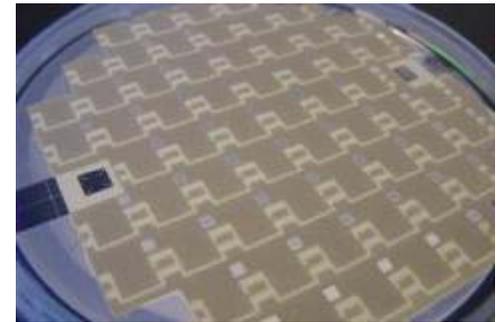




## **Piezoelectric Thick Film Technology Integrated Self-sustained Systems for Industrial Applications**

Wanda W. Wolny, Rasmus Lou-Moeller, Erling Ringgaard, Konstantin Astafjev and Tomasz Zawada  
Meggitt A/S, Hejreskovvej 18A, 3490 Kvistgaard, Denmark, wanda.wolny@meggitt.com



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# Outline

Ferroperm™ Piezoceramics

- ▶ Introduction of Meggitt A/S
- ▶ PZT thick-film technology
- ▶ Devices
- ▶ Lead free materials
- ▶ Thick film on flexible substrates
- ▶ Conclusions

# Meggitt A/S – Meggitt Sensing Systems

extreme environments

**Welcome to Meggitt Sensing Systems**

We specialise in sensing and monitoring systems that measure physical parameters in the extreme environments of aircraft, space vehicles, power generators, nuclear, oil and gas installations and test laboratories.

→ go to **Capabilities** for product information.



Meggitt Sensing Systems has operated through its antecedents since 1927 under the names of Ferroperm Piezoceramics, Lodge Ignition, Endevo, Sensorex, ECET, Vibro-Meter and Wilcoxon Research. Today, their capabilities and facilities have been integrated to one Meggitt division, providing complete systems from a single supply base.

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Latest News | 02.06.2010 - Meggitt announces a new product generation: the InSight® Total Monitoring Solution...

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Ferroperm Piezoceramics A/S

Is now

# Meggitt A/S Member of Meggitt Sensing Systems

*Producer of Ferroperm™ Piezoceramics and InSensor™*

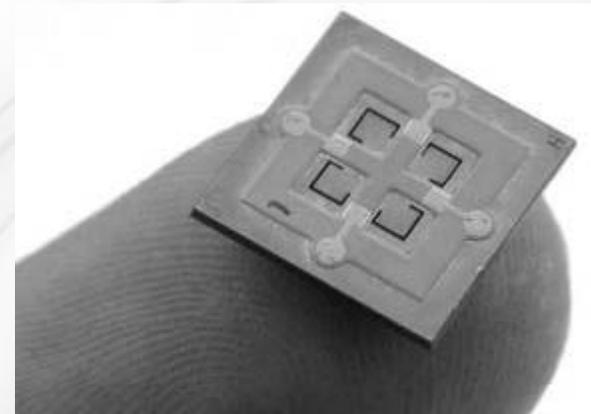
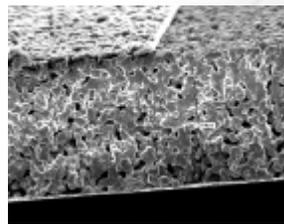
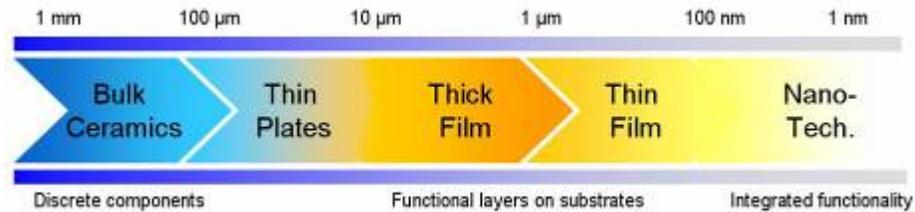
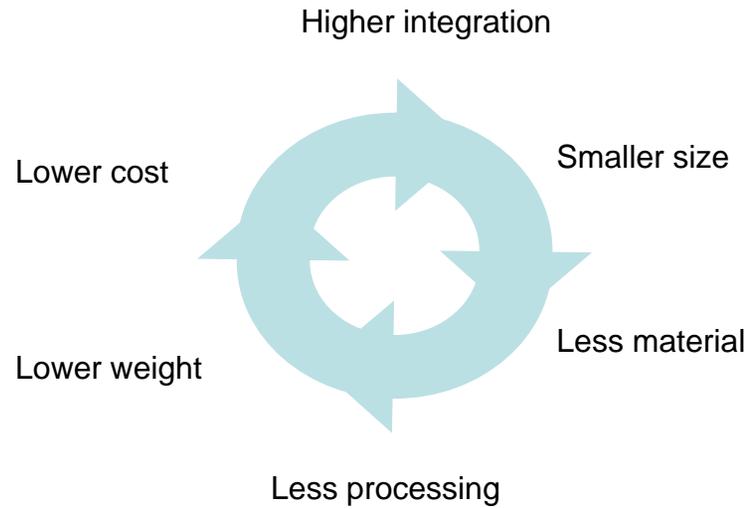
[www.meggittsensingsystems.com](http://www.meggittsensingsystems.com)





# PZT thick-film technology

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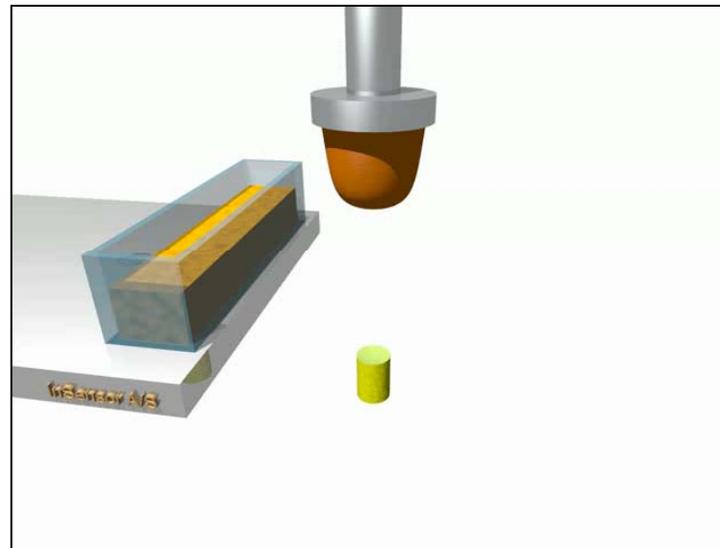
# Deposition

