Magnetocaloric devices for solid state cooling & energy harvesting

Team Advisors: Dr. Radhika Barua, Ph.D. (Mechanical & Nuclear Engineering)

Background

Since energy efficiency is one of the fundamental challenges of the 21st century, it is of utmost importance to engineer new energy efficient technologies and resolve specific critical issues that inhibit the transition of these technologies from the lab into society. Development of novel devices enabled with the “magnetocaloric” class of functional materials is proposed for two sustainable energy-related emerging technologies: (a) magnetic refrigeration - an environmentally friendly alternative to conventional vapor-compression cooling; and (b) magnetocaloric energy conversion - a thermal energy harvesting technology with an estimated energy efficiency of 60% of that of an ideal Carnot cycle. Projects will include: (1) materials design & processing, (2) materials characterization (structural, magnetic & thermal attributes), (3) device design and computational modelling and (4) device prototype fabrication and testing.

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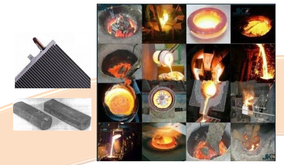
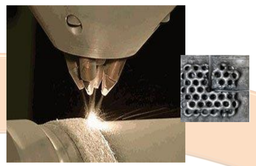
- Develop processing schemes for synthesis of magnetocaloric working material in a device prototype.
- Analyze engineering attributes (thermal transport; mechanical stability, corrosion resistance) of magnetocaloric materials in harsh environments.

Research Strategy

Develop Materials Processing Schemes

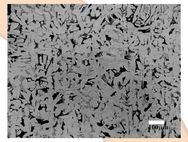


Conventional Techniques

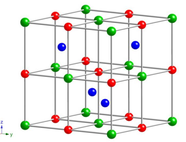


Additive Manufacturing

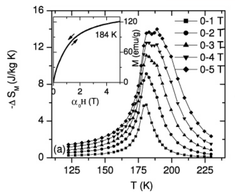
Physical Property Characterization

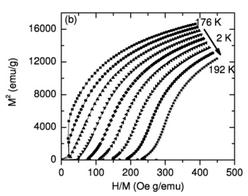


Microstructure



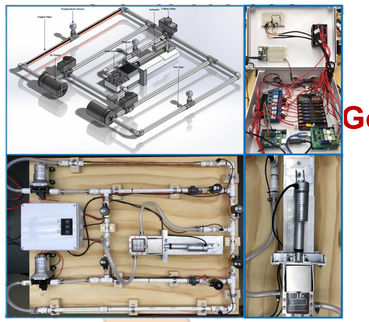
Crystal Structure



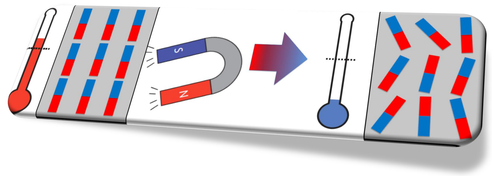


Magnetofunctional Response

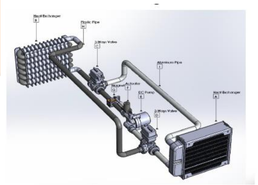
Device Prototype Fabrication & Validation



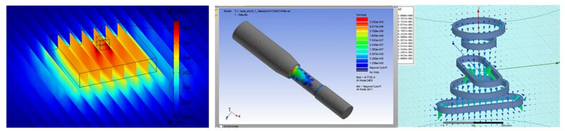
Goal: Develop Magnetocaloric Heat Pump Devices



Device Design and optimization via Computational Modelling



New device design



Modeling thermal conductivity, mechanical fatigue & electromagnetic behavior

Key Elements

materials design & processing, physical property characterization, thermal analysis, computational modelling, device design, fabrication & testing. project management, creative problem solving

Skills

- Materials design
- Materials processing
- 3D Printing
- Microscopy
- X-ray diffraction
- Magnetic property characterization
- Thermal analysis
- Computational modelling
- Device fabrication and validation
- Teamwork

Majors / Background

- Students from the College of Engineering (MNE and CLSE) and College of Humanities and Science (Chemistry, Physics).
- Students must have a strong motivation to work in cross-disciplinary teams.

VCU College of Engineering

Interested in our VIP team?
Contact: Dr. Radhika Barua, rbarua@vcu.edu

What is a magnetocaloric material ?

Magnetocaloric materials (MCMs) undergo a reversible temperature change (ΔT) upon application & removal of a magnetic field in adiabatic conditions.

