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Performance of fully integrated vibrational energy harvesting devices

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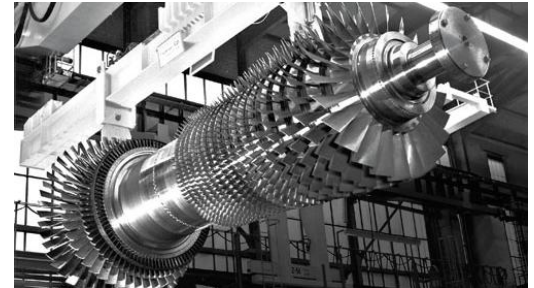
MEGGITT

Outline

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- 5 | **Conclusions**

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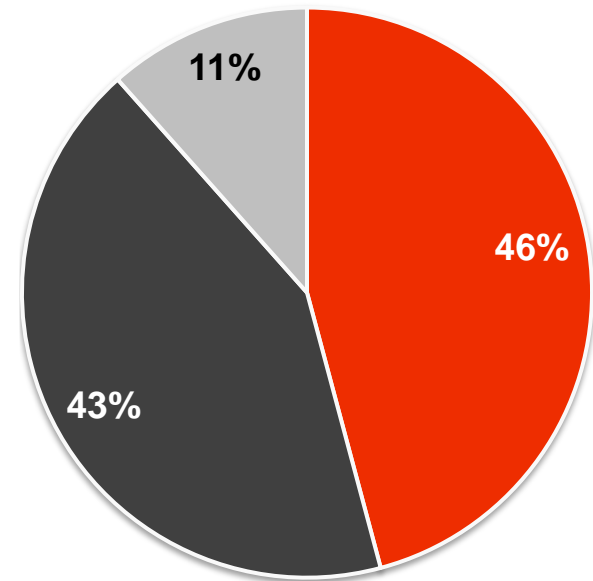
Company introduction



