Evolution of MEMS based piezoelectric thick film technology for energy harvesting applications

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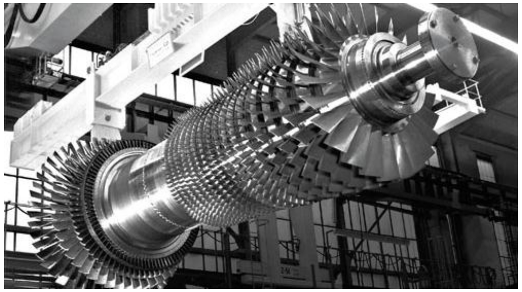
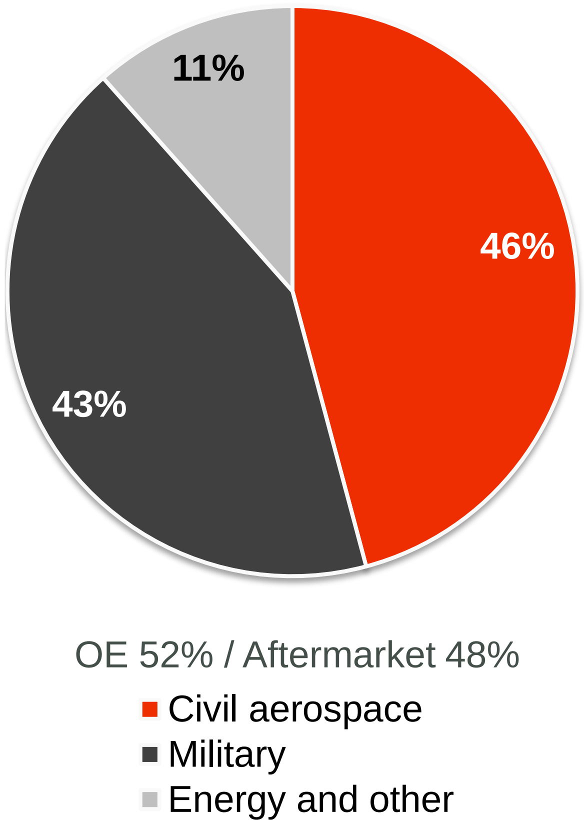
Outline

1 Company introduction



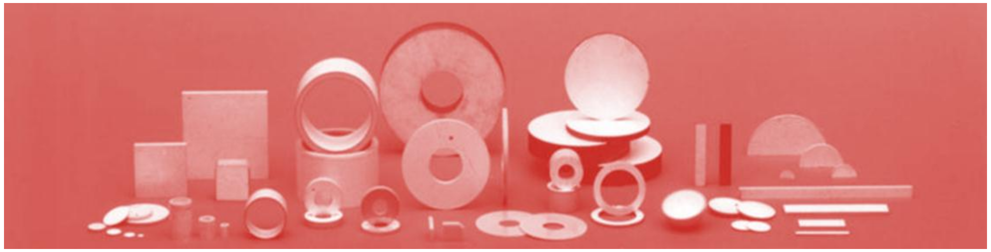
Overview

- » 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 (2012), £1,605.8 million, 10% growth in comparison to 2011
- » Listed on London Stock Exchange (MGGT)
- » FTSE100 company