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Screen printing



Pad printing





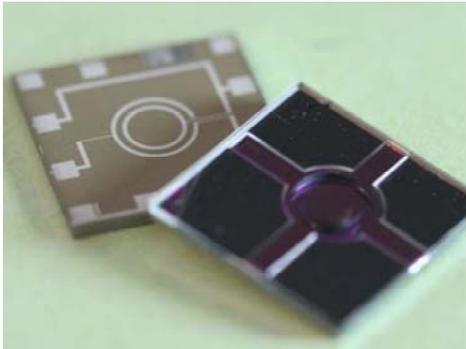
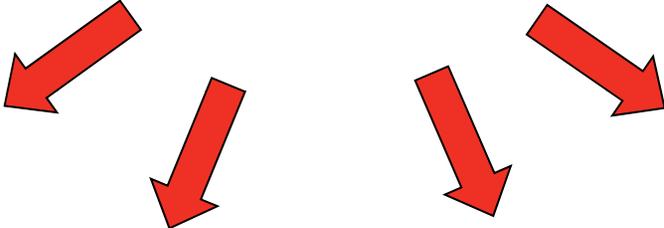
# PZT thick film compatibility

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Ceramics

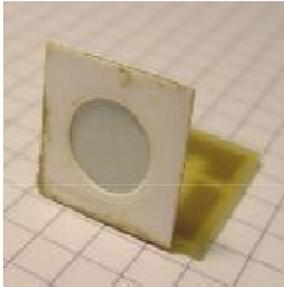
SUBSTRATES



Silicon/MEMS



Stainless steel



LTCC





# Evolution in screen printing of thick film

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## ▀ Substrate

- ▀ Ceramics incl. Alumina, pzt and others
- ▀ Steel, silicon, LTCC
  
- ▀ Polymer
- ▀ Textile
- ▀ Composites
- ▀ Laminates
- ▀ Paper

## ▀ Sintering temperature

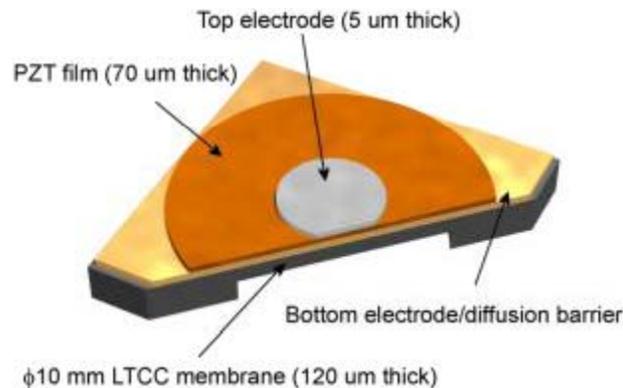
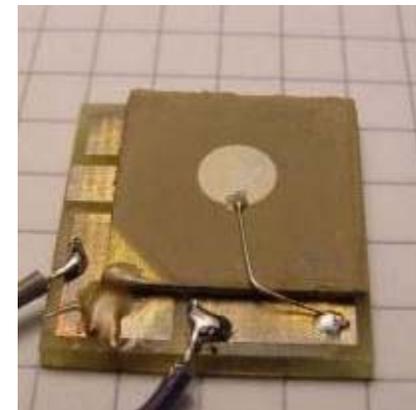
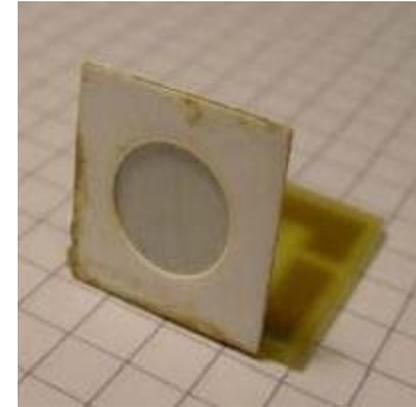
- ▀ 1100-1250°C
- ▀ 850°C
  
- ▀ 150°C
- ▀ 100°C
- ▀ ”
- ▀ ”
- ▀ ”

# Devices & Systems

- ▶ Integrated sensors (MEMS accelerometers)
- ▶ Energy harvesting devices (battery-less, wireless integrated sensors systems)
- ▶ Medical (high-frequency, ultra resolution imaging)
- ▶ SHM (Structural Health Monitoring) in aeronautics, off-shore oil platforms, wind turbines
- ▶ Implantable sensors (lead-free, biocompatible materials)
- ▶ ICT integrated devices
- ▶ Microsystems (e.g. microfluidic, micro-pumps, micro-valves)

# LTCC membrane with integrated PZT thick film Ferroperm™ Piezoceramics

- ▶ The membrane structure has been fabricated using laser patterned LTCC foils and laminated in standard conditions together with sacrificial layers
- ▶ The PZT thick film as well as the electrodes have been deposited by means of screen printing and sintered in the post firing process at 850 °C



*In cooperation with  
PWR - TML*

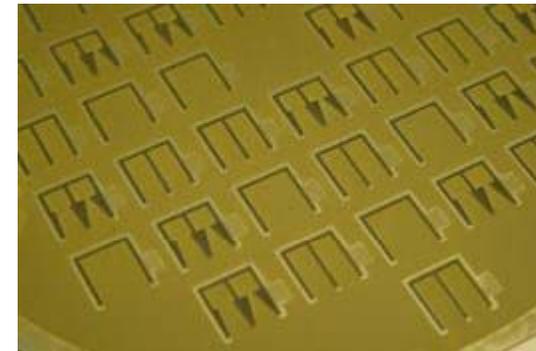
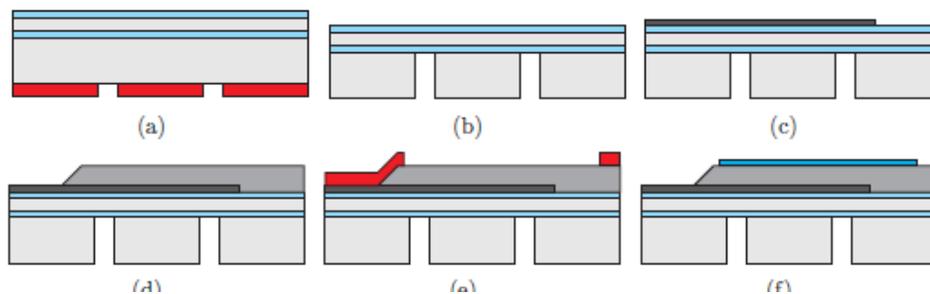
General structure and the dimensions of the membrane actuator based on the LTCC and PZT thick films