MCMs exhibit strong spin-lattice coupling, particularly in the vicinity of a simultaneous magnetic & structural transition (Example: Ni_2MnGa[1])

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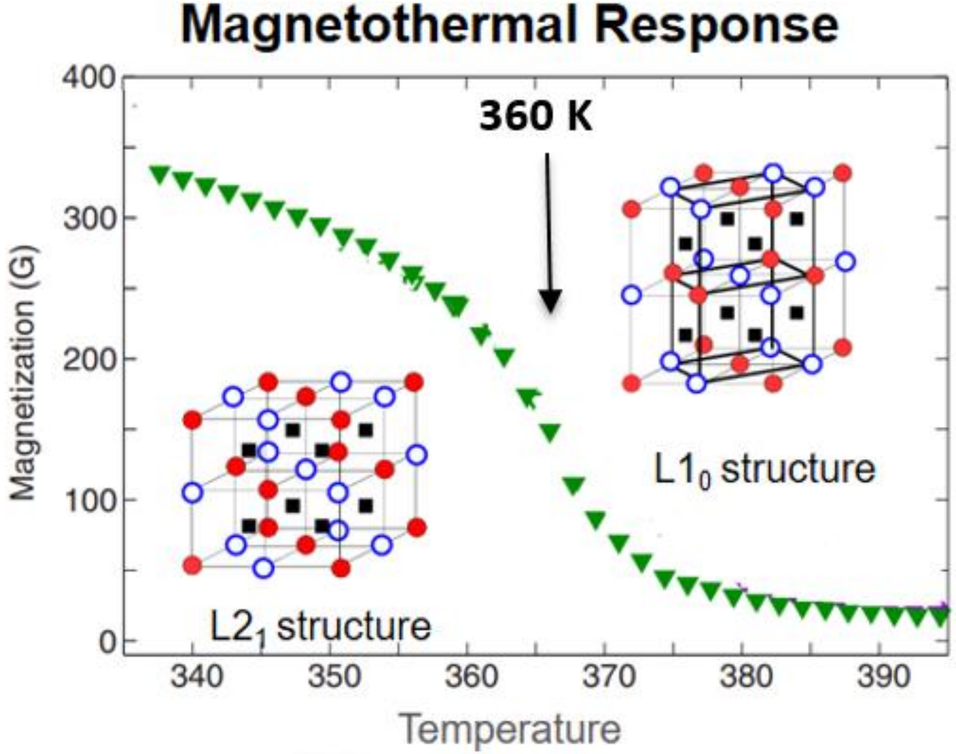

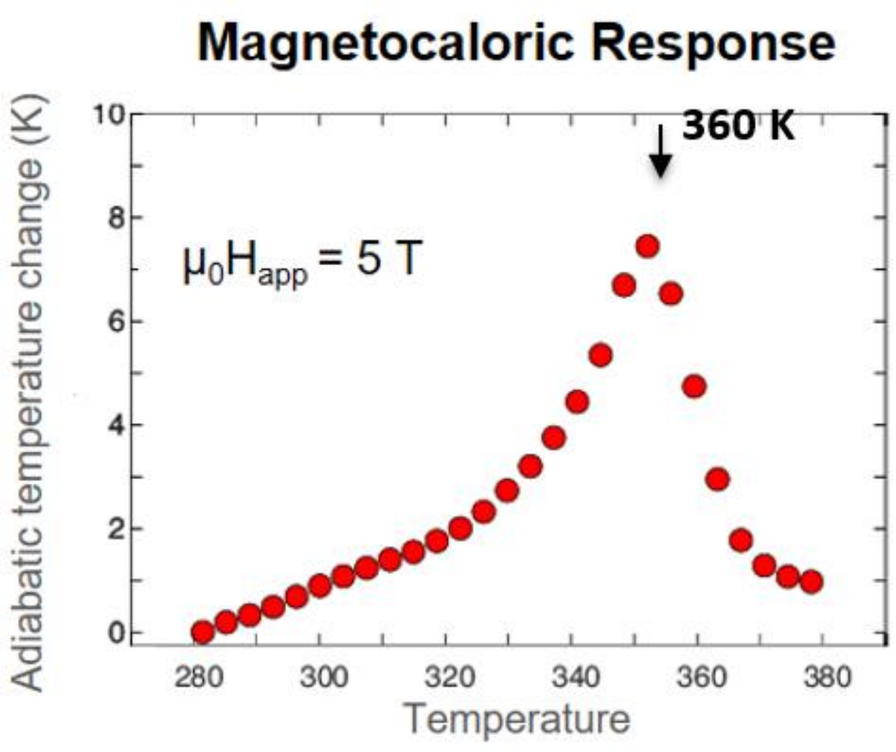

Ref: [1]Buchelnikov, V. D. et al, *Phys. Rev. B* 81 (2010)

Applications of Magnetocaloric Materials

Depending upon the transition temperature & related functional response, MCMs may be used for potential energy-related devices.

