BENCHMARKING OF PIEZOCERAMIC MATERIALS FOR GENERATOR APPLICATION

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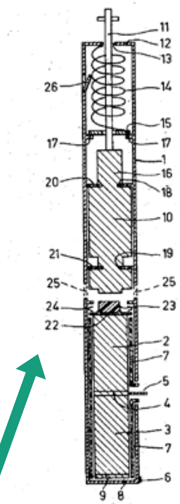
OUTLINE

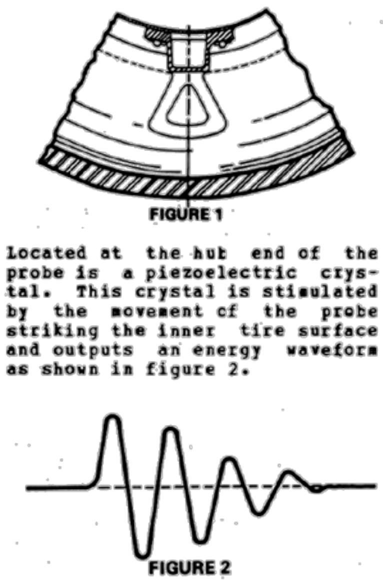
- Introduction
- Benchmarking of piezoelectric materials
  - Energy output
  - Degradation
- Proof of concept
- Conclusion and outlook

Introduction - Historical Overview

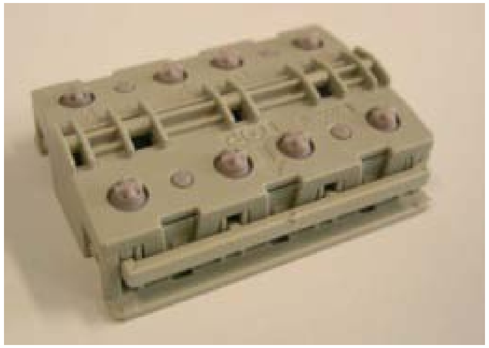
1880	Discovery of the piezoelectric effect
1950	General use of piezoelectric generator (Mason)
1959	Piezoelectric spark igniters claimed
1972	U.S. patent about a gas ignition device
1980	First possible application using piezoelectric generators in combination with low-power electronics
2003	Enocean starts commercializing wireless light switches (enocean)
today	Diversification of research objectives and markets, analysis of marketability



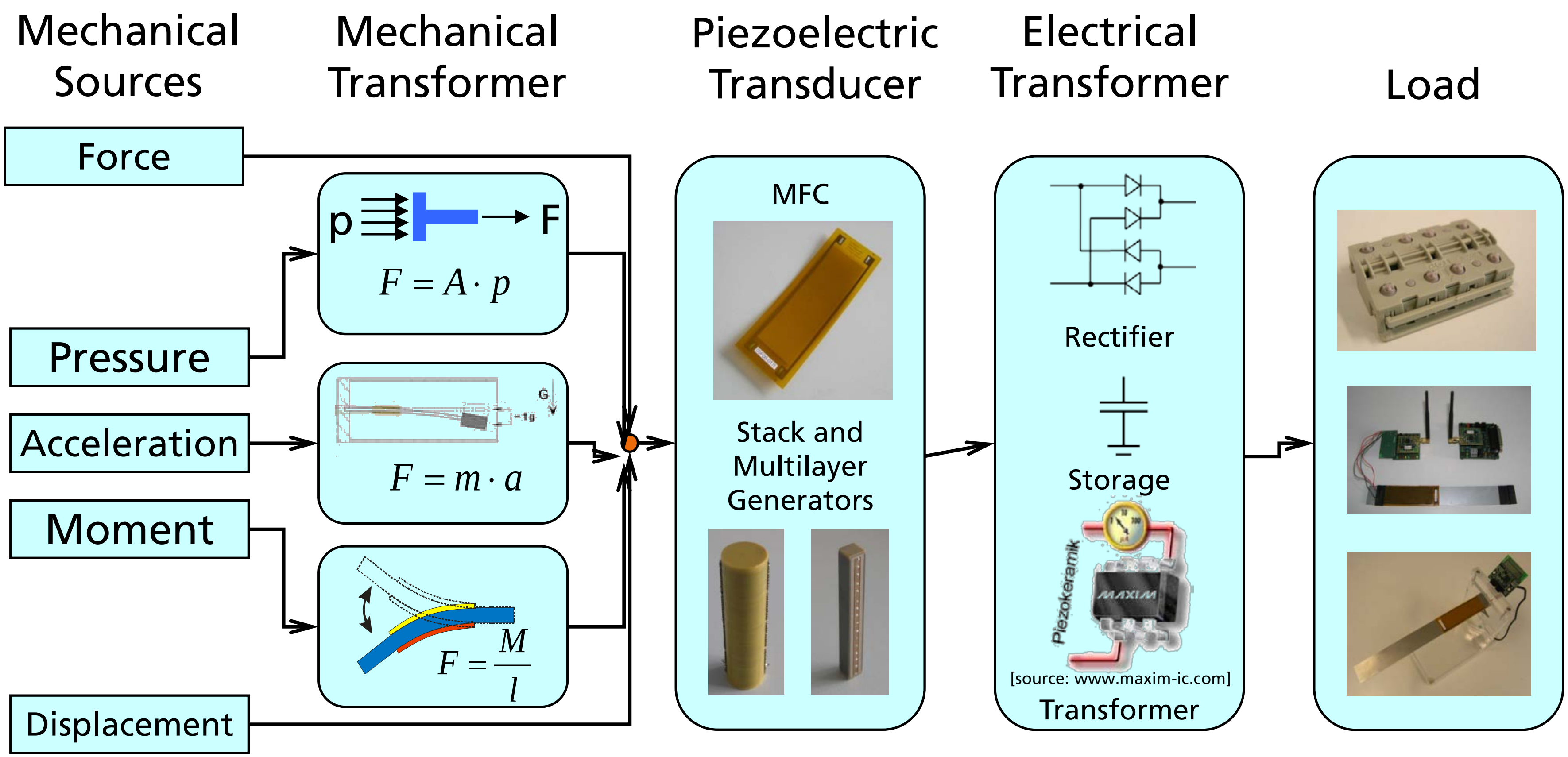
J. Schroder, H.G. Ganser and H. Öpen: „Piezoelectric Ignition Device"; U.S. Patent 3 758 827



G. W. Ledenbach, "A Piezo Powered Ic Transmitter," IEEE Trans. Consumer Electron., CE-26, 229 – 233, 1980, doi: 10.1109/TCE.1980.273353.