Meggitt - 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

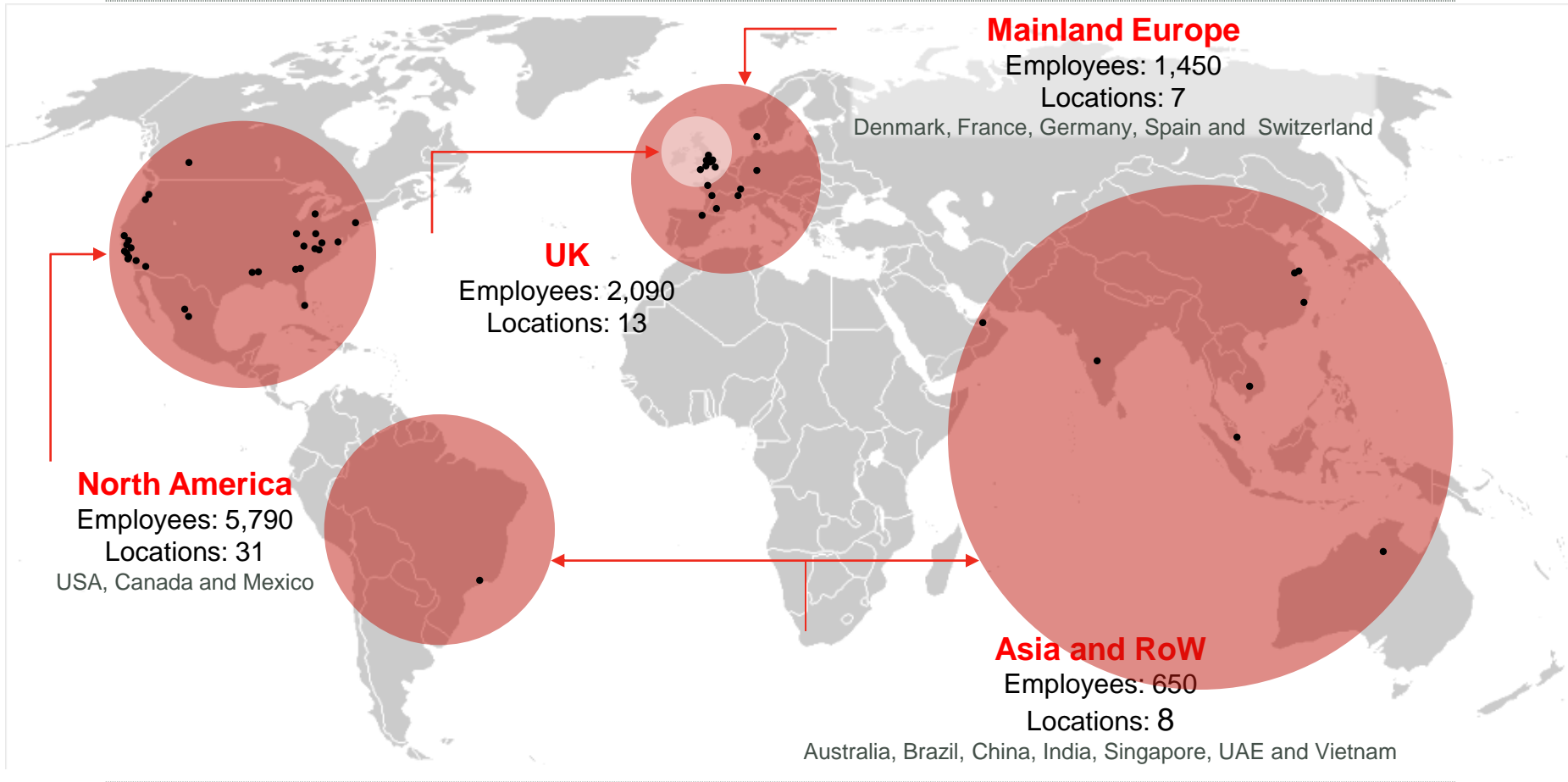


OE 52% / Aftermarket 48%

- Civil aerospace
- Military
- Energy and other

A global presence

9,980
employees worldwide



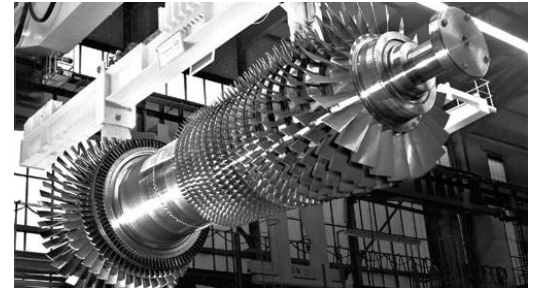
Meggitt Sensing Systems Denmark

- » Meggitt A/S is 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



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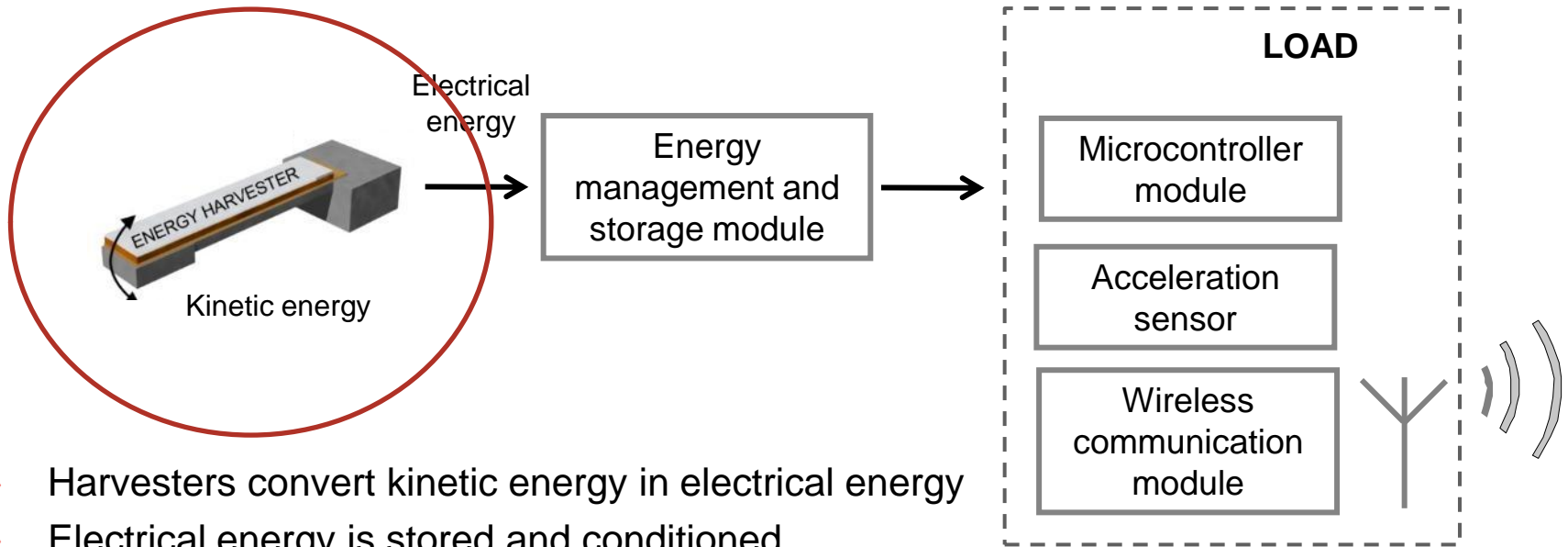
System architecture



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

