Development of a High Throughput Laser System for Soft Magnetic Materials to Revolutionize Motor Technology

Oak Ridge National Laboratory
FY19-FY21

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Overview

Project Title: Development of a High Throughput Laser System for Soft Magnetic Materials to Revolutionize Motor Technology

Timeline:

Project Start Date: 10/01/2019

Budget Period End Date: 09/30/2019

Project End Date: 09/30/2021

Barriers and Challenges:

- Limited ductility of high-performance high-Si electrical steels prevents commercialization with conventional manufacturing methods
- Current metal AM techniques have limited process throughput, increasing cost of manufacturing
- Limitations in control of the heat transfer characteristics in existing additive manufacturing (AM) systems
- Control of crystallographic texture in electrical steels can enable improved electric motor efficiency
- Scalable physics-based modeling tools are necessary for process design and optimization

AMO MYPP Connection:

- Advanced Materials Manufacturing
- Additive Manufacturing

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$4,500,000	$1,200,000	$5,700,000	21%
Approved Budget (BP-1&2)	$1,224,375	TBD	$1,029,122	TBD
Costs as of 4/30/19	$230,094	TBD	$230,094	TBD

Project Team and Roles:

- **Alex Plotkowski** – Lead, numerical heat transfer and materials science
- **Ryan Dehoff** – Materials science, expertise in microstructure control
- **Jason Pries** – Electrical engineering and computer science, simulation of electromagnetics in electric motors
- **Jamie Stump** – Applied math, simulation and computational scaling of heat transfer in additive manufacturing
- **Fred List** – Expert in additive manufacturing system operation
- **Peeyush Nandwana** – Metallurgy, post-processing heat treatments
- **Niyanth Sridharan** – Metallurgy, characterization of ordered phase domains, crystallographic texture evolution
- **Keith Carver** – AM system technician
- **Kinga Unocic** – Transmission electron microscopy
- **Chris Fancher** – Neutron and electron diffraction

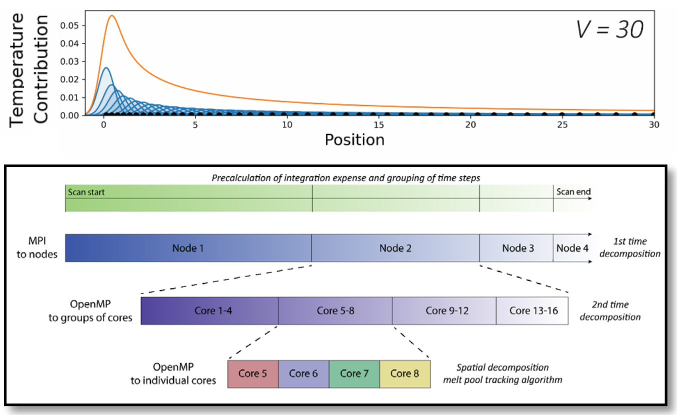
Project Objective(s)

- Electric motors account for 46% of global electricity consumption
  - \$500B/yr in electricity, 6000 Mt/yr CO_2 emissions
- Additive manufacturing offers a route to improve efficiency by 2-3% through optimized soft-magnetic motor components
  - Manufacturing of high-Si electrical steels that cannot be produced with conventional methods
  - Control of grain structure to take advantage of magnetic anisotropy in components with complex magnetic flux pathways
- High-throughput specialized systems are required
  - Multiple integrated lasers will allow for increased productivity and control over thermal conditions that govern microstructure development
- **Objective:** Design a new high-throughput metal additive manufacturing system for improving electric motor efficiency through improving the properties of soft-magnetic materials

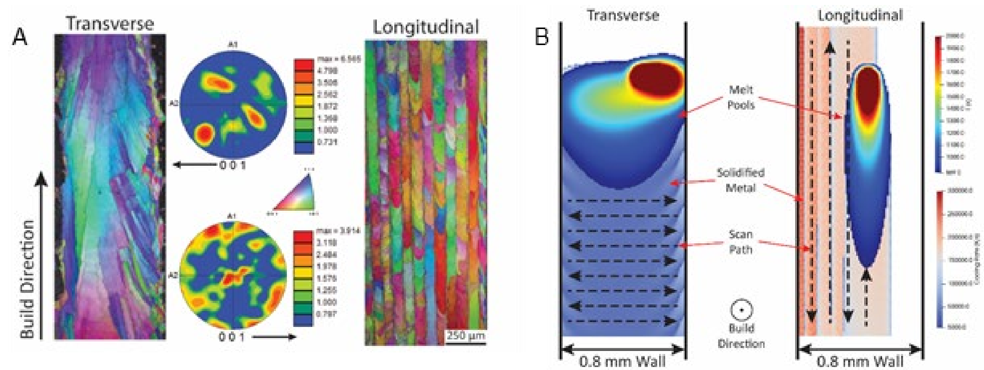
Technical Innovation

- Current soft magnetic motor components are produced by laminating rolled Fe-Si sheet
  - Limited to low Si content (3-4 wt.%) due to poor ductility of high-performance high-Si compositions
  - Uses randomly oriented grain structures that do not conform to the circumferential magnetic flux pathways in electric motors
- New additive manufacturing system will enable unprecedented control of thermal conditions and increase process throughput
  - Avoids mechanical deformation, allowing for production of high-Si electrical steels
  - Control over microstructure formation to improve magnetic properties
  - Reduce cost of additively manufactured components
- New computational tools are required to quickly assess potential system design on component structure
  - Developing reduced-order approaches for rapid heat transfer calculations and ensuring computational scalability

