# Reliability Aspects of Piezoelectric Thick Film Based Energy Harvesters

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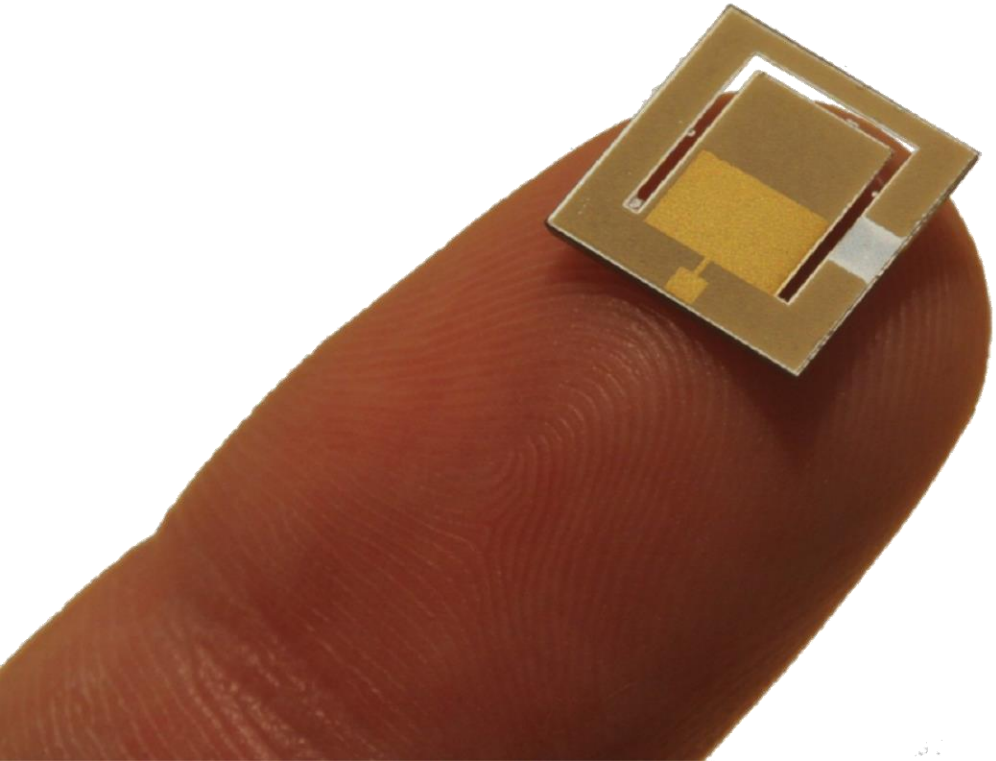

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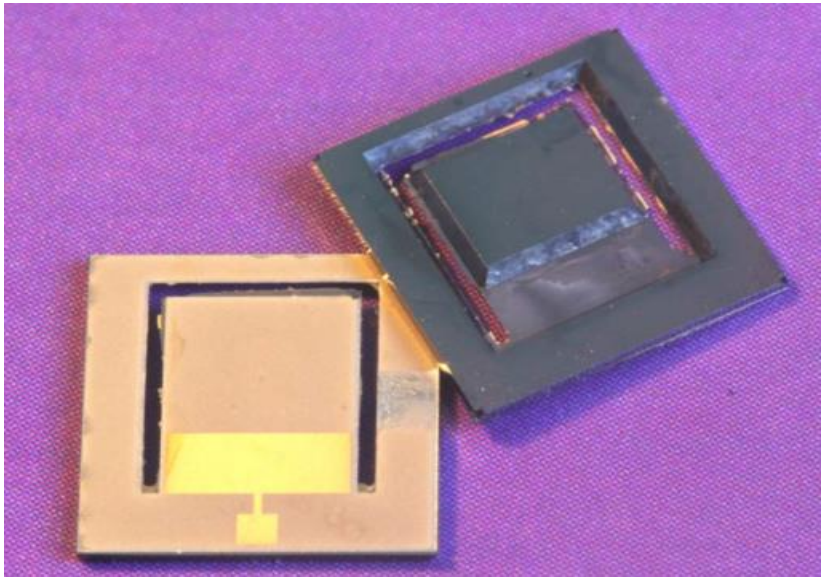
# Reliability and Lifetime of the Energy Harvesters are Key Issues to Replace Batteries and Cables

- Drive to deploy more sensors in remote areas
  - Cables are difficult and costly
  - Battery replacement is a burden

