Performance of fully integrated vibrational energy harvesting devices

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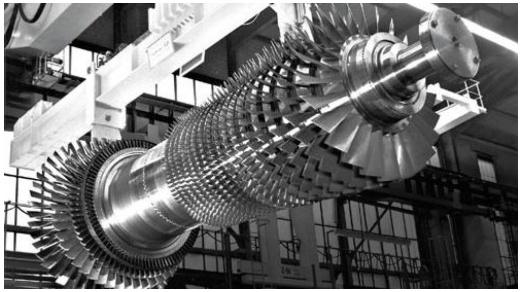
16 May 2012

Outline

1 | Company introduction

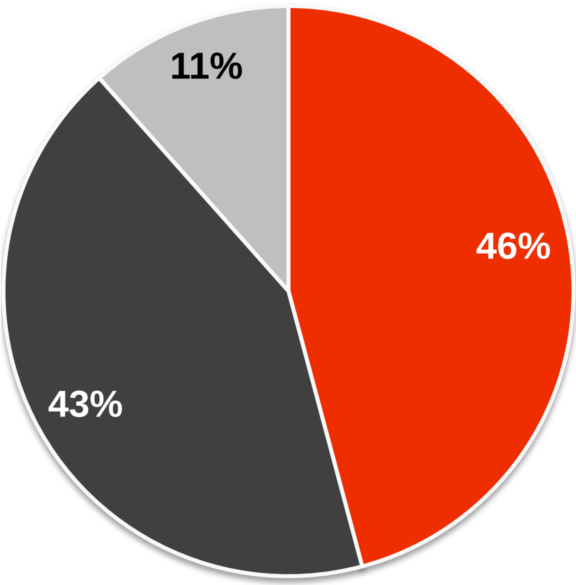




Overview

- » Provides high technology products and systems for the aerospace, defence and other specialist markets, including: medical, industrial, energy, test and automotive
- » 60 years experience in extreme environment engineering
- » Broad geographic footprint
- » Annual sales, $2.17B *[£1.41B]* *
- » Listed on London Stock Exchange (MGGT)

* including PacSci on a proforma basis

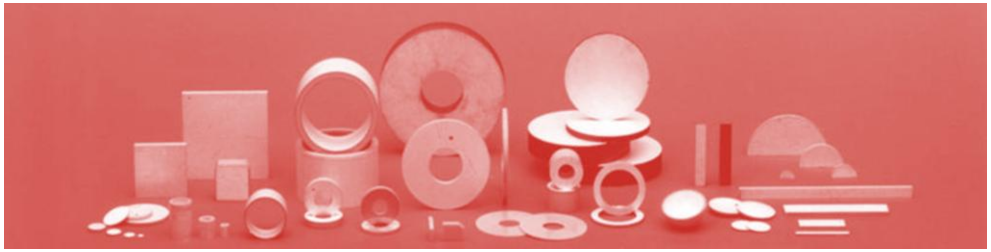


OE 52% / Aftermarket 48%

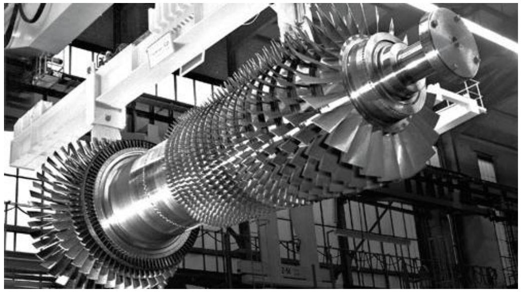
- Civil aerospace
- Military
- Energy and other

CTS Ferroperm Denmark

- We are a manufacturer of piezoelectric materials, components, devices
- 2-3 million units produced annually
- Major markets
  - Medical ultrasound
  - Underwater acoustics
  - Acceleration sensors
  - Flow meters
  - Energy Harvesting



