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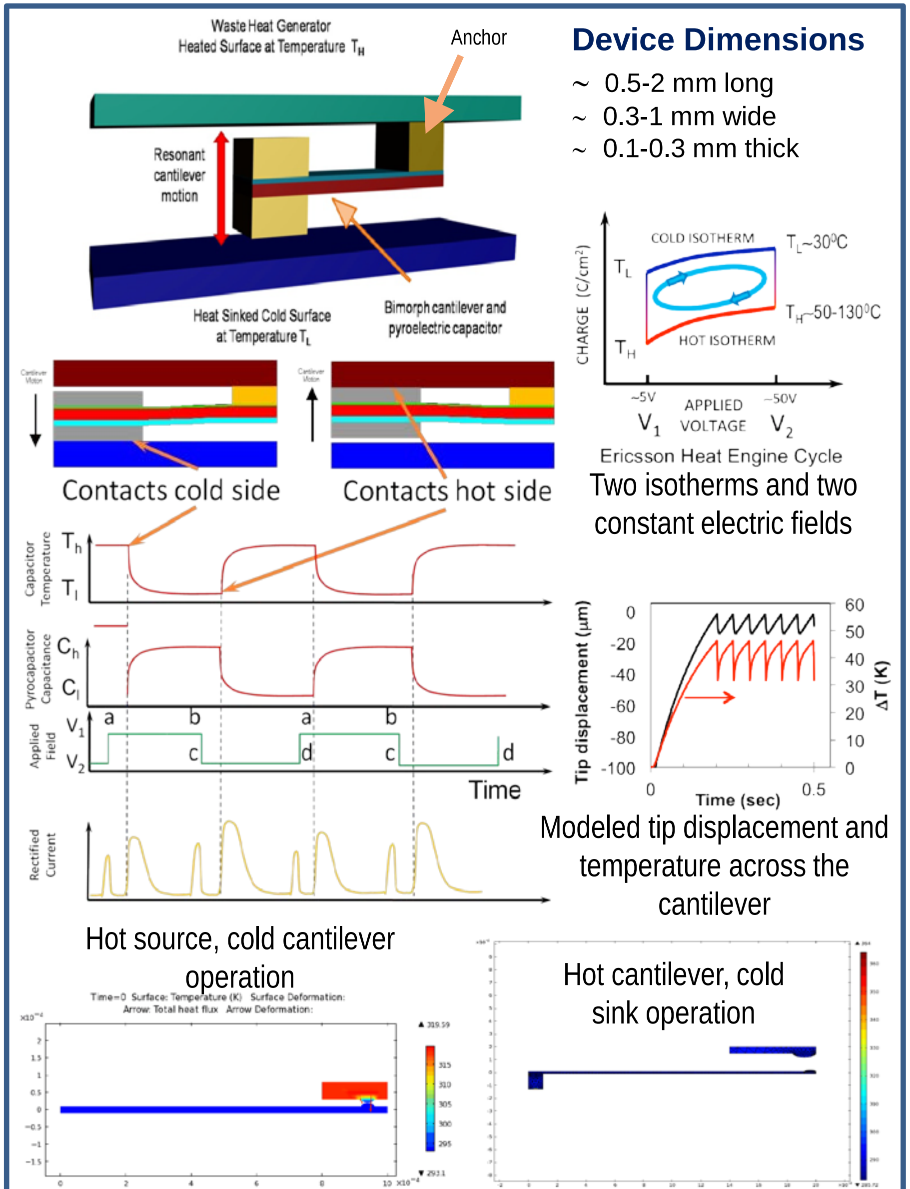
Pyroelectric Thermal Energy Harvester



- Unique features

$$\eta_{\text{Device}} = \frac{W_{out}}{Q_{in}} = \frac{W_E - W_P}{C_v \Delta T + Q_{\text{int}} + Q_{\text{leak}}}$$

