2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

All-Metal Induction Cooking

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Oak Ridge National Laboratory
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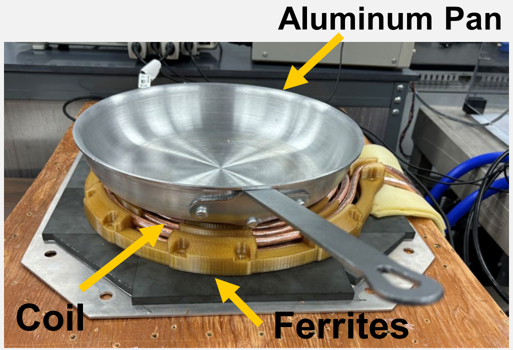
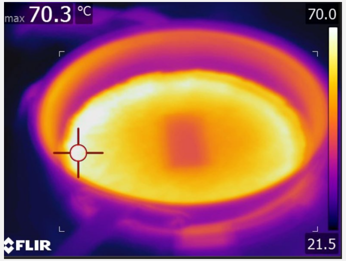
BTO WBS 03.02.02.74

Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

Design and demonstrate an induction cooktop compatible with all types of metallic cookware at a bill of materials comparable to that of incumbent cooking technologies





Thermal image of induction-heated Al-pan

TEAM AND PARTNERS

ORNL:
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Clayton Hickey
Shajjad Chowdhury
Himel Barua

STATS

Performance Period: Oct. 1, 2023–Sept. 30, 2024

DOE Budget: $300k, Cost Share: $0k

Milestone 1: Completion of multi-physics model development

Milestone 2: Completion of conceptual design of the system

Problem

- Induction cooktops directly heat the cookware and consume less electricity; however, induction cooktop–compatible cookware is required
- Induction cooktops capable of heating nonferromagnetic (e.g., aluminum) cookware are not available in the US market
- Induction heating is about three times more efficient than gas cooking and 5%–10% more efficient than conventional electric cooking. The need for compatible cookware is a barrier to its adoption
- This project aims to expand the utility of induction cooking by making it compatible with all types of metals at a price point comparable to that of conventional induction cooking technologies, thereby encouraging more households to switch from gas to induction cooking

Alignment and Impact

- ENERGY STAR estimated that if all cooktops sold in 2021 in the US were of the induction type, meeting the draft criteria, that year's energy cost savings would exceed $125 million and energy savings would exceed 1,000 GWh
- The project will support the DOE Blueprint's strategic objectives to *Increase building energy efficiency* and *Accelerate on-site emissions reductions,* as well as the blue print goals of *equity and affordability*
  - **EE**: Induction heating heats the cookware directly, minimizes heating of other components, and reduces electricity required to achieve target cooking performance.
  - **Onsite Emissions Reduction**: Half the residential buildings in the US rely on gas or other fossil fuels for primary cooking needs, leading to significant on-site carbon emissions. Use of induction cooktops instead of gas cooktops will eliminate the associated on-site emissions, as well as improve air quality and safety
  - **Affordability:** As an increasing number of households move to being all-electric, using induction technology for cooking will reduce energy bills and avoid the added cost of installing a gas line for cooking

ENERGY STAR

Increase building energy efficiency
Reduce on-site energy use intensity in buildings 35% by 2035 and 50% by 2050 vs. 2005

Accelerate on-site emissions reductions
Reduce on-site GHG emissions in buildings 25% by 2035 and 75% by 2050 vs. 2005

Approach

What we propose

An optimized, all-metal–compatible, single coil architecture providing equivalent power to all-metal cookware using the same power electronics with minimum alterations to passive components

Most commercial induction cooktops	Panasonic	Hitachi	Proposed
Only ferromagnetic metals	All-metal–compatible	All-metal–compatible	All-metal–compatible
25–50 kHz	25 kHz (ferromagnetic), 120 kHz (Al/Cu)	Up to 90 kHz	Up to 120 kHz
	Reduced cooking power (about 40% lower) for nonferromagnetic cookware	**Reduced cooking power for nonferromagnetic cookware**	Same cooking power for all types of pans
	Same coil used for both ferromagnetic and nonferromagnetic	**Different coils used for ferromagnetic and nonferromagnetic**	Same induction coil and power electronics

Approach

Electromagnetic and thermal model development → **Conceptual system design** → **Laboratory validation**