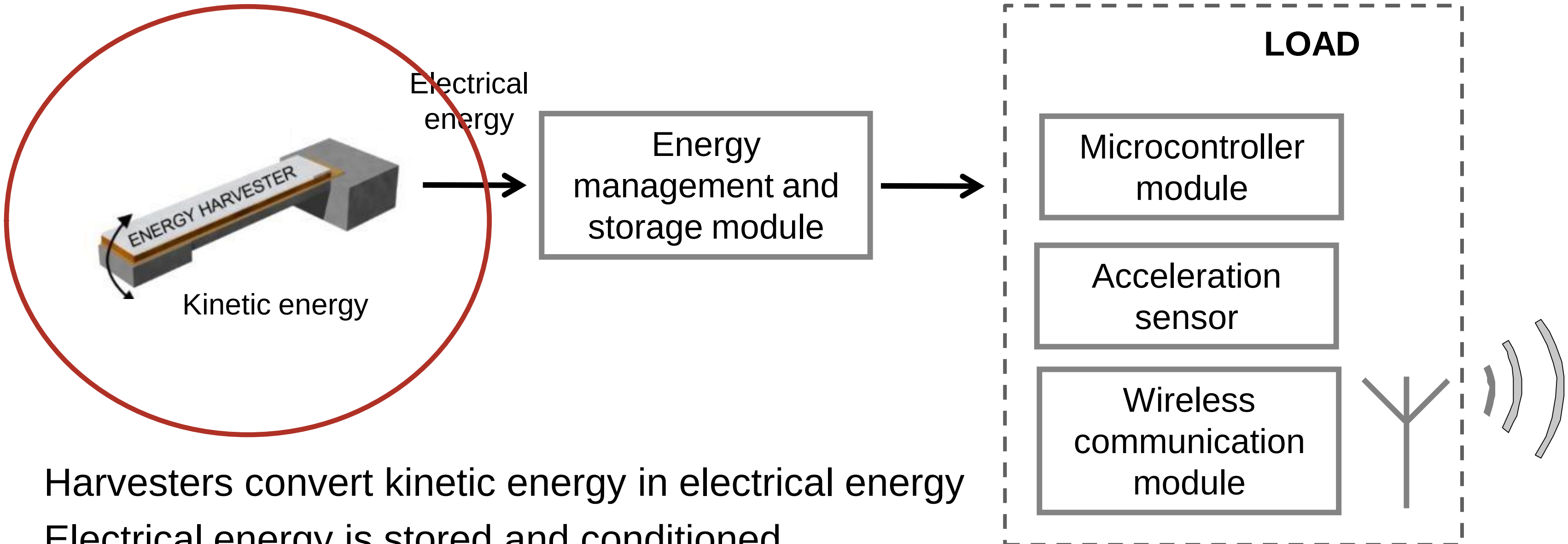
2 System architecture

Development objectives

- Micro generators
  - Easy to integrate
  - Relatively small (millimeter scale)
  - Broadband
  - Sourcing energy from vibrations
- System
  - Low weight
  - Low duty cycle
  - Energy autonomous
  - Wireless
  - Long life
  - Wide range of working temperatures

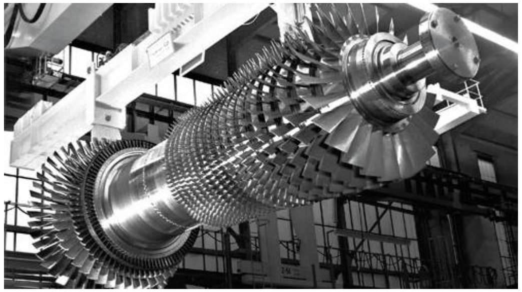
Sensor node architecture



- Harvesters convert kinetic energy in electrical energy
- Electrical energy is stored and conditioned
- When electrical energy is enough the load is powered
- Microcontroller repeats acceleration measurement and data transmission at fixed time intervals

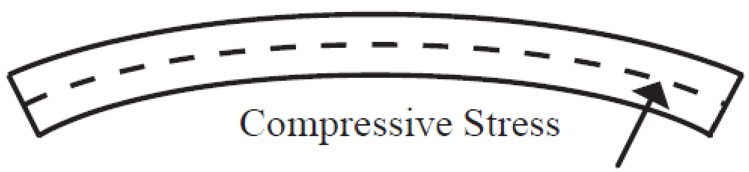
3 | Thick film technology for energy harvesting





Design criteria for bending structures

- The optimal design of a bending structure should assure the neutral bending axis to be located a the interface between active (PZT) and passive (Si) materials
- The typical device layer thickness of an SoI wafer (20 µm) requires 30-40 µm of the active material (PZT)



