MEGGITT

smart engineering for extreme environments

Piezopaint for Piezomems – industrial low temperature technology for design and production of integrated multifunctional devices,

Wanda Wolny, Rasmus Lou-Moeller, Tomasz Zawada and Konstantin Astafiev Meggitt, Copenhagen, Denmark

Outline

- Meggitt company introduction
- Integration, motivation and existing technologies
- Applications
    - Energy harvesting
    - Accelerometer
    - High frequency transducer
    - SHM
- PiezoPaint™ technology
- PiezoPaint™ demonstrators
- Summary

Leading technology positions

Meggitt Strategic Business Units

Aircraft Braking Systems

- Wheels
- Carbon brakes
- Steel brakes
- Electric brakes
- Brake control
- Gear control
- Nose wheel steering

Control Systems

- Thermal management
- ECS
- Fluid control
- Electronic control
- Engine dressings

Polymers & Composites

- Electro-thermal ice protection
- Ice protection controllers
- Composite structures
- Seals
- Fuel bladders

Sensing Systems

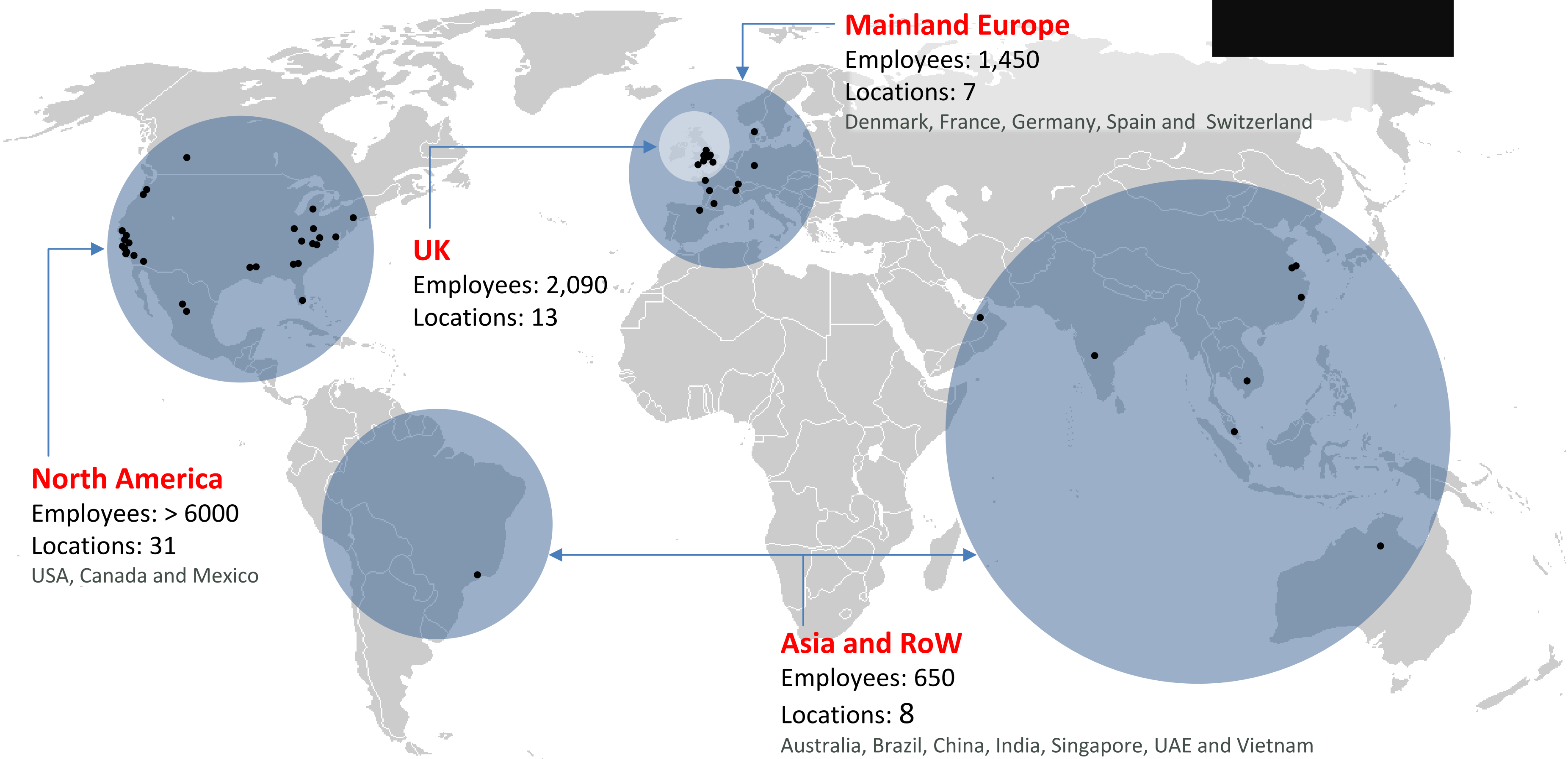
- Condition monitoring systems
- High performance sensors
- Turbine ignition

Equipment Group

- Power systems
- Actuators
- Air data computing
- Avionics
- Specialty components
- Fire protection
- Defence systems