Photograph of the membrane cavity (top) and the packaged device (bottom)

# Integration with silicon MEMS technology

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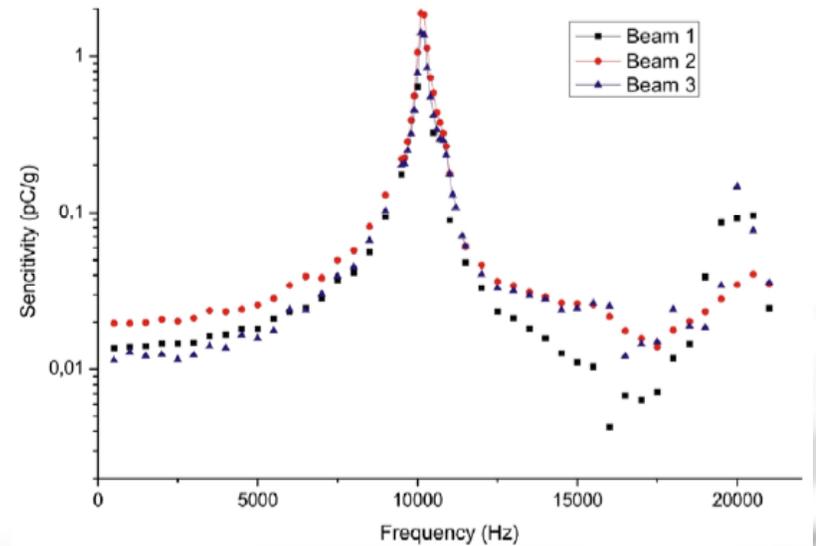
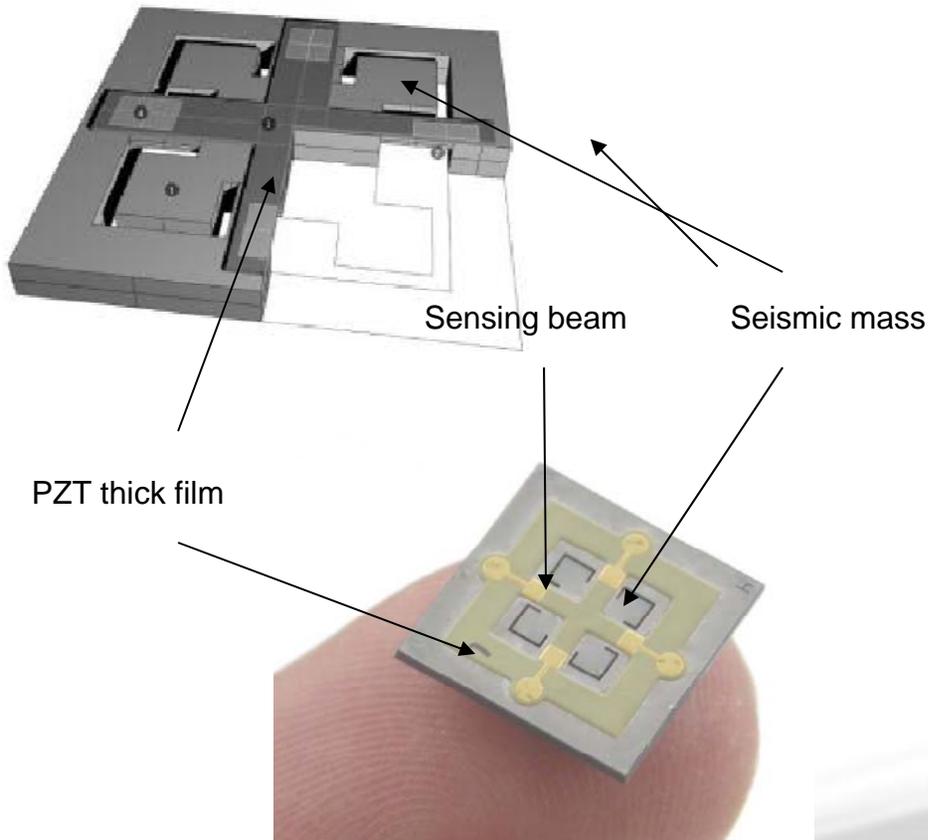
- Screen printing for making patterned thick film on a substrate
- Silicon micromachining for making complex structures in silicon
- Photolithography for making patterned electrodes



“PZT thick film can be considered as being a part of the MEMS technology portfolio”

# MEMS accelerometer

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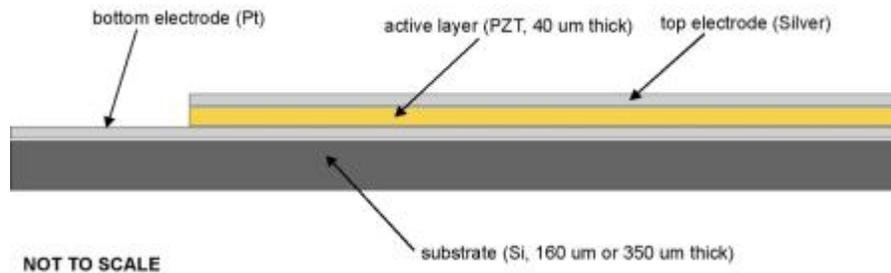


Normalized sensitivity in the vertical direction – frequency sweep

Cross-section of the MEMS structure and the fabricated accelerometer chip

# Energy harvesting devices

- ▶ PZT thick film based structure has been manufactured
- ▶ The 40 μm thick film has been deposited on 150 μm thick silicon substrate with dimensions equal to 25x3 mm<sup>2</sup>



