBR) system to produce alpha double prime iron nitride (ADPIN) magnetic powders. These powders will be developed as REE-free alternatives to permanent magnets. The project will begin by enabling the FBR system to move beyond the current rate limiting steps for manufacturing nitride and quenched powders. These output powders from the FBR system will then be cryomilled and annealed into ADPIN powders. After successful project completion, it is anticipated the FBR system will be scaled up further to conduct demonstrations at a pilot-scale level.



Schematic of proposed fluidized bed reactor using a transparent fused quartz process tube and a transparent furnace system that will allow direct observation of the fluidized bed at operating temperatures and pressures.
Graphic image courtesy of FeNix Magnetics, Inc.

Benefits for Our Industry and Our Nation

The ADPIN magnetic powders under development, targeted to deliver three to four times the magnetic energy density of existing supermagnets, could have significant impacts in sectors currently requiring REEs. For example, refrigeration and cooling processes in residential and commercial buildings accounted for approximately one-sixth of total energy use in buildings in 2014; totaling over six quadrillion Btu (over 6% of total U.S. energy use that year). Magnetocaloric cooling may achieve energy savings on the order of 20% compared to existing refrigeration and cooling technology. Additionally, using state-of-the-art FBR manufacturing techniques for the magnetic powders may provide a simpler, more scalable and less energy intensive process than traditional manufacturing of magnetic materials such as neodymium iron boron.

Applications in Our Nation’s Industry

ADPIN magnetic powders will have a variety of benefits to industries requiring REEs. The near-term target market is magnetic refrigeration because of ADPIN’s high saturation magnetization; this allows for increased cooling power in refrigeration engines without changing cost, while improving electrical efficiency and environmental benefit. Longer-term applications include wind turbines, electric vehicles, and manufacturing robotics. These markets emphasize PM applications with higher coercivity and energy density.

Project Description

The project objective is to design, develop, and demonstrate a fluidized bed reactor that yields a 100-fold increase in the amount of alpha double prime iron nitride (ADPIN) powder for the development of rare earth free, high performance permanent magnets. This project aims to accomplish this via two different fluidized bed reactor (FBR) designs: initially utilizing a transparent fused quartz processing chamber that allows for direct visualization of the fluidizing behavior, and then a stainless-steel processing chamber that allows for direct scale up to prototype quantities. The project outcomes address the current technical challenge that hinders ADPIN magnetic powder usage: large scale production. The project will utilize a three-step process: 1) nitriding & quench to achieve an austenitic phase (γ-(Fe,M):N); 2) cryo-deformation to transform the austenitic phase to a martensitic phase (α'-(Fe,M):N); and 3) annealing to transform the martensitic phase to the ADPIN (α"-(Fe,M)16N2) phase.

Barriers

- Accelerating production for the nitriding and quenching step (current lab-scale process takes weeks to produce enough 99% pure material for a single cubic centimeter magnet)
- Addressing changes in heat transfer for a full-scale FBR system using a stainless-steel process chamber

Pathways

The project is structured to address the key barriers and minimize risk. The ultimate goal is to develop FBR technology for the prototype scale production of ADPIN magnetic powders.

The first project pathway will model and experimentally validate fluidization parameters for the FBR. This validation will involve demonstrating effective gas velocity and pressure drop across the bed as a function of particle size and density for a bench-top room-temperature fluidized bed test cell. Each of these lab-scale validations will be completed on site.

The second pathway will design, develop, and demonstrate the FBR over two generations. The first generation FBR will use a transparent fused quartz processing chamber for direct visualization and comparison purposes. The second generation FBR will utilize a stainless-steel processing chamber for prototype scalability purposes. These FBRs will also be fabricated and demonstrated on site.

The third pathway will cryomill and anneal the second generation FBR output into the ADPIN magnetic powders. The cryomilling and annealing processes will transform the austenitic phase FBR output into a martensitic phase (after cryo-deformation), and then the ADPIN phase (after heat treatment).

Milestones

This two-year project began in May 2018.

- Demonstrate fluidization of 500 grams iron powder at process temperatures of ≥500°C for ≥1 hour (2019)
- Demonstrate a scalable prototype FBR-based process technology that yields a greater than 100-fold increase in the amount of ADPIN material produced by the current state of the art process (2020)

Technology Transition

FeNix Magnetics is partnering with Case Western Reserve University (CWRU) for the development and testing of the FBR to produce ADPIN powders. Following successful development, the project team plans to have an intellectual property licensing agreement negotiated with CWRU. It is anticipated FeNix would be a manufacturer and seller of ADPIN powders and magnets, through a combination of in-house and tolled processing capabilities. As a seller, FeNix would likely channel initial distribution through a limited set of strategic partners, which would focus product development on a few well-defined and specified target markets.

Project Partners

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