Low Temperature	*Room Temperature*	*High Temperature*
Hydrogen Liquefaction	***Magnetic Refrigeration***	***Waste Heat Energy Harvesting***

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Low Temperature

Hydrogen Liquefaction

Room Temperature

Magnetic Refrigeration

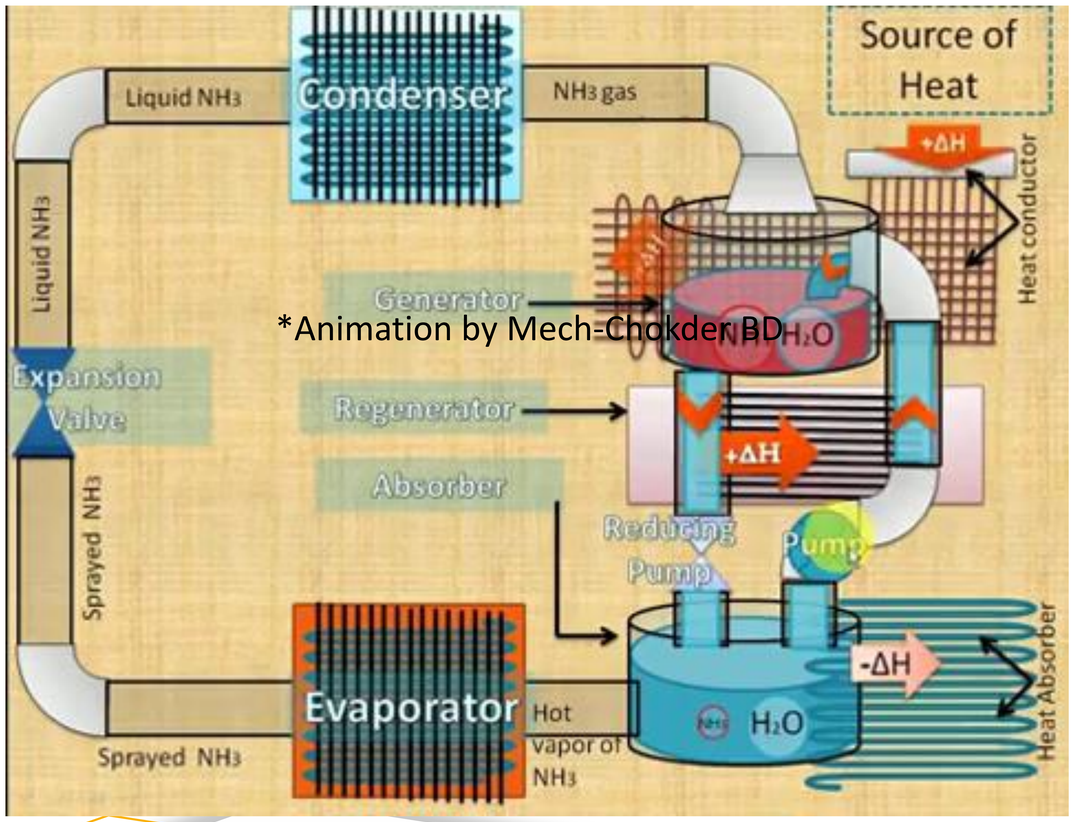
High Temperature

Waste Heat Energy Harvesting

Magnetocaloric Refrigeration

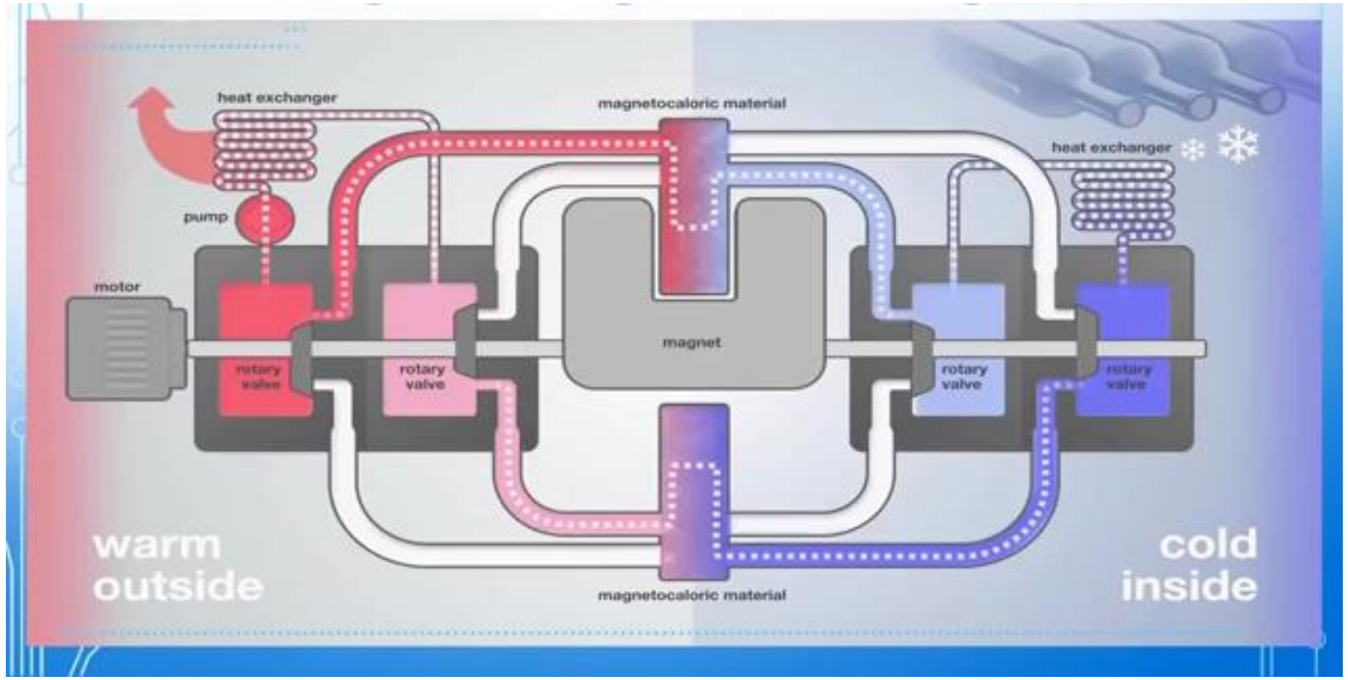