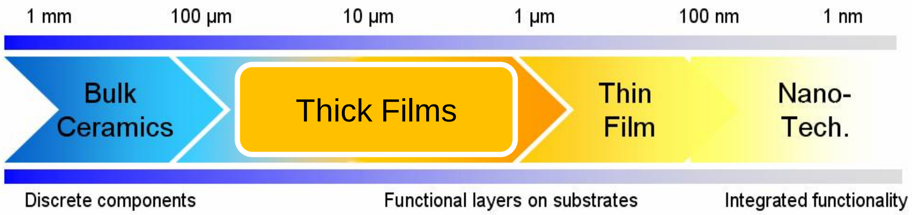
$$\frac{t_{pzt}}{t_{Si}} = \sqrt{\frac{Y_{Si}}{Y_{PZT}}}$$

Y – Young's modulus

$$t_{pzt} = t_{Si} \cdot \sqrt{\frac{Y_{Si}}{Y_{PZT}}} = 20\ \mu\text{m} \cdot \sqrt{\frac{130\ \text{GPa}}{43.6\ \text{GPa}}} = 34.53\ \mu\text{m}$$

PZT (Lead Zirconate Titanate) Thick Films – InSensor™

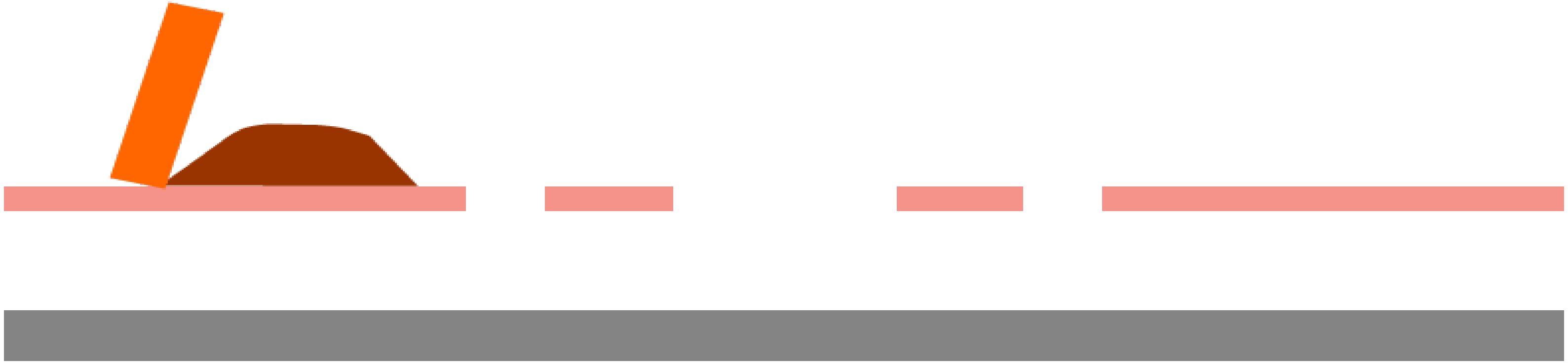
- Technology of piezoelectric thick films (InSensor™) – enabling deposition and integration of piezoelectric layers (10 to 100 µm in thickness) with high lateral resolution (100x100 µm)



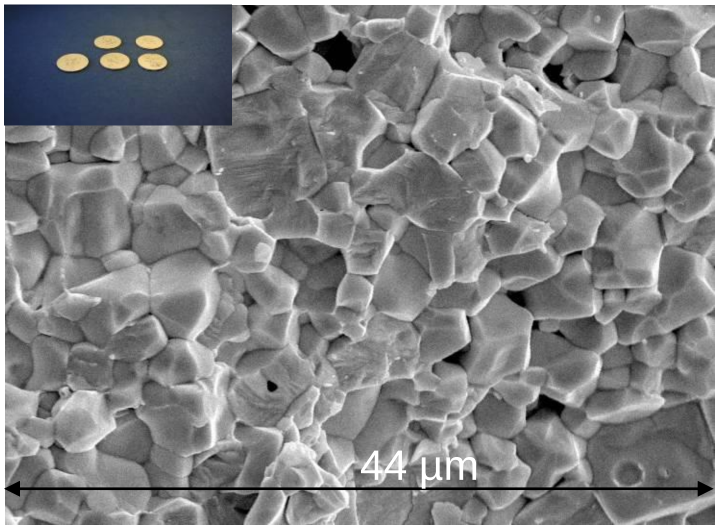
- Key features of InSensor™ technology
  - Capable of manufacturing miniaturized devices
  - Low prototyping costs
  - High volume production
  - High lateral resolution
  - High frequency
  - High response
  - Piezoelectric material can be deposited on a number of different substrates (compatible with MEMS)