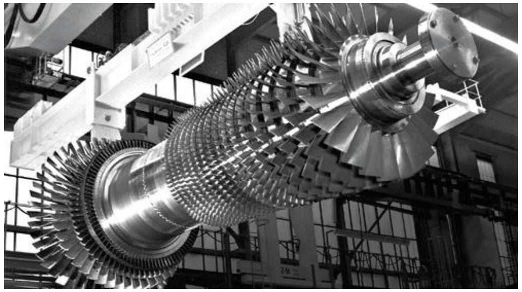


CTS | Ferroperm Denmark

- 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



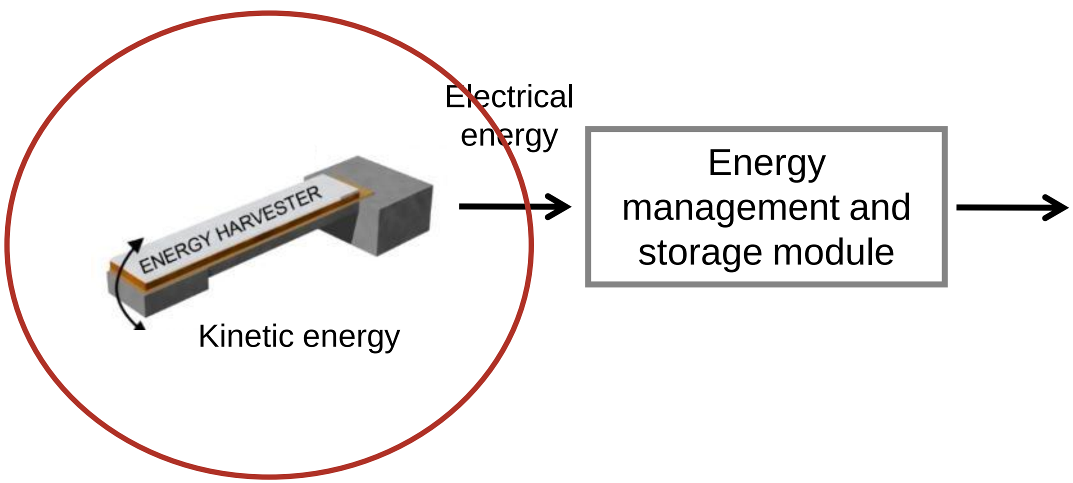
2 Development objectives

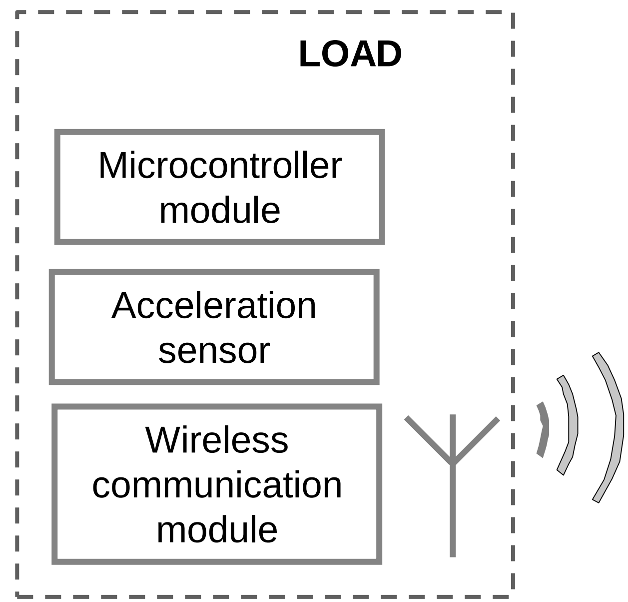


Development objectives

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

Sensor node architecture

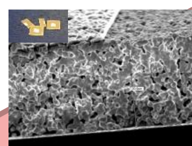




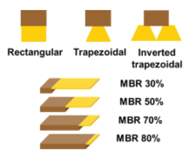
- Harvesters convert kinetic energy in electrical energy
- Electrical energy is stored and conditioned
- When electrical energy is enough the load is powered

Technology evolution

PZT thick film technology

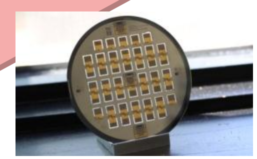


High lateral coupling films

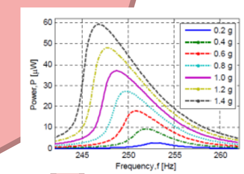


First generation energy harvesting devices

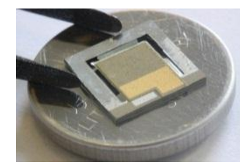
Second generation unimorphs



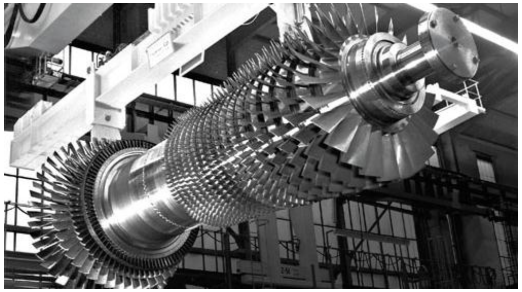
High yield unimorph and bimorph process



First generation bimorphs



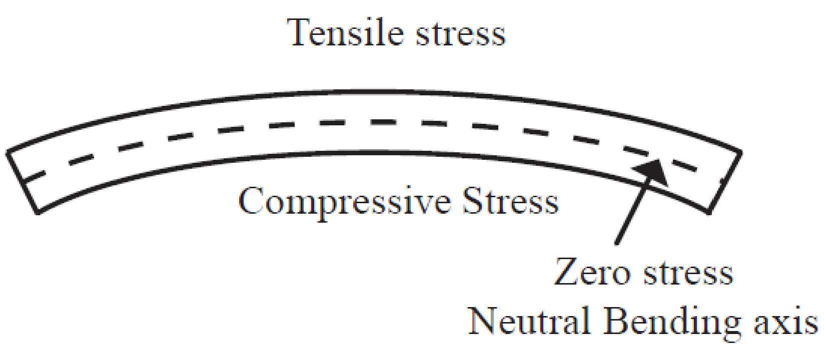
3 The basic technology



Design criteria for bending structures

» 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

» Typical device layer of an SOI wafer (20 µm) requires 30-40 µm of the active material (PZT)



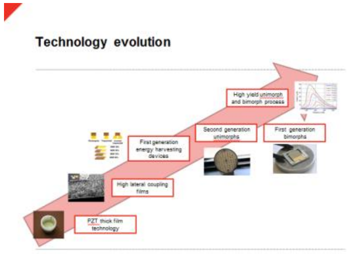
$$\frac{t_{pzt}}{t_{Si}} = \sqrt{\frac{Y_{Si}}{Y_{PZT}}}$$