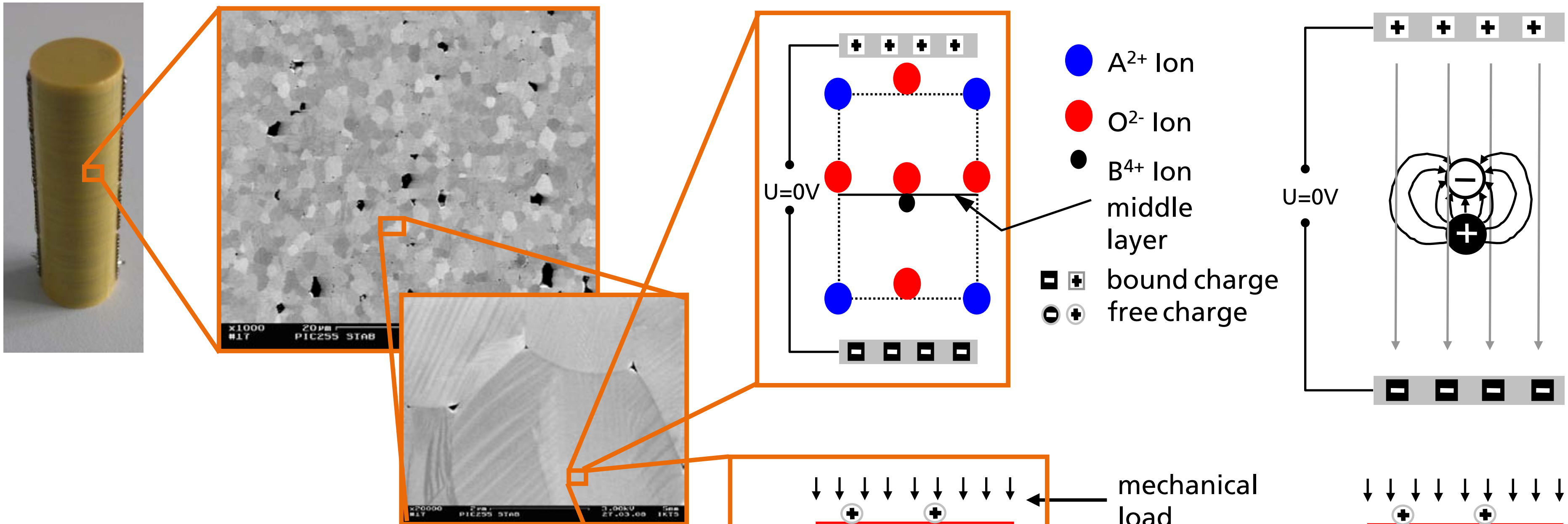
Introduction – Design of a piezoelectric generator

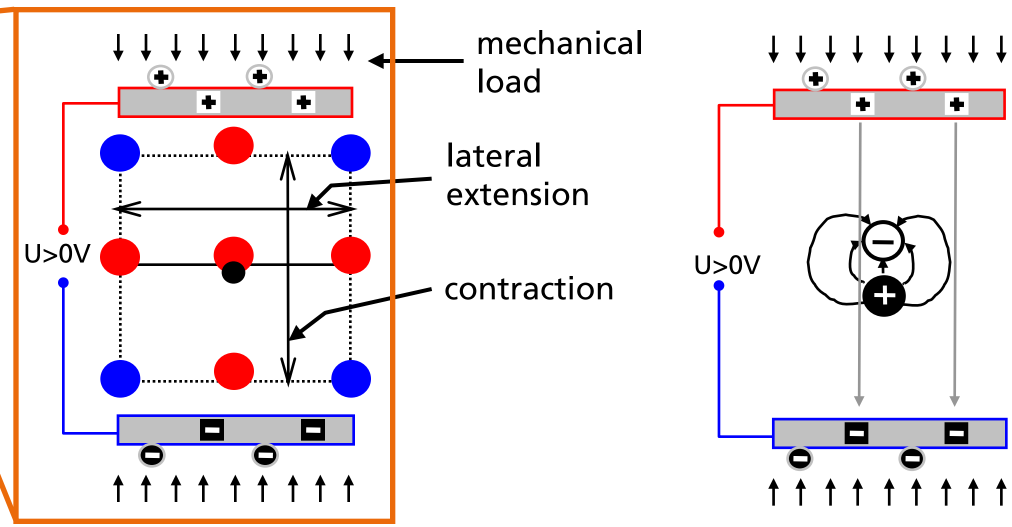


Introduction - Material Requirements vs. Applications

Typical application		Material requirements	Availability
Ultrasound	NDT, medical imaging	High electromechanical coupling (pulse-echo-method)	yes
	High power	Low losses	yes
Sensor	Acceleration	Linearity, temperature stability	yes
Actuator	Fine positioning, valves and pumps	High strain and force	yes
Generator	Igniters	High voltage, high breaking strength, high breakdown voltage, low degradation	yes
	Low power electronic	High power generation, low voltage, low degradation	?