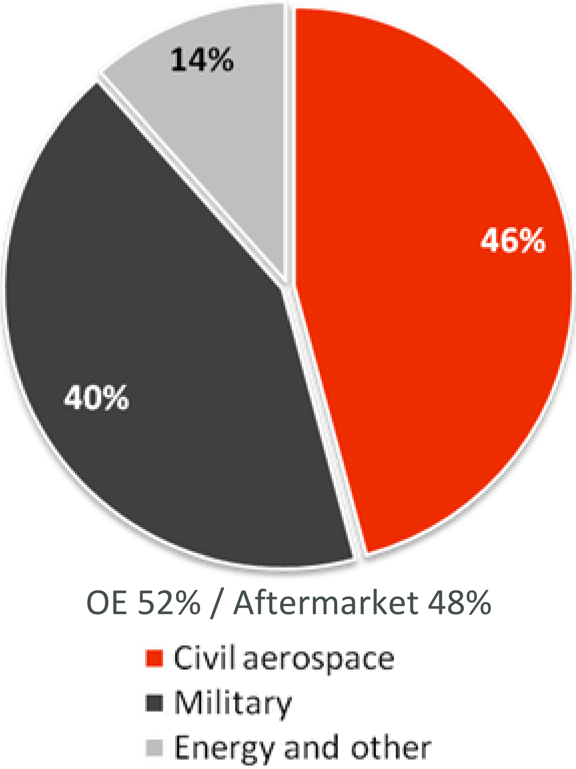
A global presence

>10 000 employees worldwide

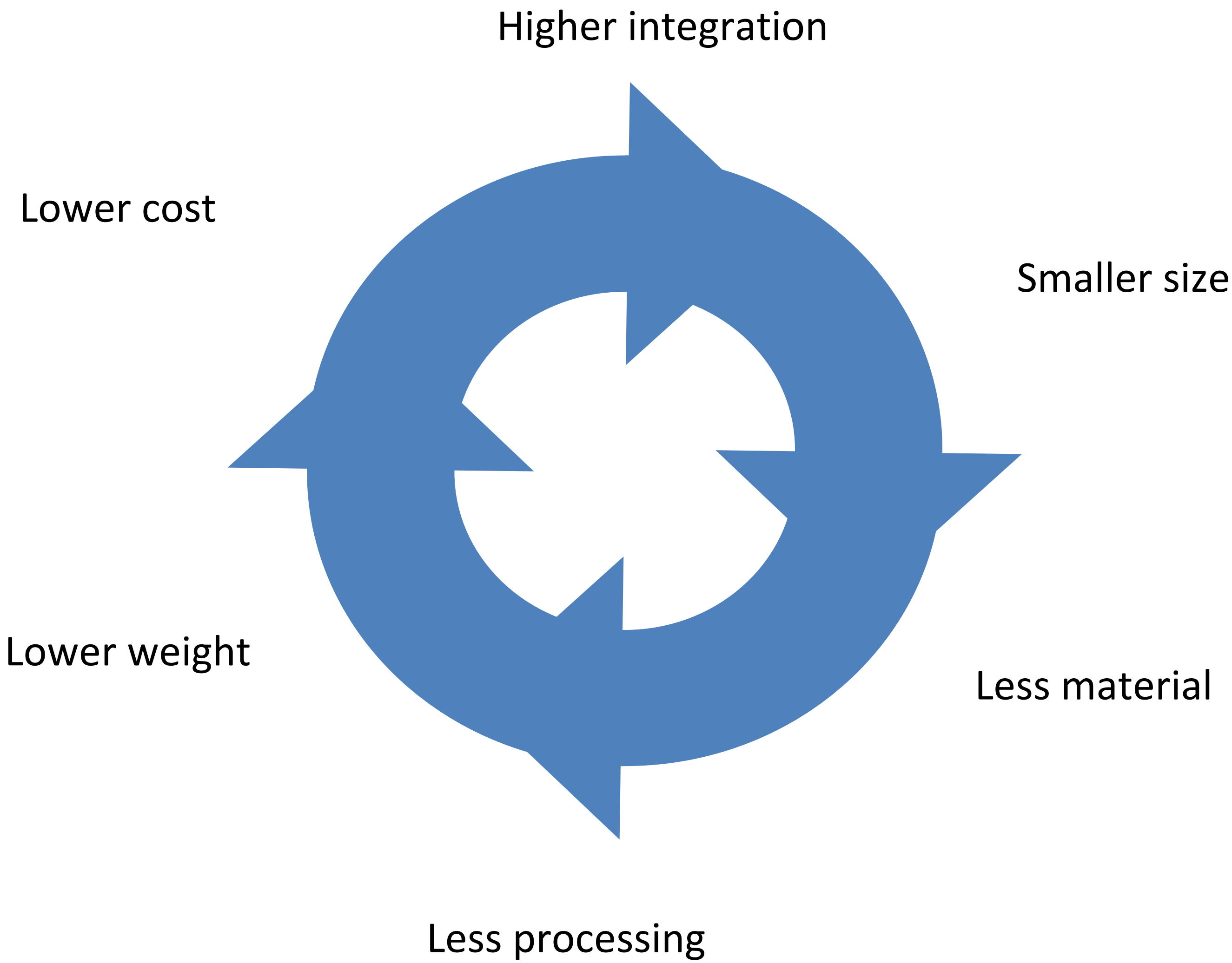


Meggitt - overview

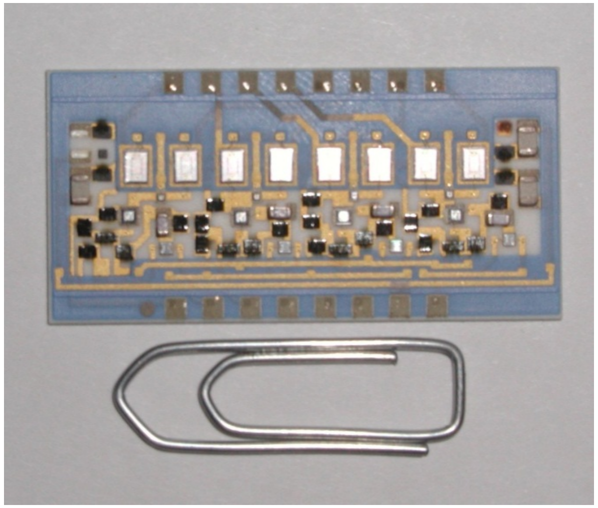
- Provides high technology products and systems for the aerospace, defence and other specialist markets, including: medical, industrial, energy, test and automotive
- 150 years of engineering innovation
- Broad geographic footprint
- Annual sales £m 1606 (USD m 2500)
- Listed on London Stock Exchange (MGGT)



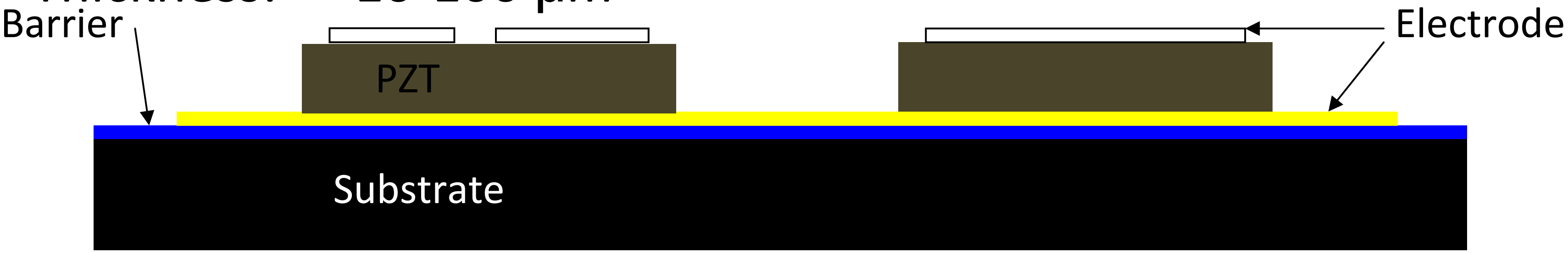
ntegration motivation and technologies I



Thick film technology I



- Doped PZT ceramic on a substrate
  - Ceramic
  - Silicon
  - Stainless steel
  - LTCC
- Thickness: 10-100 µm



Integration motivation and technologies II

Evolution in screen printing of thick film

Substrate	Sintering temperature
Ceramics incl. Alumina, pzt and others	1100-1250ºC
Steel, silicon, LTCC	850ºC
Polymer	150ºC
Textile	100ºC
Composites	”
Laminates	”
Paper	”

Typical Thick Film Properties

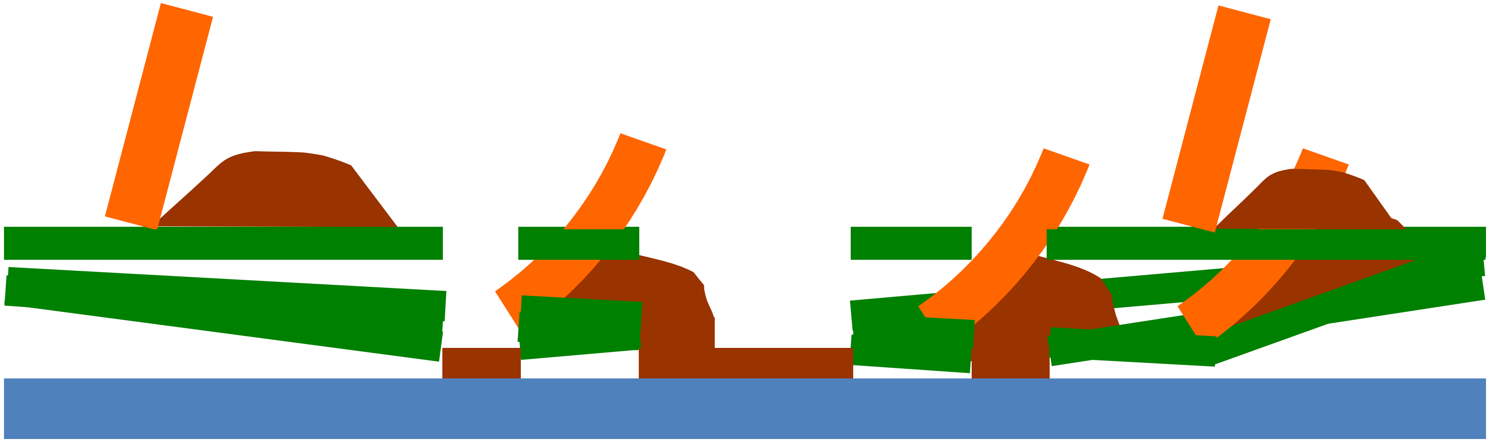
Materials	**Piezoelectric charge coefficient, d_{33} (pC/N)**
PZ26 (bulk component)	290
TF2100 InSensor® (thick film)	200
Lead free thick film	**150**
Flexible thick film Piezopaint ™	40
PVDF (thin film)[1]	-8
Copolymer P(VDF-TrFE)[2]	-33

[1] Kawai, H., *Jpn. J. Appl. Phys*, 8, 975-976, (1969)
[2] Kenji, O., Hiroji, O., Keiko, K., J. Appl. Phys. 81, 2760, (1996)

Thick film technology II

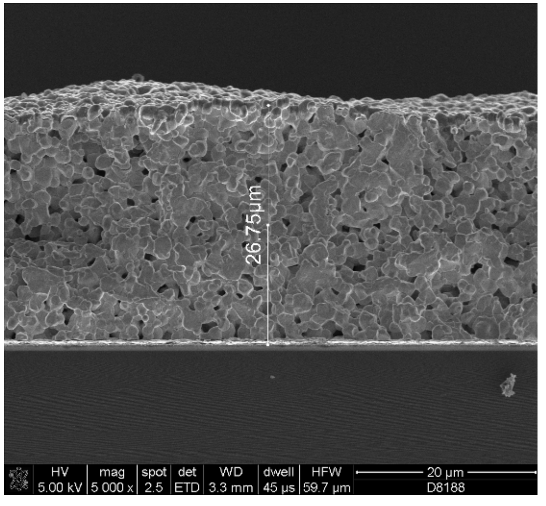
Screen printing

PZT powder is suspended in an organic vehicle

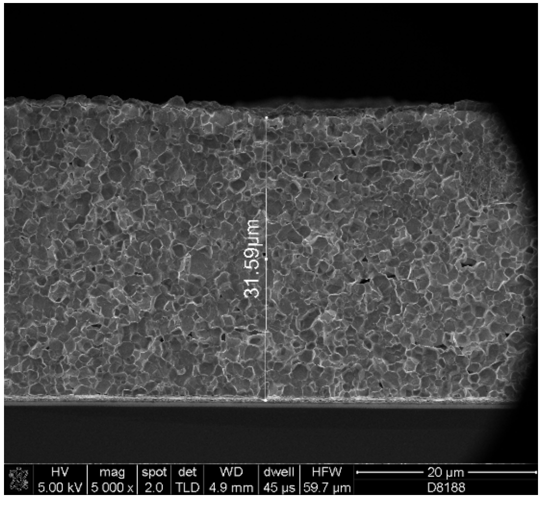


Thick film technology III

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

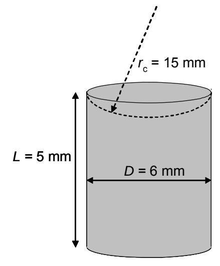


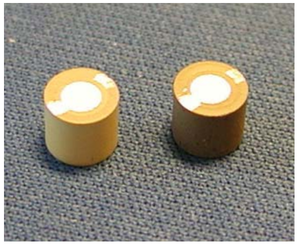
Micrograph of standard PZT thick film (on silicon)

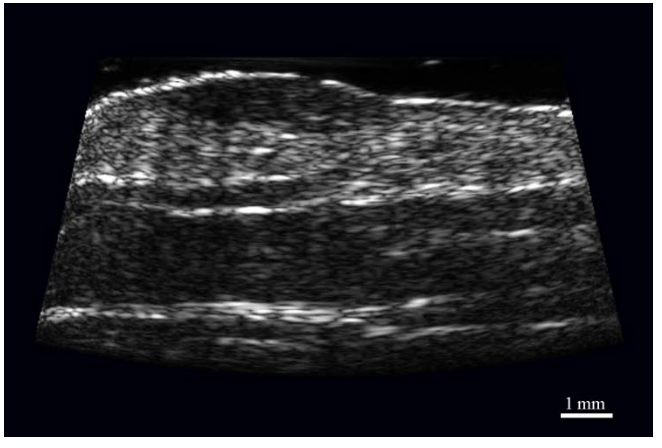


Micrograph of PZT thick film (on silicon) processed using high pressure processing