Y – Young's modulus

t – thickness

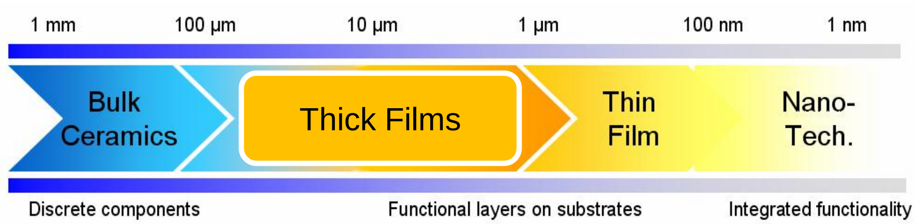
$$t_{pzt} = t_{Si} \cdot \sqrt{\frac{Y_{Si}}{Y_{PZT}}} = 20\ \mu\mathrm{m} \cdot \sqrt{\frac{130\ \mathrm{GPa}}{43.6\ \mathrm{GPa}}} = 34.53\ \mu\mathrm{m}$$

Source: Jesper Kenneth Olsen, Master Thesis, "Piezoelectric Components in Microfluidic Devices", DTU, 2007



The foundation - PZT Thick Film technology

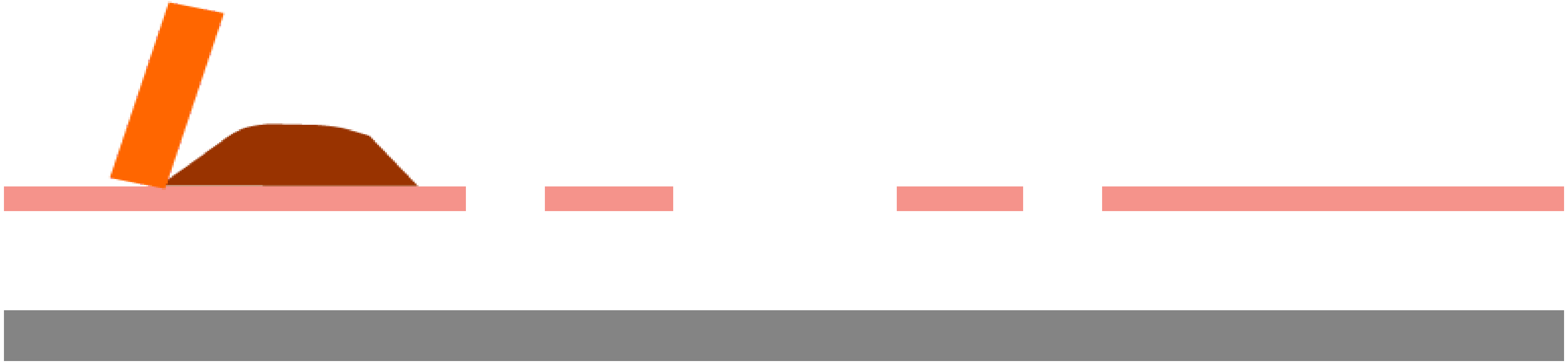
» Technology of piezoelectric thick films (InSensor™) – enabling deposition and integration of piezoelectric layers (10 to 100 µm in thickness) with high lateral resolution (100x100 µm)



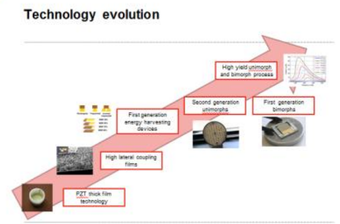
» Key futures of InSensor™ technology
- Capable of manufacturing miniaturized devices
- Low prototyping costs
- High volume production
- High lateral resolution
- High frequency
- High response
- Piezoelectric material can be deposited on a number of different substrates (compatible with MEMS)

Deposition - Screen printing

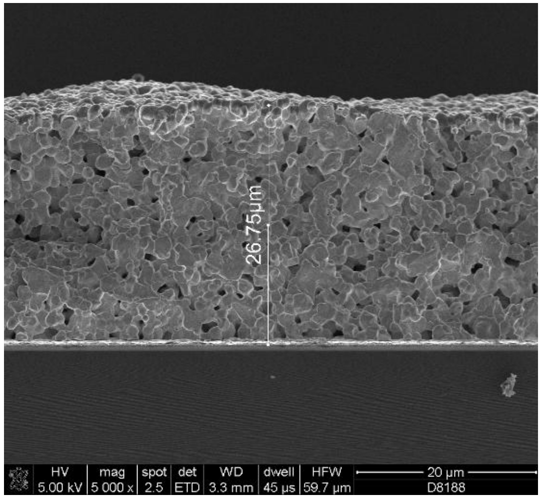
PZT dispersed in an organic vehicle



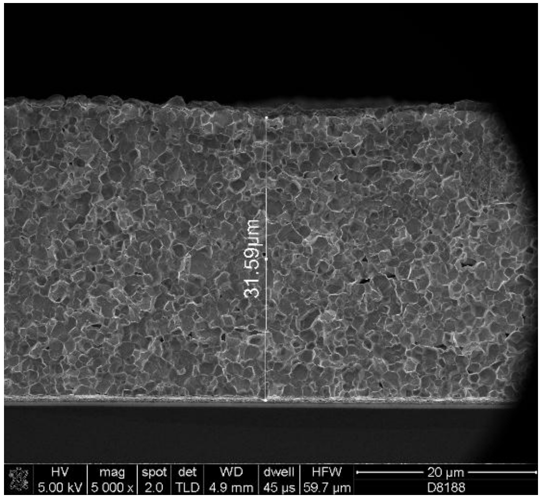
High coupling thick films – important step towards efficient micro-generators