Piezoelectric generator effect





Voltage: (open circuit)

$$U \approx \frac{d}{\varepsilon^T} \cdot F \approx g^T \cdot F$$

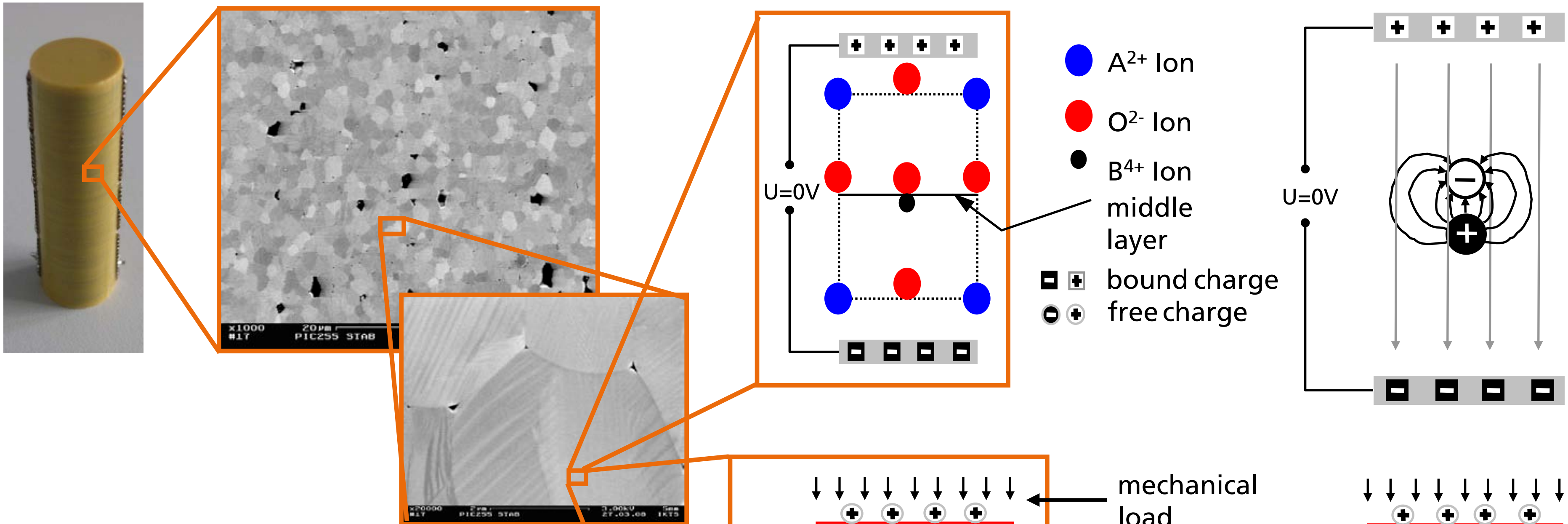
Charge: (short circuit)

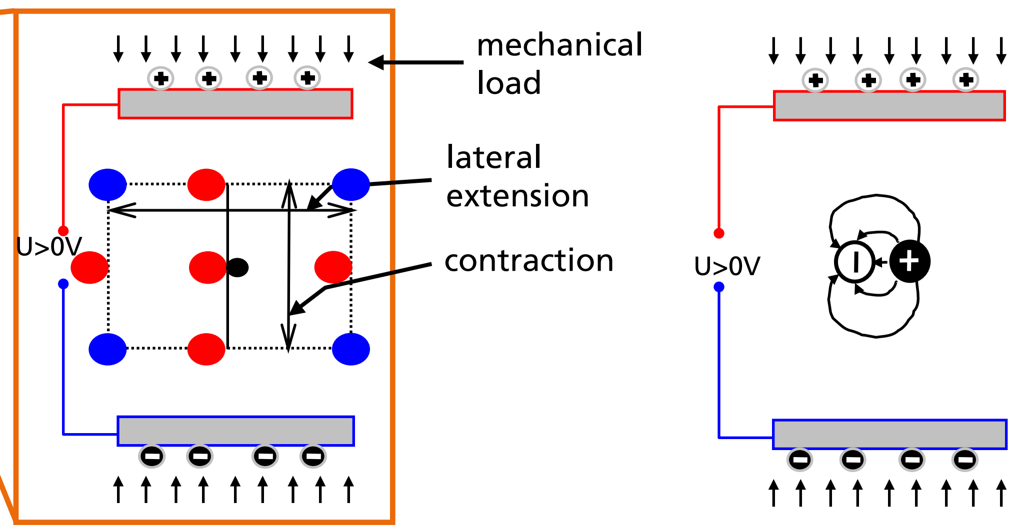
$$Q \approx d \cdot F$$

Energy:

$$E \approx \frac{d^2}{\varepsilon^T} \cdot F^2$$

Ferroelectric generator effect

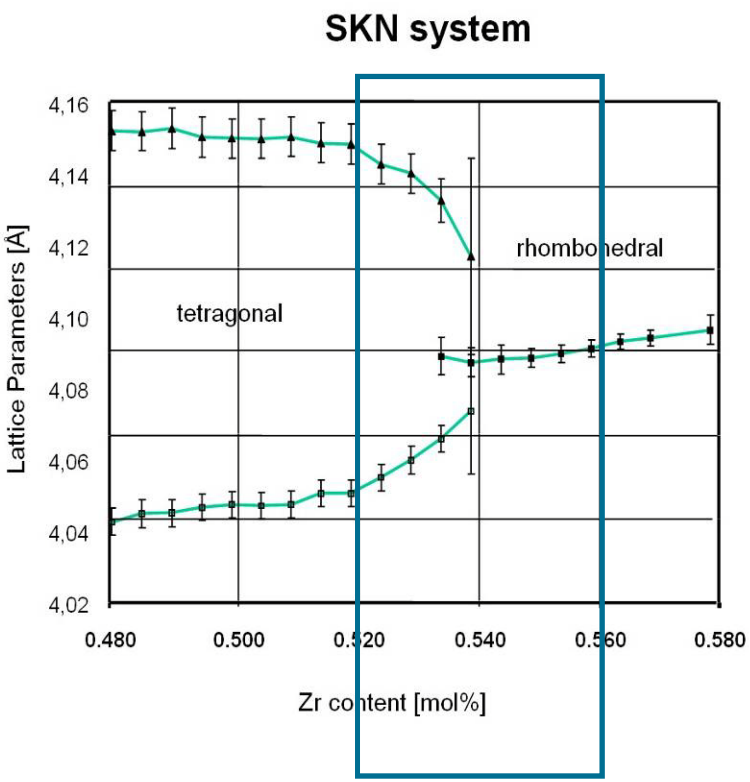


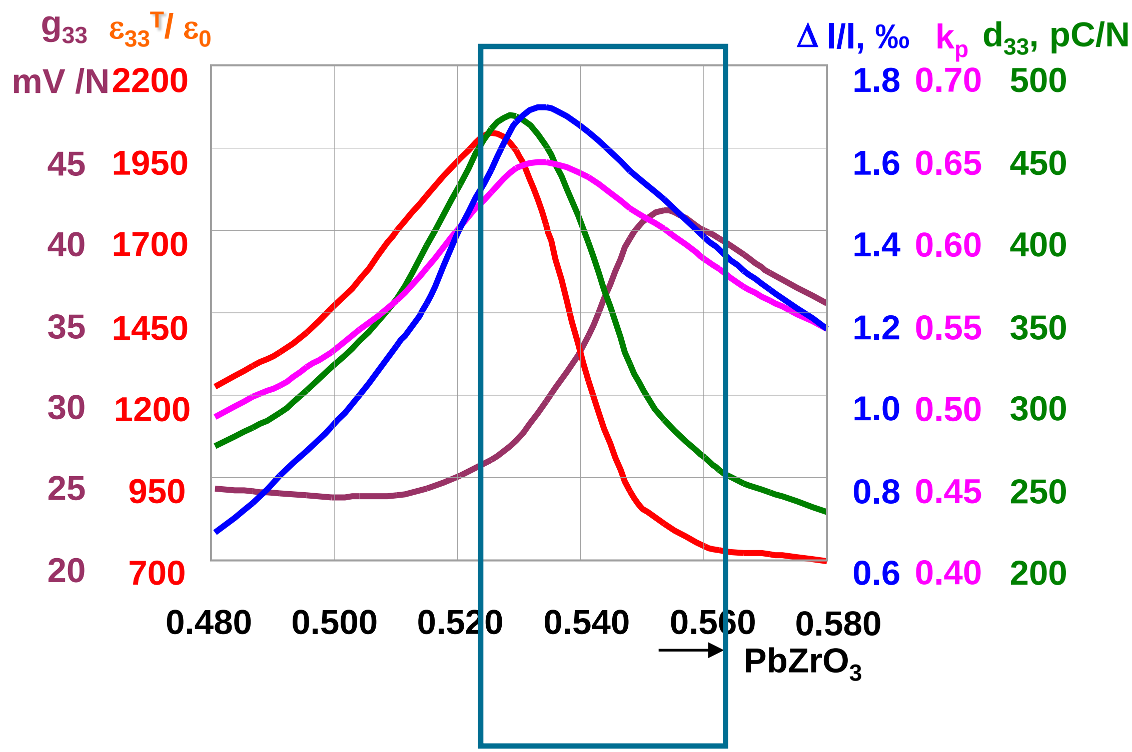


- Domain switching
  - Reversible
    → higher charge release
  - Irreversible
    → material degradation

Combination of piezoelectric and ferroelectric effect

- lattice distortion and properties of PZT-SKN





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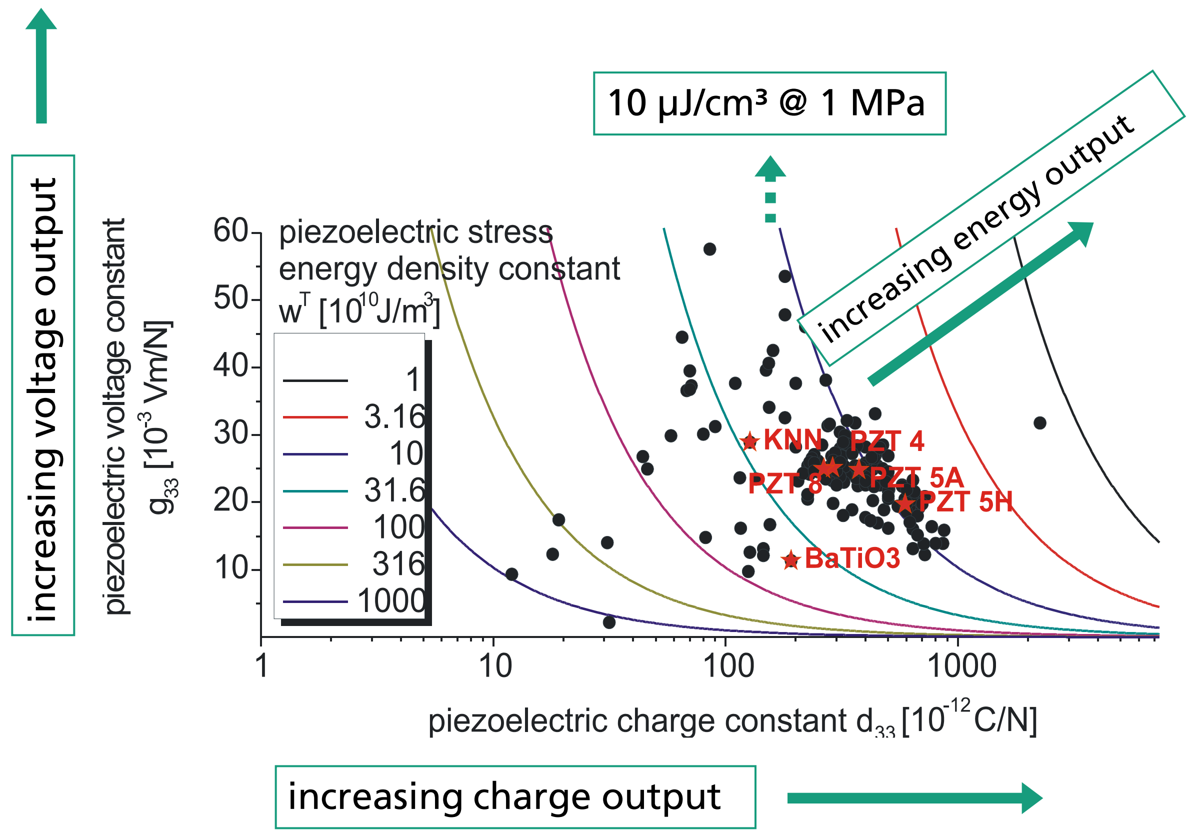
Benchmarking – Energy Output