Electromagnetic and thermal model development

- Definition of frequency range for heating two representative metals
- Determine pan parameters for circuit simulations
- Survey and simulate different power electronics circuits

Conceptual system design

- Power electronics topology down-selection
- Resonant network design
- Magnetic coil and shielding system design
- Calculate electromagnetic field emissions

Laboratory validation

- Coils and power electronics component procurement and prototyping
- System integration
- Functionality verification
- Performance evaluation

Approach

Date	Tasks	Detailed Tasks
FY24/ Q2	1. Multi-physics model development	1. Multi-physics (thermal and electrical) coil models will be developed to determine temperature rise owing to induction heating of different pan types 2. The operating frequency range required to achieve induction heating for different types of metallic cookware will be determined 3. Power electronics converter topologies will be surveyed and down-selected
FY24/ Q3	2. System conceptual design	1. Simulation studies on the down-selected power electronics topologies 2. Selection of switches and design of filters 3. Accurate power electronics loss models 4. Resonant network design 5. Design of coils and shielding
FY24/ Q4	3. System performance analysis	1. Accurate power electronics loss models 2. Coil Q-factor and loss calculation, control system design, and implementation in simulation models 3. Quantification of system performance

Approach

Date	Tasks	Detailed Tasks
FY25/ Q1	1. Down-selection of the lowest cost, smallest footprint concept	1. Four different concepts that can achieve all-metal induction cooking developed in FY24 will be compared 2. The lowest cost and smallest footprint concept will be down-selected 3. Pan detection algorithms will be simulated
FY25/ Q2	2. Design and procure components	1. Decide on number of turns of induction coil, ferrite dimensions 2. Design matching transformers and inductors 3. Identify opportunities to reduce cost 4. Select and order resonant capacitors 5. Select and order power electronics switches

Approach

Date	Tasks	Detailed Tasks
FY25/ Q3	3. Prototype build, integration, and controls implementation	1. Procure components and assemble system 2. Implement controls 3. Prepare bill-of-materials cost
FY25/ Q4	4. System testing and final report	1. Test system under different conditions–including with different types of metals (ferromagnetic, aluminum, and copper) 2. Prepare final report

Progress and Future Work

Progress

- Surveyed academic journals on all-metal induction cooking, down-selected working concepts, and conducted multiphysics electromagnetic and thermal simulation studies
- Identified the frequency range and coil parameters required to achieve induction heating of nonferrous cookware
- Developed and simulated four concepts that can achieve induction heating of nonferrous cookware
- Down-selected one concept and completed an initial design
- Developed and implemented algorithms to achieve sufficient heating in case of improper pan placement
- Assembled an initial proof-of-concept induction coil and resonant network and verified the technical feasibility of heating nonferromagnetic cookware

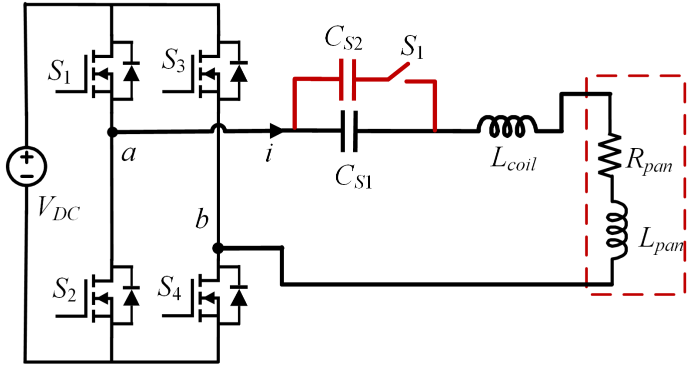
Progress and Future Work

Identification of technical barriers

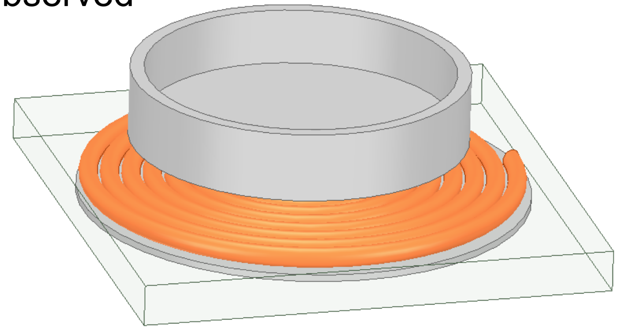
- Parameters of an induction coil designed for heating ferromagnetic cookware were identified
- Simulation models for operation of the induction coil with ferromagnetic and nonferromagnetic cookware were developed and compared