» The piezoelectric properties of the PZT thick film can be improved by using an additional processing of the green films in high pressure



Micrograph of standard PZT thick film (on silicon)



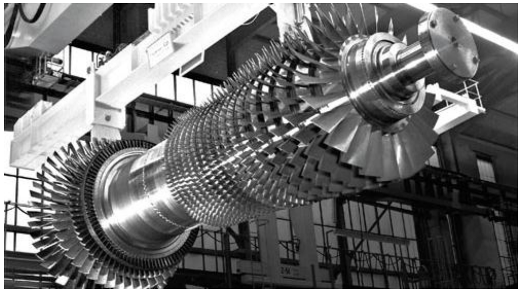
Micrograph of PZT thick film (on silicon) processed using high pressure processing

High coupling materials

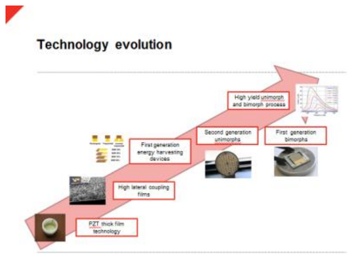
- The following properties of both materials have been used in the FEM

	Piezoelectric coeff. (estimated) *d*31 [pC/N]	Relative dielectric permittivity (measured) ε_r
STD TF2100	-50	584
MOD TF2100	**-93**	730

