High Efficiency Waste Heat Harvesting Using Novel Thermal Oscillators

Contract Number: N/A

University of Pennsylvania; Rutgers University; Yale University

08/2018-07/2020

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U.S. DOE Advanced Manufacturing Office Program Review Meeting

Washington, D.C.

July 17-19, 2018

Overview

Timeline

- Recommended for award: 03/18
- Award relocation and negotiation in progress
- Anticipated performance period: 08/2018-07/2020complete

Budget

	FY 18 Costs	FY 19 Costs	FY 20 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	_	$480K	$480K	$960K
Project Cost Share	_	$120K	$120K	$240K

Barriers

- High performance pyroelectric harvesting of low-grade waste heat requires efficient, simple thermal switching to control heat flows.
- Suitable thermal switches have yet to be developed.

Partners

- University of Pennsylvania (Lead)
  - Materials processing
  - Device fabrication and characterization
- Yale University
  - Materials synthesis; Modeling
- Rutgers University
  - Device fabrication and characterization

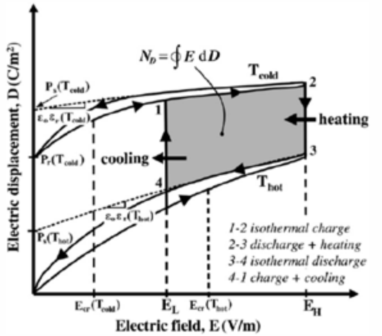
Project Objective(s)

- Pyroelectric (PE) waste heat harvesting is compelling:
  - Current PE materials are intrinsically capable of efficiencies that eclipse current thermoelectric materials.
- PE harvesting requires ***periodic*** variation of the temperature of a generating device placed in contact with a ***steady*** heat source.
- Efficient and sustained generation of such temperature variations in PE devices is the critical barrier to practical PE waste heat harvesting.
- **Objective**: Enable practical energy recovery from low temperature waste heat with unprecedented efficiency using pyroelectric materials in manufacturing-relevant settings.
  - Approach: Develop and model switching technology relevant for manufacturing
    - Passive and active switching
  - Target: "Bolt-on" devices; $1/Watt, 35% efficiency (Carnot).

Technical Innovation

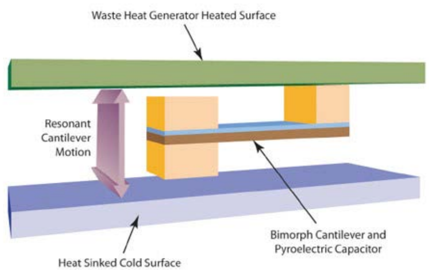
- PE harvesting has been explored largely using MEMS devices and large-scale thermal cycling by pumped fluids.
- **Limitations**:
  - MEMS devices: Complex; costly; not readily scalable.
  - Pumped fluids: Large frictional losses; not easily deployed.
- **Proposed Approach**: Develop simple thin planar devices that can be "bolted on" to warm surfaces
- Thermal switching in planar devices by development of new, scalable thermal management solutions:
  - Shape memory contact switching (passive)
  - Electrohydrodynamic switching (active)
- Critical Innovations:
  1. Scalable fabrication.
  2. Efficient switching.
  3. Geometry enables easy deployment/installation.

Technical Innovation



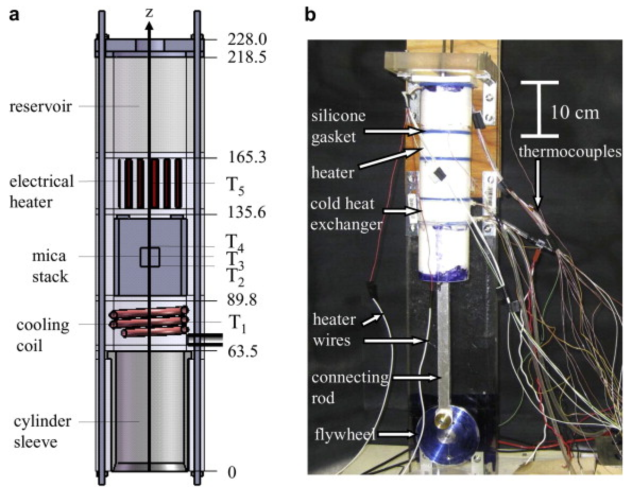
Navid, A. et al. *Int. J. of Heat and Mass Trans.* (2010)