→ Harvest energy from ambient sources using energy harvesters

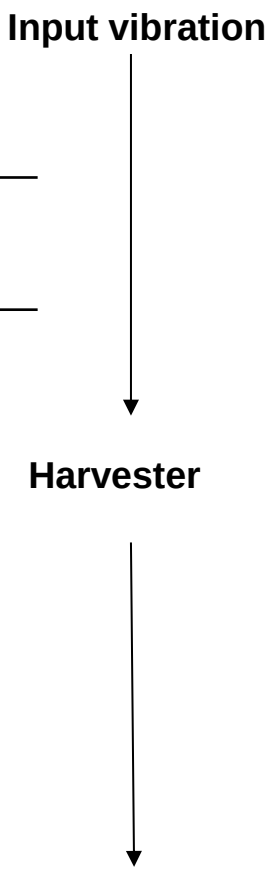


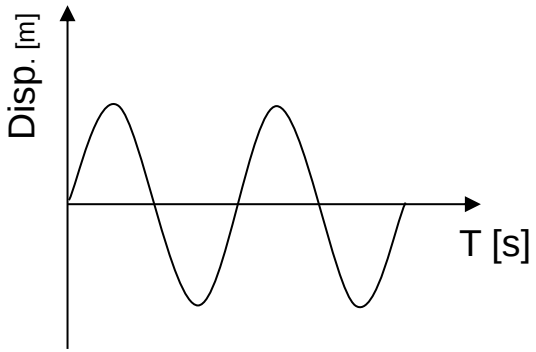
*A. Lei et al. IEEE MEMS 2011*

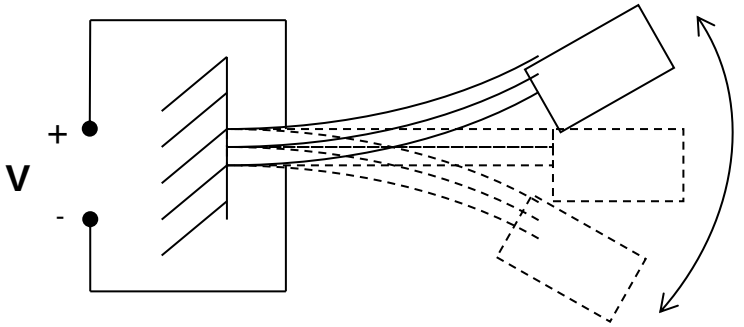
# Harvest Energy from Vibrations

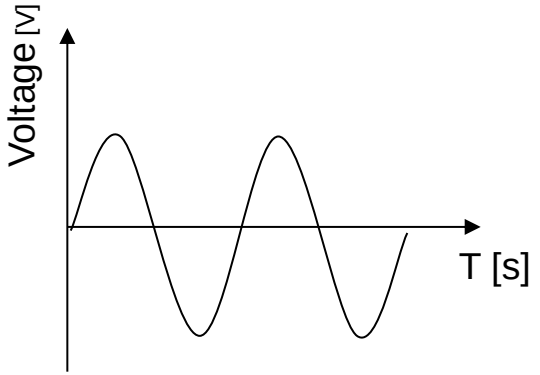
| Vibration source | A [$m/s^2$] | $F_{peak}$ [Hz] |
|---|---|---|
| Car engine compartment | 12 | 200 |
| Blender casing | 6.4 | 121 |
| Clothes dryer | 3.5 | 121 |
| Small microwave oven | 2.5 | 121 |
| Windows next to a busy road | 0.7 | 100 |
| CD on notebook computer | 0.6 | 75 |

