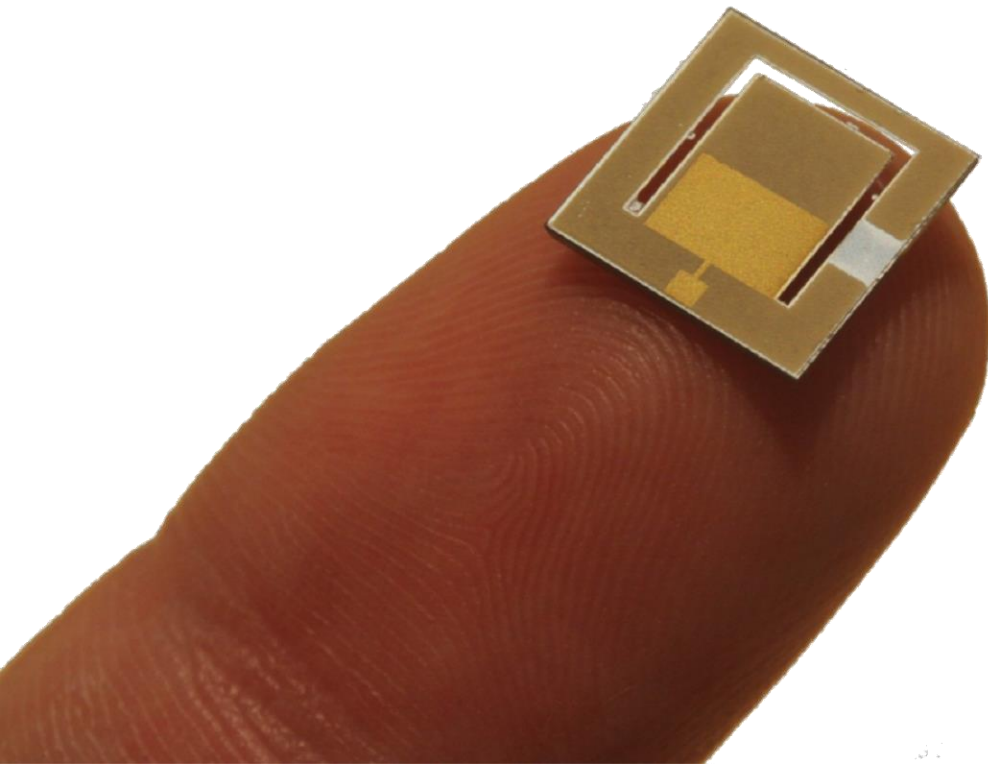


Reliability Aspects of Piezoelectric Thick Film Based Energy Harvesters

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smart engineering for
extreme environments



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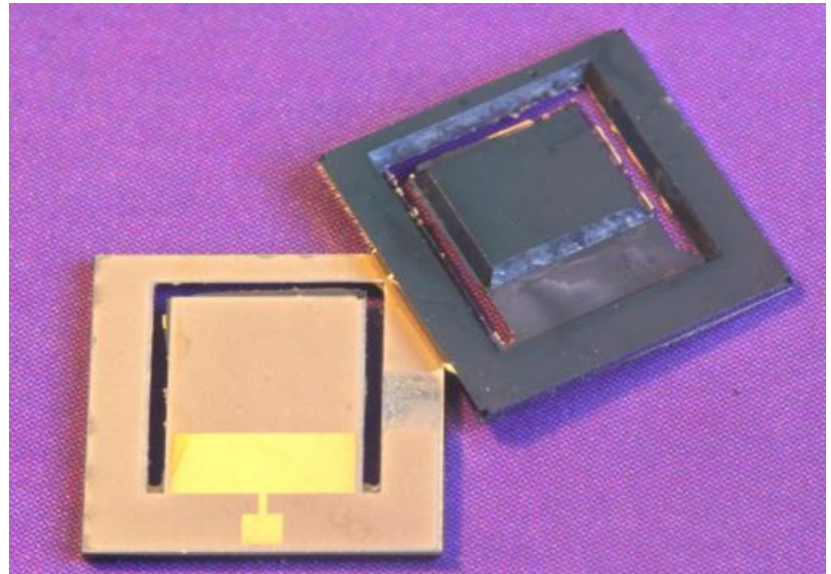
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Reliability and Lifetime of the Energy Harvesters are Key Issues to Replace Batteries and Cables

