Institute of Sensor and Actuator Systems
(ISAS)

Silizium MEMS
Sensoren und Aktoren

U. Schmid

Univ.-Prof. Dr. Ulrich Schmid

- 1993-1998 Study of physics in Munich, Kassel, Nottingham (GB) and Frankfurt/Main
- 1998 Diploma thesis at the microelectronics research lab of the Daimler-Benz AG in Frankfurt/Main
  „Preparation and characterization of lateral field effect transistors in 6H-SiC“
- 1999-2001 Ph.D. student at the microsystem research lab of the DaimlerChrysler AG (EADS Deutschland GmbH) in Ottobrunn/Munich
- 2001-2003 Project leader at the EADS Deutschland GmbH in the field of advanced injection technologies
- 2003 Ph.D. degree of the TU Munich with a thesis entitled:
  „Robust flow sensor for high pressure automotive injection systems“
- 2003-2008 Post doc at the Chair of Micromechanics at Saarland University
- 10/2008 - Full professor for Microsystems Technology at the
- Vienna University of Technology
- 01/2012 - Head of Institute for Sensor and Actuator Systems

- Email Contact: ulrich.e366.schmid@tuwien.ac.at
- > 400 peer reviewed journal and conference papers (h-index: 31, Google)
- > 50 granted patent families

Institute of Sensor and Actuator Systems

2 research groups:

- Micro- and Nanosensors (MNS)

Univ.-Prof. Dr. S. Schmid, ao.Prof. Dr. F. Keplinger

- Microsystems Technology (MST)

Univ.-Prof. Dr. U. Schmid

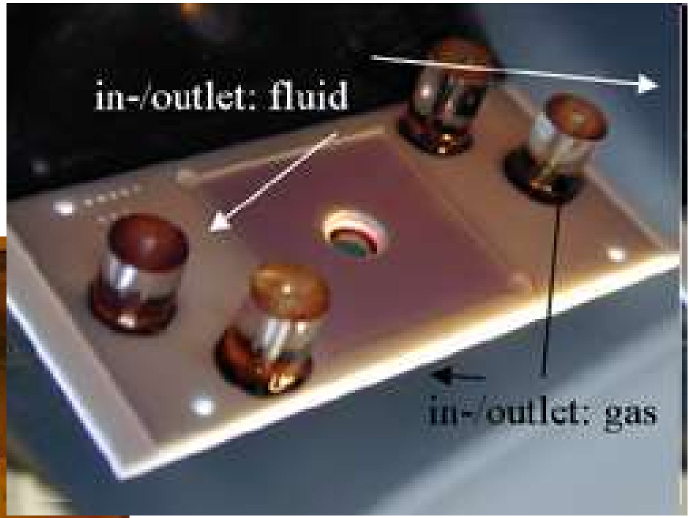
Currently circa 30 (state) + 25 (project funded)
(of which 20 PhD students)
+ ca. 10 undergraduate students

Infrastructure for MEMS

- Center for Micro- and Nanostructures (*ZMNS*)
- MEMS Technology Lab

In total about 250 m^2 laboratory for sensor realization

Facilities include backside aligner, spray coater, wafer bonder.
Key equipment: DRIE, PECVD, LPCVD, electrochemical cell