*Roundy et.al.*



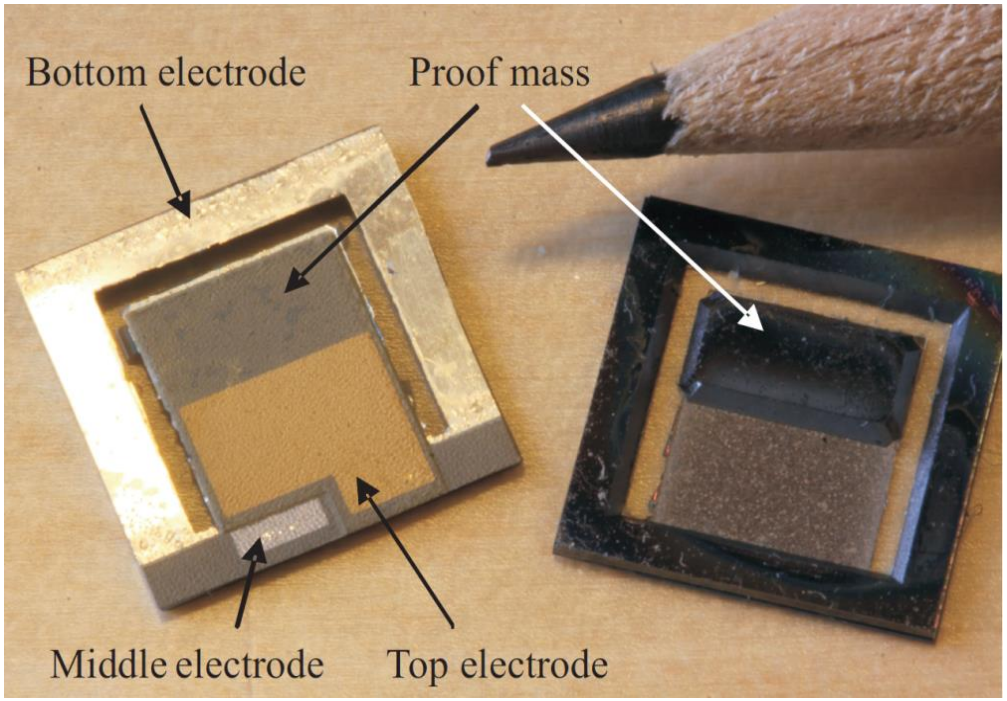



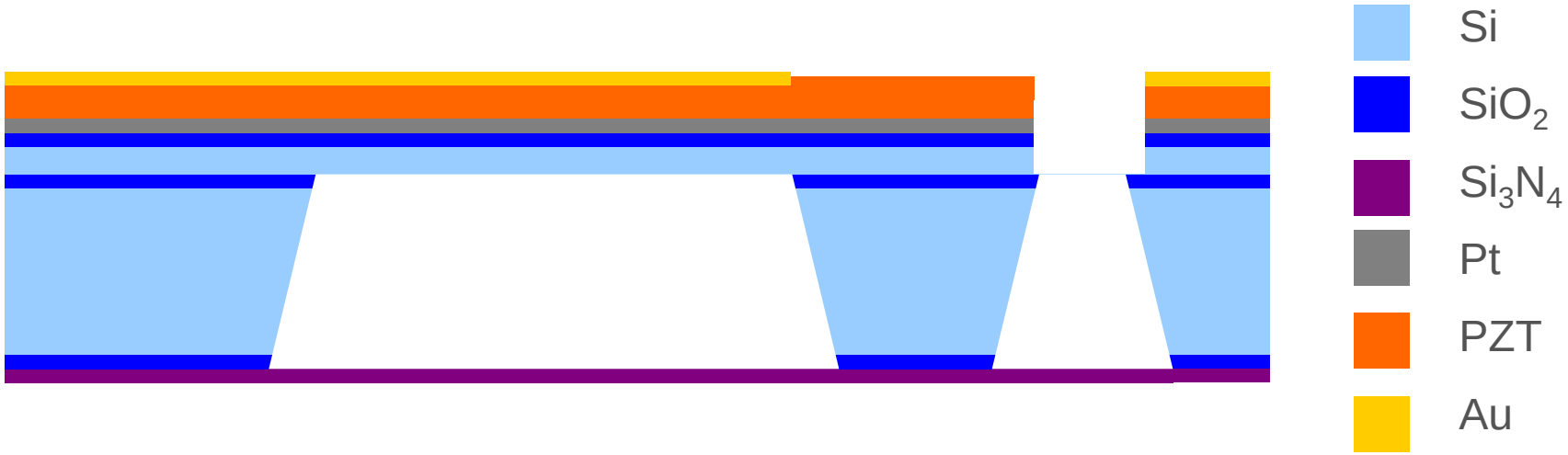
# Fabricated Energy Harvesters

- PZT thick film energy harvesters
  - PZT screen printing
  - MEMS integration
- Two types:
  - Unimorph, silicon/PZT
  - Bimorph, PZT/PZT
- Dimensions:
  - Harvester size: 10 mm X 10 mm