- ▶ 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

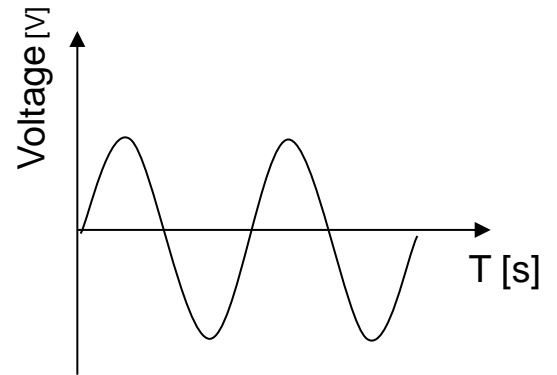
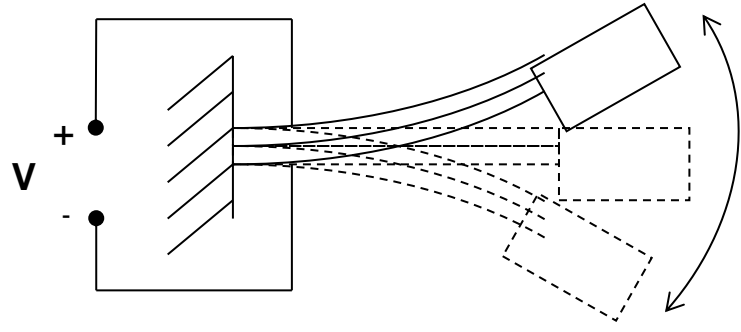
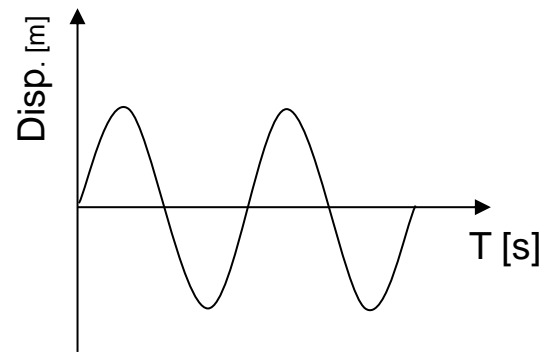
| Vibration source | A [m/s ²] | F _{peak} [Hz] |
|-----------------------------|--------------------------|---------------------------|
| Car engine compartment | 12 | 200 |
| Blender casing | 6.4 | 121 |
| Clothes dryer | 3.5 | 121 |
| Small microwave oven | 2.5 | 121 |
| Windows next to a busy road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

Roundy et.al.