- Traditional pyroelectric (PE) power generators have low generation efficiencies
  - ✧ Large energy cycling power losses (W_P) and leakages (Q_{leak})
  - ✧ Low overall power conversion efficiencies - 10-25% of the Carnot efficiency
- Self resonating PE generators have the potential for very high efficiency
  - ✧ Heat source is used as the temperature cycling power source (W_P~0)
  - ✧ Vacuum or low pressure encapsulation to minimize heat leakages (Q_{leak}~0)
  - ✧ High conversion efficiencies - >80% of the Carnot efficiency

$$P(t) = \Delta V_a I_p(t) = \Delta V_a A p \frac{dT}{dt}$$

- Efficient power generation requires:
  - ✧ Operation at high frequency is the key to high rate of heat conversion and generating large amounts of electrical power
  - ✧ Optimal choice of pyroelectric material with large pyroelectric coefficient and wide operating temperature range
  - ✧ Efficient transfer of thermal energy from heat source to cold sink

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Technical Details

- Output per device = 1 -10 mW – 1mm long, 0.5 mm wide, 0.3 mm thick
- Peak power = 5-50 watts – 10 x 10 x 0.2cm^3 array (100 x 50 devices)
- Heat Source temperatures = 50-1000^{0}C
  - Many pyroelectric materials are stable up to 1200^0 C or more
- Heat Sink temperatures = 30-100^{0}C
  - Will work with small temperature differentials > 20^0 e.g. $\Delta T = 50^0 - 30^0$
- Size – Harvester can be fabricated into arrays from 1 mm^2 up to several cm^2
  - Arrays can be stacked to make much larger arrays
- Efficiency – Potential efficiency is 80% of Carnot
  - Present techniques for energy conversion – thermoelectric, piezoelectric and pyroelectric all suffer from low thermal to electrical energy conversion efficiency – 5% at most for commercially available systems - Snyder(2009)
  - Pyroelectric converters are relatively unexplored – possible opportunities for 15-20% system conversion efficiencies – Sebald (2009)
- Durability – should last > 10-20 years
  - Technology is similar to that found in Texas Instruments DLP theater displays – operating life shown to be > 100,000 hours
- Projected Cost - $50-100 for a 10 cm^2 device with a market > 1 million/year
  - Gives $1/peak watt for a 50 watt module

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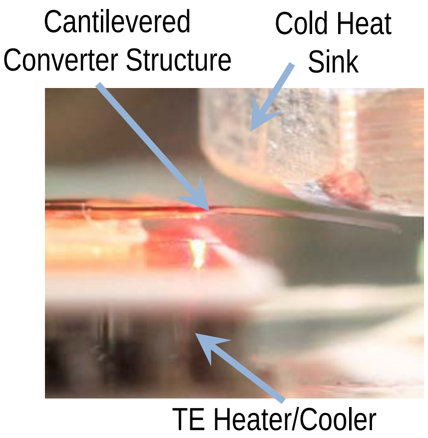
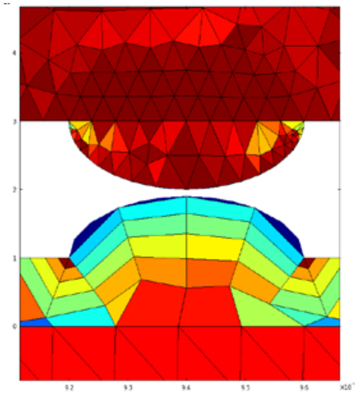
Development Needs

- Concept feasibility demonstrated at the lab bench level
- Efficiency and electric current generation is driven by energy transfer across the cantilevered structure
- Need to demonstrate high thermal conductance across the cantilever/heat source and heat sink interfaces
- Need to control radiation losses across vacuum gaps
- Need pyroelectric materials with large pyroelectric coefficient over a wide temperature range
- Thermal to mechanical cantilever motion well modeled – need to model full pyroelectric capacitor and energy extraction electronics
- Need to build a working bench top prototype to demonstrate efficiency and scalability
- Development and scaling will demonstrate 1 W lab scale device, next level development will get to 50-100 W arrays.
- DOE funded thermoelectric development work for automotive applications showed feasibility of ~ 1 kW converters



Self resonating cantilever
f ≈ 20 Hz



Modeling cantilever heat source interface