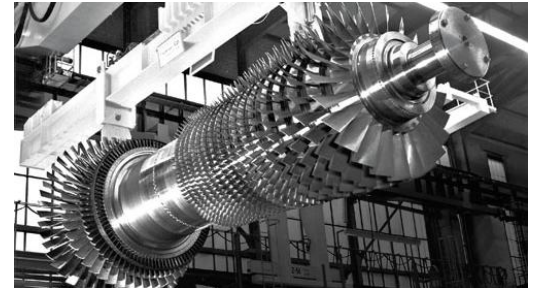
Sensor node architecture



- » 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

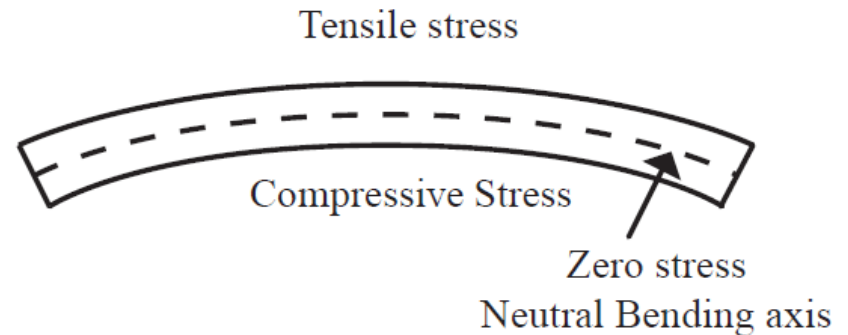
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Thick film technology for energy harvesting



Design criteria for bending structures

- » The optimal design of a bending structure should assure the neutral bending axis to be located at 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)



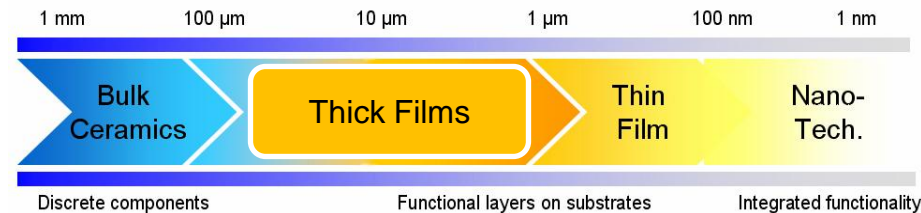
$$\frac{t_{pzt}}{t_{Si}} = \sqrt{\frac{Y_{Si}}{Y_{PZT}}}$$