Deposition - Screen printing

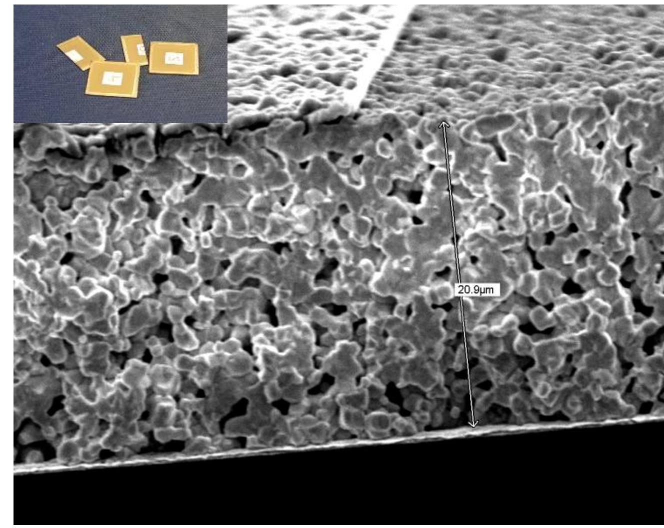
PZT dispersed in an organic vehicle



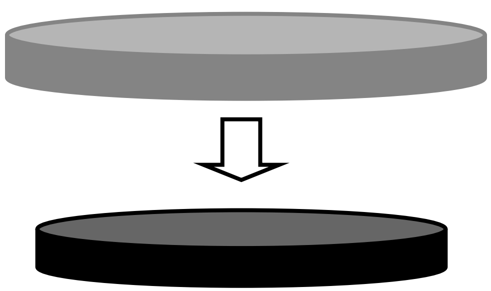
InSensor™ PZT thick film on a substrate



Similar composition with different microstructure

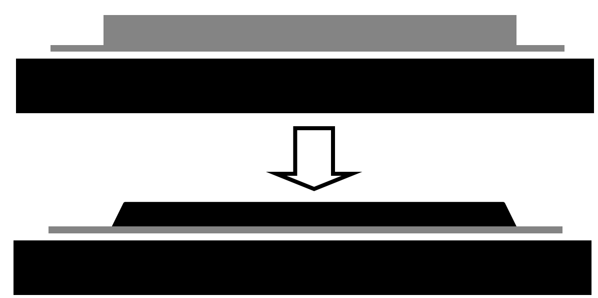


Bulk (ρ = 7.7 g/cm^3)

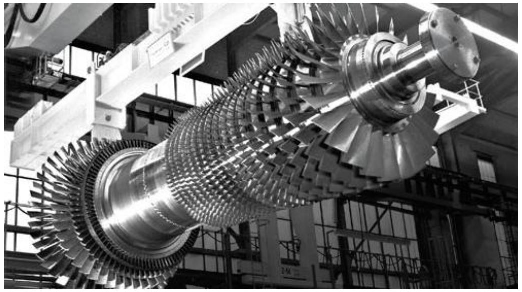


Energy harvesting requires additional densification of the film

TkF (ρ ~ 6.0 g/cm^3)