Magnetic refrigeration is an environmentally-friendly, energy-efficient alternative to conventional vapor-compression refrigeration.

Vapor-compression refrigeration



*Animation by Mech-Chokder BD

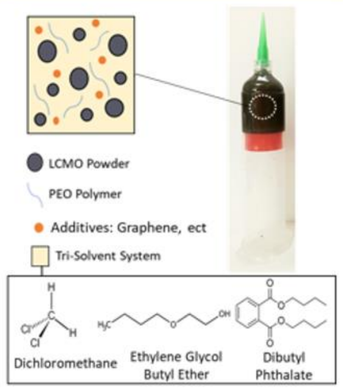
Magnetic refrigeration



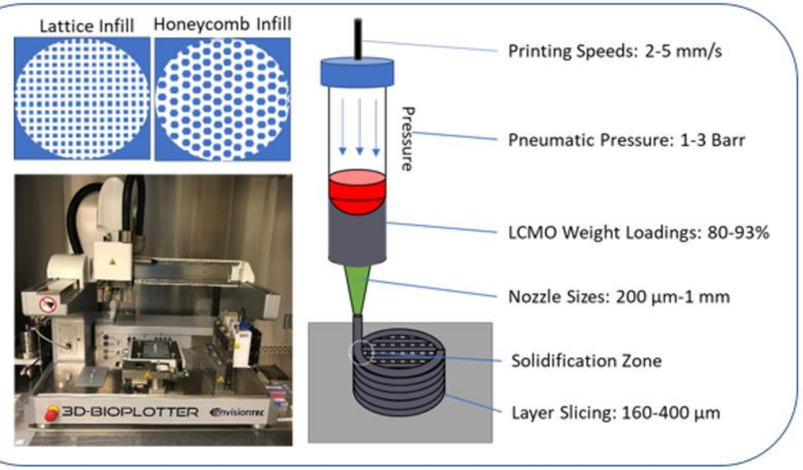
Project 1: Materials Processing

Develop 3D Printed Magnetocaloric Structures with unique architectures for incorporation in device prototypes