*R. Xu et al. JMM 2012*

# Example of the Fabrication Process



# Reliability Testing

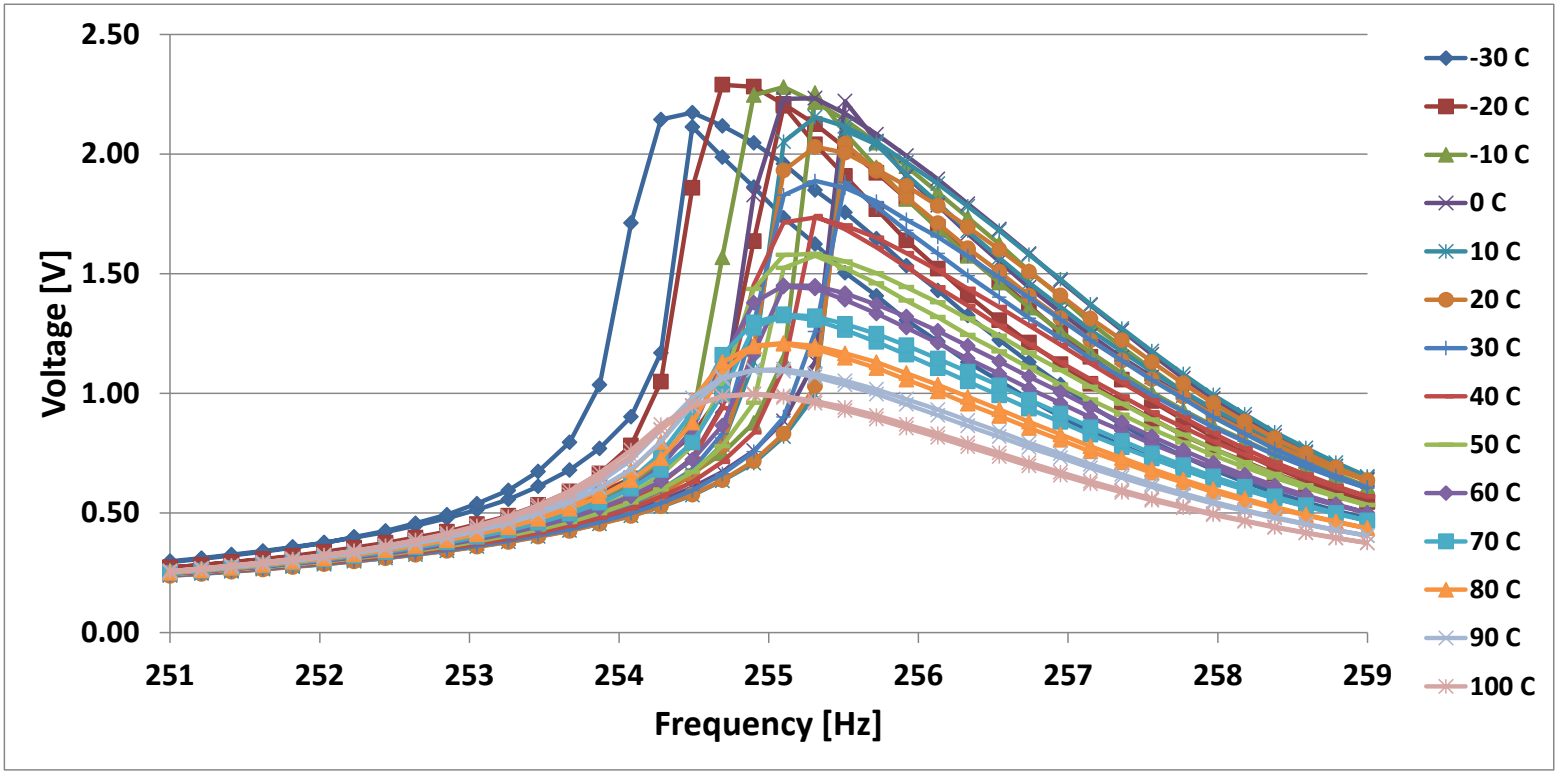
- Temperature is the most used acceleration factor to determine the lifetime of the device
- Investigate performance over a temperature range
- Determine degradation curves over time

# Test Setup

- Setup
  - Shaker mounted in climatic chamber
  - Harvester and fixture mounted on the reference accelerometer
  - Temperature sensor close to the tested harvester