Structure of the thick film based silicon actuator/bender



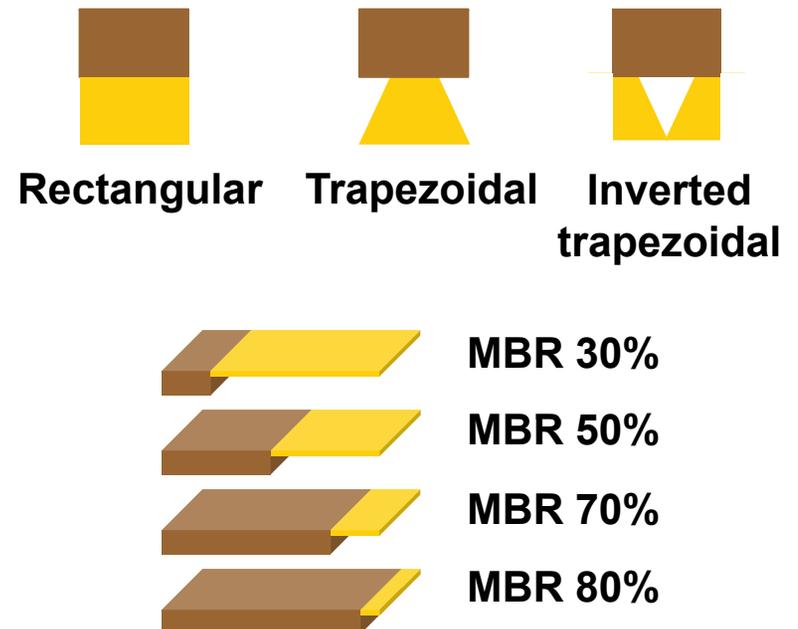
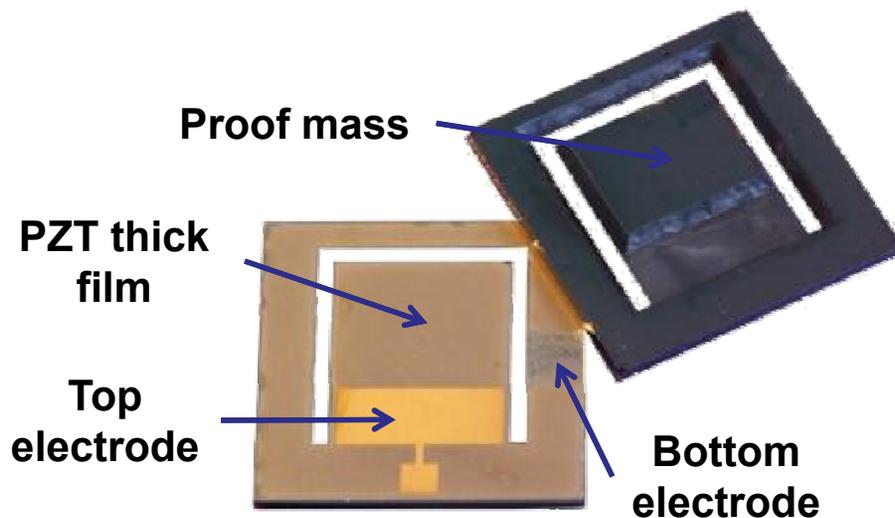
Energy harvesting device mounted on the shaker