Ink Formulation

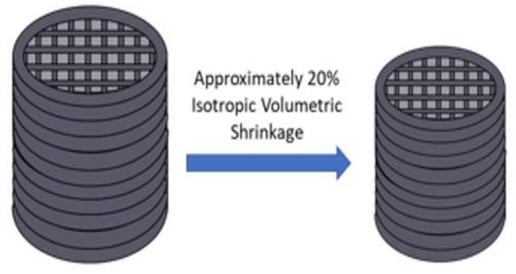


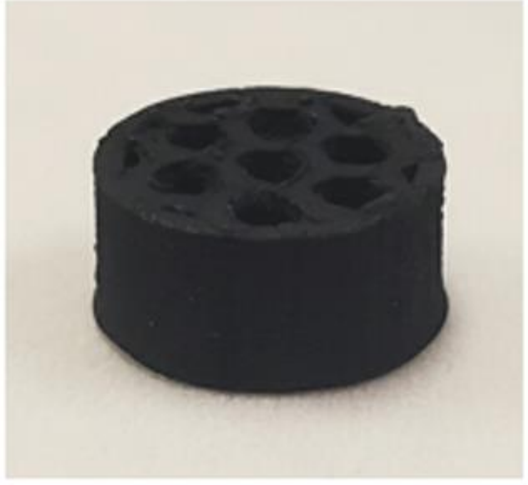
3D-Printing Optimization



Post Treatment

1. Low Temperature Sintering (Debinding): 400°C
2. High Temperature Sintering (Densification): 1100°C





Magnetocaloric Regenerators

As-Printed Microchannel resolutions down to 150 µm

Project 2: Computational Design of Regenerator

Modeling, Assessing, and Optimizing Fluid Flow Performance of Magnetocaloric Regenerators

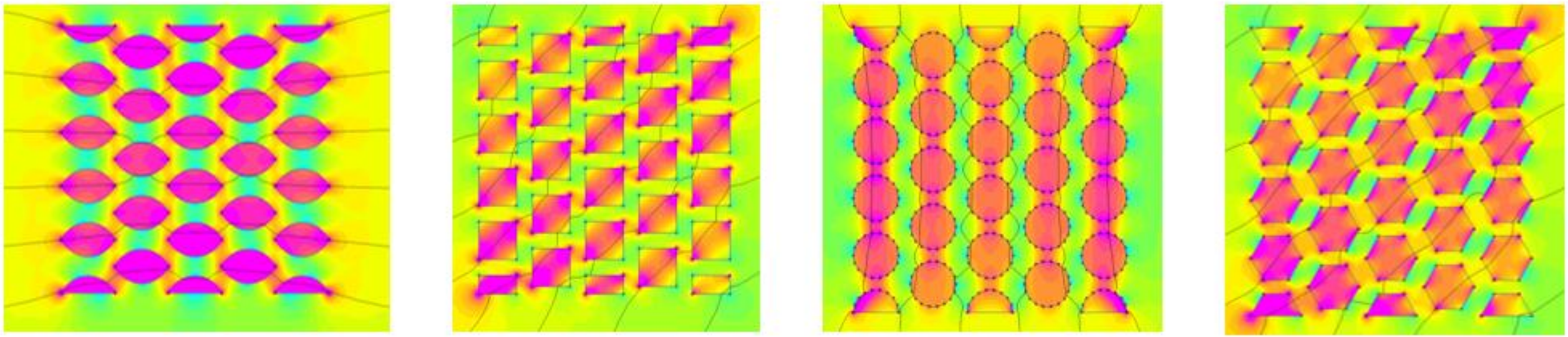


Figure 1: FEMM magnetic simulation of (left to right): Foil pins staggered in 0 degree field; Square pins staggered in 45 degree field; Rod pins staggered in 90 degree field; Hexagon pins staggered in 45 degree field

Project 3: Advanced Material Characterization

- Evaluate processing-structure-property correlations
- Evaluate functional response, mechanical robustness & chemical stability