# Measurement Data

- PZT-PZT bimorph harvester, chip 1



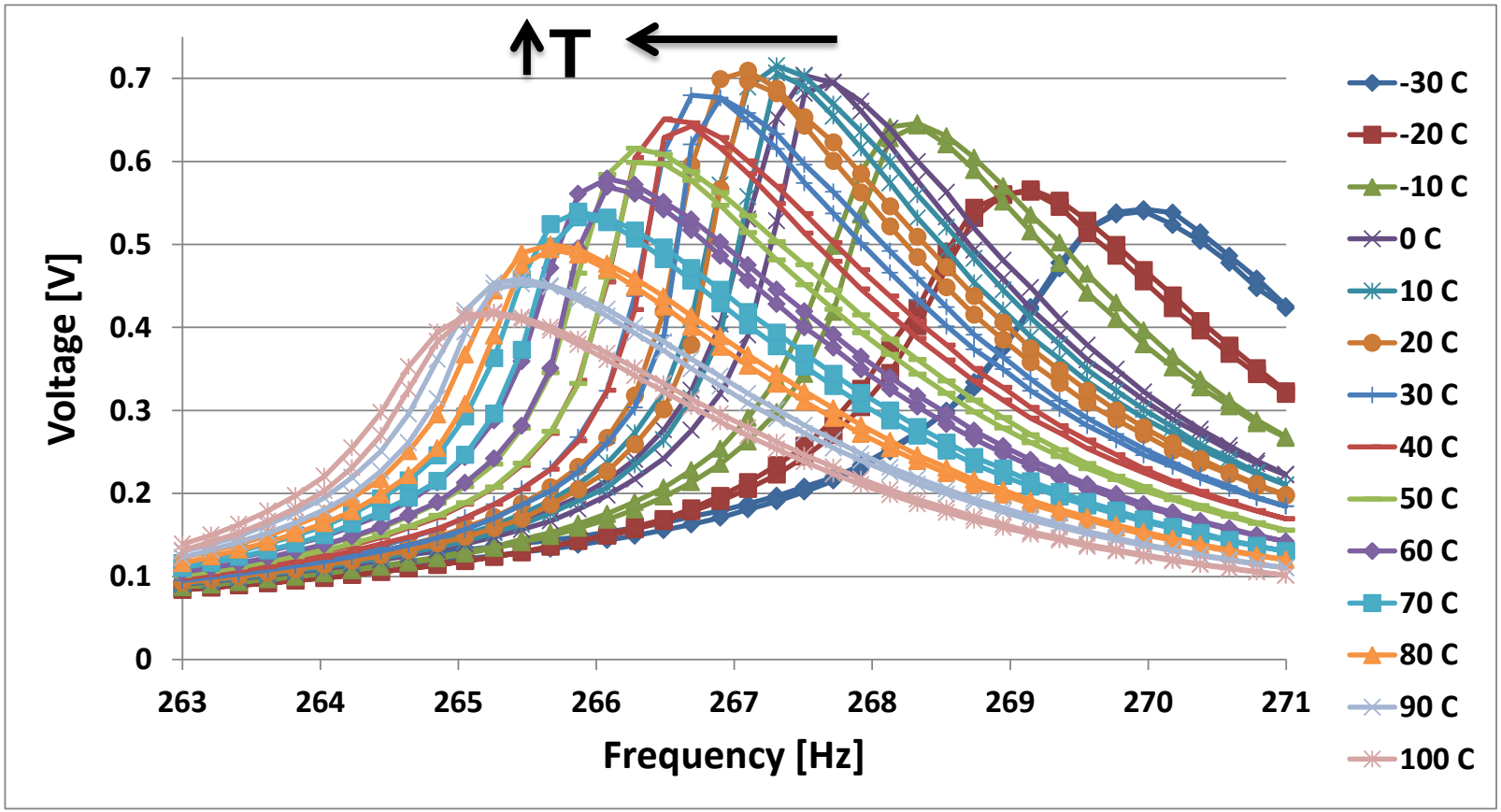

Measurements made at 0.1 *g*

Frequency sweep with 0.2 *Hz* resolution

Resonant frequency and open circuit voltage are key performance indicators

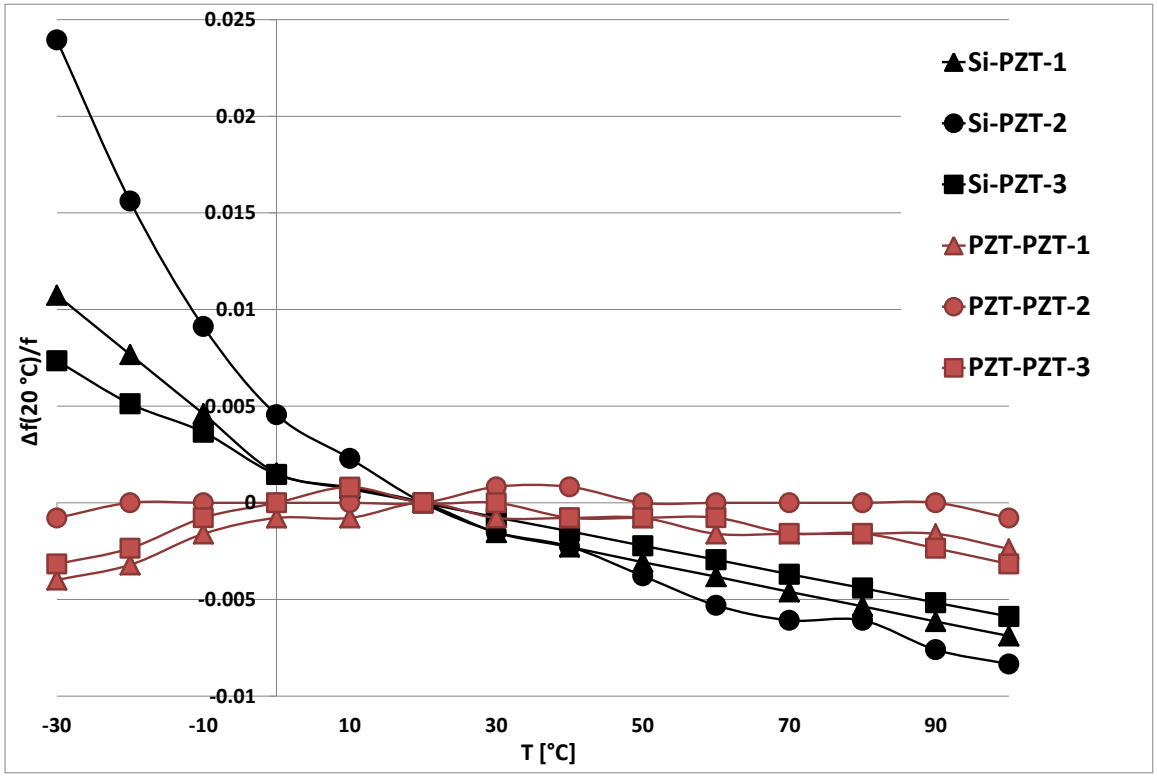
# Measurement Data

- Si-PZT unimorph harvester, chip 1




- Resonant frequency changes with temperature
- Open circuit voltage at resonance changes with temperature