*In cooperation with DTU Nanotech*

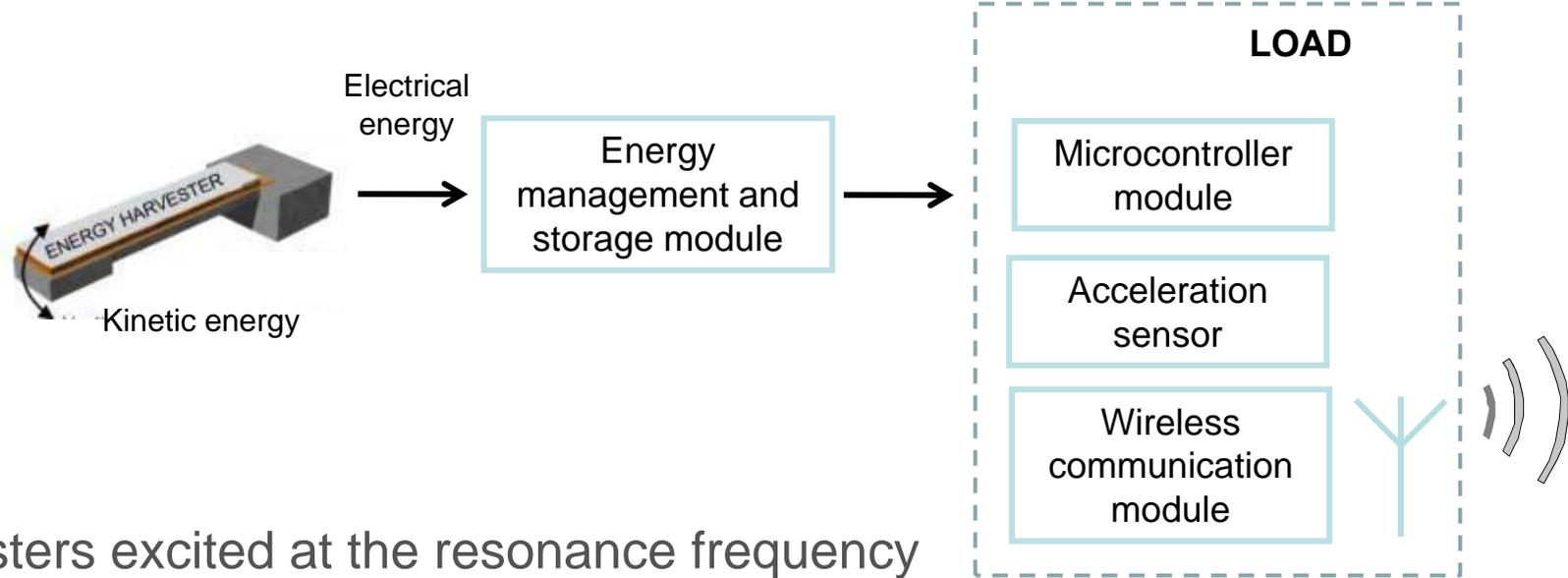
# Energy harvesters

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

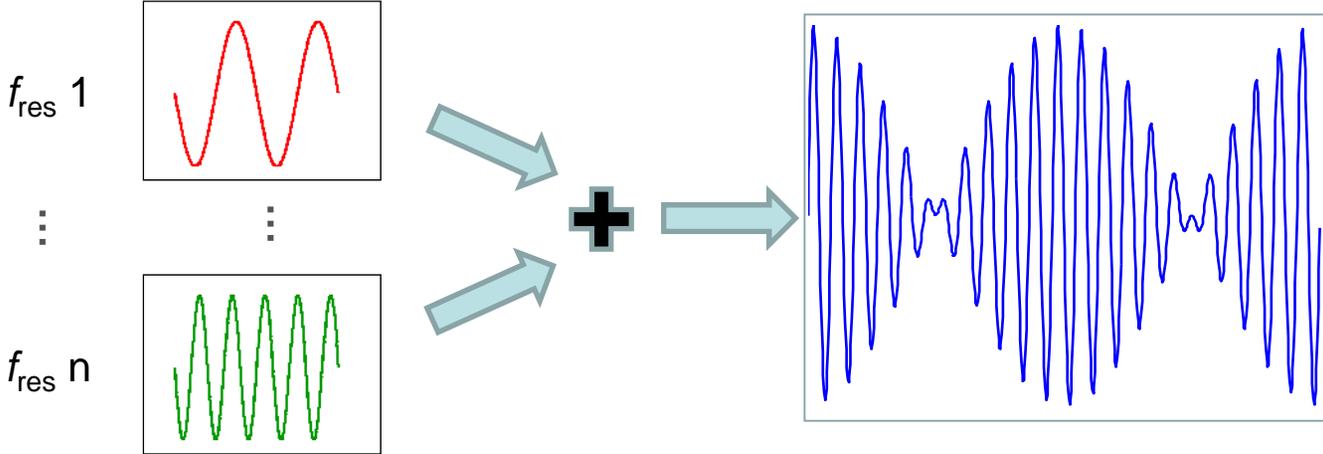


# Wireless sensor prototype

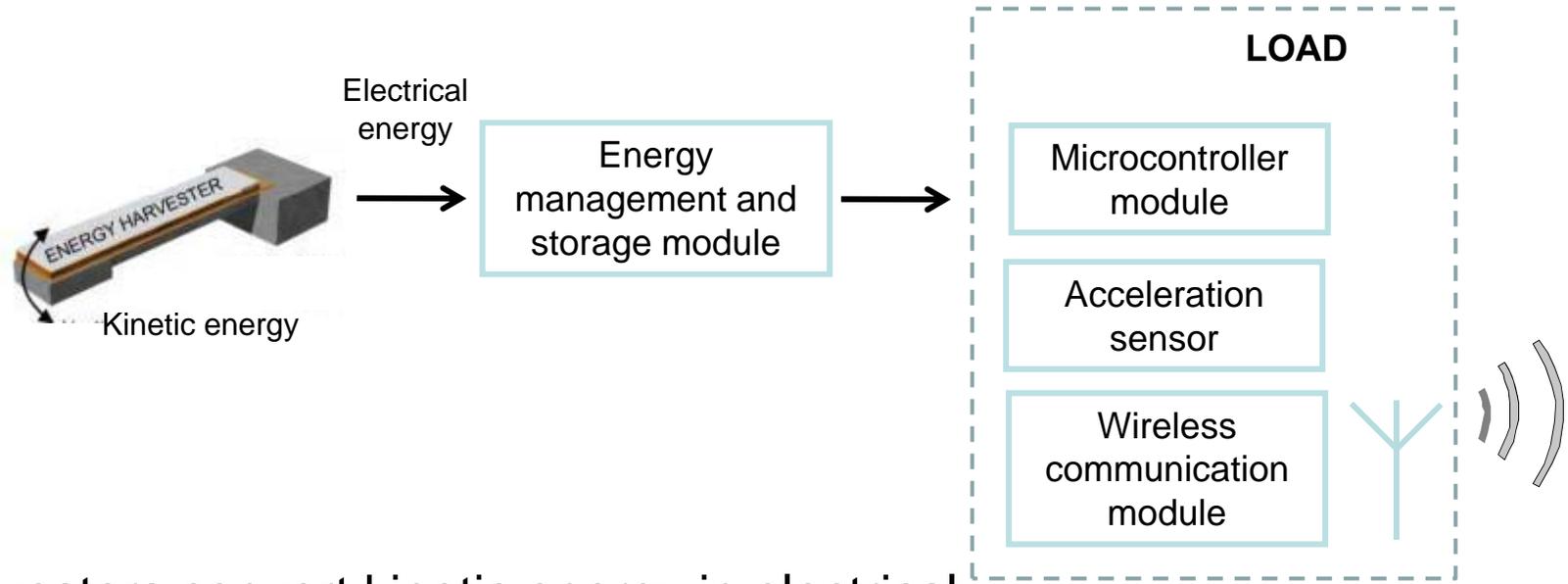


## Harvesters excited at the resonance frequency

- Multi-frequency excitation signal (RMS acceleration 0.77 g)