Input vibration

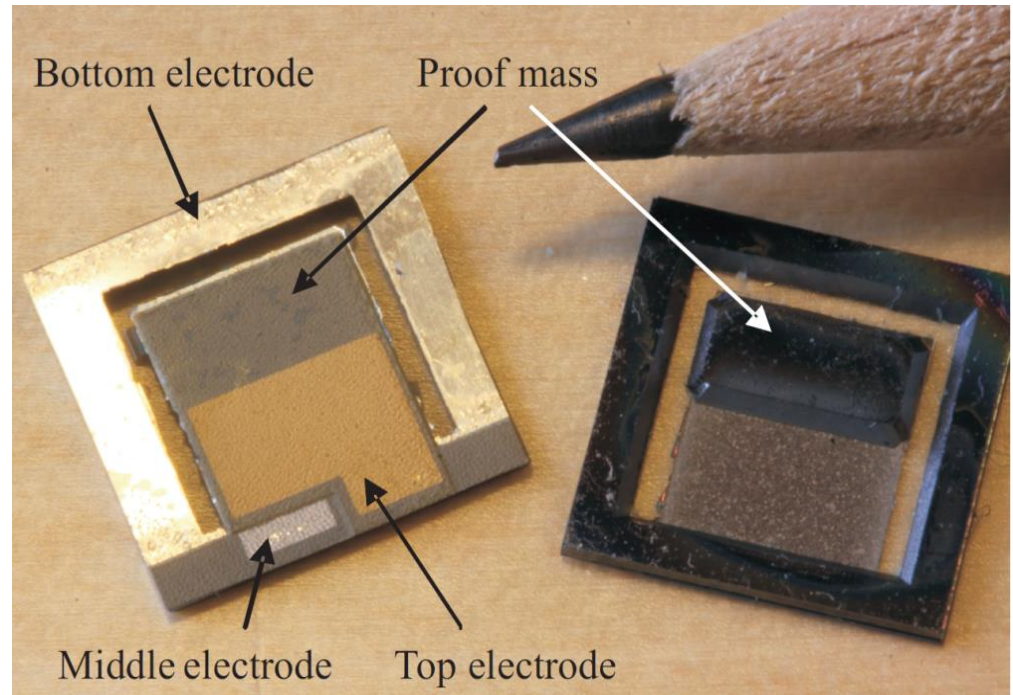
Harvester

Output signal



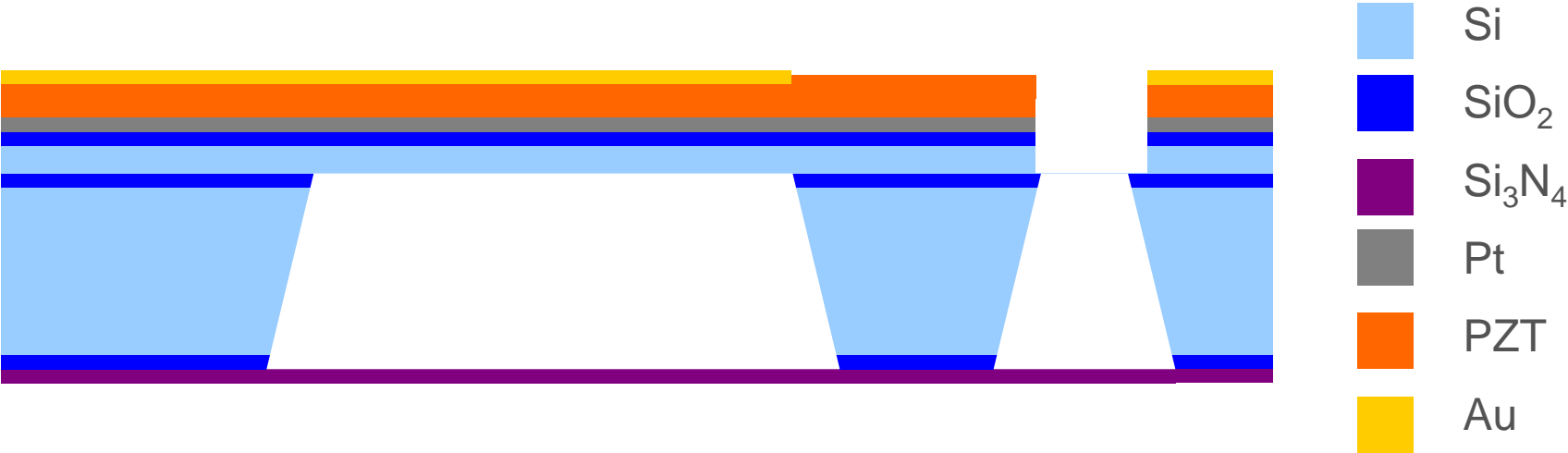
Fabricated Energy Harvesters

- ▶ 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

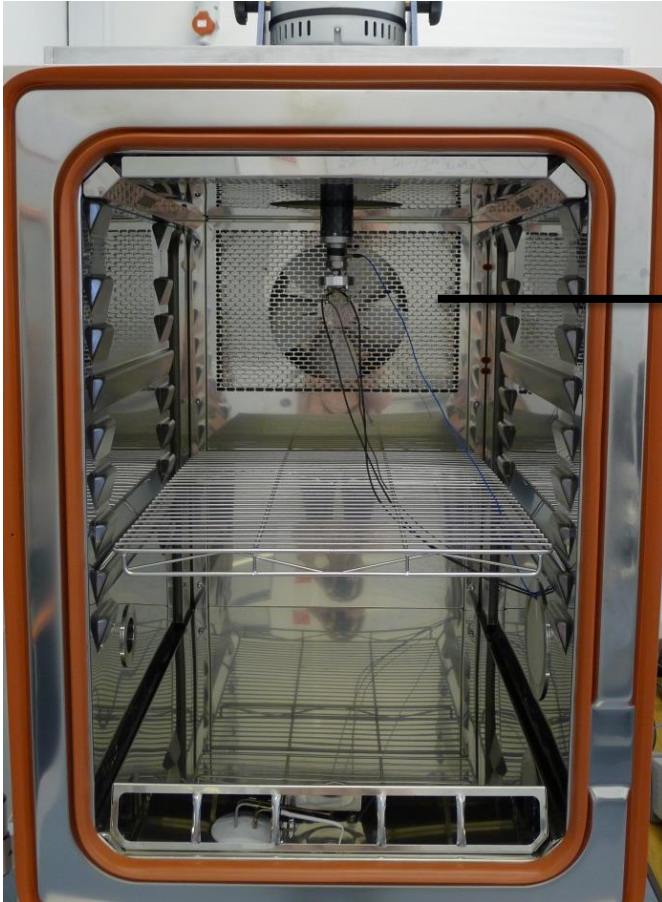
Example of the Fabrication Process