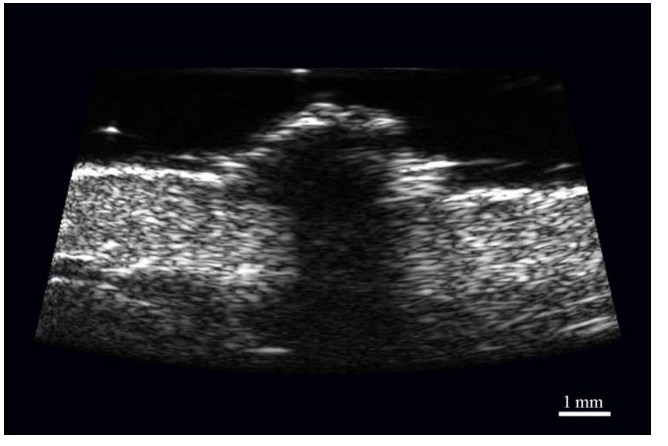
TF2100 transducer







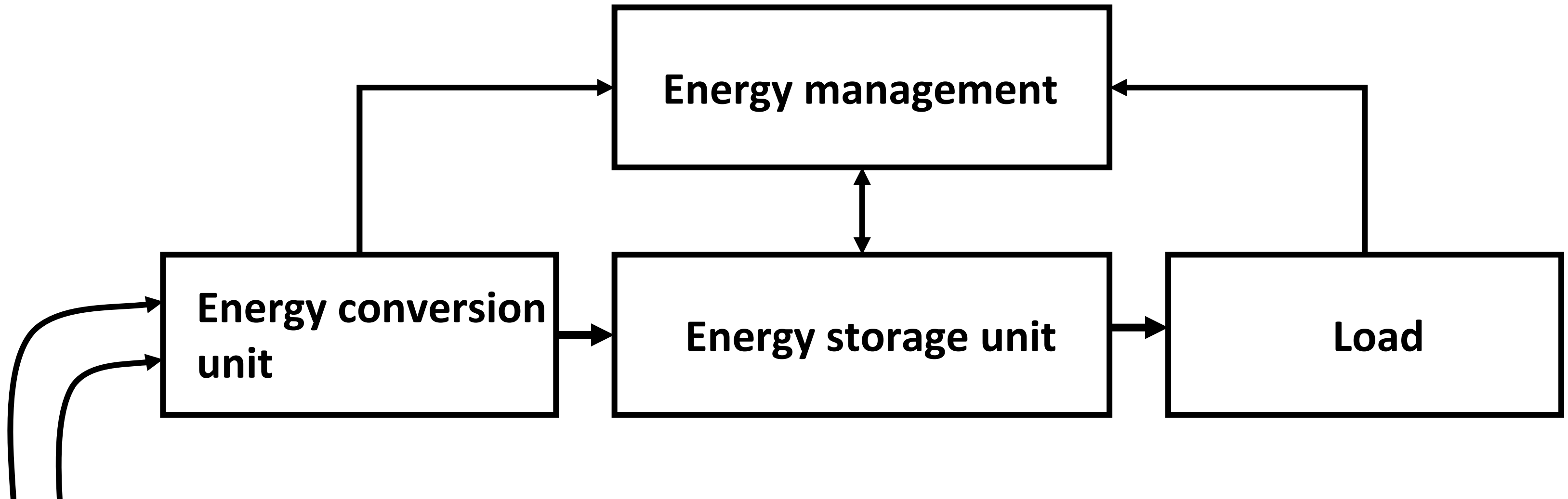
Ultrasonic image of the skin with anginoma.

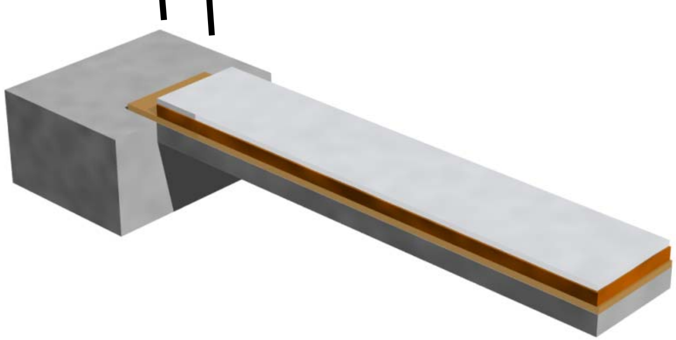


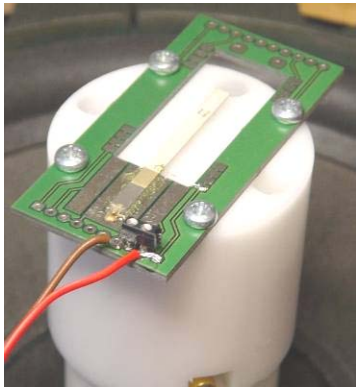
Ultrasonic image of the skin cancer spinocellular carcinoma.

With IPPT

Energy harvesting



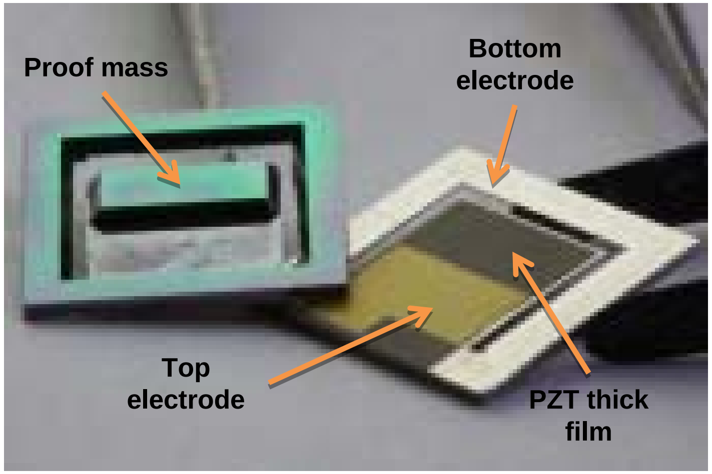




Energy Harvesting micro-generators

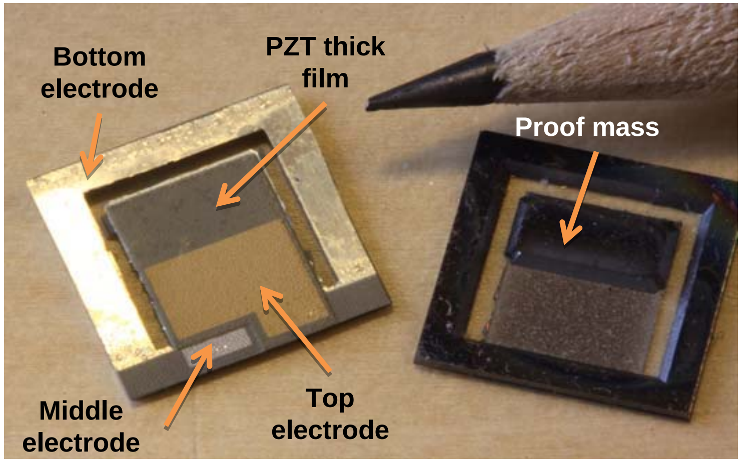
- Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- Single clamped cantilevers with a silicon proof mass at the free end
- Unimorph configuration
- High yield (> 90%) using KOH wet etch in the last part of the fabrication process

In cooperation with DTU Nanotech



Energy Harvesting micro-generators - bimorph

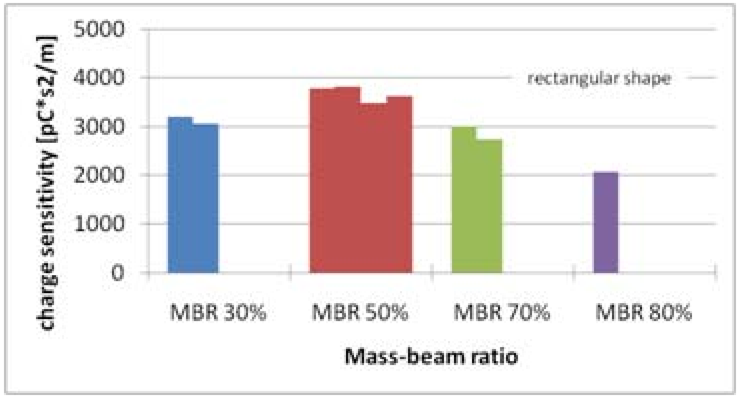
- Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- Single clamped cantilevers with a silicon proof mass at the free end
- Bimorph configuration
- Higher voltage and power compared to unimorph
- Si/PZT fabrication + middle electrode + 2nd PZT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

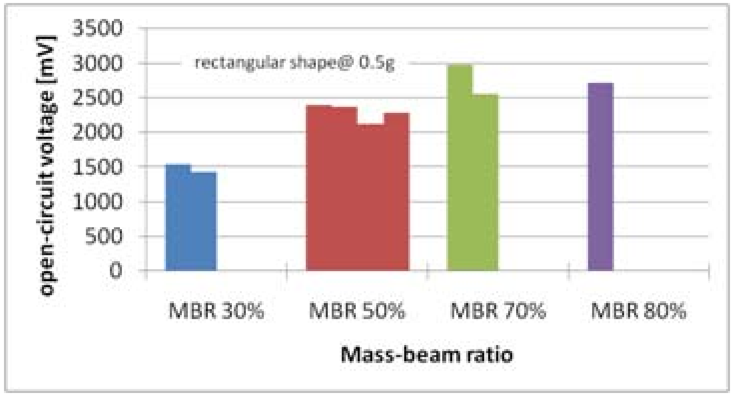


In cooperation with DTU Nanotech

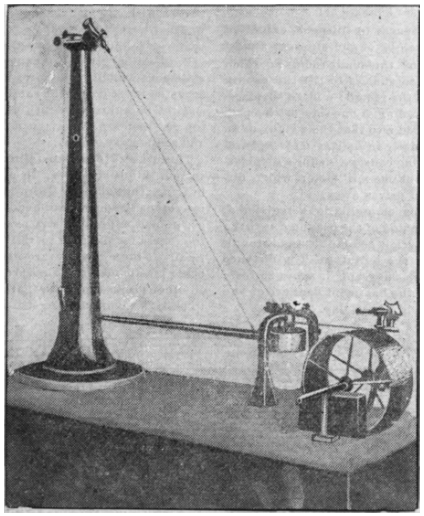
Comparison of the structures

- 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)
  - 12 µW ÷ 20 µW @ 0.5 g peak (bimorph)