Observations

- Very high frequencies (1 MHz) may be required
- Prohibitively high voltage across the resonant capacitor was observed



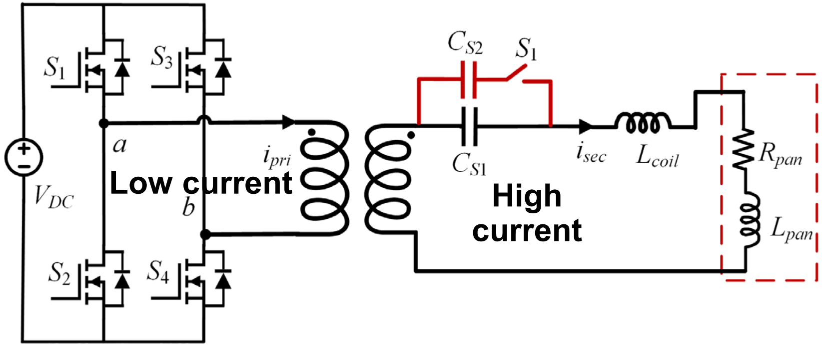
Coil diameter [mm]	Ferromagnetic pan	Nonferromagnetic (aluminum) pan
Operating frequency [kHz]	20	1000
Number of coil turns	100	100
Coil current [A]	4.3	10
Heating power [W]	1043	926
Voltage across the capacitor [kV]	0.64	23.7

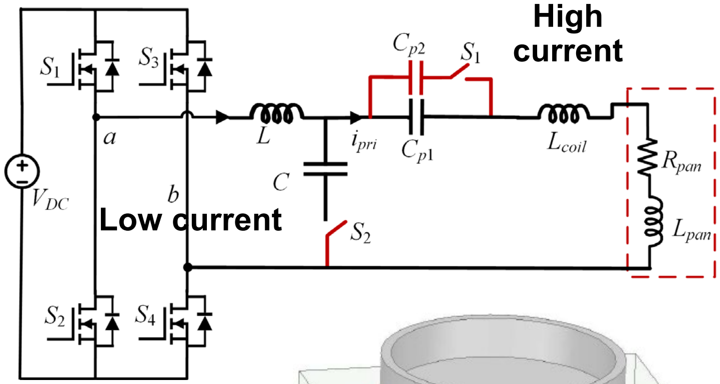


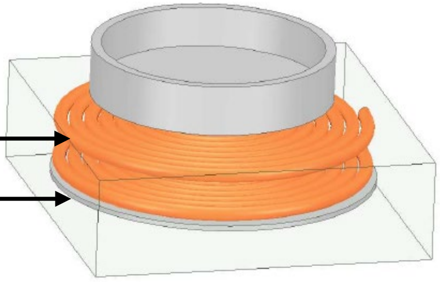
Progress and Future Work

Identification of solutions

- It was found that increasing the induction coil current can reduce the capacitor voltage and required operating frequency
- Because large currents cannot be drawn from the supply, a circuit topology that can boost the current provided to the induction coil is required
- Three different approaches for boosting the current were evaluated
  - Use of a matching transformer
  - Use of a resonant network
  - Use of two induction coils