# Wireless sensor prototype



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



# Results

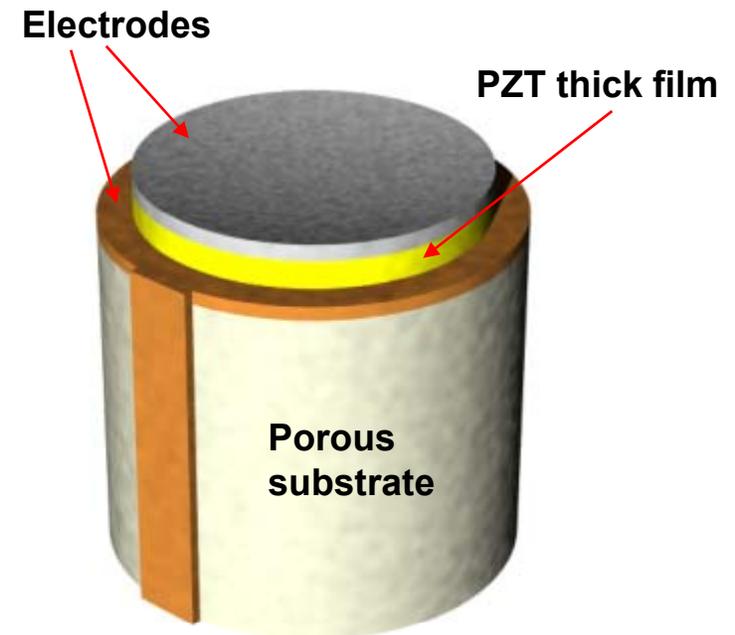
- ▶ Power harvesters realized with silicon micromachining technology and screen-printed PZT thick films
  - ▶ Open-circuit voltage up to 3 V @ 0.5 g peak
  - ▶ Maximum power range 12  $\mu$ W ÷ 16  $\mu$ W @ 0.5 g peak
- ▶ Self-power wireless sensor prototype
  - ▶ Excitation frequency tuned with the harvester resonance frequency
  - ▶ fixed wake up interval
  - ▶ 3D acceleration measurement
  - ▶ Radio frequency data transmission

# Structural Health Monitoring (SHM) AISHA II



# High Frequency Acoustic Transducers

- ▶ The porous structure of the film makes it a perfect candidate for medical imaging due to the following:
  - ▶ Low acoustic impedance
  - ▶ Low dielectric constant
  - ▶ High frequency (more than 20 MHz)



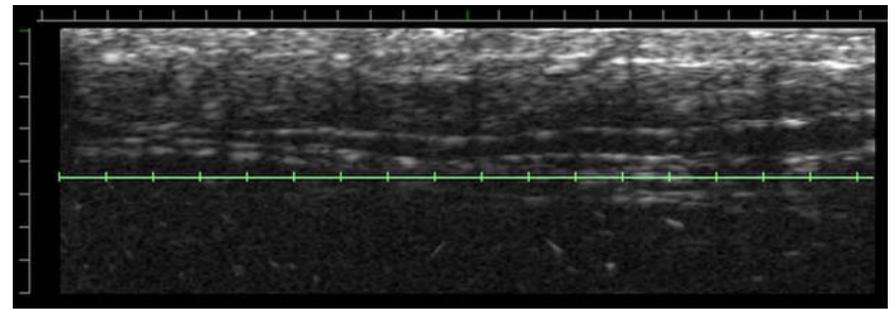
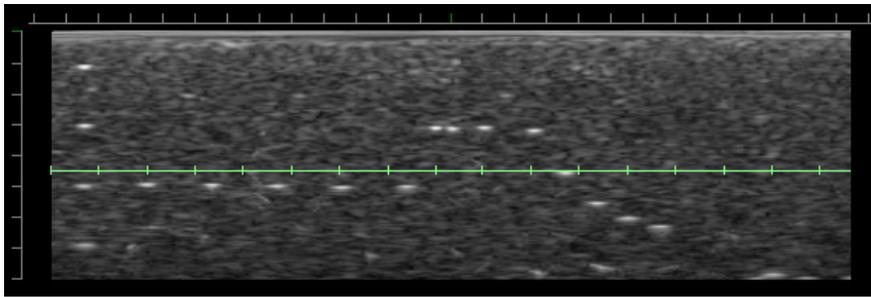
Typical structure of a thick film based HF acoustic transducer





# High frequency imaging transducer

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Focused ultrasound over time grinds down collagen fibers into multiple layers skipping intervening tissue



Oct 12<sup>th</sup> 2014  
Reached  
2 Million

THE VIEW



# Thick films properties, PZT and KNN

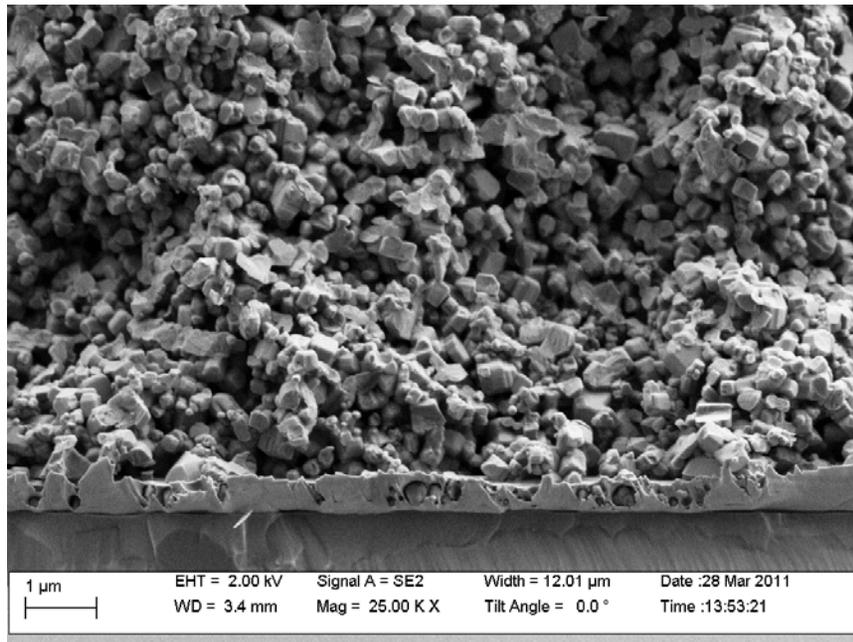
	<b>TF21 standard</b>	<b>TF21 Pre-treated</b>	<b>TF6131 on alumina</b>	<b>TF6131 on silicon</b>
Material	PZT-based	PZT-based	KNN-based	KNN-based
Dielectric Constant	520 (free standing)	750 – 800 (free standing)	250 - 350 (semi-clamped)	330 – 340 (semi-clamped)
tan δ, %	0.8		0.7 – 1.0	1.5 – 2.0
$d_{33}$ , pC/N	200*	200*	130 – 140	120 - 130

\*Apparent value, measured for the free standing PZT material of the same composition and with the same level of porosity.