- > 200 materials available
- 47 materials under investigation at IKTS
- Interesting values:
  - Charge constant:
    d_{33} = 200…1000 pC/N
  - Voltage constant:
    $g_{33} = d_{33} / \varepsilon_{33}$
    = 10…50 mVm/N
  - Energy density constant:
    $w^T_{33} = d_{33}\, g_{33}$
    = 100 mJ/cm³



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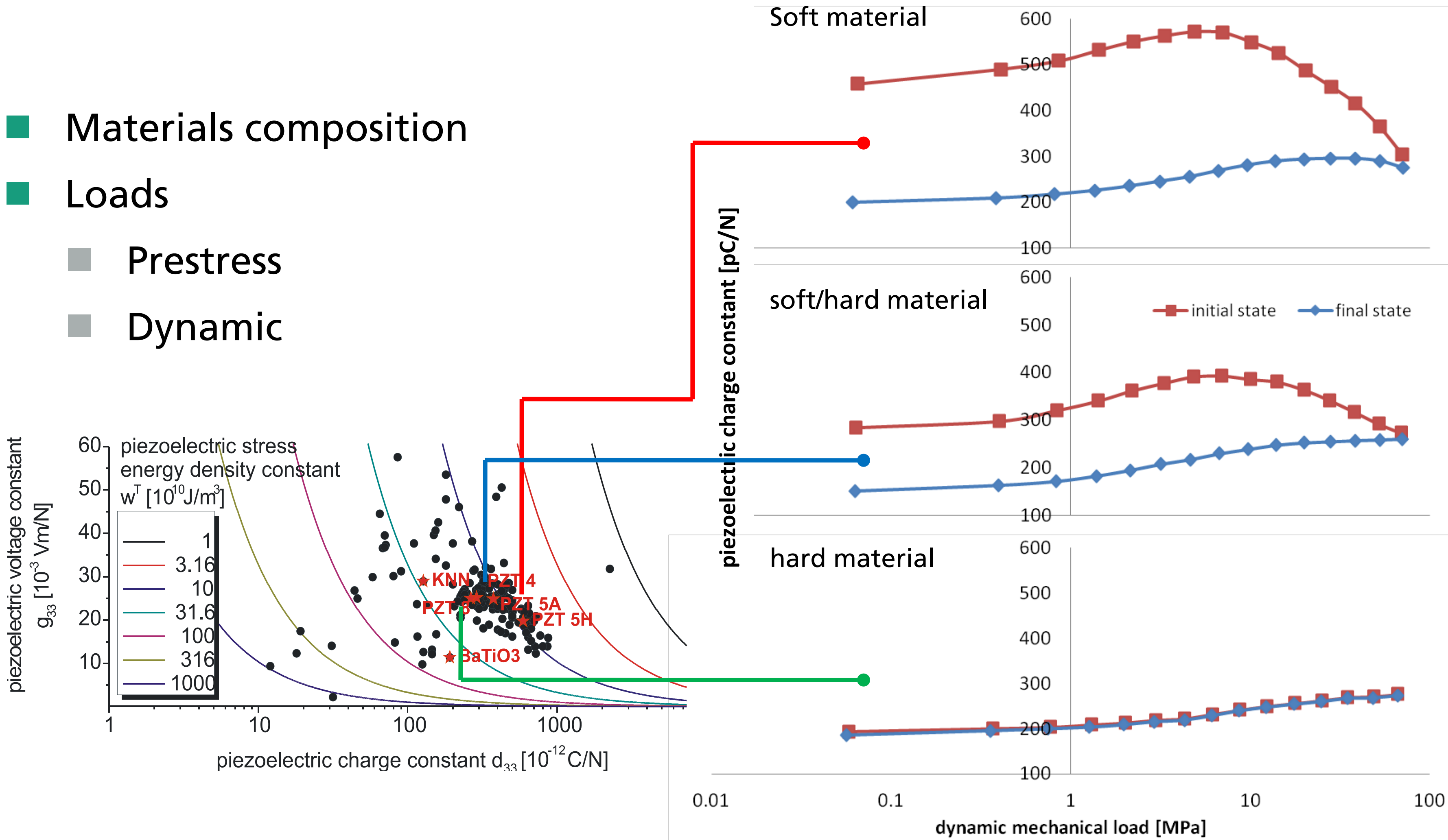
Benchmarking - Depolarisation