# Change in Resonant Frequency

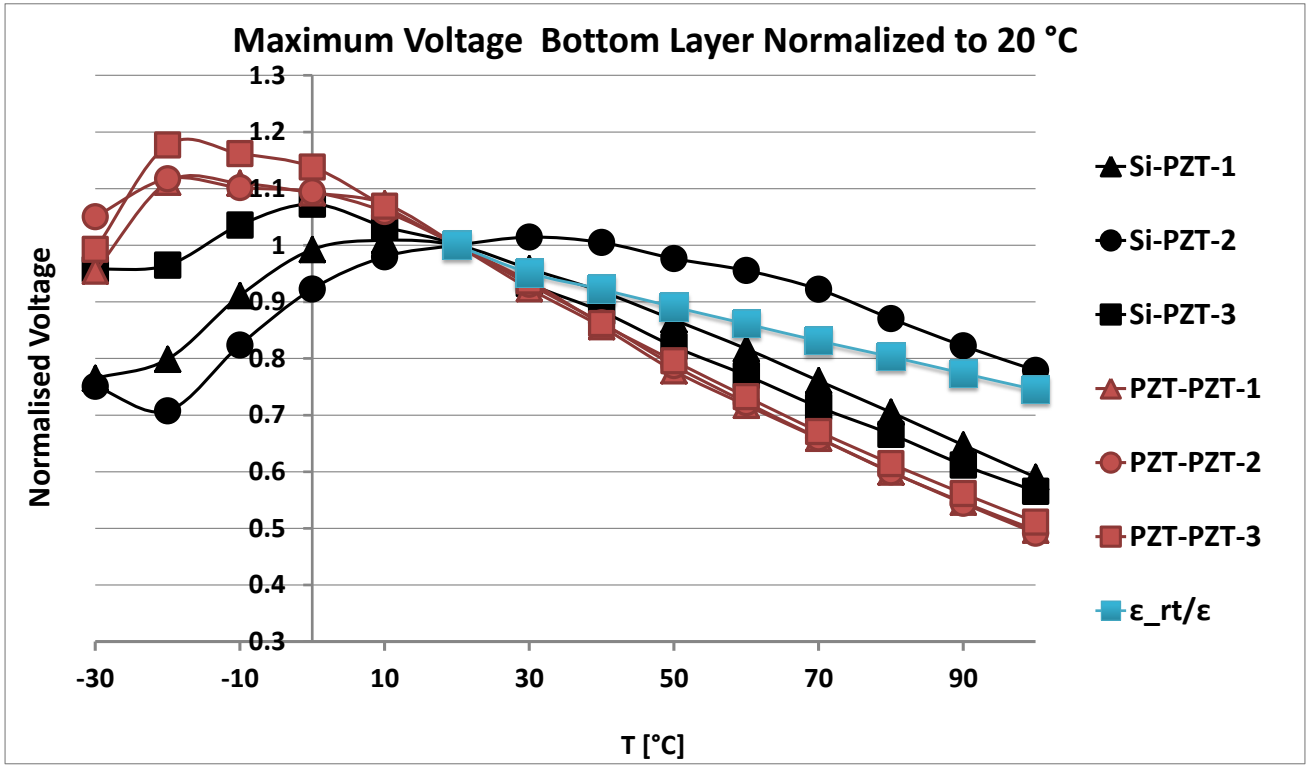



## Trends

- Si-PZT: Decrease in resonant frequency when temperature increases
- PZT-PZT small variations
- Below 20 °C variation in results are larger
  - Impact from change in humidity or the fact that ice forms on the harvester surface

Explanations:
Stiffness decreases with increasing temperature and decreases the resonant frequency
Small variations for PZT-PZT possible good matching of layers