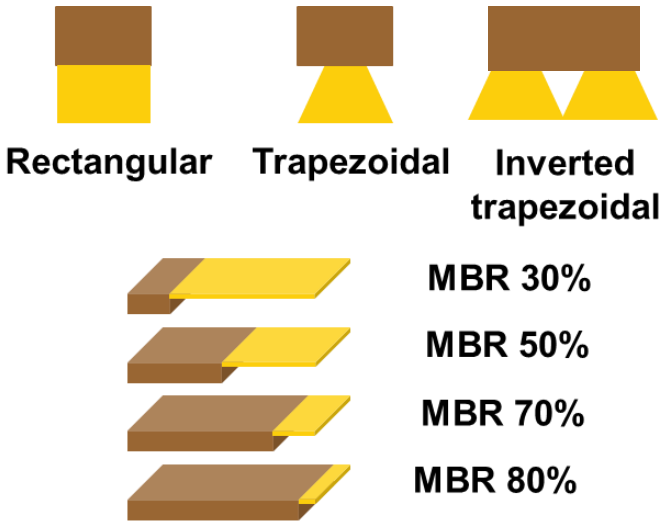
4 Micro generators

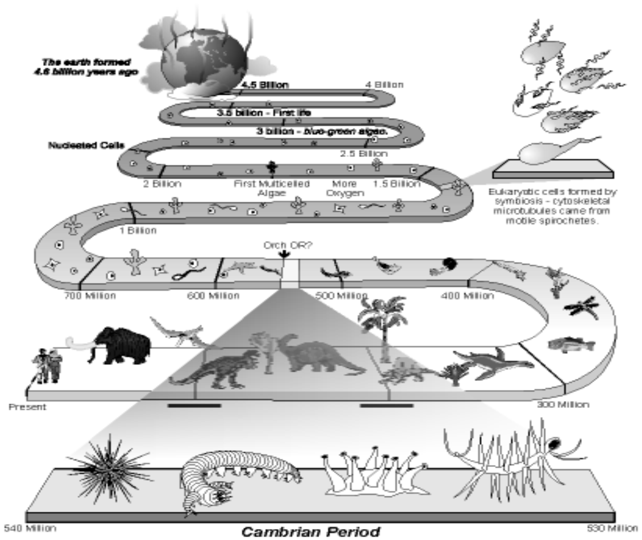


First generation devices
Cambrian period

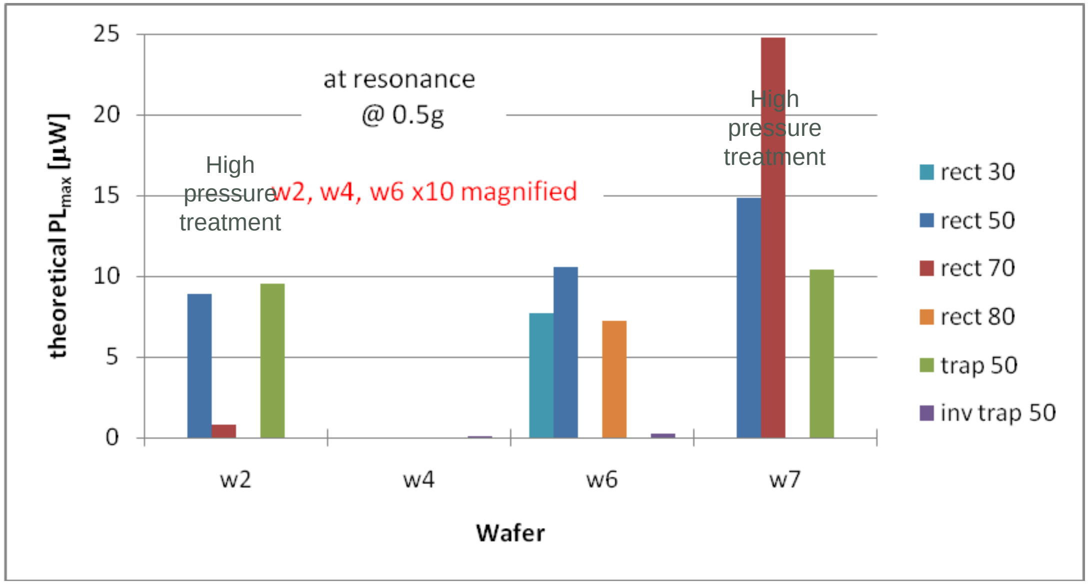


- Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- Single clamped cantilevers with a silicon proof mass at the free end
- Planar dimension 10x10 mm^2
- Different cantilever shapes, and mass-beam length ratios (MBR)

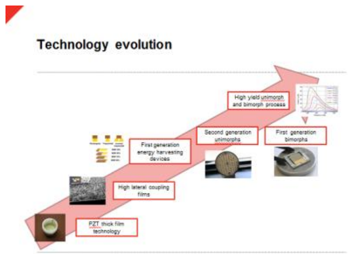




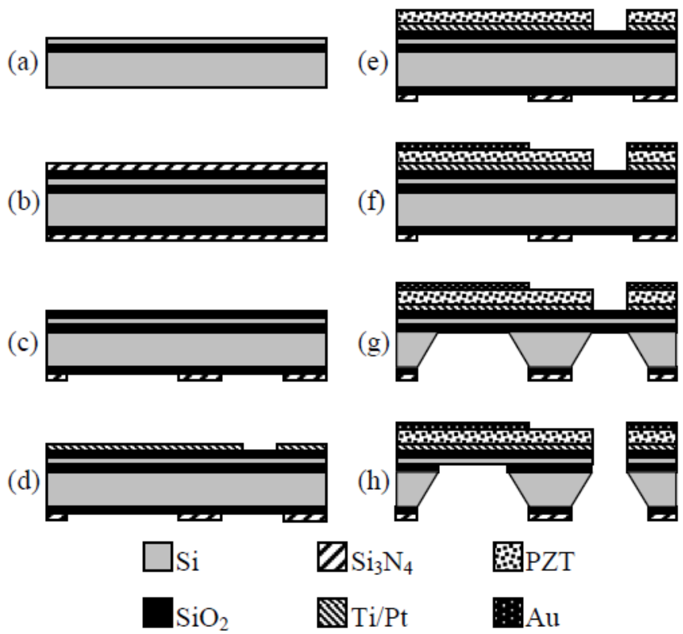
First generation devices – performance comparison