ZMNS

Research Group Microsystems Technology

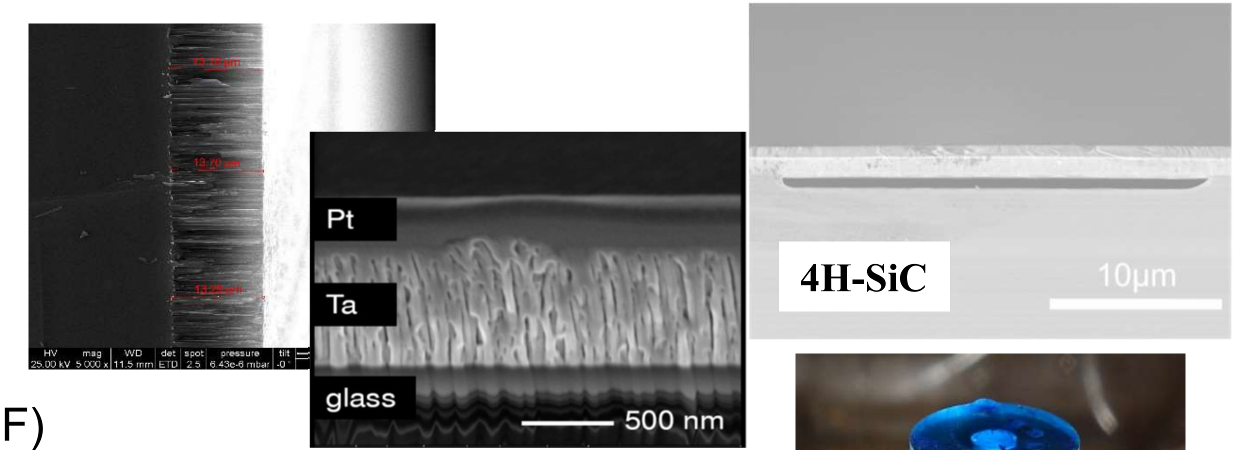
- **Expertise in the design, realization and evaluation of MEMS devices and systems**

• Research topics

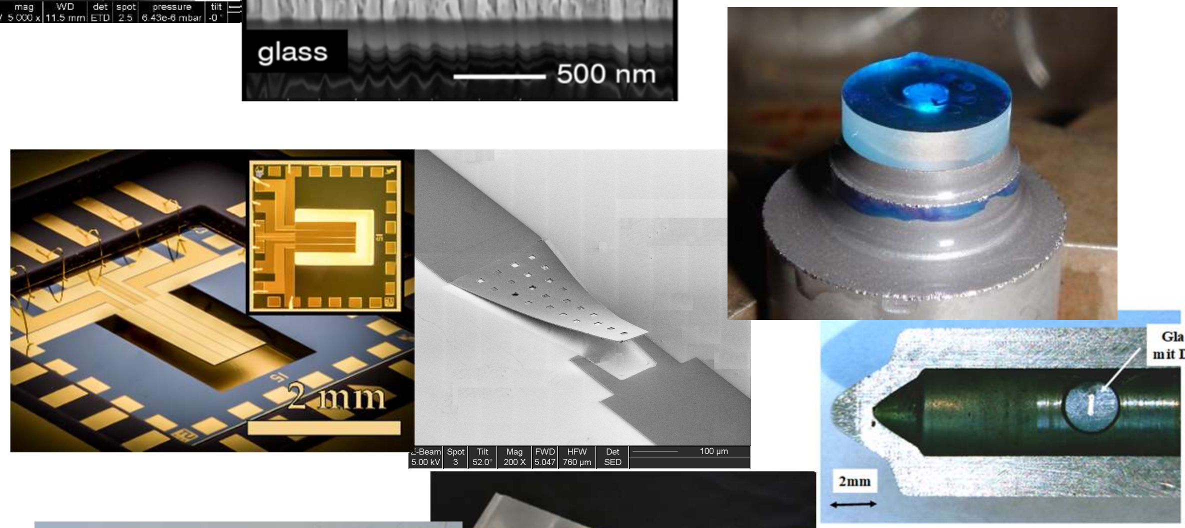
- **Technology related activities:**
- Functional thin films (Al(Sc)N, SiC, PVDF)
- Robust thin film systems up to 600°C
- Porosification/Etching techniques
- LTCC/ceramics, Si, silicon carbide

- **Device related activities:**
- Mass sensitive MEMS resonators
- Acoustic MEMS
- Energy harvesting/storage devices
- High temperature (pressure) sensors
- Modelling and simulation of MEMS