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

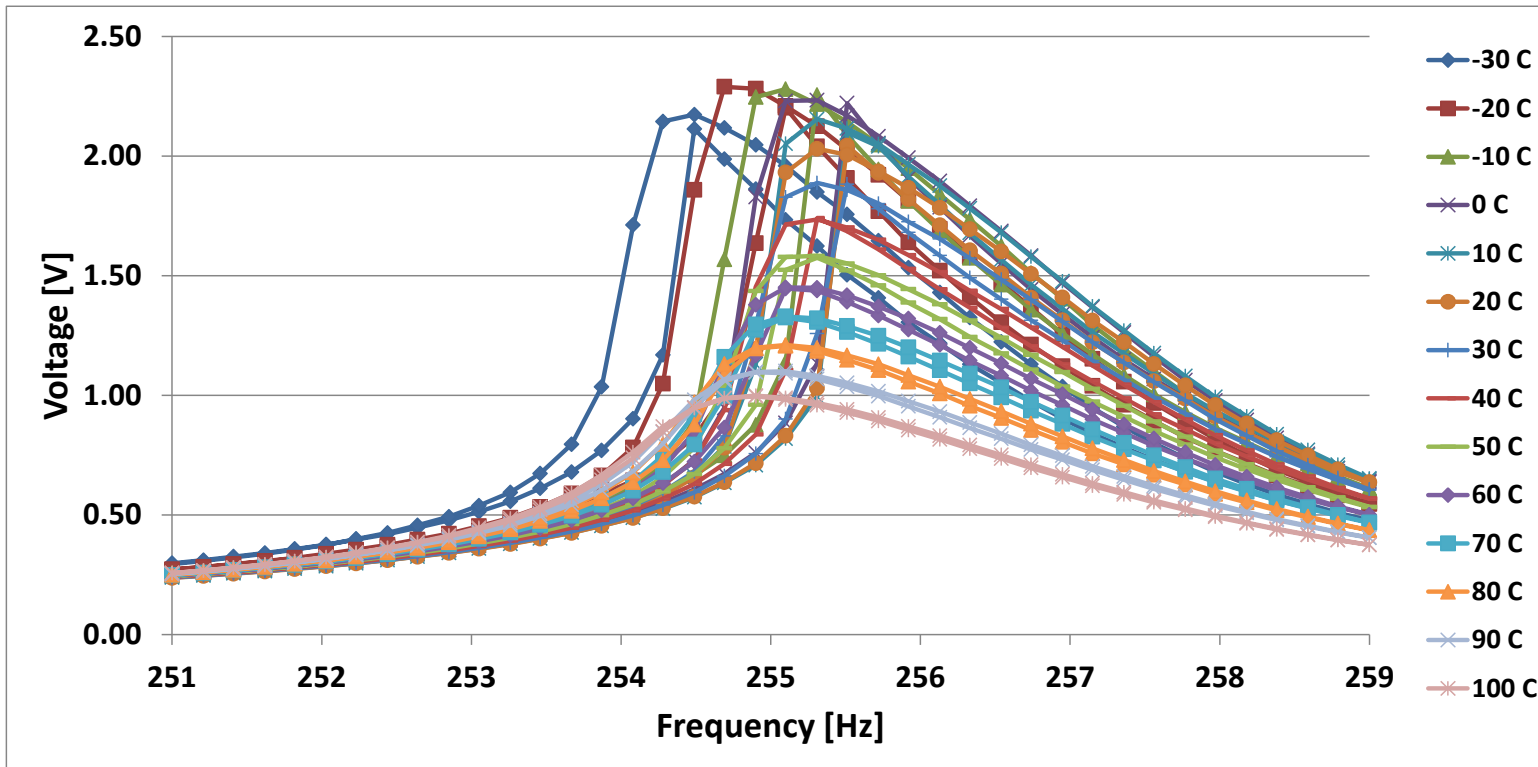


Setup

- ▶ 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



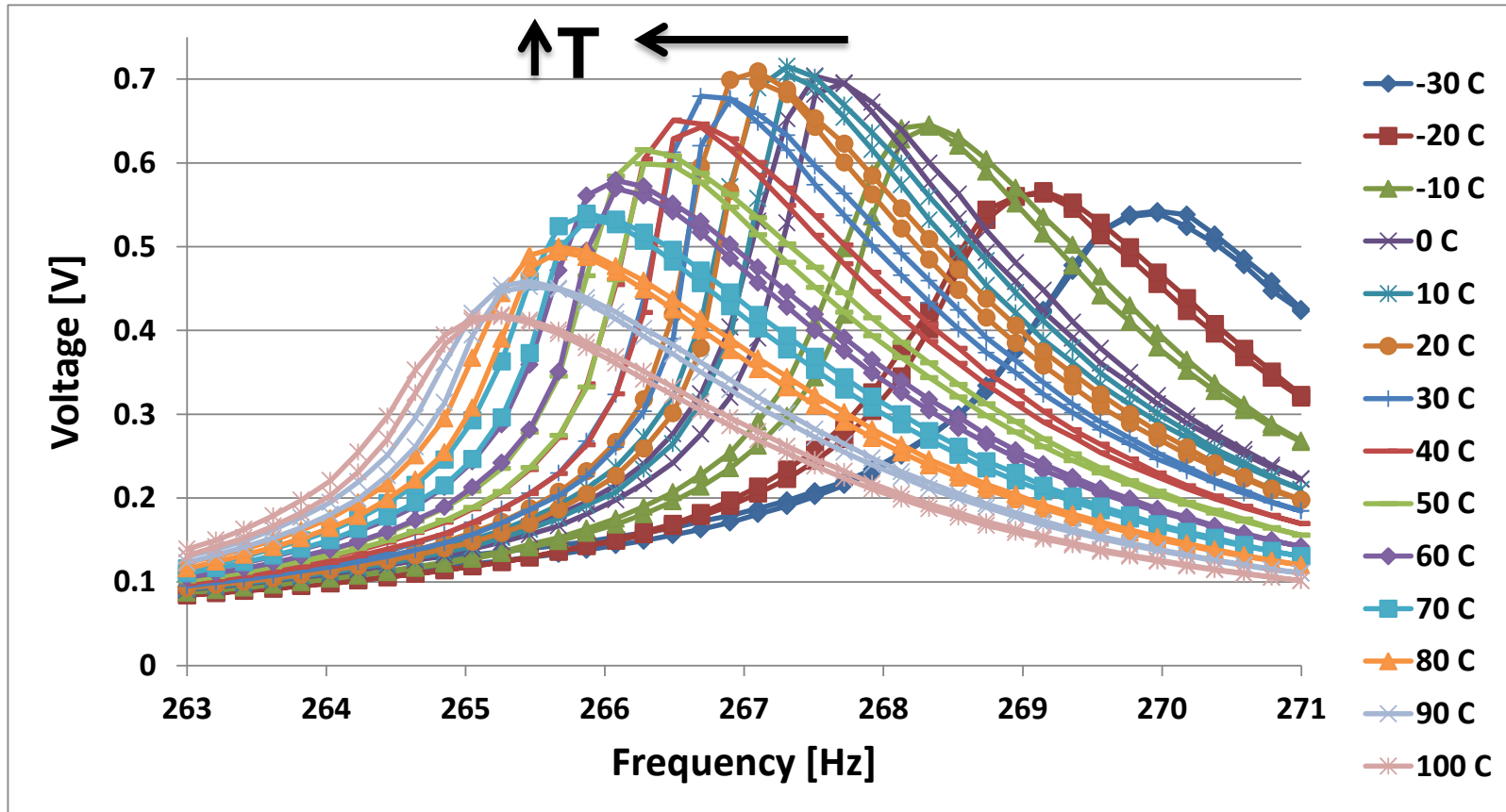
Measurements made at 0.1 g

Frequency sweep with 0.2 Hz resolution

Resonant frequency and open circuit voltage are key performance indicators