- Materials composition
- Loads
  - Prestress
  - Dynamic



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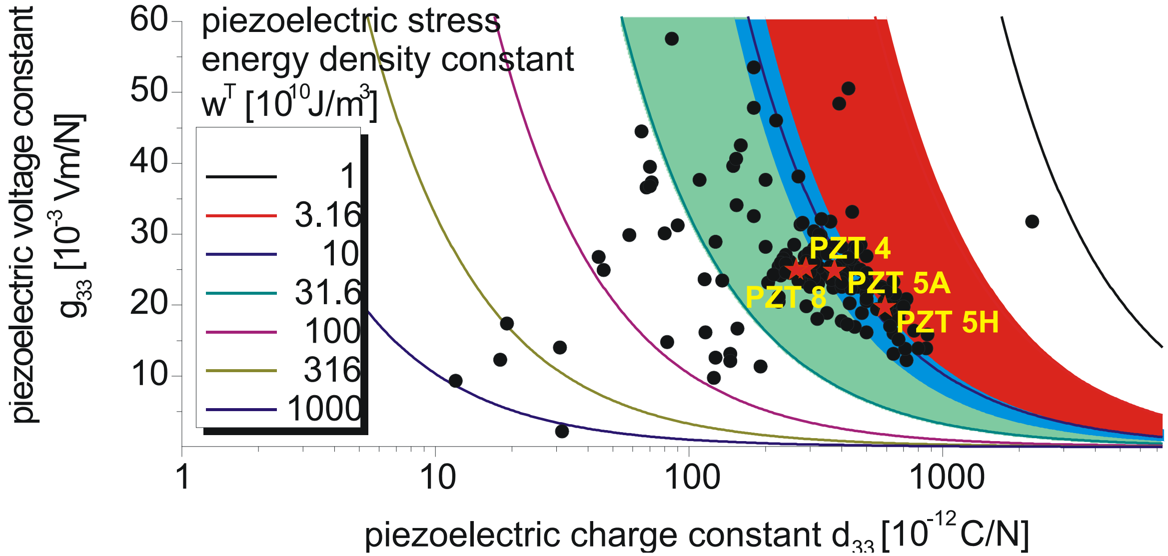
Benchmarking - Depolarisation

- Depolarization behavior assumed depends on energy density level

Property		Unit	PZT 4	PZT 5A	PZT 5H	PZT 8
Piezoelectric stress energy density constant (10^{10})		J/m³	13.8	10.8	8.6	15.1
Maximum tolerable pressure	In poling direction (static)	MPa	68	20	10	82
	In poling direction (dynamic)	MPa	82	20	17	95
	Perpendicular to poling direction (static)	MPa	55	13	10	55

low depolarization ← | → high depolarization



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- Proof of concept
- Conclusion and outlook

Proof of Concept – Leading-Edge-Project

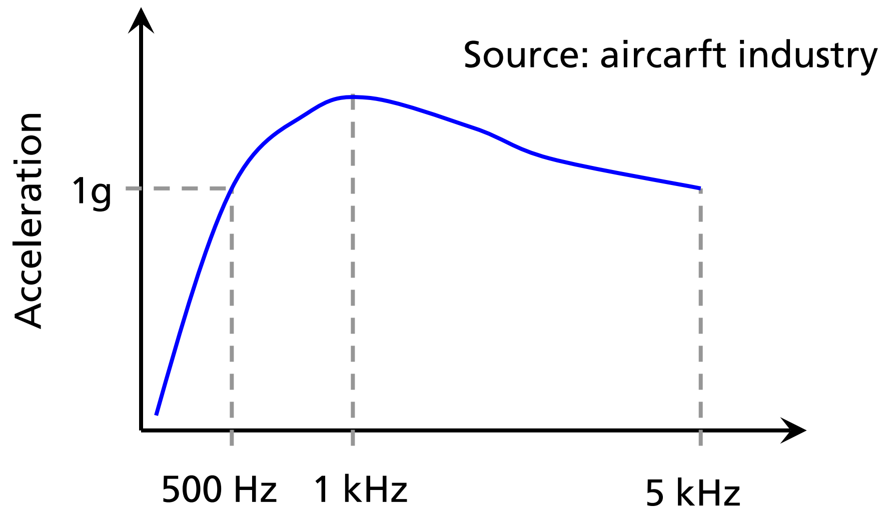
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

- The project CoolSensorNet is part of the Leading-Edge Cluster „Cool Silicon", which is sponsored by the Federal Ministry of Education and Research (BMBF) within the scope of its Leading-Edge Cluster Competition
- Aim: next generator aircrafts made of carbon fiber reinforced materials
- Example:
  - Boeing Dreamliner
  - Airbus A350
- Challenge:
  - Structural health monitoring
  - Lifetime 30 years