MEMS device



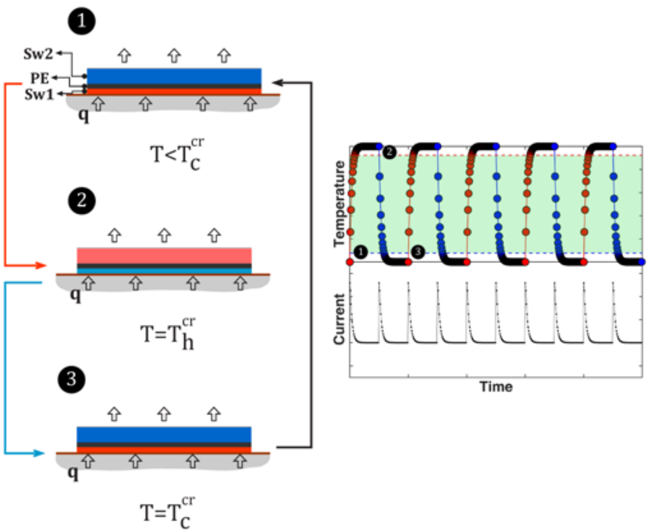
Datskos, P. G. et al. International Society for Optics and Photonics (2011)

Pumped fluid device



Pilon, L. et al. *Applied thermal engineering*, **30**(14): p. 2127-2137 (2010)

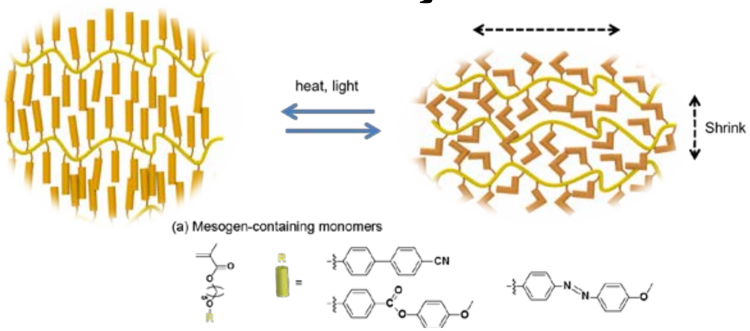
Thermal oscillator planar device

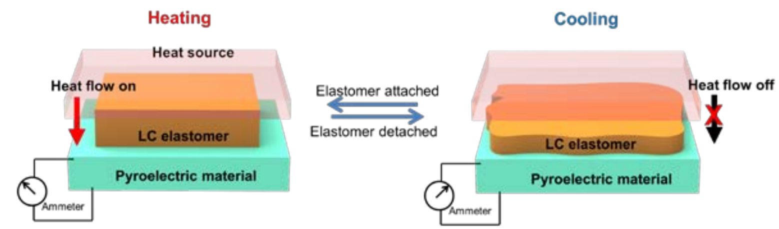


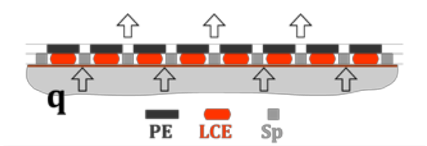
KEY CONCEPTS : Pyroelectric energy generation from waste heat is compelling due to impressive intrinsic efficiencies which far surpass thermoelectric conversion. The inability to readily generate sustained temperature cycles in compact systems represents the single biggest challenge to practical energy recovery using pyroelectric devices today. Prior research efforts have explored MEMS devices and fluid circulators for thermal switching. The proposed work will develop unique “thermal oscillator” switches to enable practical and efficient planar PE energy harvesting devices.

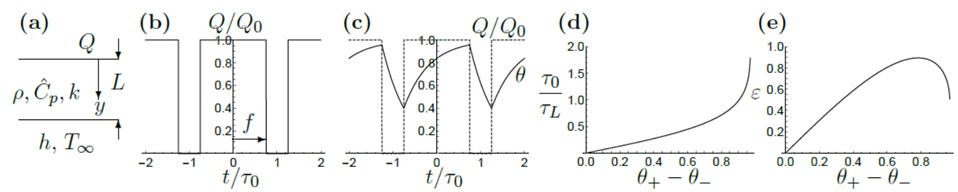
Technical Approach A

- Thermally actuated shape memory switches

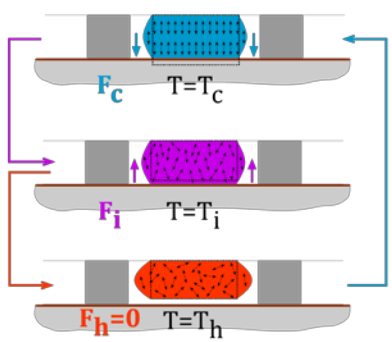








Modeling: *Lumped*, *distributed parameter*, and *multiscale* calculations.