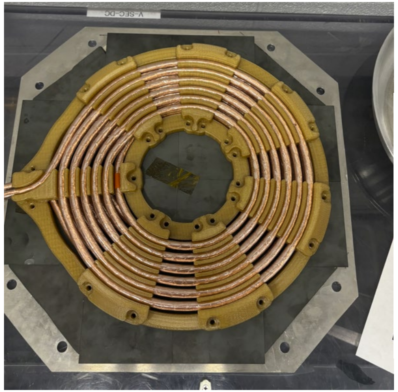


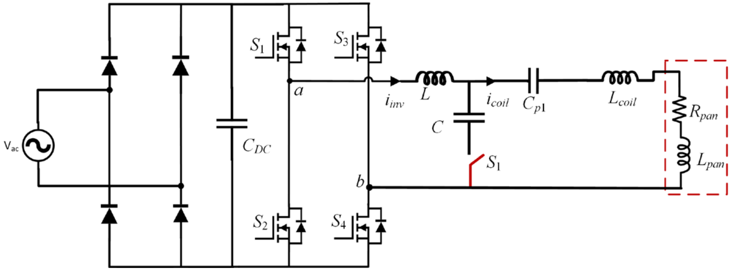




Progress and Future Work

Proof of concept coil design to demonstrate heating of nonferromagnetic pans



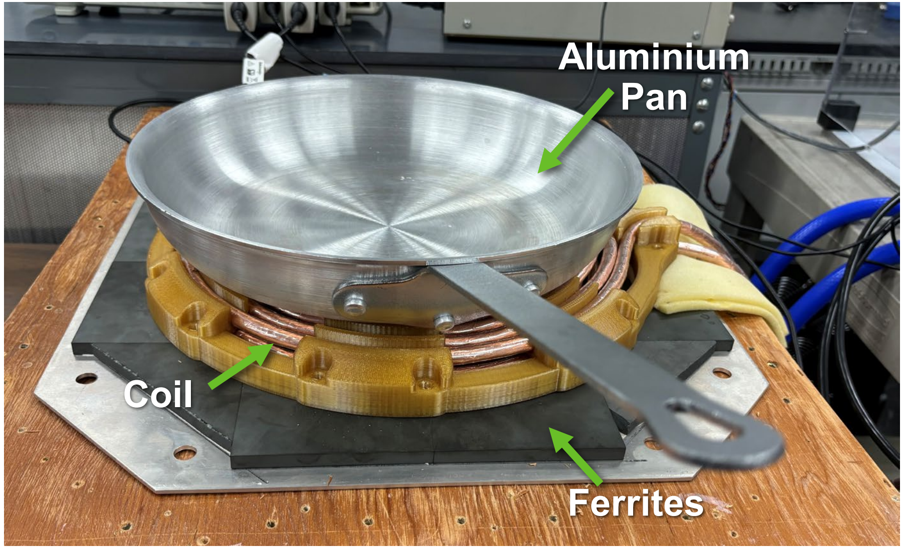


S_1: Closed for all-metal heating
Open for ferrous metal heating

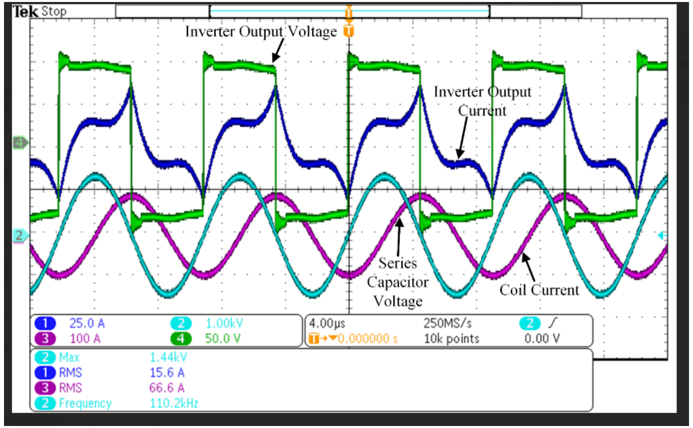
	Aluminium	Ferrous
Coil diameter [mm]	300	300
Operating frequency [kHz]	110	80
Number of coil turns	12	12
Coil inductance, uH	21	35
Pan resistance referred to coil (ohm)	0.1	3
Coil current, rms [A]	101	19
Input current [A]	10.1	19
Expected power, kW	1	1