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

Y – Young's modulus

PZT (Lead Zirconate Titanate) Thick Films – InSensor™

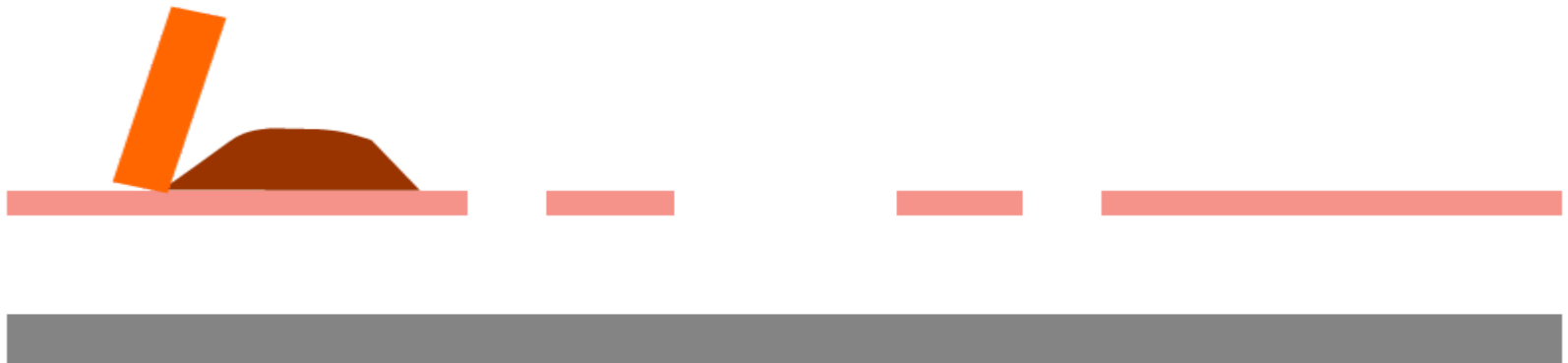
- » Technology of piezoelectric thick films (InSensor™) – enabling deposition and integration of piezoelectric layers (10 to 100 μm in thickness) with high lateral resolution (100x100 μm)



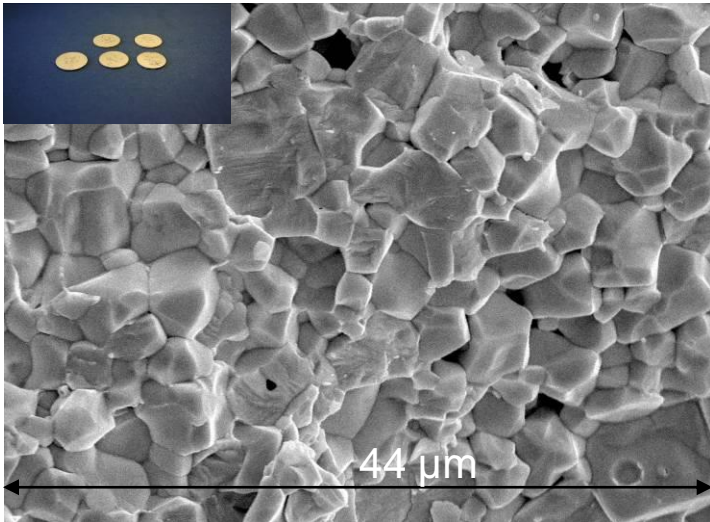
- » Key features of InSensor™ technology
 - Capable of manufacturing miniaturized devices
 - Low prototyping costs
 - High volume production
 - High lateral resolution
 - High frequency
 - High response
 - Piezoelectric material can be deposited on a number of different substrates (compatible with MEMS)