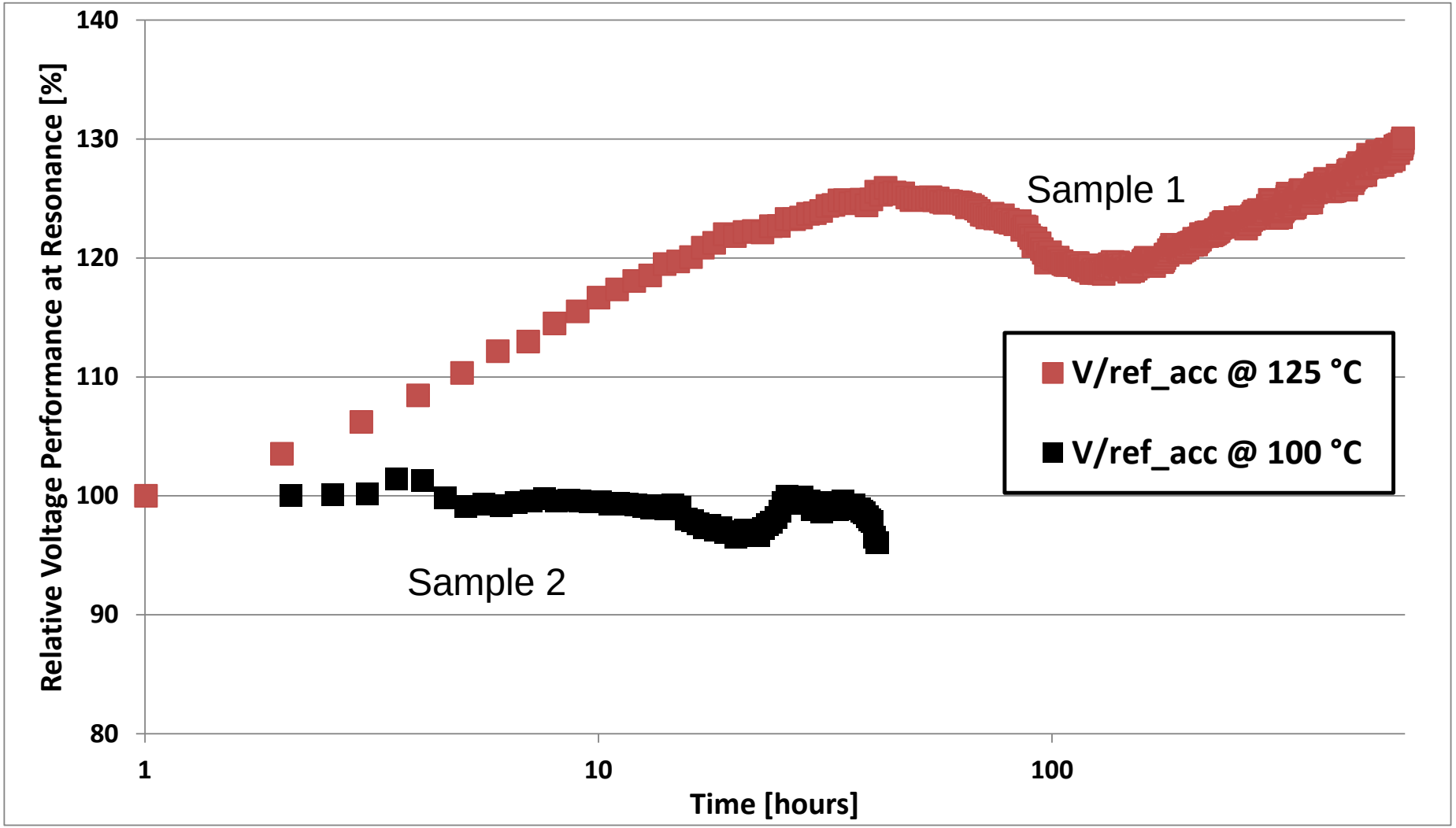
# Change in Voltage at Resonant Frequency