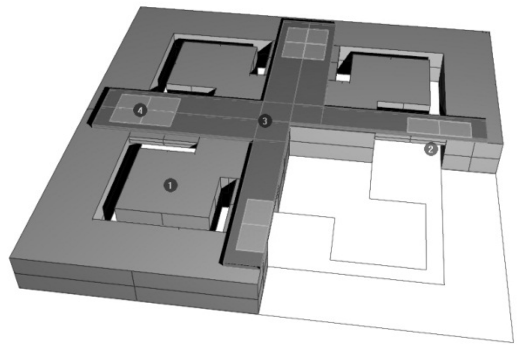


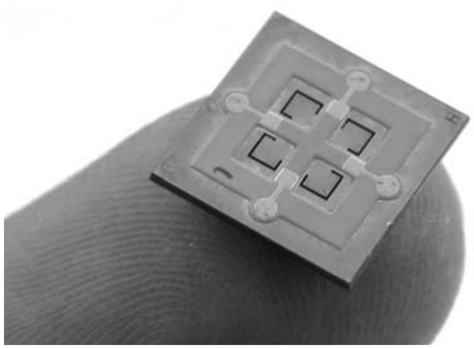


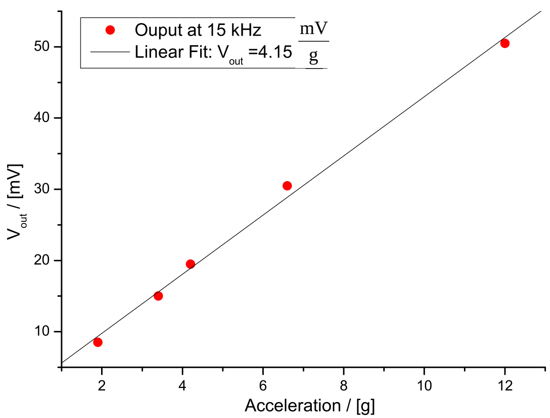
Accelerometer



http://chestofbooks.com/crafts/popular-mechanics







Π-MEMS projektet finansieret af højteknologifonden

I samarbejde med Nanotech DTU

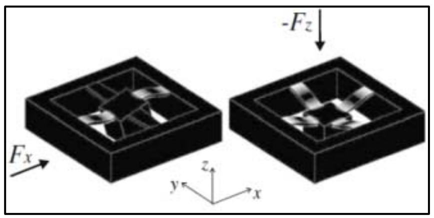
PMN-PT accelerometer

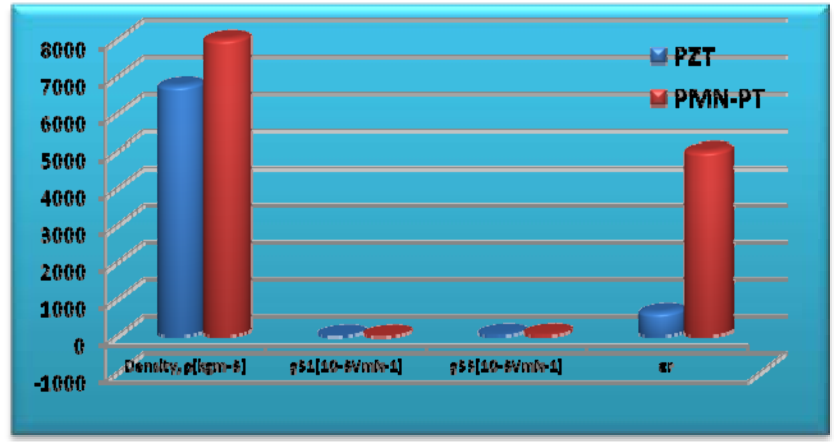
J Electroceram (2010) 25:108–115
DOI 10.1007/s10832-010-9597-4

Triaxial MEMS accelerometer with screen printed PZT thick film

Christian C. Hindrichsen · Ninia S. Almind · Simon H. Brodersen · Rasmus Lou-Møller · Karsten Hansen · Erik V. Thomsen

MEMS based accelerometers are interesting as they have potential for being more cost efficient and miniaturized compared to conventional accelerometers [11]. MEMS based accelerometers can with advantage use the piezoelectric effect as their transducer element due to more controlled temperature dependence, no need for a stable driving source, better long term stability and higher possible bandwidth compared to the two other main transducer principles: capacitive and piezoresistive [12]. Applications for piezoelectric type





Material	PZT	PMN-PT
Density, ρ[kgm^{-3}]	6740	8080
g31[$10^{-3}VmN^{-1}$]	-9	-15.6
g33[$10^{-3}VmN^{-1}$]	39	44
ε_r	640	5000

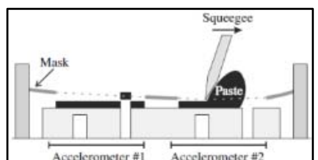
❖ **The advantages of the use of piezoelectric.**

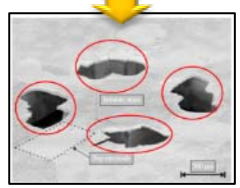
① More controlled temperature dependence

② No need for a stable driving source

③ Better long term stability

④ Higher possible band width





❖ Disadvantage(PZT)

- Over printing
- Low properties

PZT paste

Substitute

PMN-PT

$$S_Q = C \cdot S_V = A2 \cdot \bar{E}_3 \cdot \varepsilon_r \cdot \varepsilon_0$$

$$Capacitance = \frac{A1 + A2}{piezo\ thickness} \cdot \varepsilon_r \cdot \varepsilon_0$$

$$\bar{E}_3 = [g][\sigma]$$

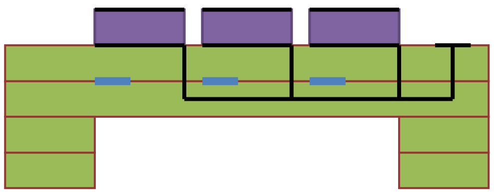
S_Q : Charge sensitivity
S_V : Voltage sensitivity
C : Capacitance
A : Electrode area

∴ **In order to increase the sensitivity, the dielectric constant and the voltage coefficient should be higher.**

Fraunhofer IKTS

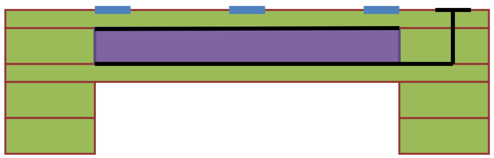
- **Monolithic Integrated Piezoelectrics for Smart Microsystems**

On Top



Piezoceramic Thick Films

Inside



LTCC/PZT Multilayer

- **Teamwork of Substrate and Piezoceramic**

Substrate Material

- Al_2O_3
- LTCC
- Silicon
- others

→

Chemical Reaction

Mechanical Interaction

Thermal Mismatch

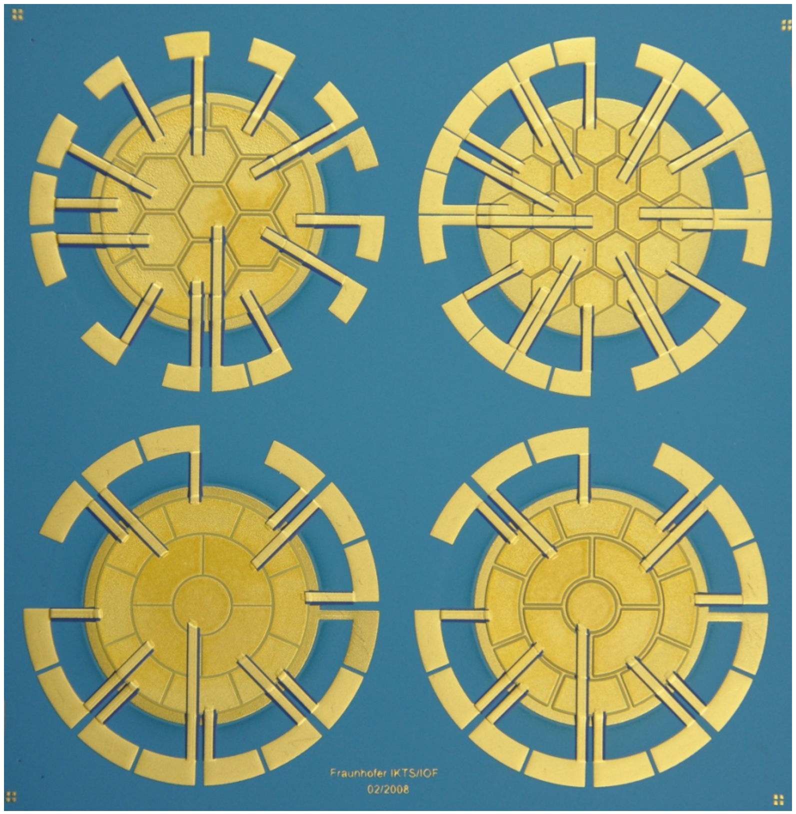
←

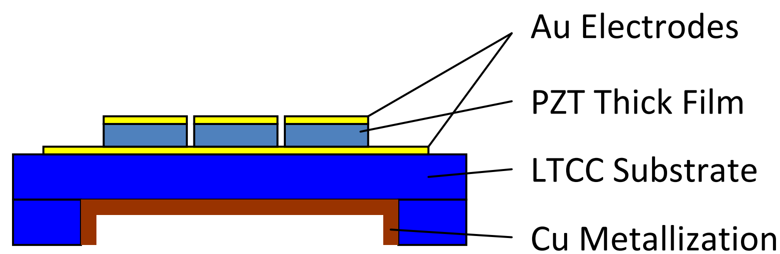
Piezoceramic Material

- PZT
- PMN-PT
- KNN
- Others

PZT thick film on LTCC

- **Deformable Mirror for Laser Beam Shaping**





- **Multilayer Setup**
  - LTCC material: DP 951
  - LTCC Membrane: t = 220 µm
  - LTCC Frame: t = 660 µm
  - Membrane Diameter: d = 34.7 mm
  - Thickness PZT Film: t = 100 µm
  - Thickness Cu Film: t = 150 µm