Deposition - Screen printing

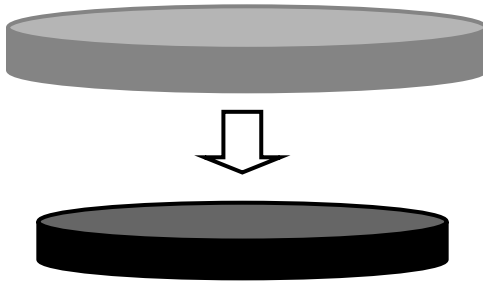
PZT dispersed in an organic vehicle



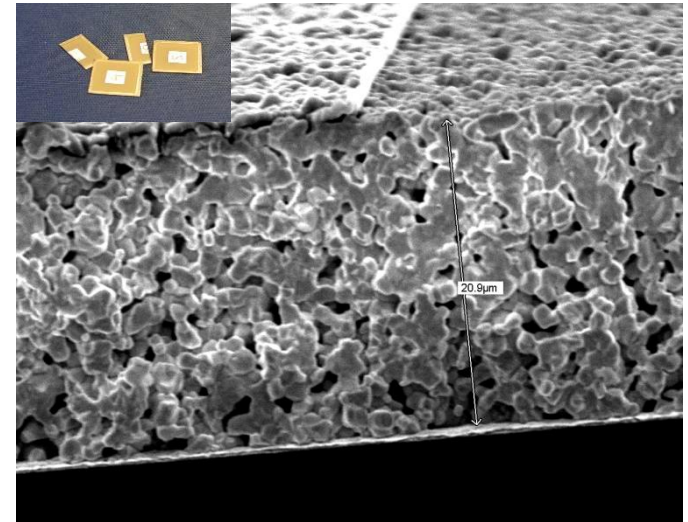
InSensor™ PZT thick film on a substrate



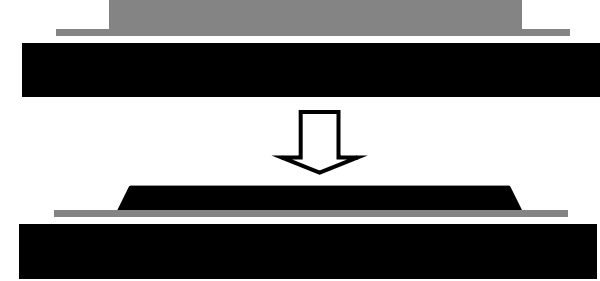
Bulk ($\rho = 7.7 \text{ g/cm}^3$)



Similar composition with different microstructure



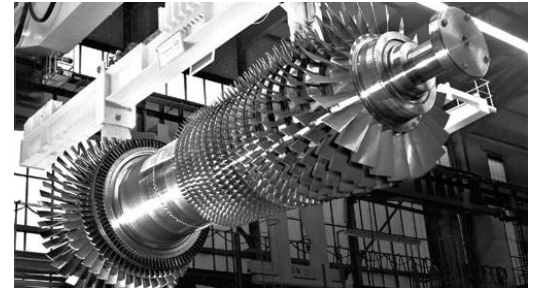
TkF ($\rho \sim 6.0 \text{ g/cm}^3$)