Proof of Concept – Starting Situation and Requirements

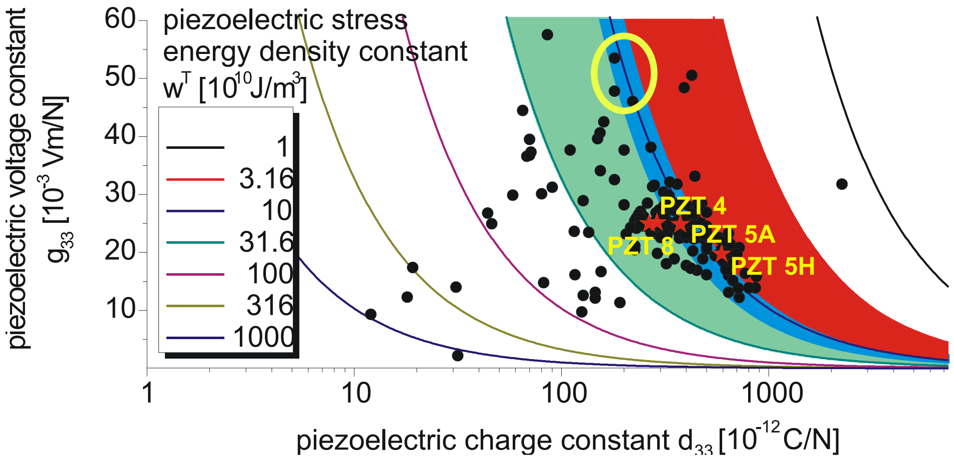
- Origin: stall at the fuselage
- Low vibration amplitude
  → (1g @ 500 Hz ≈ 1 µm)
- High frequency

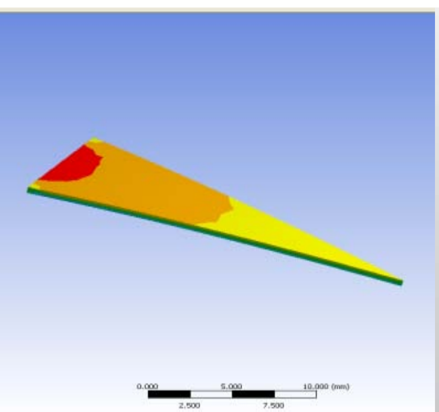
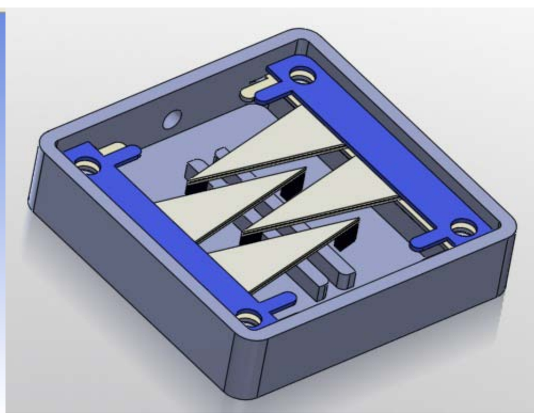
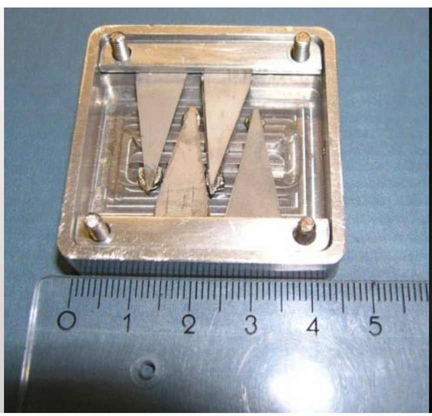
- Electrical requirement:
- Voltage = 3.3Vdc
- Power > 100 µW



Proof of Concept – Generator Design and Material Selection

- Material selection:
  - High voltage constant
  - Soft/hard, medium depolarization
  - High energy output

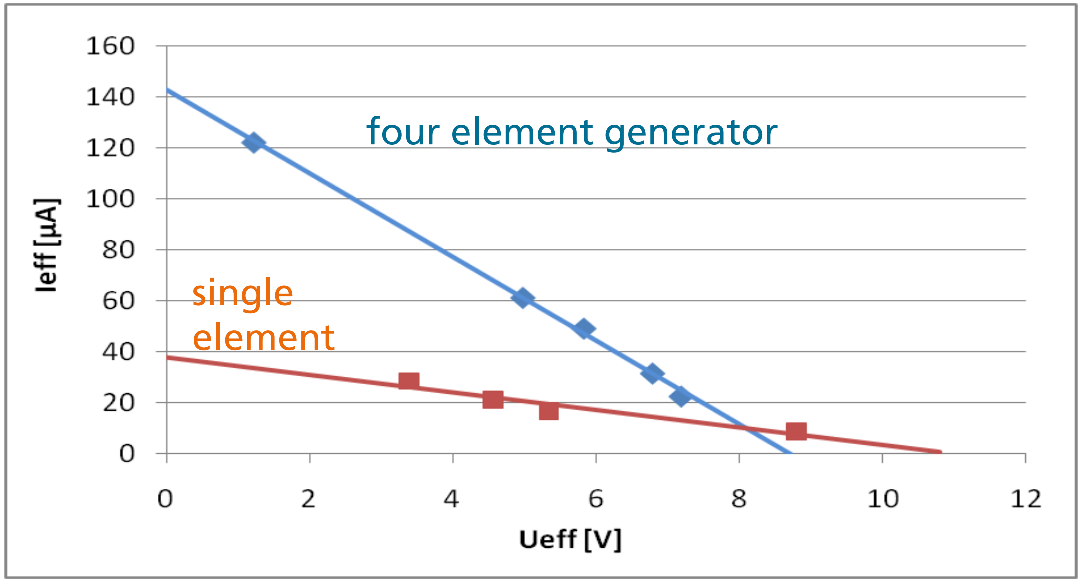



Proof of Concept – Results

- Results @ 1g, f_R , load resistor:

Generator	P_{max} [µW]	U [V]	I [µA]
Single element	104	5.5	19
Four element	310	4.3	71