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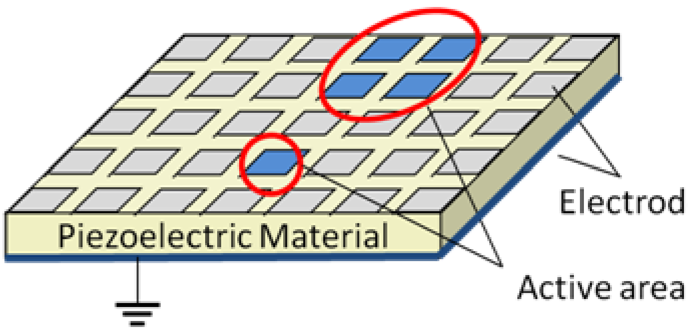
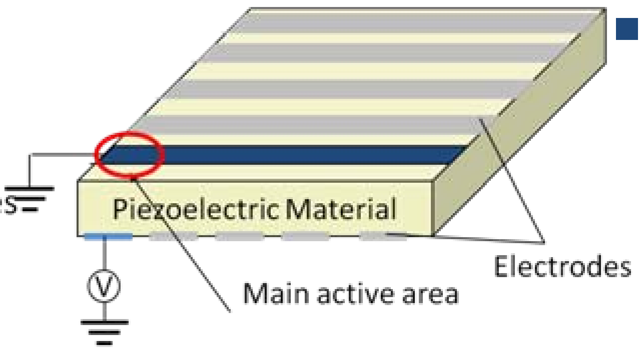
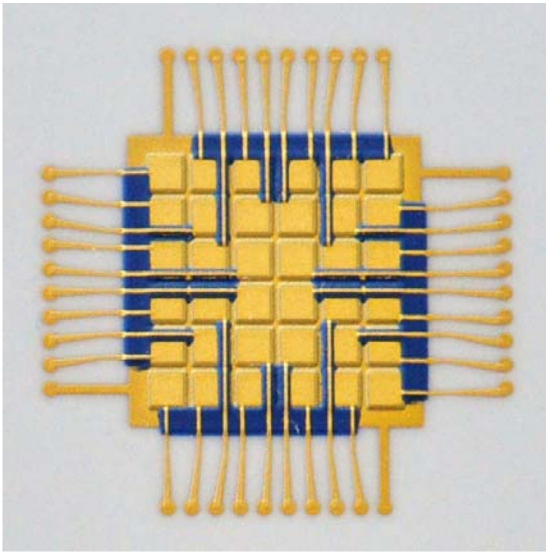
PZT thick film array

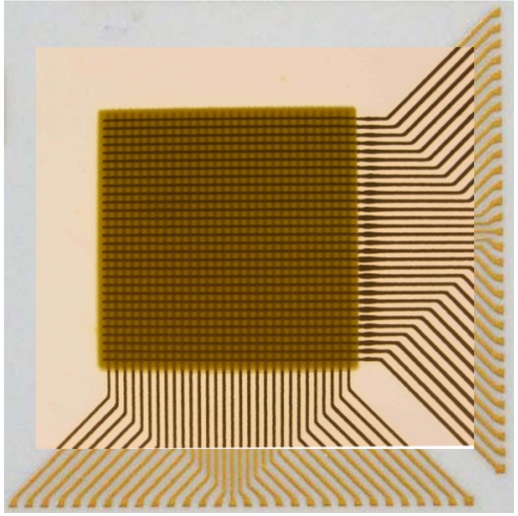
- **2D Ultrasonic Transducer for Particle Manipulation**





- **2D Array**
  - 6 x 6 element 2D array
  - 2 mm element pitch
  - PZT thickness t = 140 µm





- **Crossed Electrode Array**
  - 30 x 30 crossed electrodes
  - 0.5 mm electrode pitch
  - PZT thickness t = 140 µm

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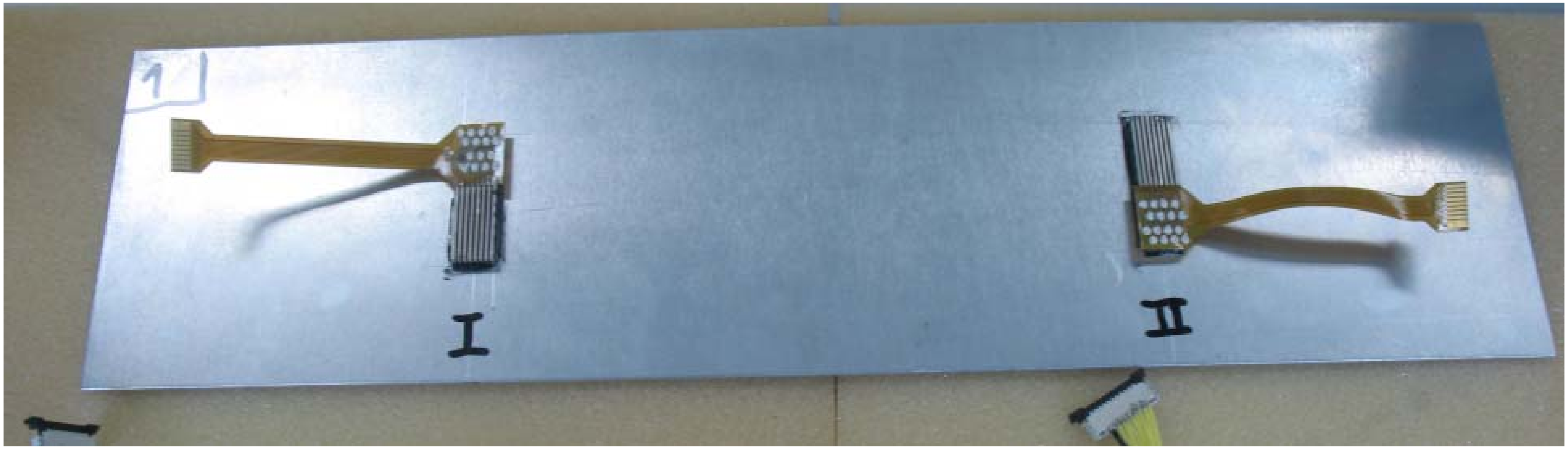
University of Dundee IMSAT sono Tweezers Fraunhofer IKTS

SHM – lamb waves

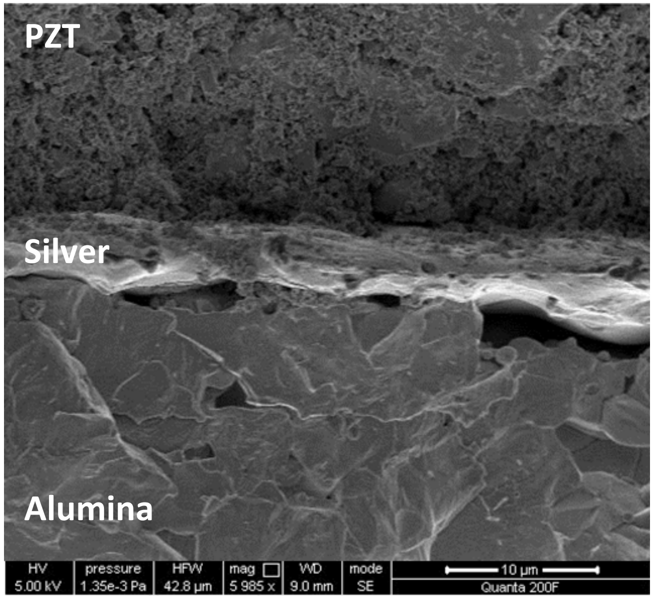
- Arrays mounted with flex PCB by soldering
- Two arrays glued to an aluminium plate
- Both arrays connected to a dedicated SHM electronics module
  - High-frequency excitation (bandwidth up to 2 MHz)
  - PULSECHO functionality (emission and reception on same piezoelectric patch)
  - 4 channels per daughter board



Flexible piezoelectric materials - PiezoPaint™

Low temperature flexible piezoelectric materials has been developed on the basis of commercially available piezoelectric PZT based ceramics and polymer materials.

- Ultra low processing temperature (100 °C),
- High piezoelectric activity (d_{33} > 40 pC/N) and low dielectric losses (no power dissipation – no unnecessary heating),
- Flexibility and compatibility with screen-, pad-, and stencil printing techniques,
- Low manufacturing cost and suitable for large scale production,
- Ability to adjust the properties, depending on the final application.

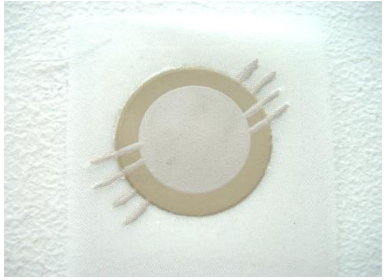


PiezoPaint™ - The substrates

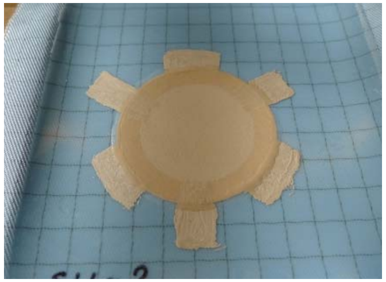
Can be applied onto:

- Fabrics
- Textiles
- Composites
- Metals
- Plastics/polymers
- Laminates
- Ceramics
- Paper
- PCB
- Etc.