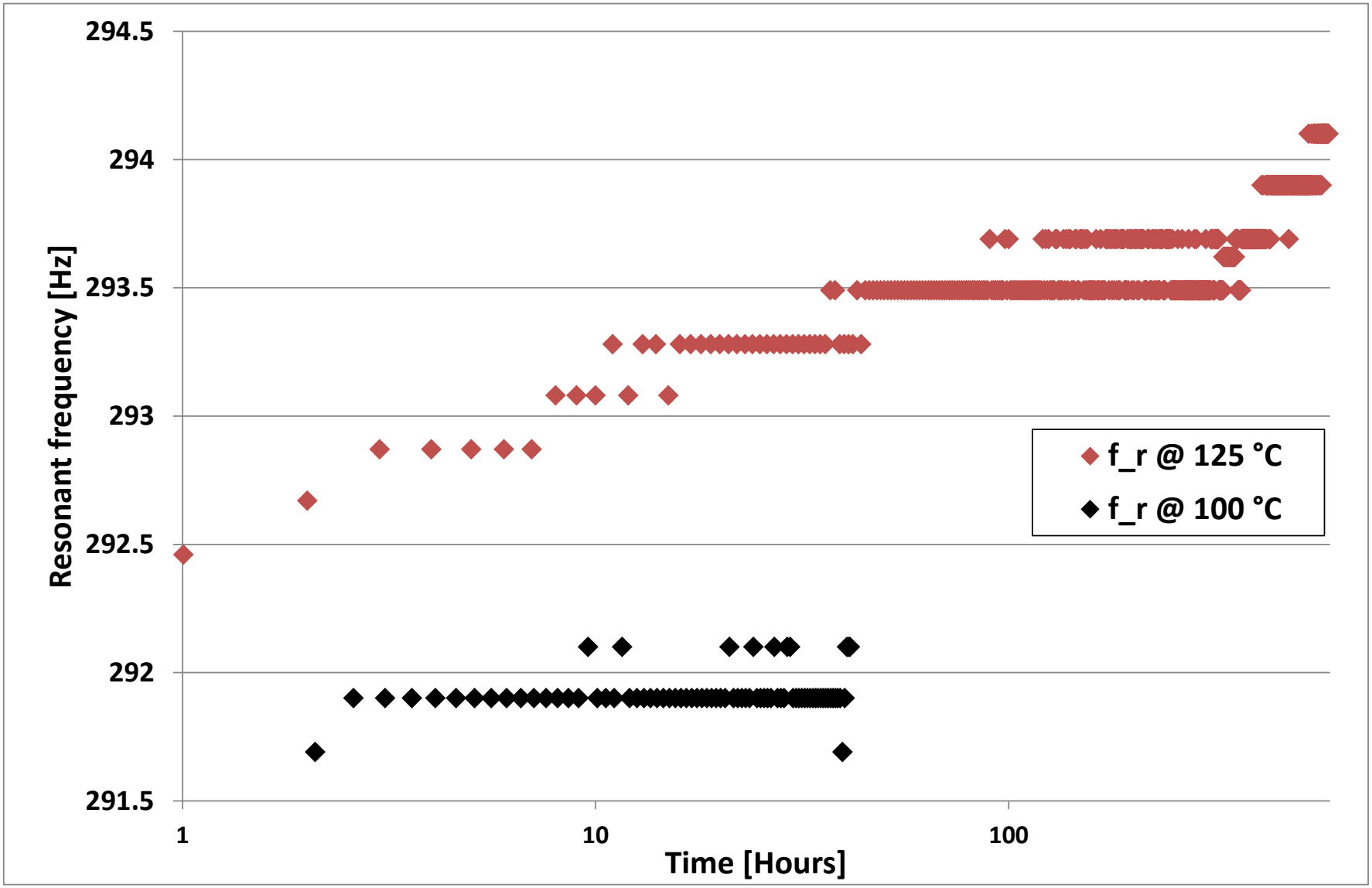

Decrease in voltage can partly be explained by an increase in the permitivity.
Other contributions could be change in the coupling factor, damping and Youngs modulus

The harvesters are working satisfactory below zero, where batteries do not function. Potential placement in harsh environments

# Relative Voltage Performance over 600 hours



# Resonant Frequency over 600 hours



# Conclusion

- The surrounding temperature has a significant impact on the performance of the energy harvesters
- The two types of harvesters do not have the same shift in resonant frequency over temperature
- Open circuit voltage decreases for temperatures over 20 °C for both harvester types
- Increase in permittivity explains part of the decrease in voltage.
- Good stability @ 125 °C for ~ 600 hours and @ 100 °C for ~ 50 hours

## Co-workers

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- Ruichao Xu

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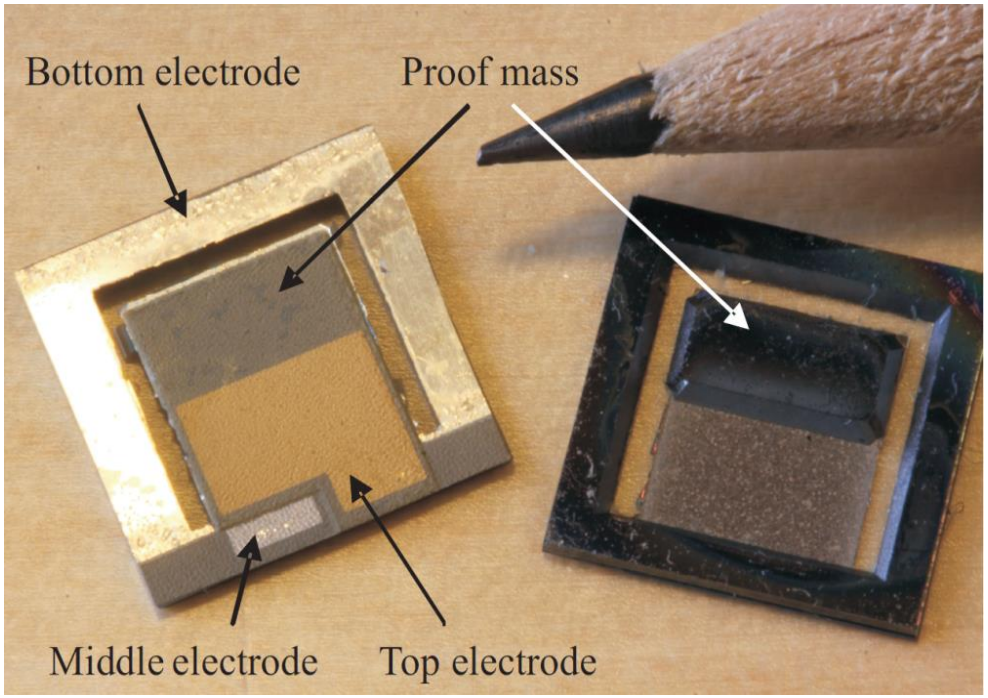
- Anders Lei
- Erik V. Thomsen




*R. Xu et al. JMM 2012*

Thank you for your attention!