Energy harvesting requires additional densification of the film

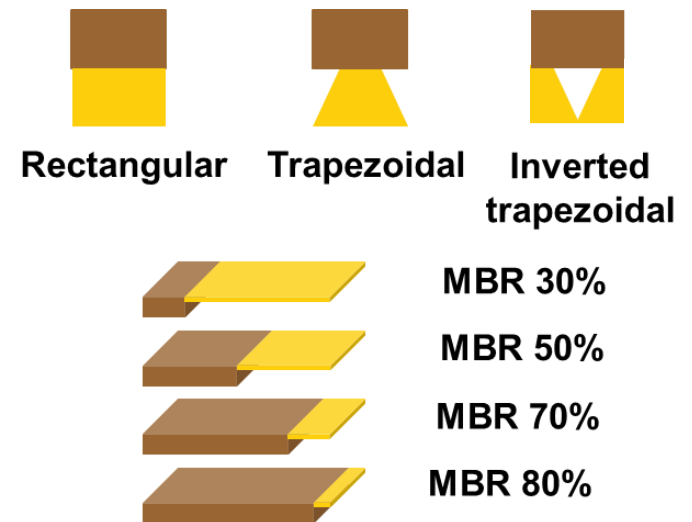
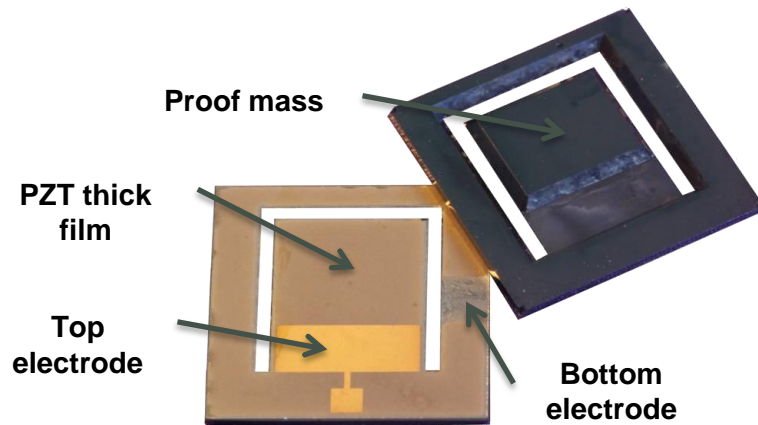
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Micro generators and sensor nodes



PZT Thick film based micro-generators

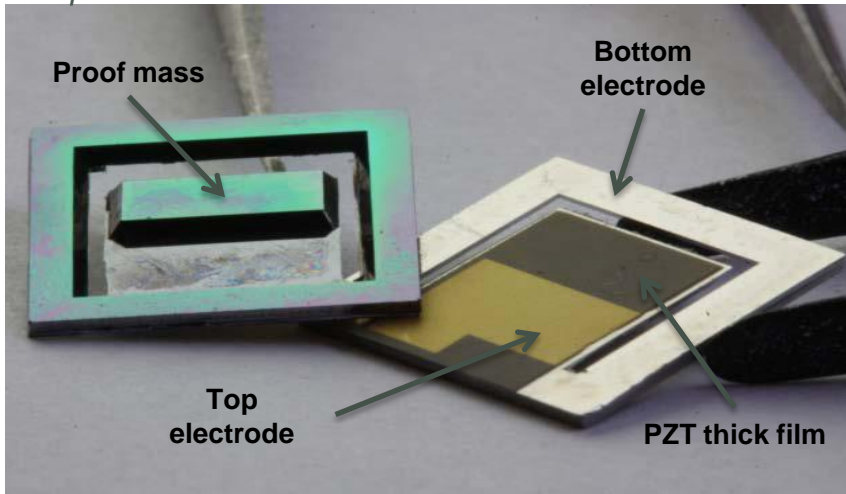
- Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- Single clamped cantilevers with a silicon proof mass at the free end
- Planar dimension 10x10 mm²
- Different cantilever shapes, and mass-beam length ratios (MBR)
- Unimorph and bimorph configuration