Progress and Future Work

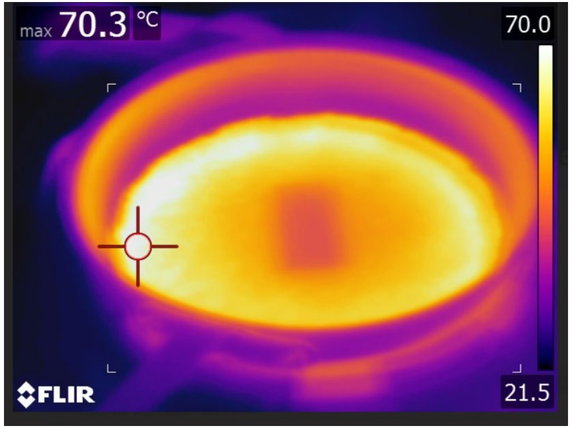
Laboratory demonstration



Prototype coil



Measured waveforms at 750W input power



Thermal image of induction heated Al-pan

Progress and Future Work

Technical barriers and risks

Risk	Mitigation plan
The bill-of-materials cost of the all-metal induction cooktop may be high compared with the cost of incumbent induction heating systems	Investigate methods to reduce cost (use of one-switch power electronics converters, coil topologies with reduced ferrites)
Electromagnetic field emissions when operating with nonferrous cookware may be high	Implement shielding and control systems

Progress and Future Work

Future work

- Identify the lowest-cost, smallest-volume system among those studied in FY24
- Optimize components so that they that have a footprint comparable to that of a commercial induction cooktop
- Procure and/or build the system components
- Develop and implement algorithms that can adjust the operating point depending on the pan material and correct for improper placement
- Complete prototype integration and testing
- Produce final report on the comparison of the all-metal cooktop with conventional induction cooktops in terms of bill of materials and economic feasibility

Thank you

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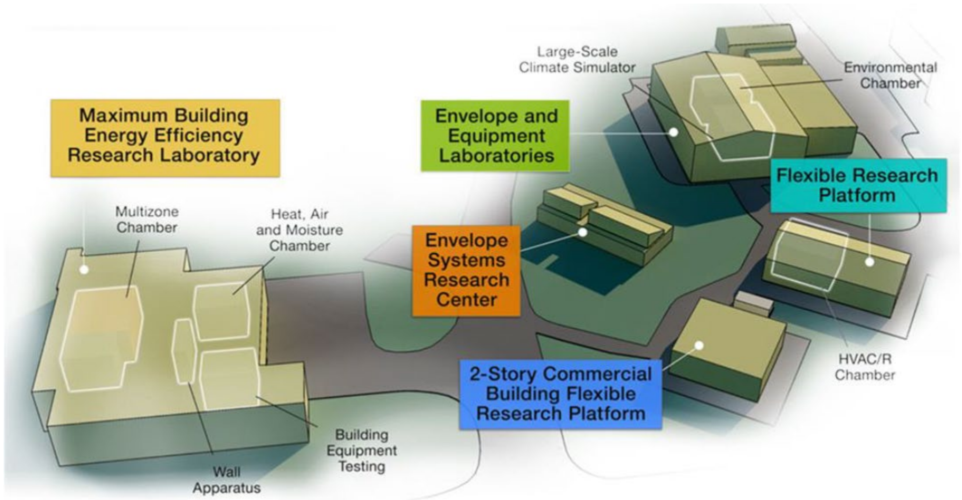

The **Building Technologies Research and Integration Center (BTRIC)** at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

Reference Slides

Control algorithm that ensures uniform heating

- The heating of nonferromagnetic pans is highly sensitive to their placement over the induction coil
- An innovative control algorithm that adjusts the power converter operating points (duty cycle and switching frequency) to achieve the desired heating irrespective of pan placement was developed and verified through simulation and laboratory tests

Project Execution

	FY2024				FY2025			
Planned budget	$300,000				$323,000			
Spent budget	$192,791.56							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work								
Q3 Milestone: Completion of multiphysics model development for the all-metal inductive heating system								
Q4 Milestone: Completion of conceptual design of the system								
Current/Future Work								
Q1 Milestone: Two concepts that can perform all-metal induction cooking with minimum bill-of-materials will be downselected								
Q2 Milestone: Pan detection algorithm development and initial lab verification								
Q3 Milestone: Induction coil, resonant network, and power electronics build completed								
Q4 Milestone: System integration, testing, and reporting								

GNG 1: If detailed multi-physics finite element and circuit simulations indicate viability of proposed concept proceed with detailed hardware design and development.

Team

Vandana Rallabandi

ORNL R&D Staff

Project role:
PI and electromagnetics design

Subho Mukherjee

ORNL R&D Associate

Project role:
Power electronics converter and controls design

Jon Wilkins

ORNL Technical Staff

Project role:
Coil prototyping and assembly

Clayton Hickey

ORNL Technical Professional

Project role:
System assembly and mechanical design