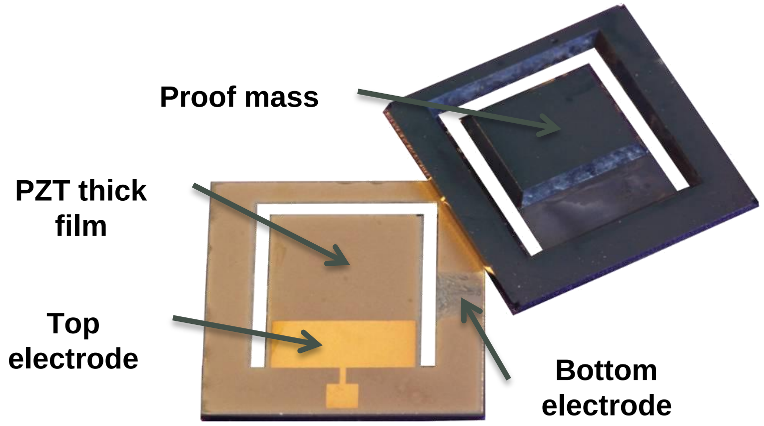


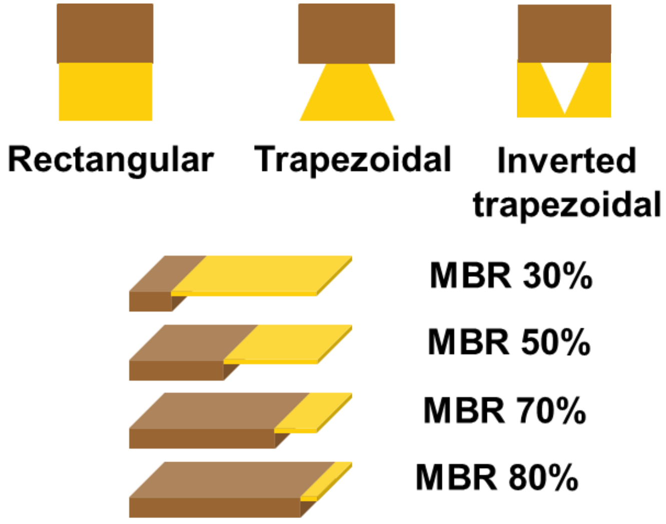
4 Micro generators and sensor nodes



PZT Thick film based micro-generators

- Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- Single clamped cantilevers with a silicon proof mass at the free end
- Planar dimension 10x10 mm^2
- Different cantilever shapes, and mass-beam length ratios (MBR)
- Unimorph and bimorph configuration

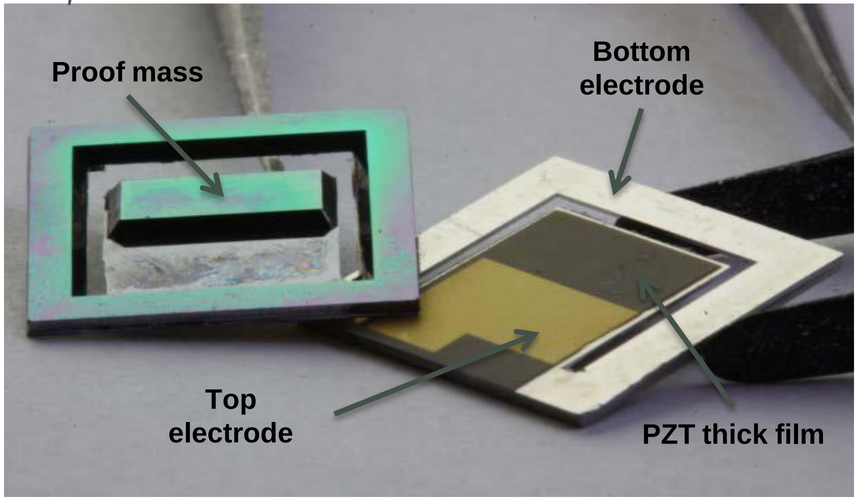




Energy Harvesting micro-generators - unimorph

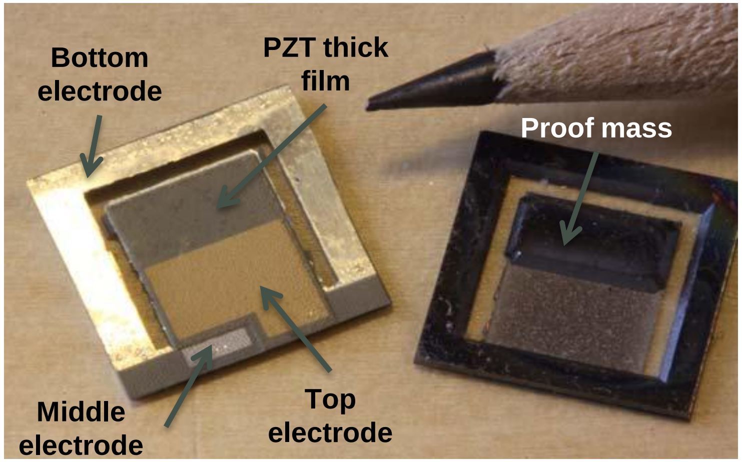
- Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- Single clamped cantilevers with a silicon proof mass at the free end
- Unimorph configuration
- High yield (> 90%) using KOH wet etch in the last part of the fabrication process