Energy Harvesting micro-generators - unimorph

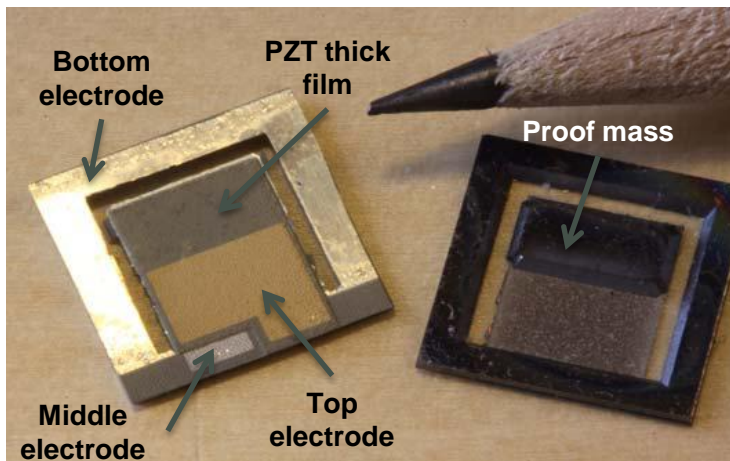
- » Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- » Single clamped cantilevers with a silicon proof mass at the free end
- » Unimorph configuration
- » High yield (> 90%) using KOH wet etch in the last part of the fabrication process

In cooperation with DTU Nanotech



Energy Harvesting micro-generators - bimorph

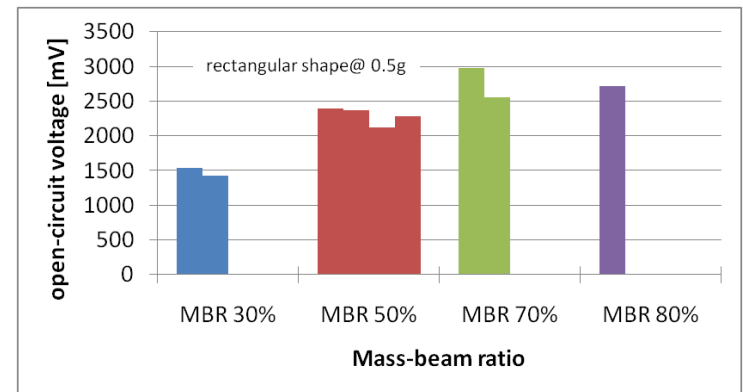
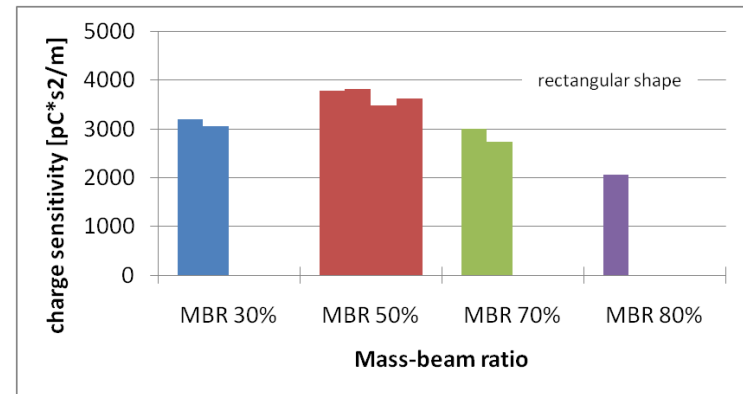
- » Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- » Single clamped cantilevers with a silicon proof mass at the free end
- » Bimorph configuration
- » Higher voltage and power compared to unimorph
- » Si/PZT fabrication + middle electrode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