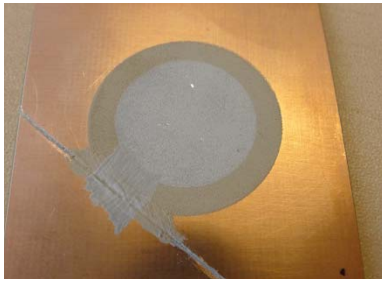
PiezoPaint™ on polymer



PiezoPaint™ on fabric



PiezoPaint™ on PCB



PiezoPaint™ - Properties

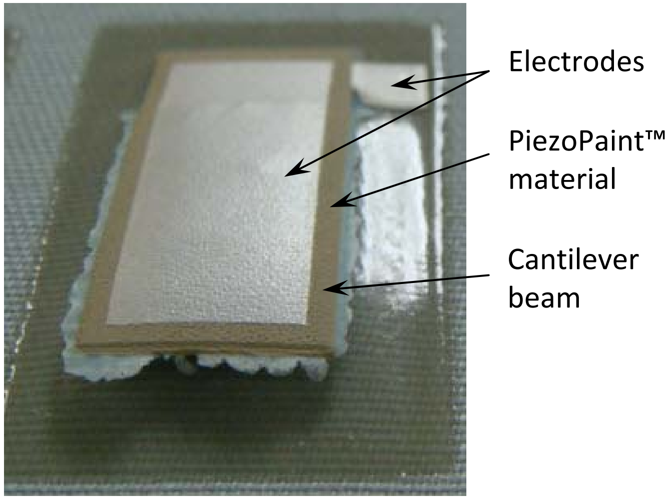
Properties of PiezoPaint™ materials can be adjusted, depending on the final application and customer requirements:

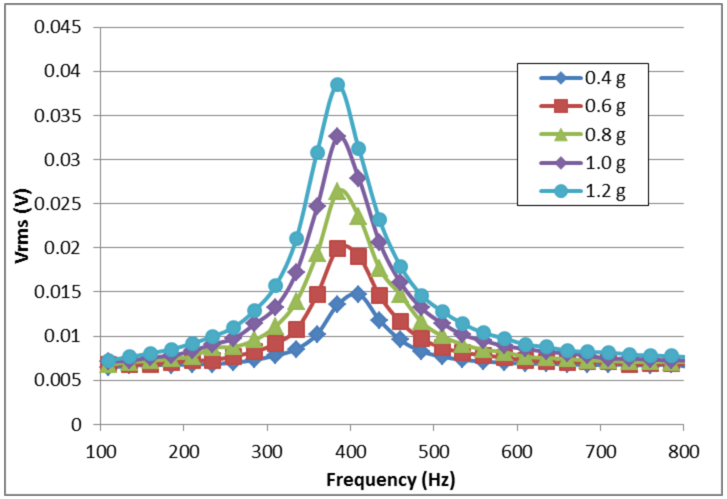
Material	Type	ρ, g/cm^3	T_{op}, °C	ε	tanδ, %	d_{33}, pC/N
PVDF	Co-polymer	1.8	< 90	10 – 12	-	-30
PP-30	PZT	4.9	< 150	90	2.5	28
PP-50A	PZT	5.0	< 150	100	2.5	40
PP-50B	PZT	5.2	< 150	125	3.0	40
PP-50LF	Lead-Free	< 4	< 150	250	4.0	25

Properties are for semi-clamped samples, in the case of the films printed onto alumina substrates (cured)

Energy harvesting

Piezoelectric accelerometer / energy harvester:

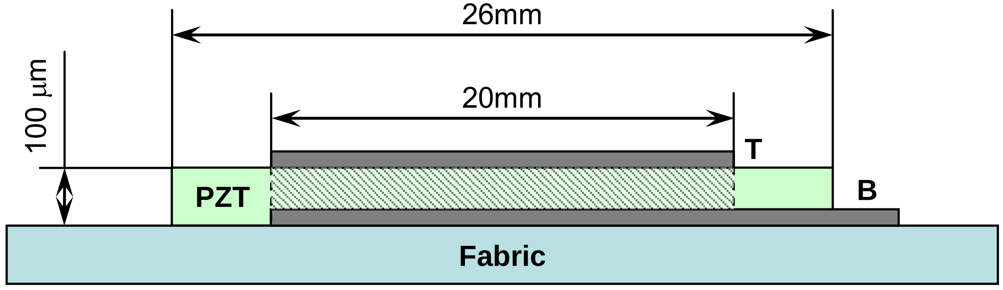


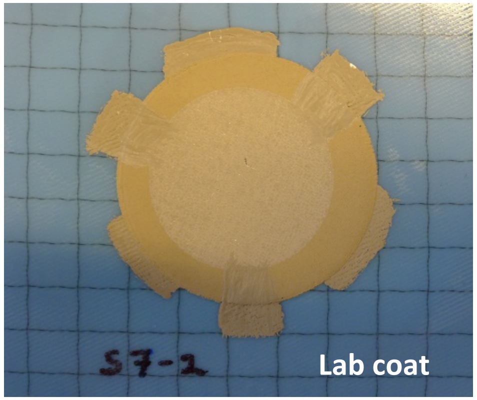


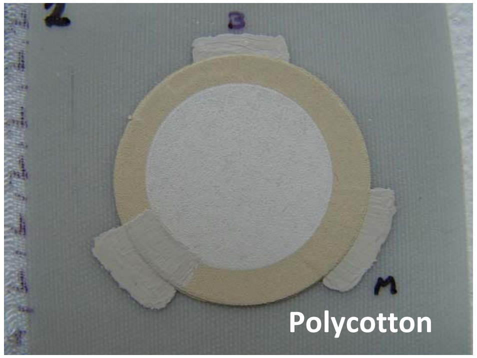
Courtesy of University of Southampton, UK

- The sensor has good linearity and produces a peak output of nearly 60 mV which would be sufficient for a motion sensor detection system.

Piezoelectric buzzers



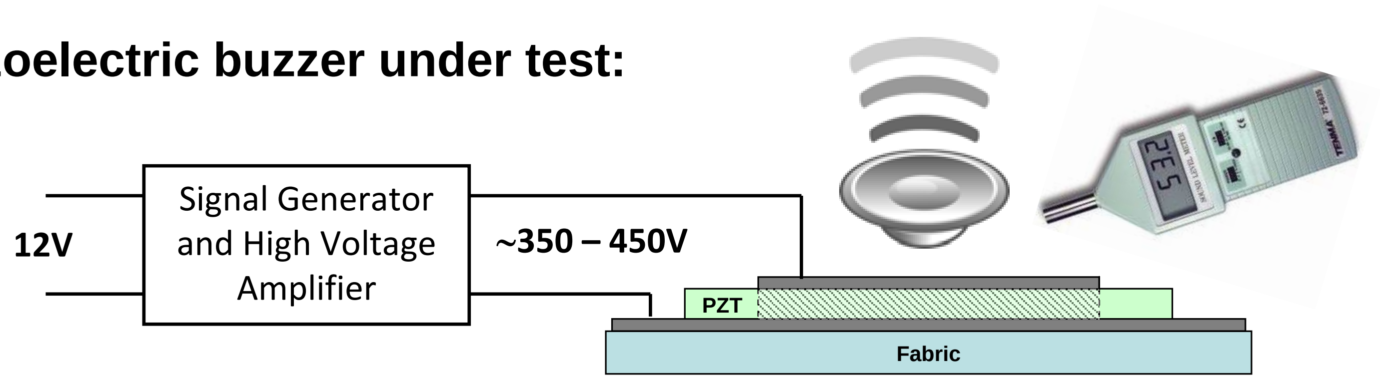




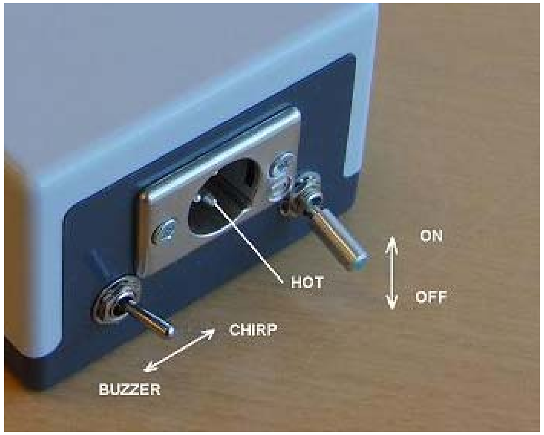
- Represents a simple structure, where the piezoelectric thick film is sandwiched between the top and the bottom electrodes,
- The entire structure can be encapsulated with PVC or UV curable dielectrics, available e.g. from DuPont,
- Flexible and can be applied on any structures, including lab coats or work wear.

Piezoelectric buzzers

- **Piezoelectric buzzer under test:**



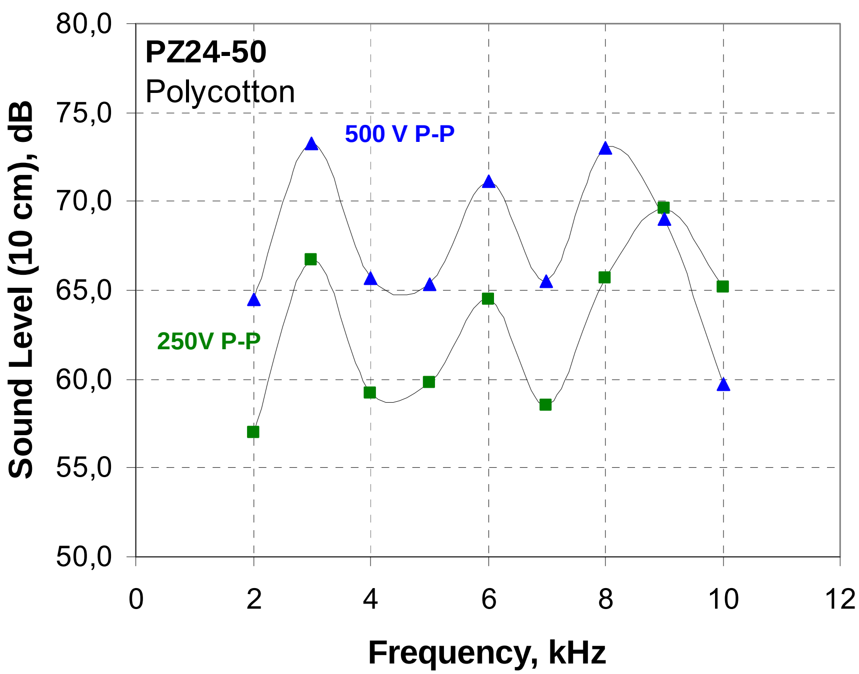
- **High voltage driver generator:**

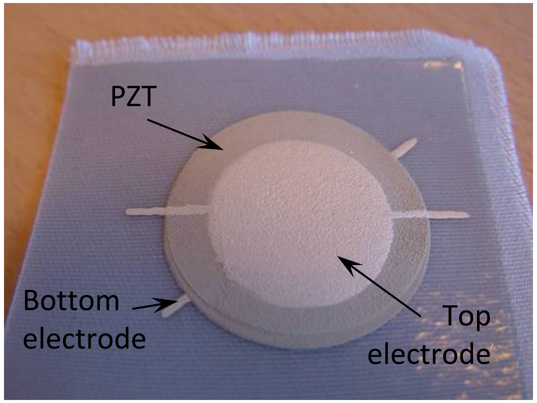


- 12V input voltage, and 350 – 450V output signal (peak to peak),
- Full square wave output: 100Hz – 7kHz (two modes: buzzer and chirp),
- Short circuit protection – safe to use.