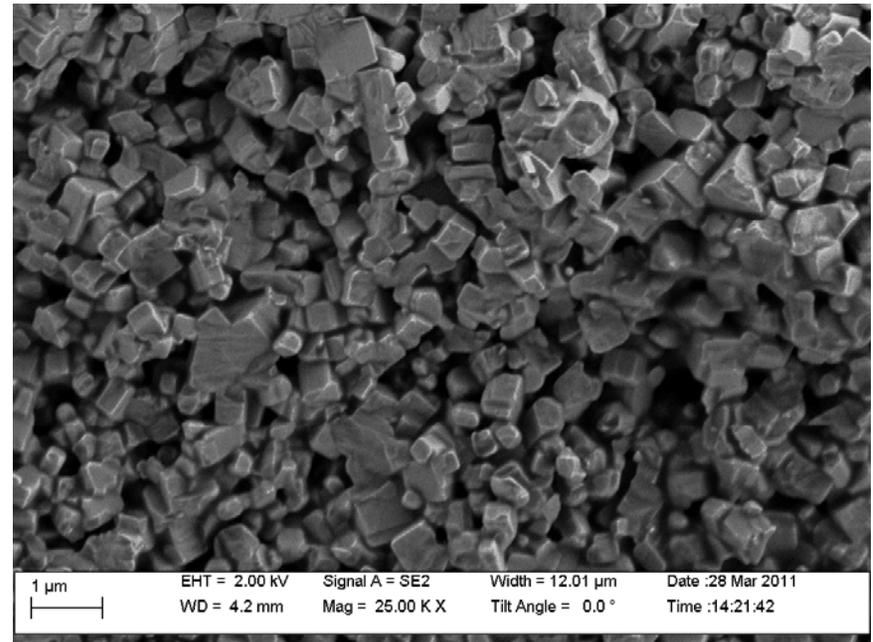
# KNN - Thick films microstructure

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*TF6130 film on silicon substrate*



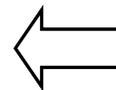
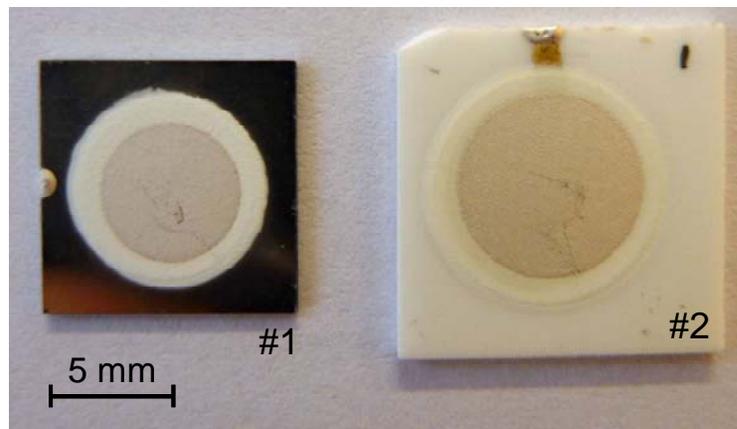
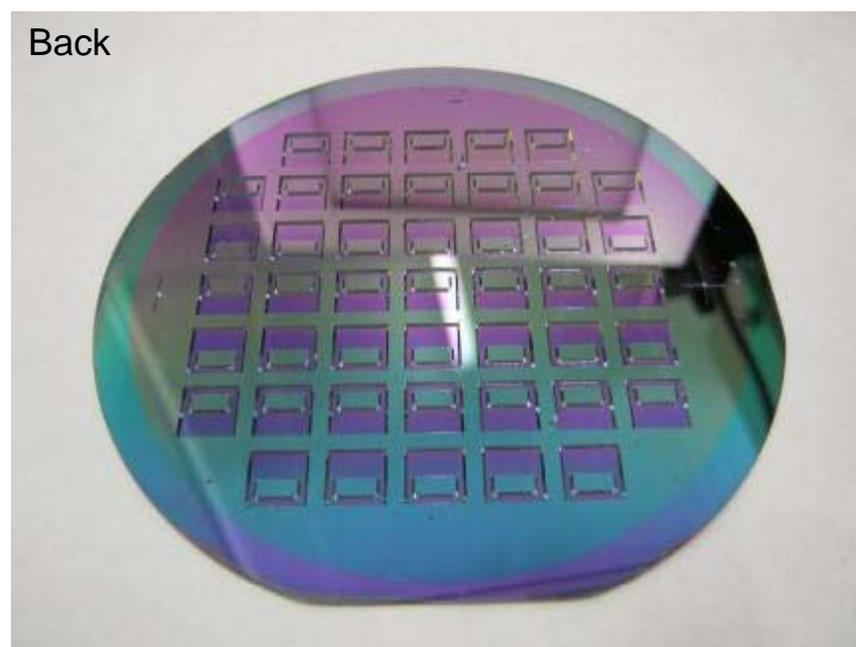
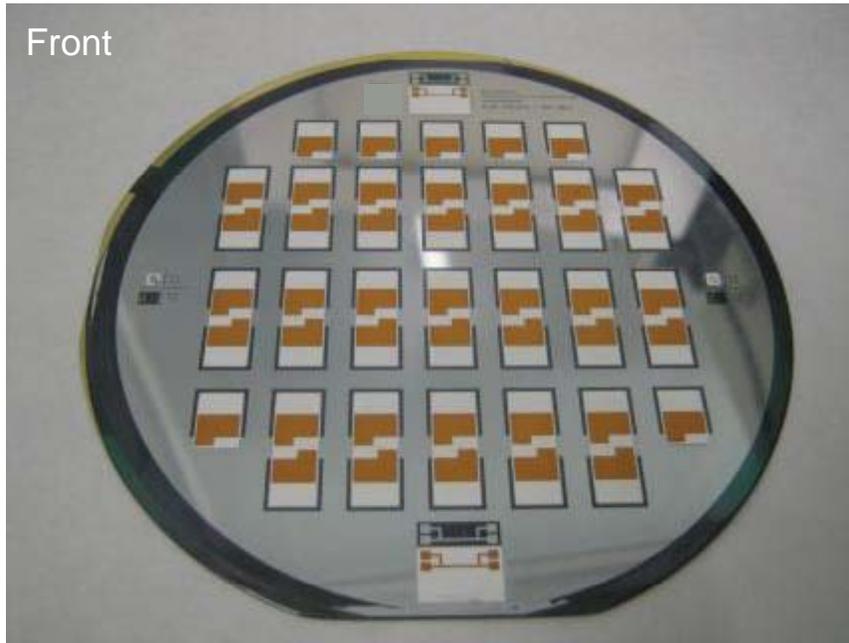
*TF6131 film on alumina substrate*



# Lead-free thick film devices

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Lead-free thick films based MEMS devices



KNN-based thick films printed on silicon (#1) and alumina (#2) substrates.