X-ray Diffraction

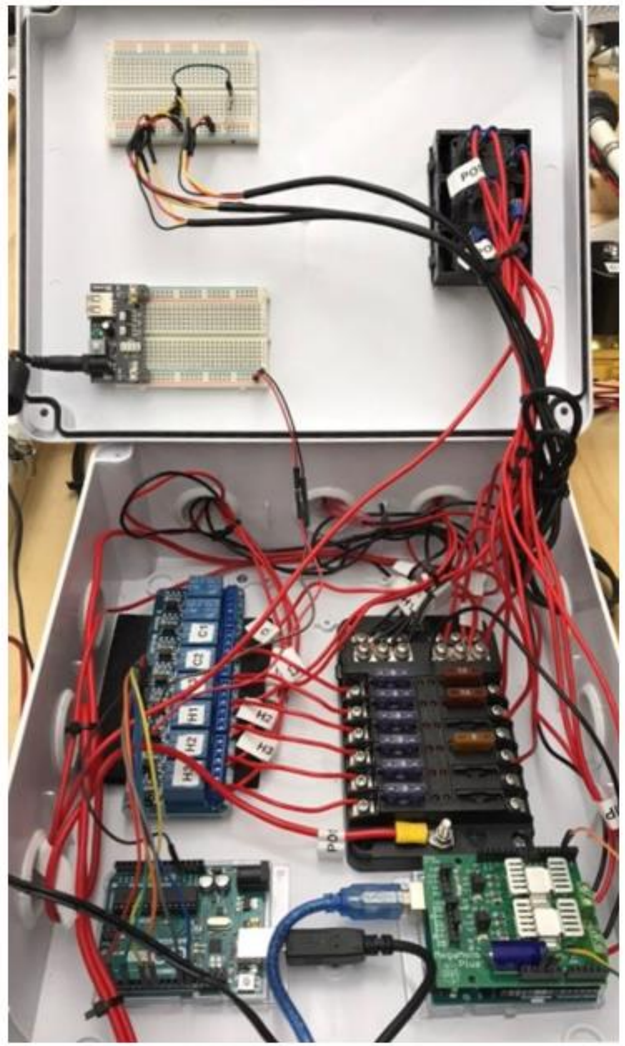
Calorimetry

Scanning Electron Microscopy

Magnetomtry

Project 4: Device Prototyping

Refine & customize design of magnetic cooling device prototyoe



<u>Innovation</u>: microcontrollers dynamically control the timing of valves to regulate flow of heat exchange fluid.

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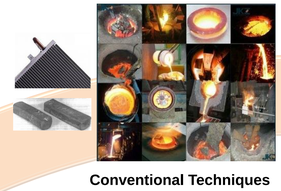

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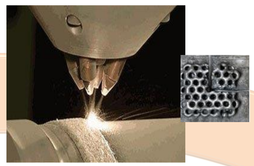

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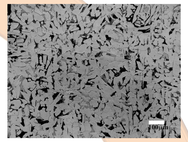

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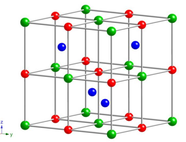

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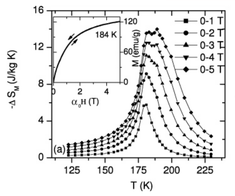

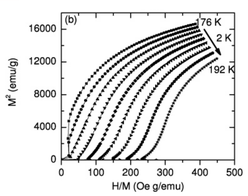

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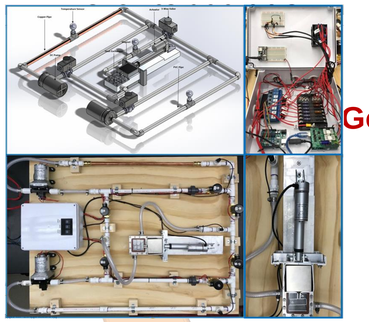

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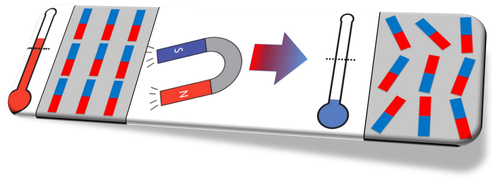

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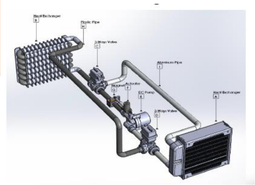

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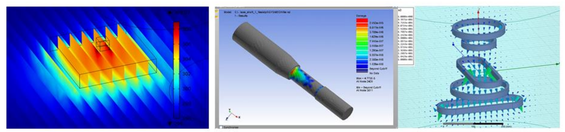

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