In cooperation with DTU Nanotech



Energy Harvesting micro-generators - bimorph

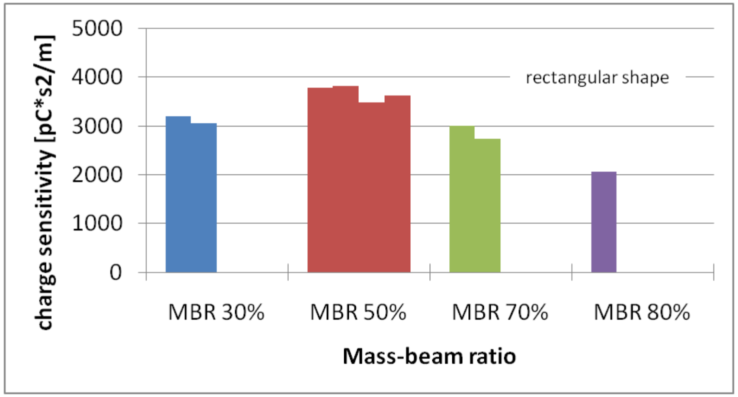
- Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- Single clamped cantilevers with a silicon proof mass at the free end
- Bimorph configuration
- Higher voltage and power compared to unimorph
- Si/PZT fabrication + middle electrode + 2nd PZT layer + Si membrane removal