Measurement Data

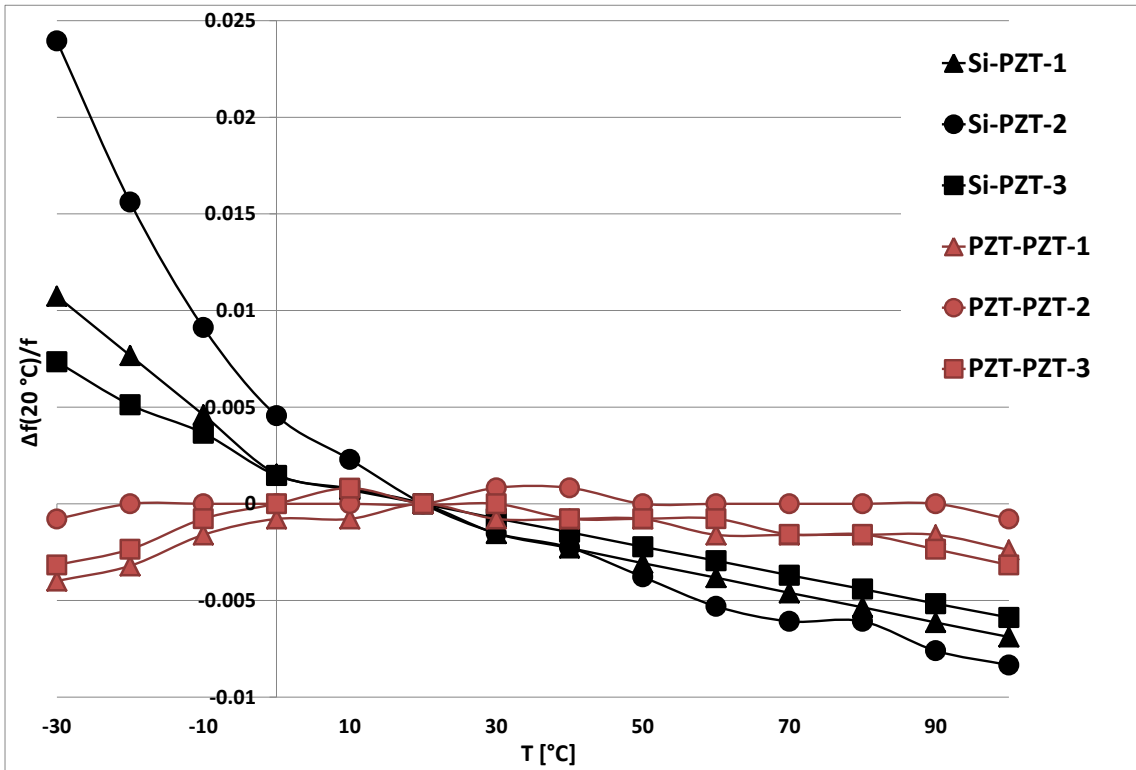
Si-PZT unimorph harvester, chip 1



Resonant frequency changes with temperature

Open circuit voltage at resonance changes with temperature

Change in Resonant Frequency



Trends

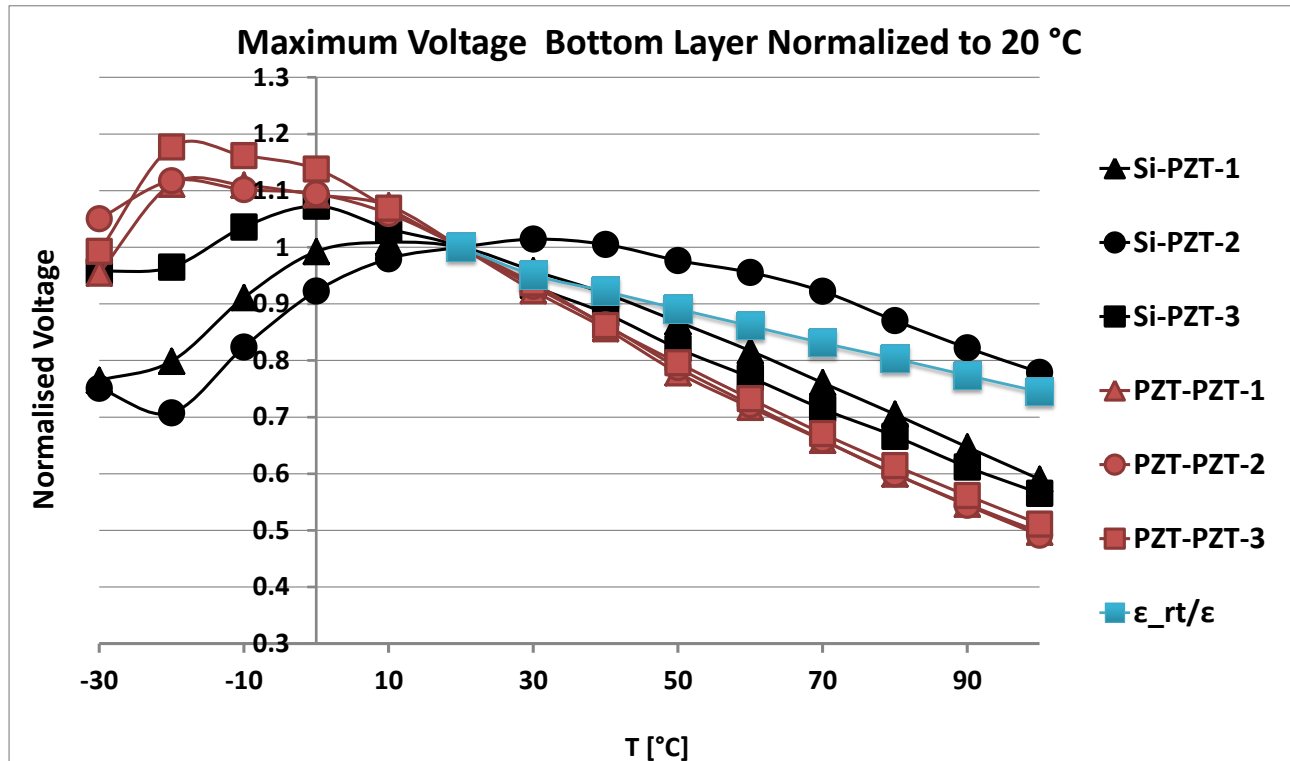
- Si-PZT: Decrease in resonant frequency when temperature increases
- PZT-PZT small variations
- Below 20 °C variation in results are larger
- Impact from change in humidity or the fact that ice forms on the harvester surface

Explanations:

Stiffness decreases with increasing temperature and decreases the resonant frequency