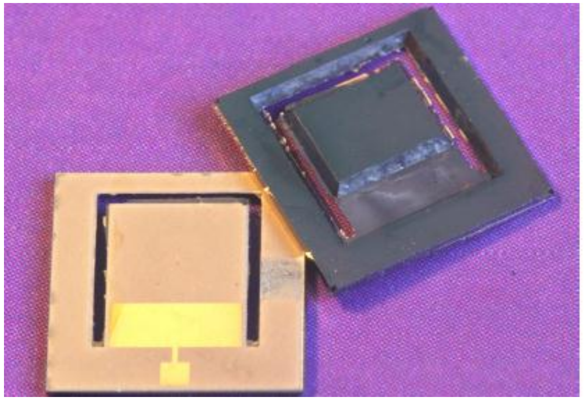
Power output @ 0.5 *g* at resonance



Second generation unimorphs

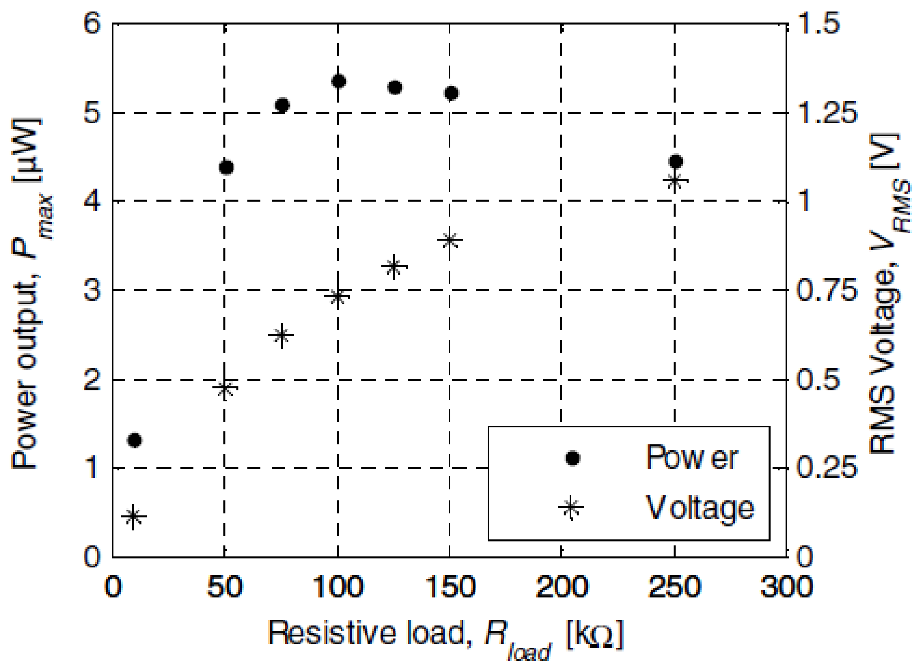


Process flow



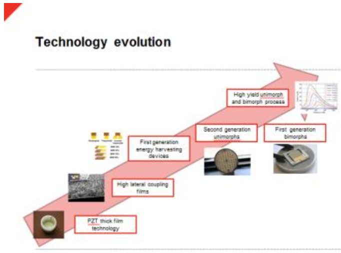
Unimorph energy harvesting devices

Second generation devices - performance



Power output as a function of resistive load (at resonance) @ 0.5 *g* harmonic excitation (240 Hz)

Wafer scale process analysis leading to next generation devices



	A	B	C	D	E	F	G
1		5.342	5.448	5.495	5.234	5.096	
2	5.336	5.640	5.693	5.679	5.600	5.506	5.343
3	5.139		5.799	5.769	5.636	5.564	5.398
4	5.768	5.766	5.839	5.924		5.724	5.004
5	5.789	5.868	5.884	5.924	5.934	5.896	5.449
6	5.765	5.958	5.671		5.779	5.615	5.588
7			5.812	5.853	5.749	5.869	

[nF]
6
5.64
5

	A	B	C	D	E	F	G
1		0.75	1.06	0.985	1.30	0.507	
2	1.173	0.96	1.21	1.32	1.52	1.07	1.88
3	2.40		1.08	1.41	1.07	1.27	2.08
4	2.09	2.15	2.25	1.31		1.72	1.10
5	2.27	2.20	1.84	1.00	1.28	1.60	2.41
6	2.70	2.07	2.11		1.55	1.99	1.83
7			2.10	1.53	1.77	1.79	

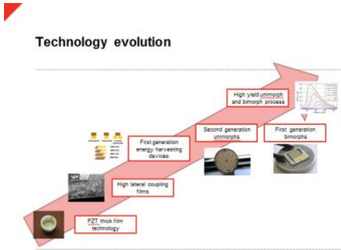
[V]
2.7
1.6
0.5

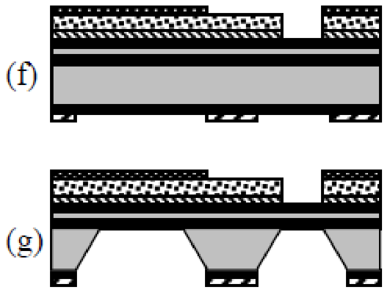
Wafer level distribution of capacitance (left) and open circuit voltage (right)

Comparative study of distribution of the properties

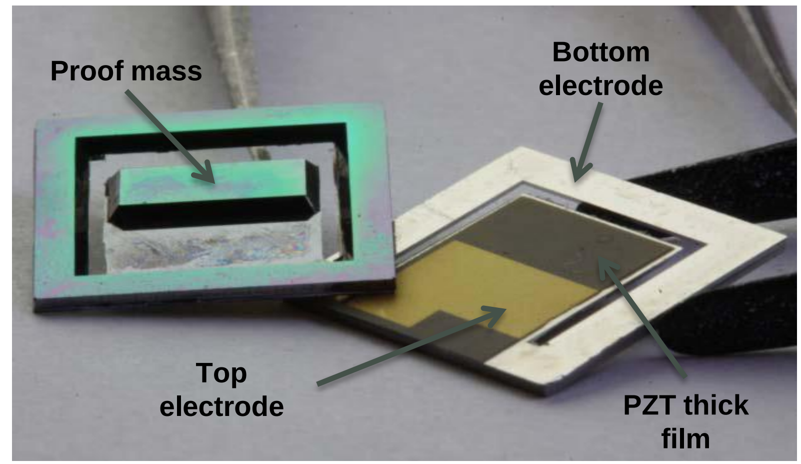
Chip	BW_{FWHM}	Q_{total}	RMS Power [μW]		
	[Hz]		0.5g	0.75g	1g
A6	5.00	65.9	12.5	25.0	39.3
G3	6.80	50.7	10.5	22.1	35.0
B4	6.80	49.7	9.6	21.3	35.8
B6	6.60	49.3	9.7	21.4	34.7
F5	8.20	40.1	6.7	15.7	25.7
D7	9.00	37.1	6.1	14.8	24.3
E6	8.50	39.2	5.5	13.1	22.5
C2	8.75	37.7	4.8	11.1	17.9
A2	8.20	38.4	5.1	10.9	15.3
C3	10.25	31.1	2.9	7.2	13.3