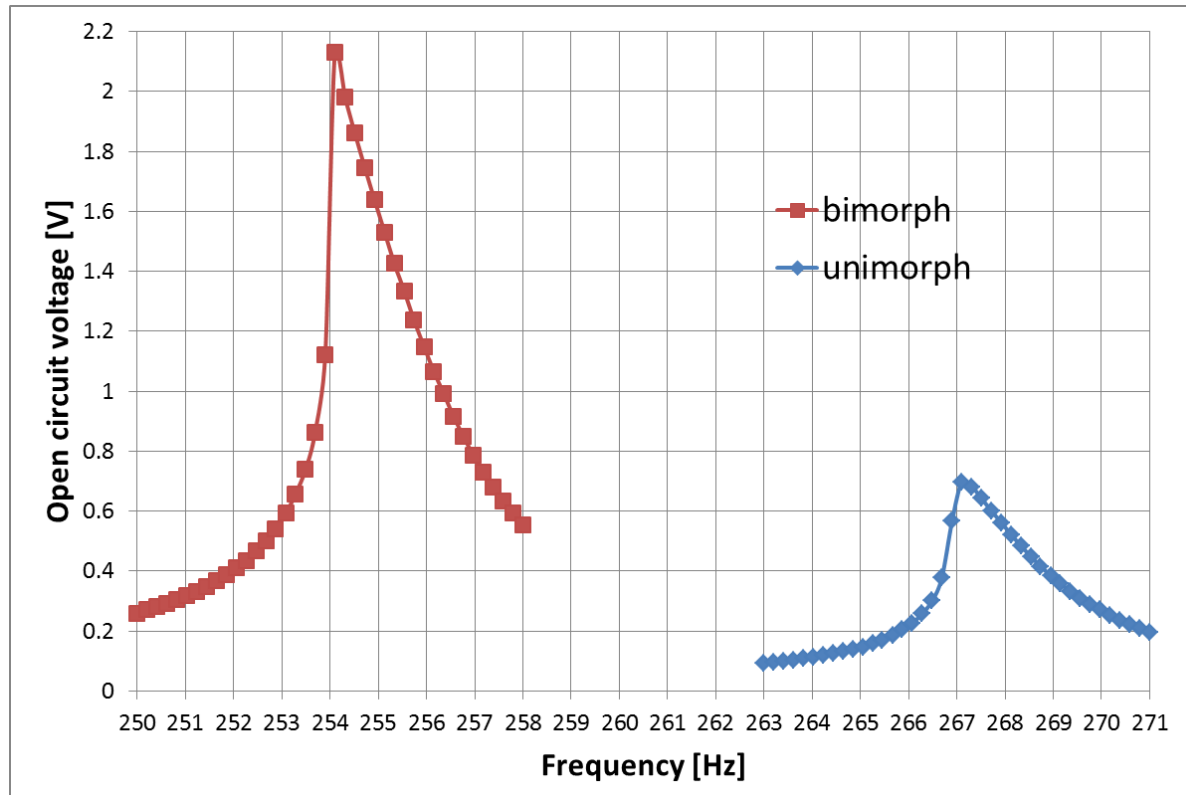
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Comparison of the structures

- » 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 μ W ÷ 12 μ W @ 0.5 g peak (unimorph)
 - 15 μ W ÷ 20 μ W @ 0.5 g peak (bimorph)



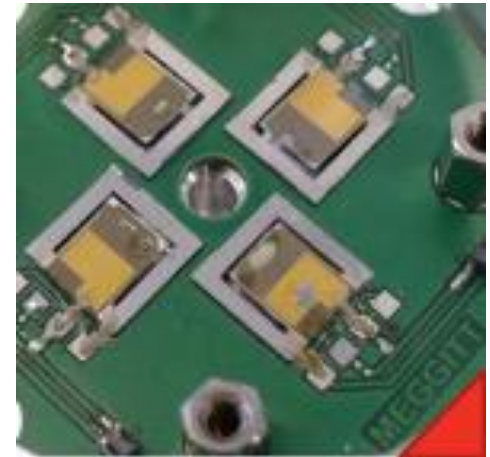
Bimorph vs. unimorph



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 °C
- » 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

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- Lise Nielsen

» DTU Nanotech Team

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- Ruichao Xu
- Anders Lei

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The logo for the ELBA project, consisting of the letters "ELBA" in a bold, white, sans-serif font centered within a dark gray rectangular box.

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