Small variations for PZT-PZT possible good matching of layers

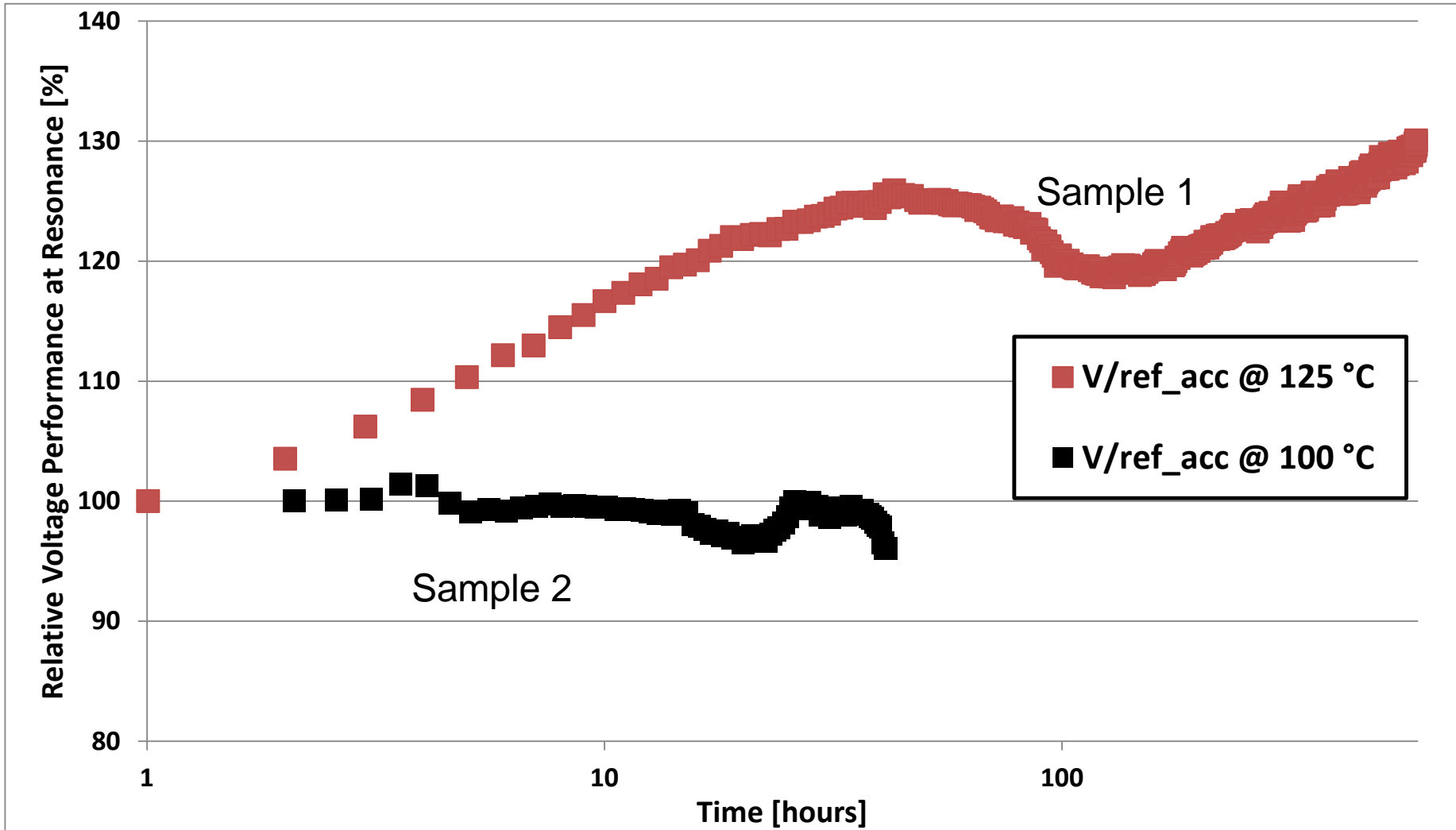
Change in Voltage at Resonant Frequency



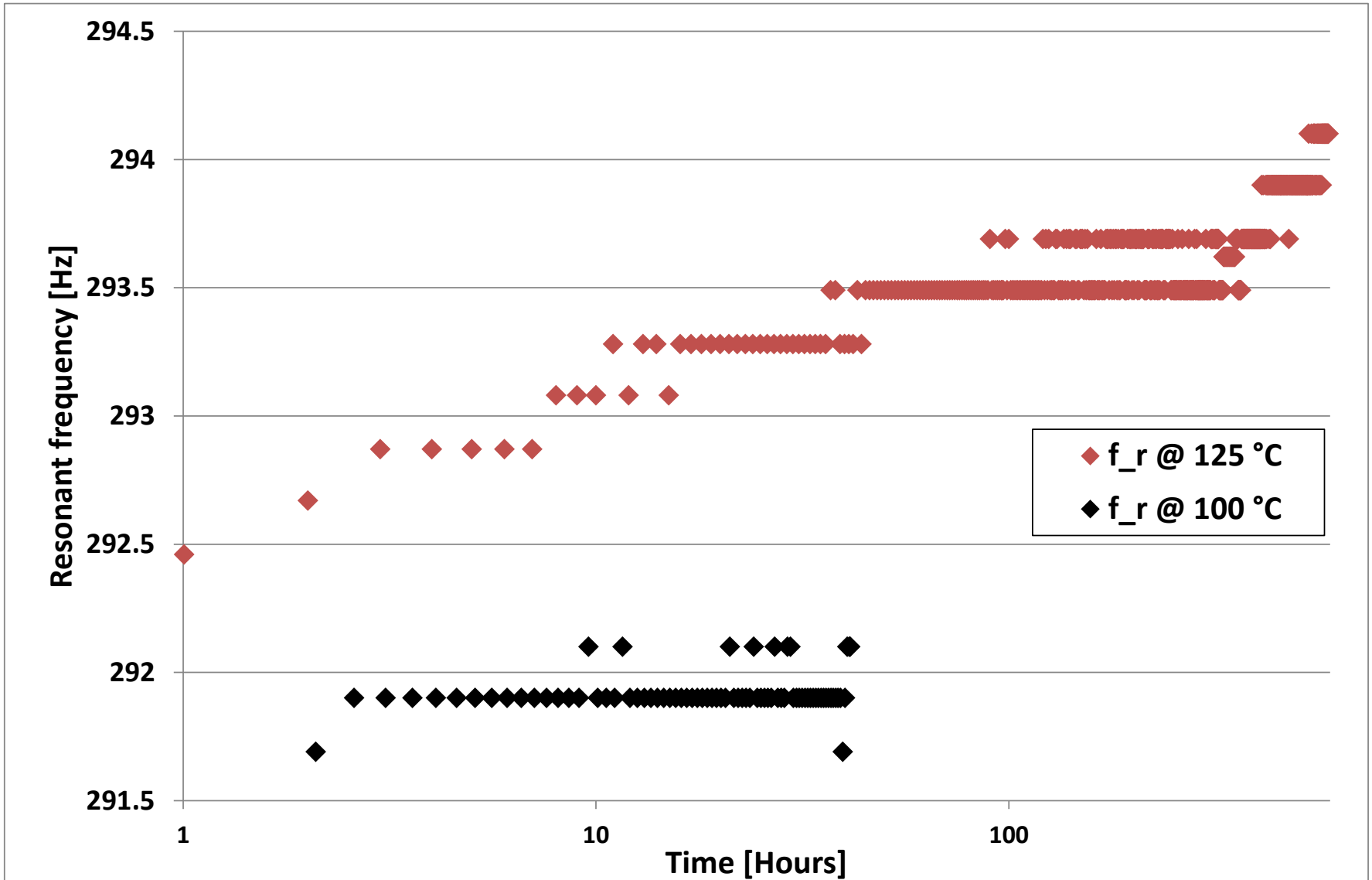
Decrease in voltage can partly be explained by an increase in the