Piezoelectric buzzer

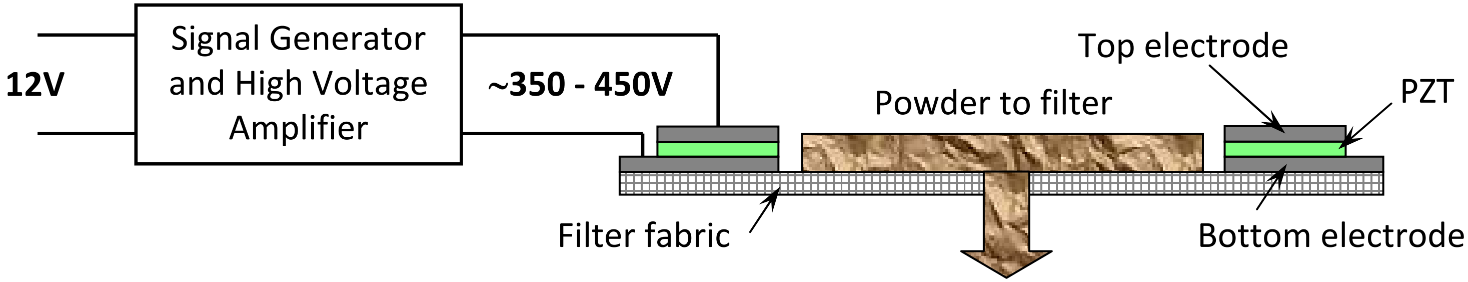
Piezoelectric buzzer on textile:

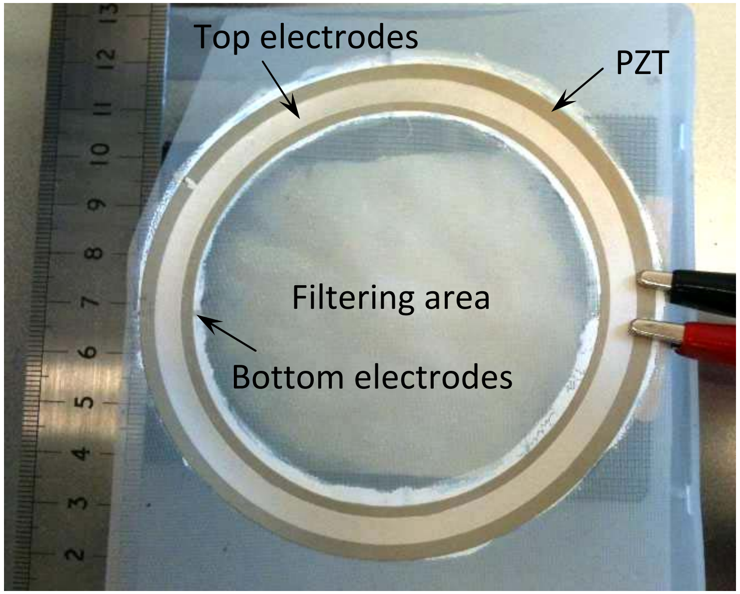


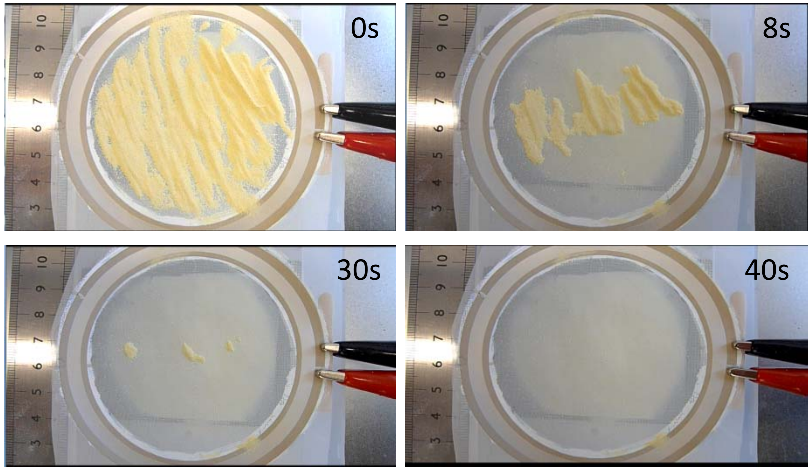


- Up to 75 dB of sound pressure,
- Flexible and can be applied on any structures, including lab coats or work wear.

Piezoelectric active filter cleaner



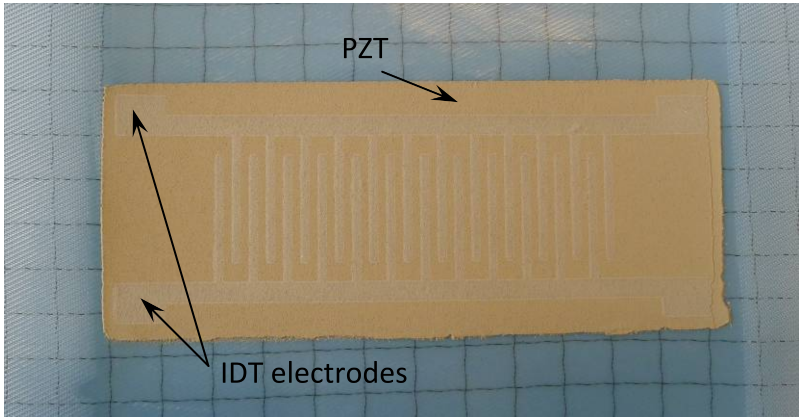


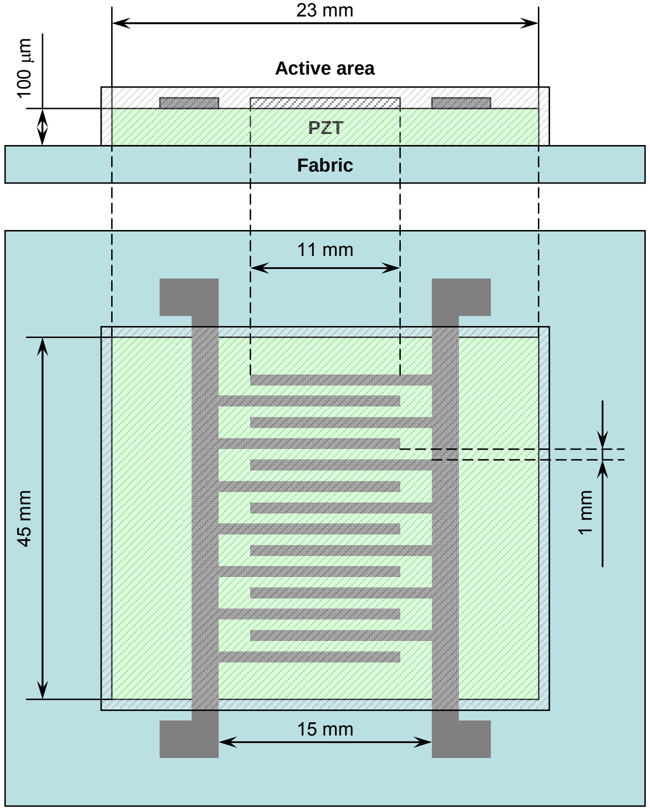


Piezoelectric motion sensor

Piezoelectric motion sensor:

- Printed on lab coat's sleeve,
- The sensor is connected to the work wear's control system and sensing the bending of the sleeves.