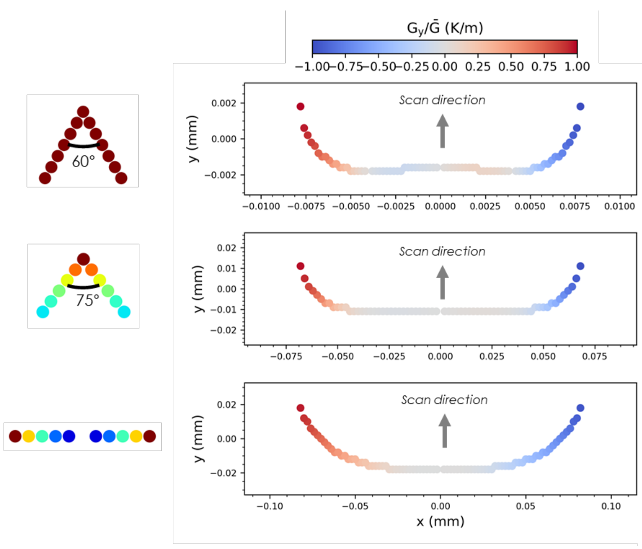
Technical Approach



Development of scalable computational algorithms for component scale process models of solidification conditions in additive manufacturing



Using computational models to build process-microstructure-property correlations and single-laser experiments on existing systems to validate model predictions.



Validated model is used to generate cost-functions for optimization of candidate multi-beam configurations for producing ideal microstructures in electrical steel.

Process Models: Development of scalable reduced-order modeling approaches for predicting process-microstructure relationships in additive manufacturing.

System Optimization: Validation of models and optimization of multi-beam system configuration for improved throughput and optimal microstructure development.

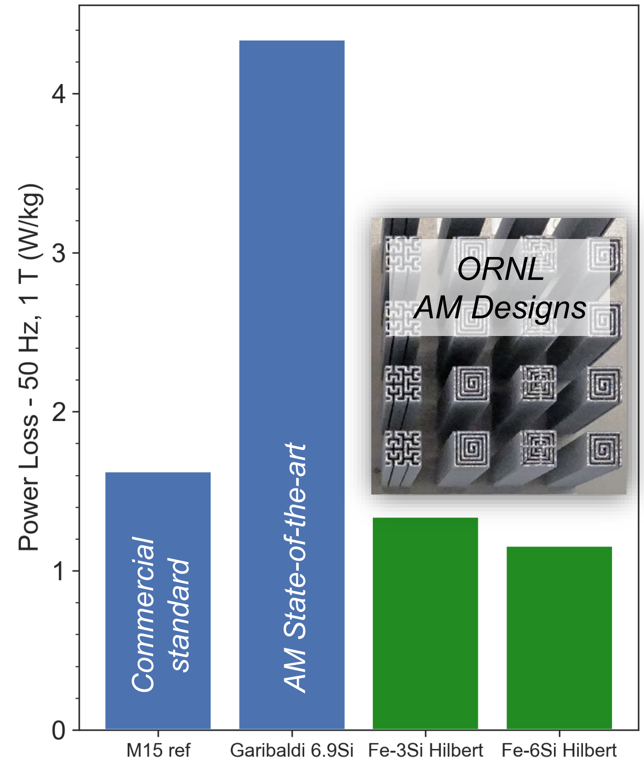
Alloy Chemistry: Selection of alloys for improved processability and soft-magnetic properties.

Component Design: Unique cross-sections for maximizing energy efficiency using additive manufacturing capabilities designed using computational tools for electromagnetics.

Advanced Characterization: Characterization of material structure and magnetic properties using ORNL capabilities (advanced microscopy, neutron diffraction).

Results and Accomplishments

- Unique designs and materials science research have helped reduce power losses in AM produced soft magnets
- High-Si alloy chemistry selection and powder production completed
- Computationally scalable heat transfer model for process optimization completed
- New system development to be completed in FY19 and FY20
- Optimized component demonstration in FY21



Additive manufacturing enables unique components designs for improved magnetic performance.

Transition (beyond DOE assistance)

- Commercialization by industrial partner for system development
  - IP development and/or licensing to industrial partner
- Additional research at ORNL on impact of multi-beam systems for control of microstructure and residual stress in other materials to expand marker to other industries
  - Ni-base superalloys for the aerospace industry
  - Novel Al alloys to replace Ti in automotive applications