# Low temperature processing <sup>Ferroperm™ Piezoceramics</sup>

- Trade mark
- Patent pending





# Paste

Paste is based on Meggitt A/S powder

The piezoelectric charge coefficient ( $d_{33} \sim 30 \text{ pC/N}$ ) is measured by Berlincourt method

Screen printing have been successfully carried out on several fabrics/textiles including poly-cotton, filters and polyurethane coated fabrics

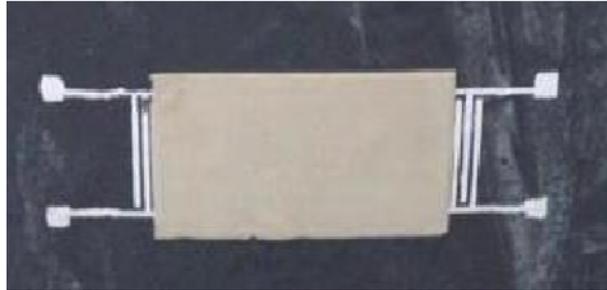


Fabricated piezoelectric paste



# Demonstrators

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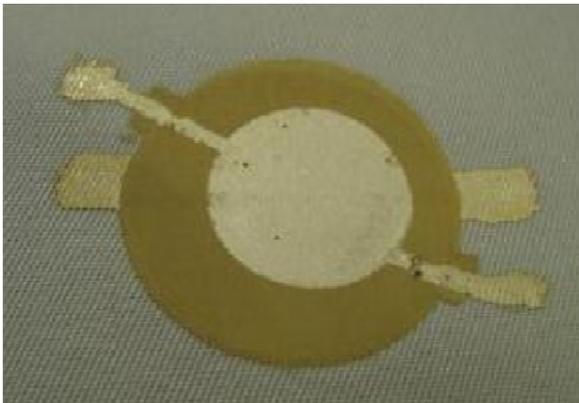
Thick film on plastic



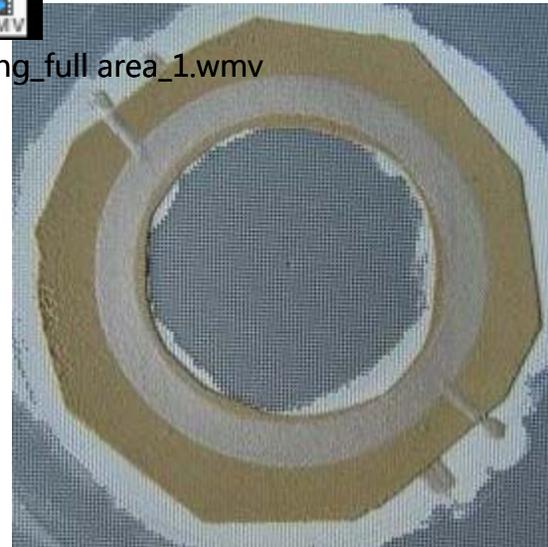
Cross section: Thick film on fabric



Filter Cleaner testing\_full area\_1.wmv



Thick film on Polycotton



Thick film on Filter



Filter Cleaner testing\_full area\_1.wmv



<b>Materials</b>	<b>Piezoelectric charge coefficient, <math>d_{33}</math> (pC/N)</b>
PZ26 (bulk component)	290
TF2100 InSensor® (thick film)	200
<b>Lead free thick film</b>	<b>150</b>
Flexible thick film (PZT on textile)	40
PVDF (thin film) <sup>1</sup>	-8
Copolymer P(VDF-TrFE) <sup>2</sup>	-33

<sup>1</sup> Kawai, H., *Jpn. J. Appl. Phys.*, 8, 975-976, (1969)

<sup>2</sup> Kenji, O., Hiroji, O., Keiko, K., *J. Appl. Phys.* 81, 2760, (1996)



# Conclusions

- ▶ Thick film properties are well established and reproducible.
- ▶ The technology can be applied to different substrates incl. silicon and textile and used for MEMS
- ▶ Printing technology offers integration opportunities
- ▶ Printing technology can be used for large area light weight active devices
- ▶ Printing technology can be fast and efficiently scaled up
- ▶ The next generation of devices can also include energy harvesting device and be self sustainable and maintenance free



## Acknowledgements

Ferroperm™ Piezoceramics

Danish National Advanced Technology Foundation through **π-MEMS**, (Contract No. 009-2005-1) and **EL**minating **BA**tteries – energy harvesters for integrated systems, project no. 036-2009-1

## **π-MEMs & ELBA**

EC through the **MINUET** project (Contract No. NMP2-CT-2004-505657), the **MICROFLEX** project (Contract No. CP-IP 211335-2) and the **NoE MIND** (Contract No. NMP2-CT-2004-505657) and

**The Piezoinstitute AISBL**

# New facility

Ferroperm™ Piezoceramics



- Office area for R&D and InSensor: 135 m<sup>2</sup>
- Area with process ventilation for labs and production: 300 m<sup>2</sup>
- Dust free area with humidity and temperature control: 120 m<sup>2</sup>
- New equipment for tape casting
- Lead free lab with separate ventilation to avoid cross contamination 30 m<sup>2</sup>

# New facility (engineers lab) Ferroperm™ Piezoceramics



## R&D group

- Seven full time engineers (Msc. and PhD)
- One technical assistant

- Fully equipped testing room including environmental testing chamber



# New facility (lead free lab)

Ferroperm™ Piezoceramics



# PIEZO 2013

Electroceramics for end- users VII

17-20 March 2013

Hotel du Golf

Les Arcs 1800, French Alps (810 to  
3226 m)

[piezo2013@univ-tours.fr](mailto:piezo2013@univ-tours.fr)







# Thank you

Ferroperm™ Piezoceramics

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