Piezoelectric motion sensor

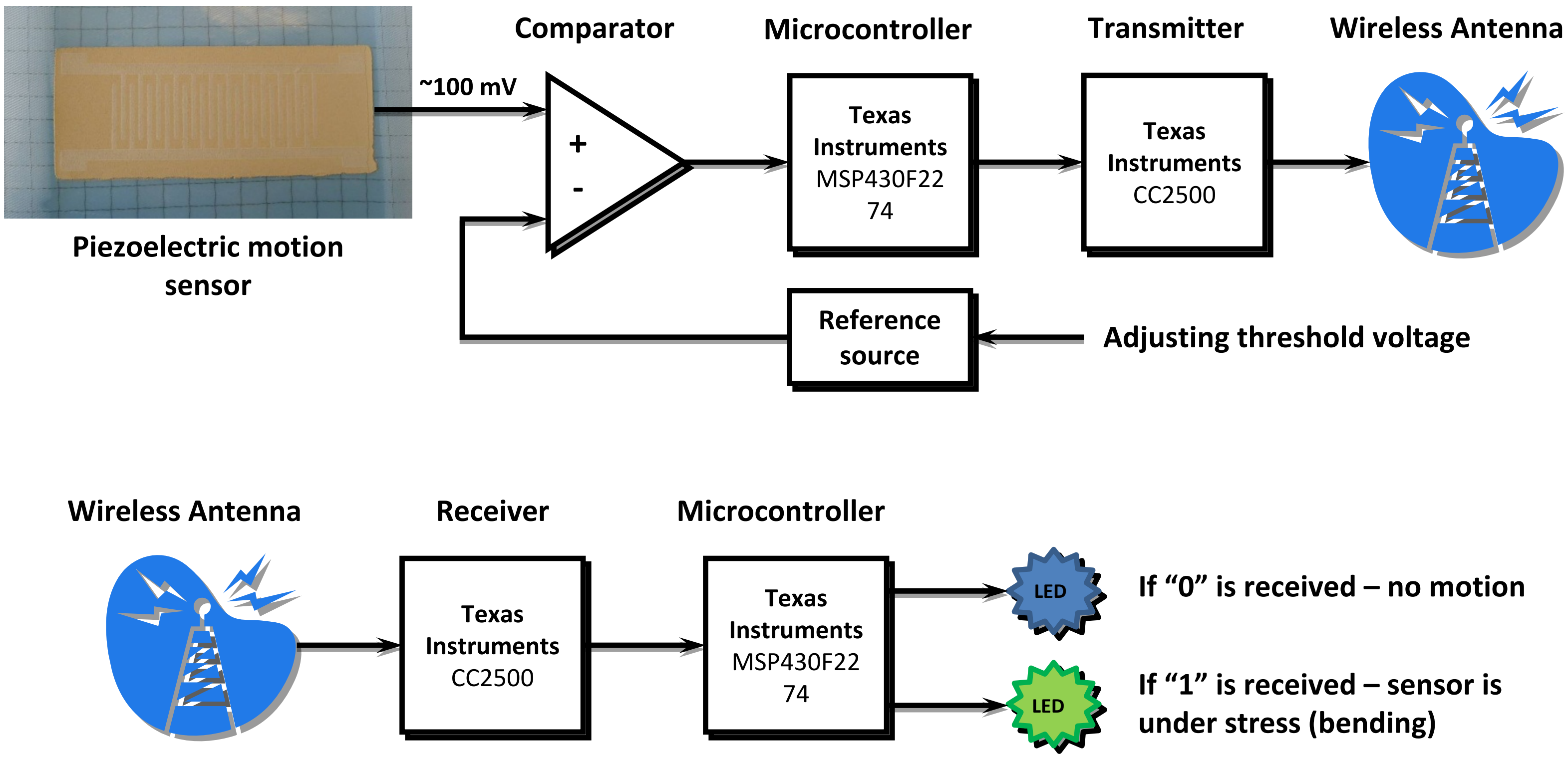
Piezoelectric motion sensor printed on Kermel fabric, Polycotton fabric, and lab coat sleeves:

Kermel

Polycotton

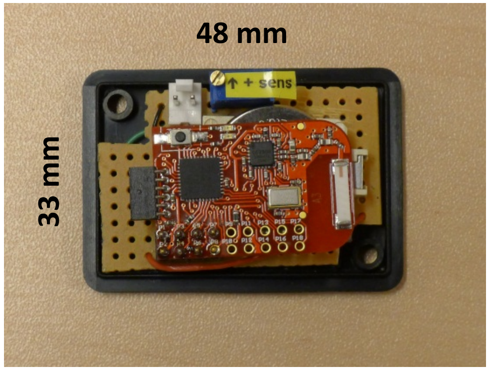
Lab coat

Piezoelectric motion sensor

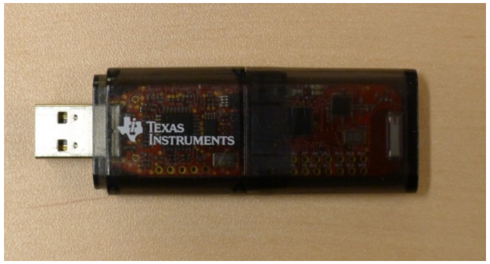


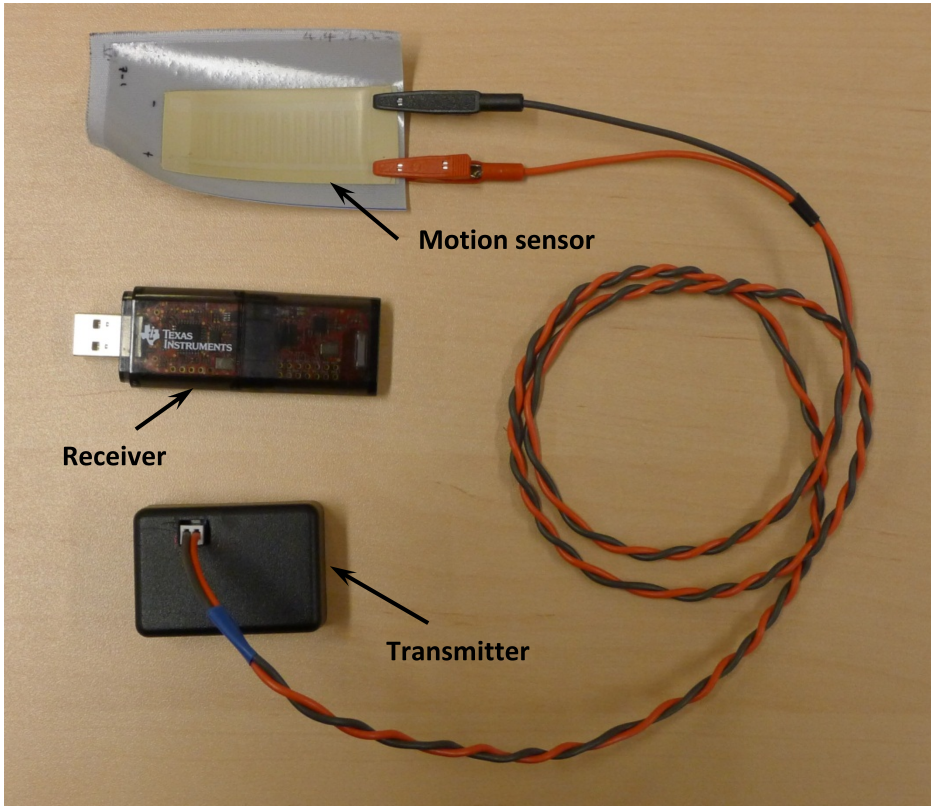
Piezoelectric motion sensor

Transmitter

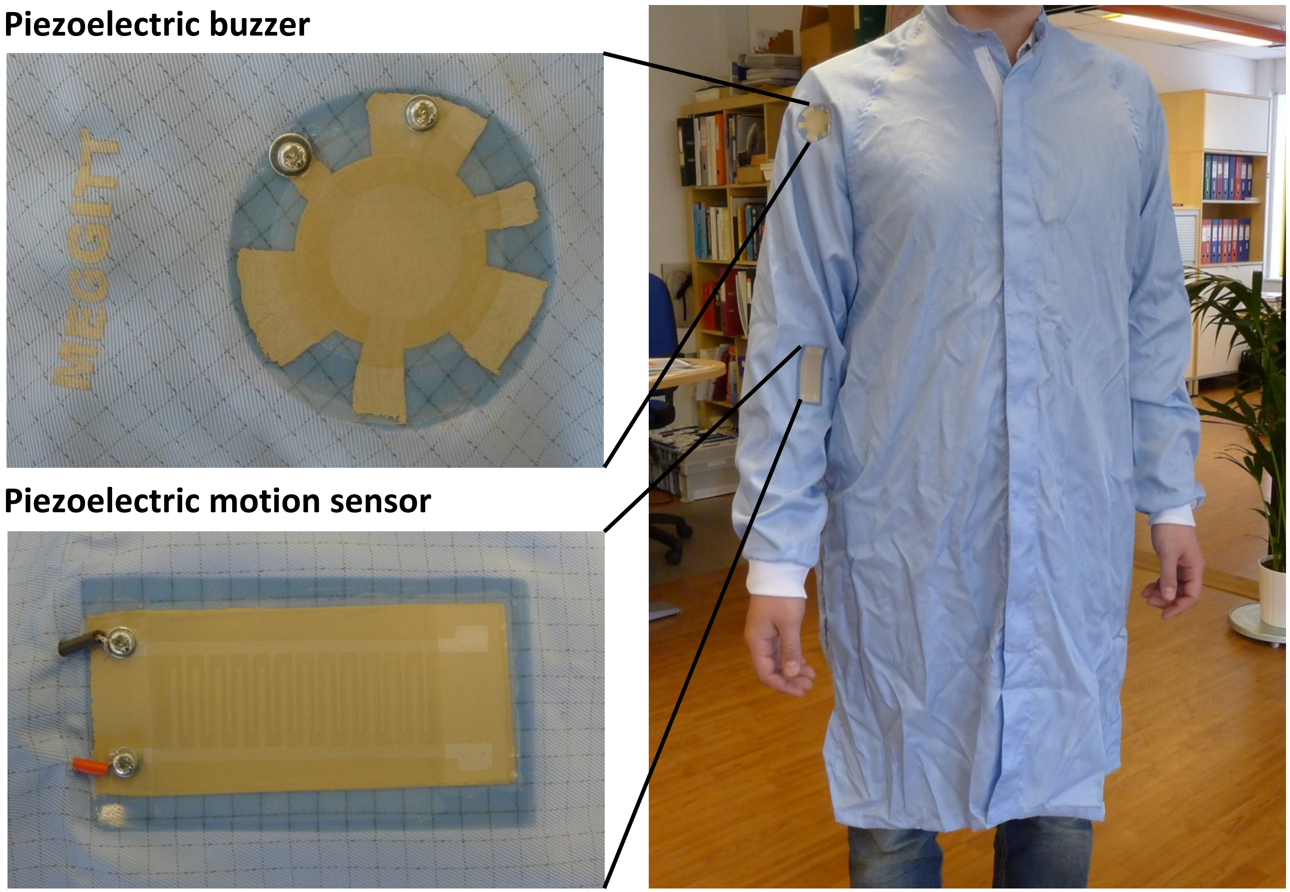


Receiver (USB stick)





Lab coat prototype



Summary

- New technologies support
  - Miniaturisation
  - Integration
  - Resource, cost and energy reduction
  - Open for new applications
  - **Implementation of piezoelectric lead free materials**
- PiezoPaint™
  - New technology for low temperature processing
  - Compatible with several flexible substrates

Thank you for your attention

Questions?