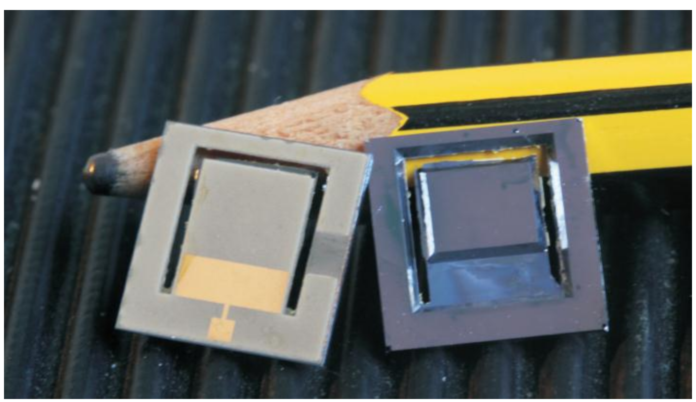
Third generation unimorph devices



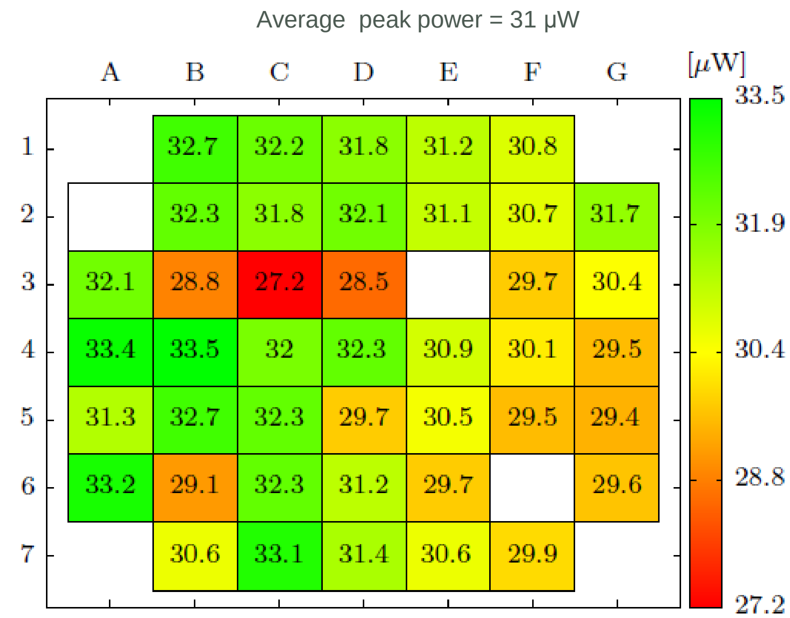


DRIE replaced by KOH etch

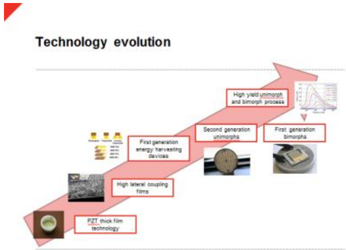




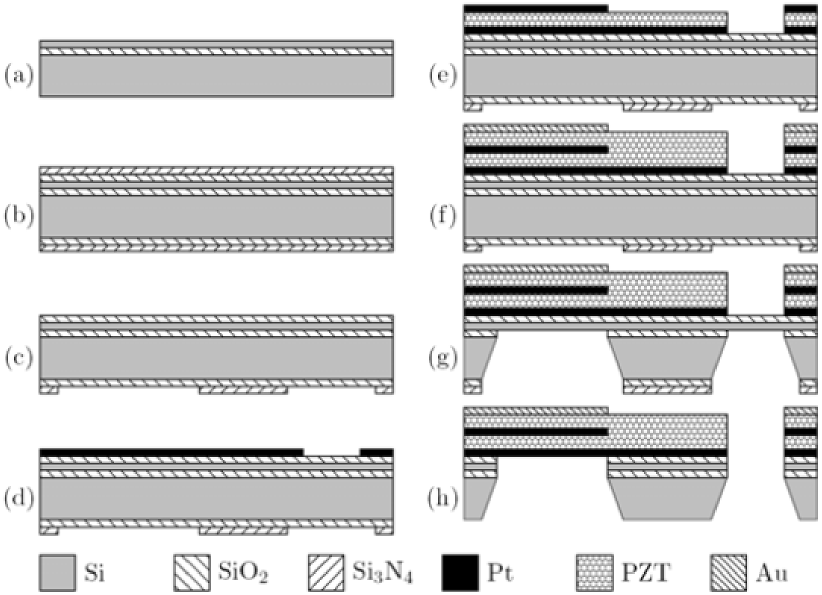
Third generation - performance



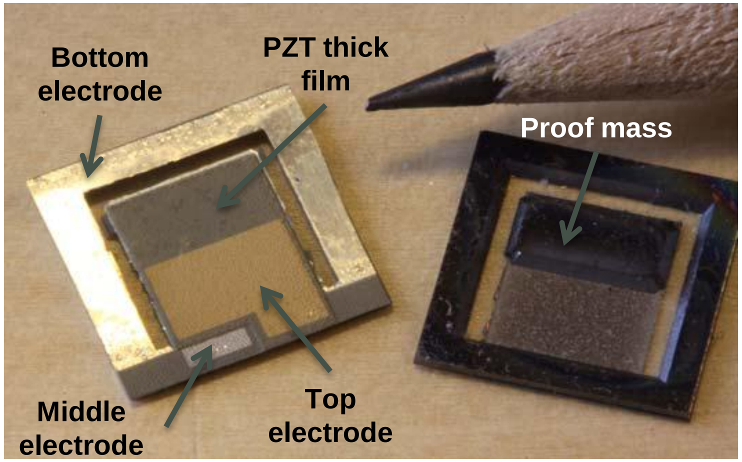
Wafer level distribution of quality factor (left) and peak power output at optimal load and acceleration 0.5 *g* RMS (average frequency 482 Hz)



Parallel evolution path - bimorphs

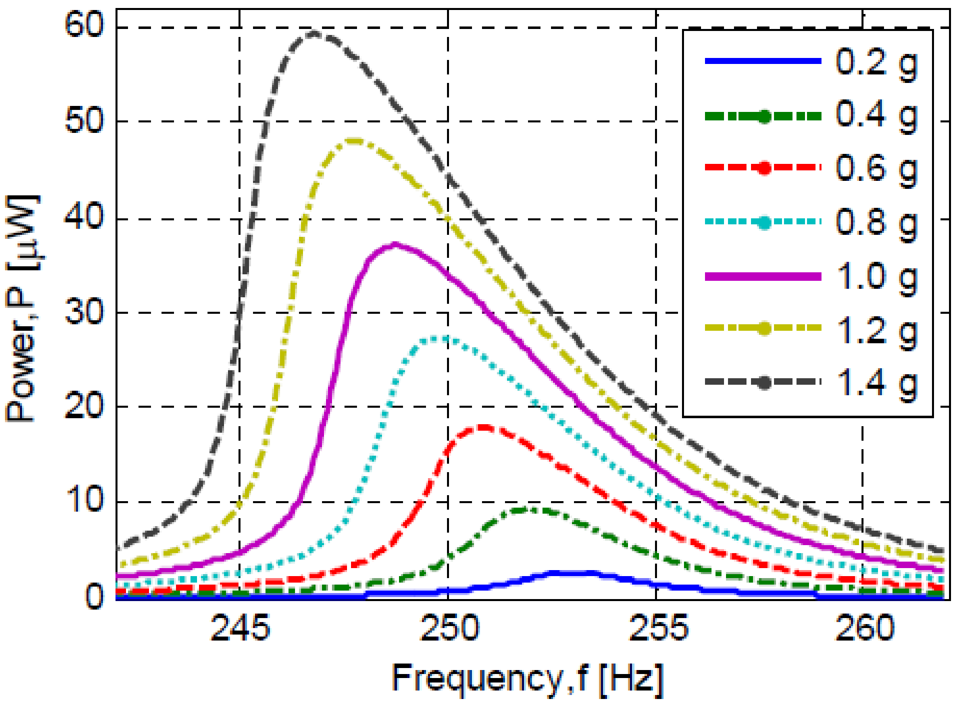


Process flow



Bimorph energy harvesting devices

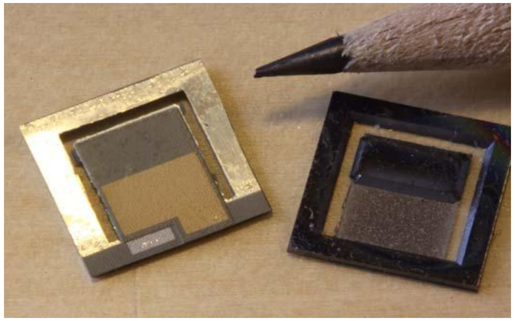
Bimorphs - performance

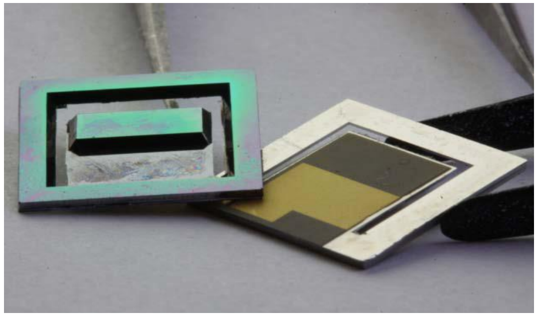


Power output as a function of excitation frequency (at optimal resistive load)

Summary

- PZT thick film technology for energy harvesting devices has gone through several iterations leading towards high yield process (> 93%) producing very efficient devices
- The evolution has been targeting two mutually supporting development directions higher power output at lower excitation accelerations
- Current generation of devices is capable of generation of 30-40 μW of power at moderate accelerations of about 0.5 *g* in relatively wide range of frequencies, producing output voltage of 4-5 V





Contributors

- CTS | Ferroperm Denmark Team
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- DTU Nanotech Team
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  - Anders Lei

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ELBA


Thank you