permittivity. Other contributions could be change in the coupling factor, damping and Young's modulus

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

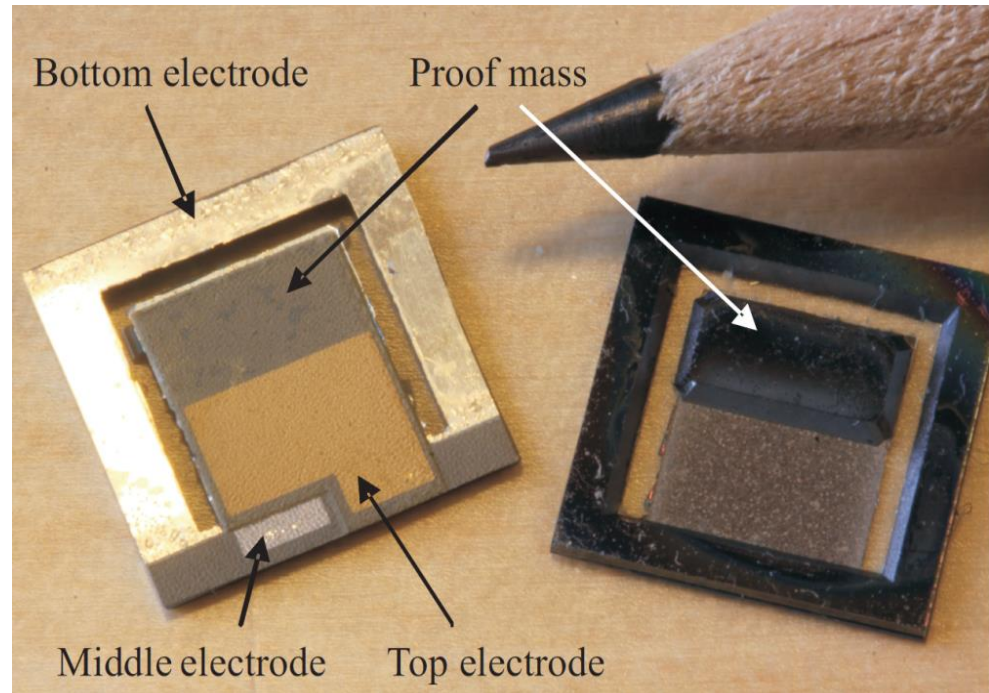
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