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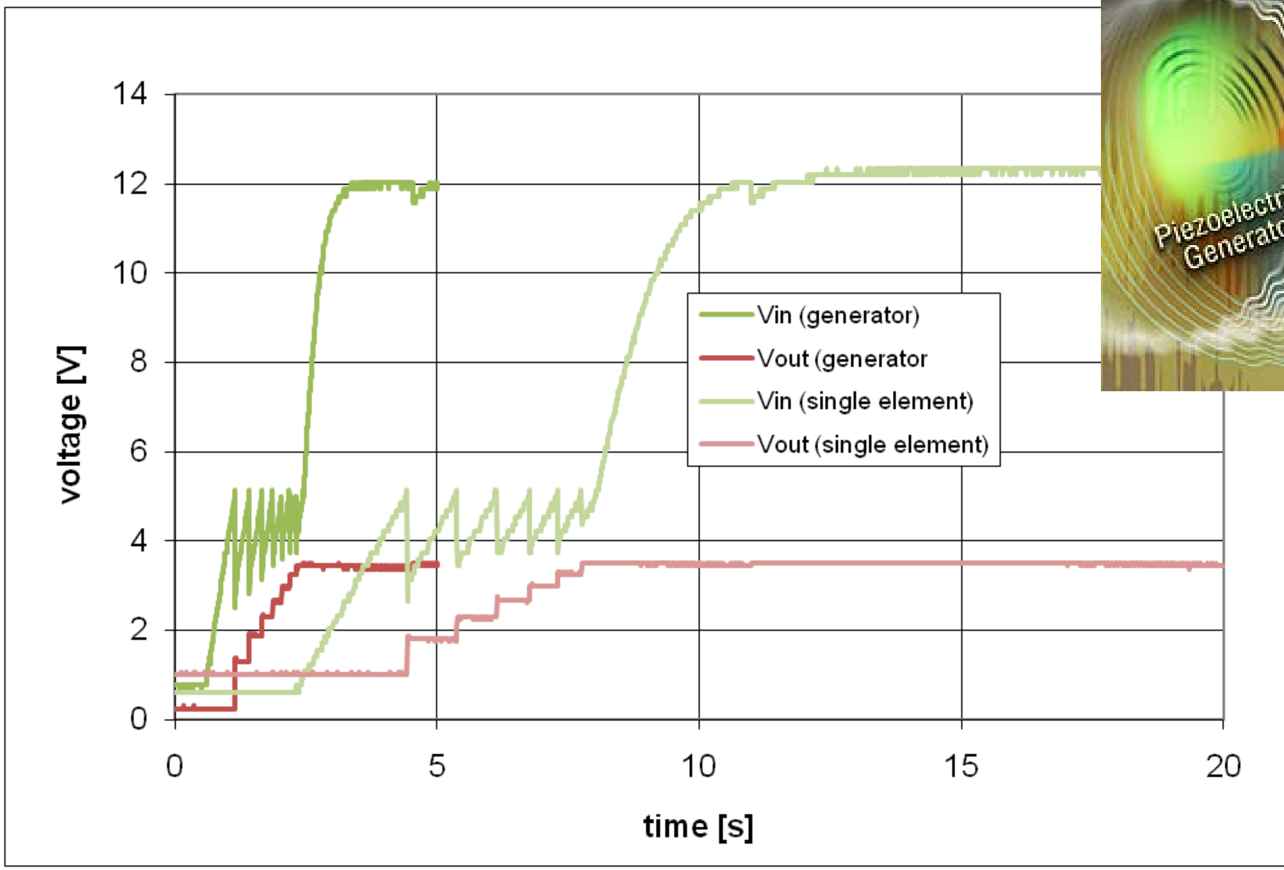
Proof of Concept – Electric transformer – LTC3588



www.linearnews.com/photopost/data/500/medium/LTC3588.jpg

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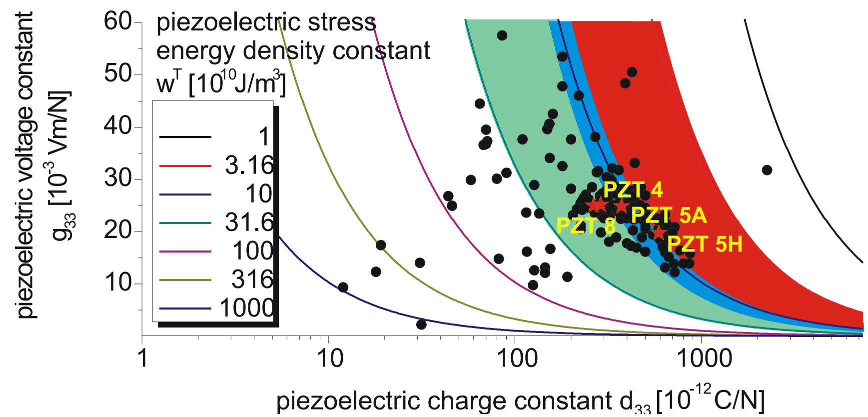
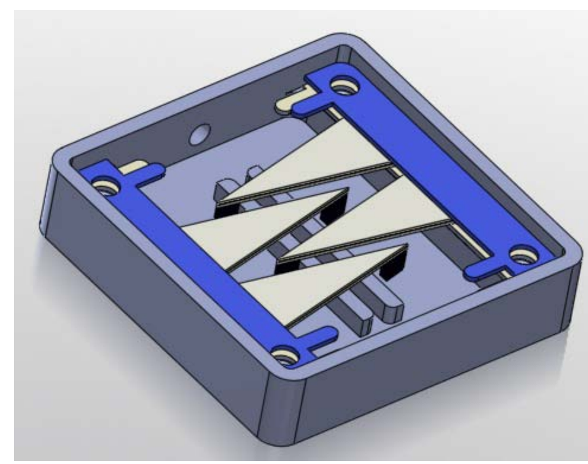
Conclusion and Outlook

- Commercial piezoceramic materials for generator applications available
- Wide range of
  - Charge constant
  - Voltage constant
  - Degradation resistance
- Proof of concept of SHM power generator successfully finished
- Next step is designing a new electronic modul to power low power electronics





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