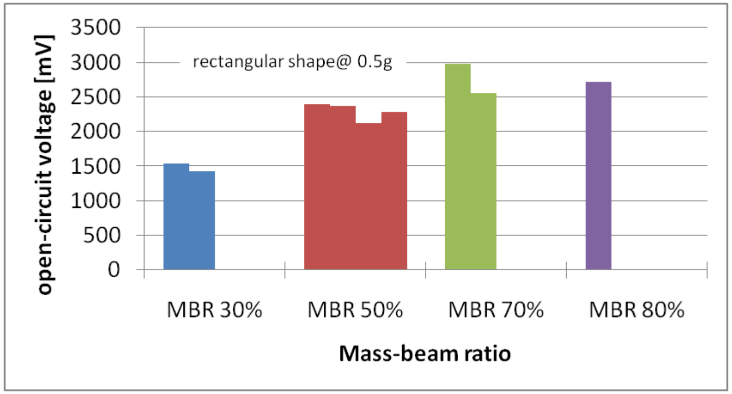


In cooperation with DTU Nanotech

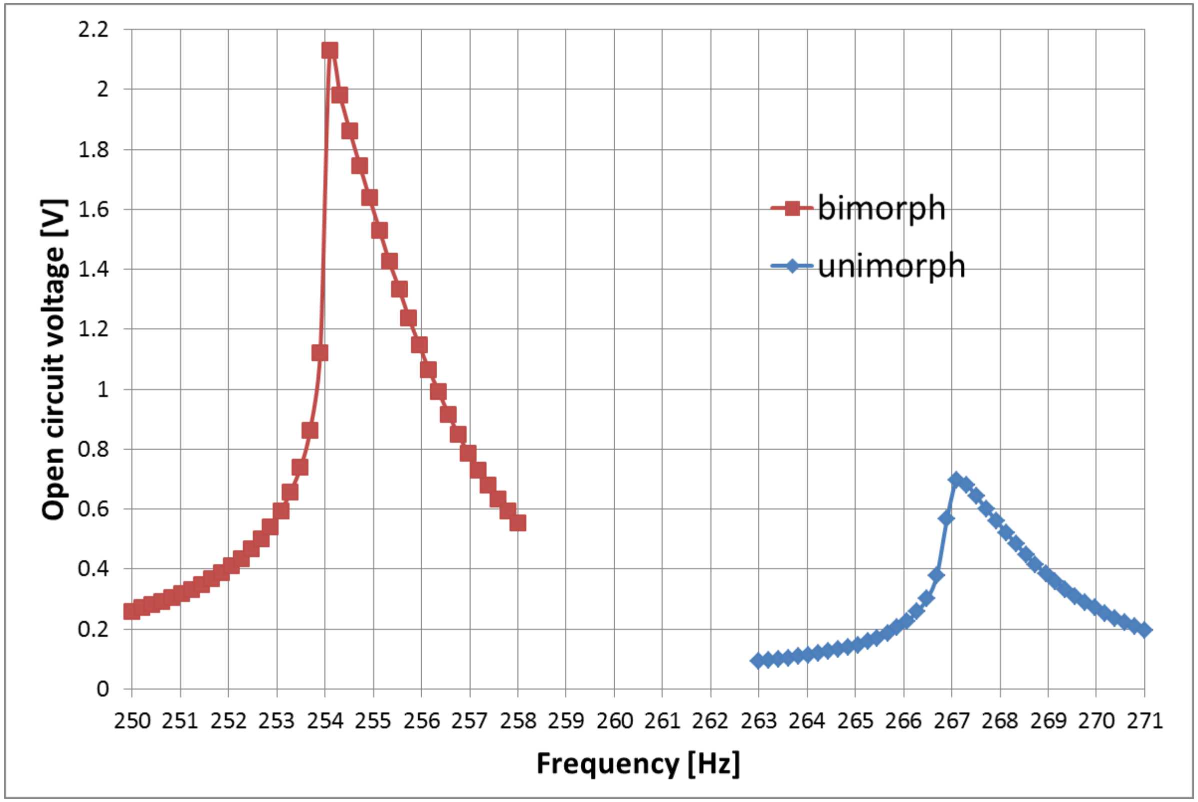
Comparison of the structures

- Charge sensitivity up to 37 nC/g @ 0.5 g peak
- Open-circuit voltage up to
  - 3 V @ 0.5 g peak (unimorph)
  - 4 V @ 0.5 g peak (bimorph)
- Maximum power range
  - 10 µW ÷ 12 µW @ 0.5 g peak (unimorph)
  - 15 µW ÷ 20 µW @ 0.5 g peak (bimorph)





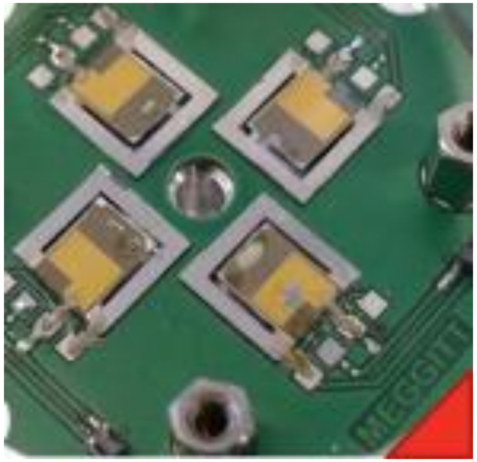
Bimorph vs. unimorph



Open circuit voltage (RMS) @ 0.1 *g*

Sensor node

- Acceleration measurement
  - 3D acceleration measurement
  - Sampling frequency = 1600 Hz
  - Resolution = 13 bits
- Temperature measurement
  - Resolution 0.5 ºC
- Sensor nodes are linked using 2.4 GHz wireless communication forming star-like network architecture



Up to 4 microgenerators are combined (two are sufficient for the proper system functionality)

Conclusions and outlook

- PZT thick film technology is suitable for fabrication of energy harvesting devices on micro-machined silicon
- The devices are capable of generation of 15 to 20 µW of power at moderate accelerations of about 0.5 *g*
- The bandwidth of the microgenerators can be increased by introduction of non-linear effects (magnetic coupling, mechanical nonlinearity)
- The PZT thick-film microgenerators can successfully power sensor nodes, enabling energy-autonomous, wireless measurement of acceleration and temperature

Contributors

» CTS | Ferroperm Denmark Team
  - Louise Borregaard
  - Lise Nielsen

» DTU Nanotech Team
  - Prof. Erik V. Thomsen
  - Ruichao Xu
  - Anders Lei

Acknowledgments

Danish National Advanced Technology Foundation through the ELBA project [**EL**iminating **BA**tteries – energy harvesters for integrated systems] contract no. 036-2009-1

ELBA

Thank you