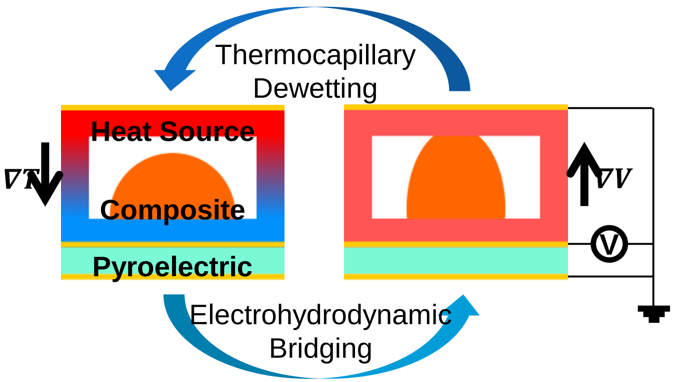


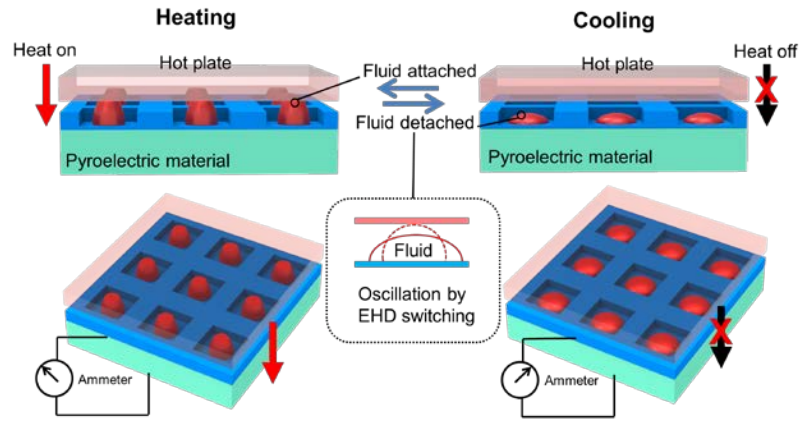
Osuji: Processing of LCEs; Device fabrication and characterization; Thermophysical property optimization.
Zhong: Molecular engineering and synthesis of LCEs; Thermophysical property optimization.
Loewenberg: Modeling of transport properties

Shape memory passive switching: Shape memory effect (SME) in aligned liquid crystalline elastomers (LCEs) produce reversible dimensional changes on heating and cooling above LC clearing temperatures.
Materials and Methods: Siloxane polymers; cyanobiphenyl and azobenzene mesogens; magnetic field alignment. P(VDF-TrFE) and other PEs. Transport modeling.
Shape Memory Thermal Oscillator (SMTO) Challenge: Engineering shape memory effects to reversibly make and break thermal contacts to control heat flow to a pyroelectric layer.

Technical Approach B

- Electrically actuated thermal fluid switches





Singer: Formulation of thermal fluids; Device fabrication and characterization; R2R device fabrication; Optimization of thermophysical properties.
Osuji: Characterization of thermal transport.
Loewenberg: Modeling of transport properties.

Electrohydrodynamic active switches: Device utilizes field present in Olsen cycle. Field application drives electrohydrodynamic bridging to make thermal contact with the heat source. Field removal breaks thermal contact due to thermocapillary dewetting.
Materials and Methods: Nanoparticle filled silicone and other fluids for active thermal fluid. P(VDF-TrFE) and other PEs. Transport modeling.
Electrohydrodynamic Thermal Oscillator (EHTO) Challenge: Engineering thermal fluids for desired thermophysical properties and responsiveness.

Results and Accomplishments

- Material selection complete for initial thermal fluid and LCE preparation.
- Preliminary calculations demonstrated for lumped parameter analysis.
- Award currently in negotiation.

Transition (beyond DOE assistance)

- Technology readiness (TR) level of 4-5 anticipated by project end.
- Intellectual property licensing or recruitment of further development funding beyond 07/2020.

Questions?