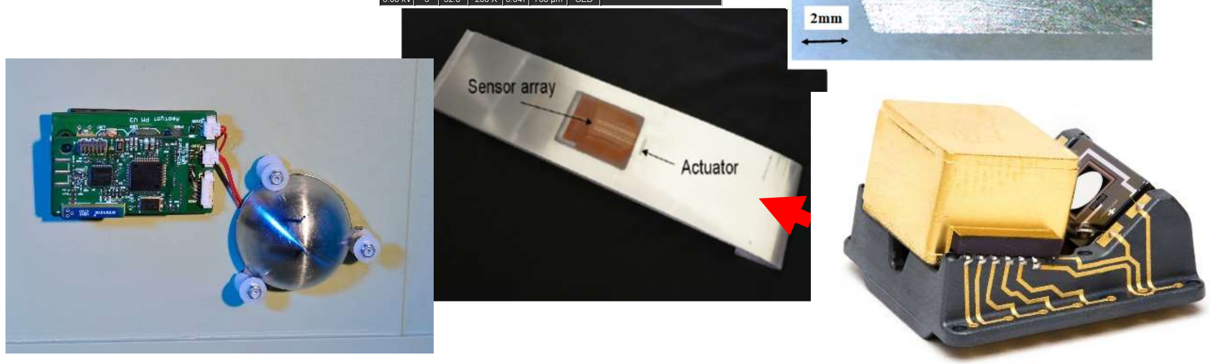
Materials



Devices



Systems



Research topic:

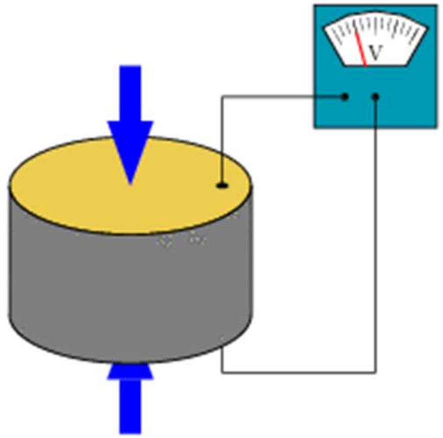
Piezoelectric Resonators

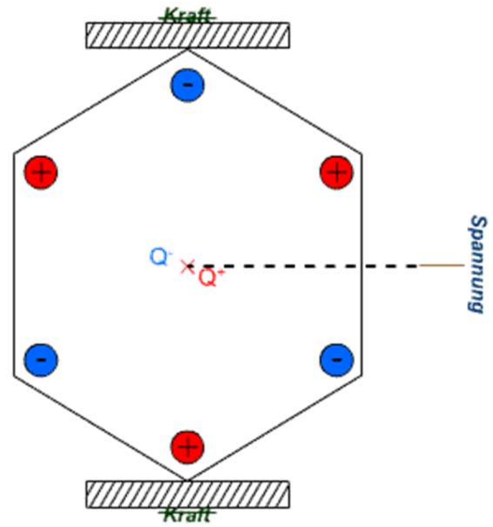
Basics: Piezoelectric Effect

- Change of electrical polarization due to mechanical deformation of solids
  → **direct piezoelectric effect**
- Deformation due to applied electric field
  → **converse piezoelectric effect**

- **Non-centrosymmetric** crystal structure (not having a centre of symmetry)

- **Common materials:**
  - Crystals (e.g. quartz, $LiNbO_3$, $GaPO_4$)
  - Ceramic thin films (e.g. PZT, ZnO, AlN)
  - Polymers (e.g. PVDF)





https://en.wikipedia.org/wiki/Piezoelectricity
https://de.wikipedia.org/wiki/Piezoelektrizit%C3%A4t

Mathematical description of piezoelectric effect:

Mechanical stress $T_i = c_{ij}^E S_j - \boxed{e_{mi} E_m}$

Mechanical strain $S_i = \underbrace{s_{ij}^E T_j}_{\text{pure mechanical}} + \underbrace{\boxed{d_{mi} E_m}}_{\text{electro mechanical coupling}}$

MEMS Resonators: Cantilever Manufacturing Process

a) SOI (silicon on insulator) wafer with 20 µm device silicon thickness and coating of SiO_2 and Si_3N_4

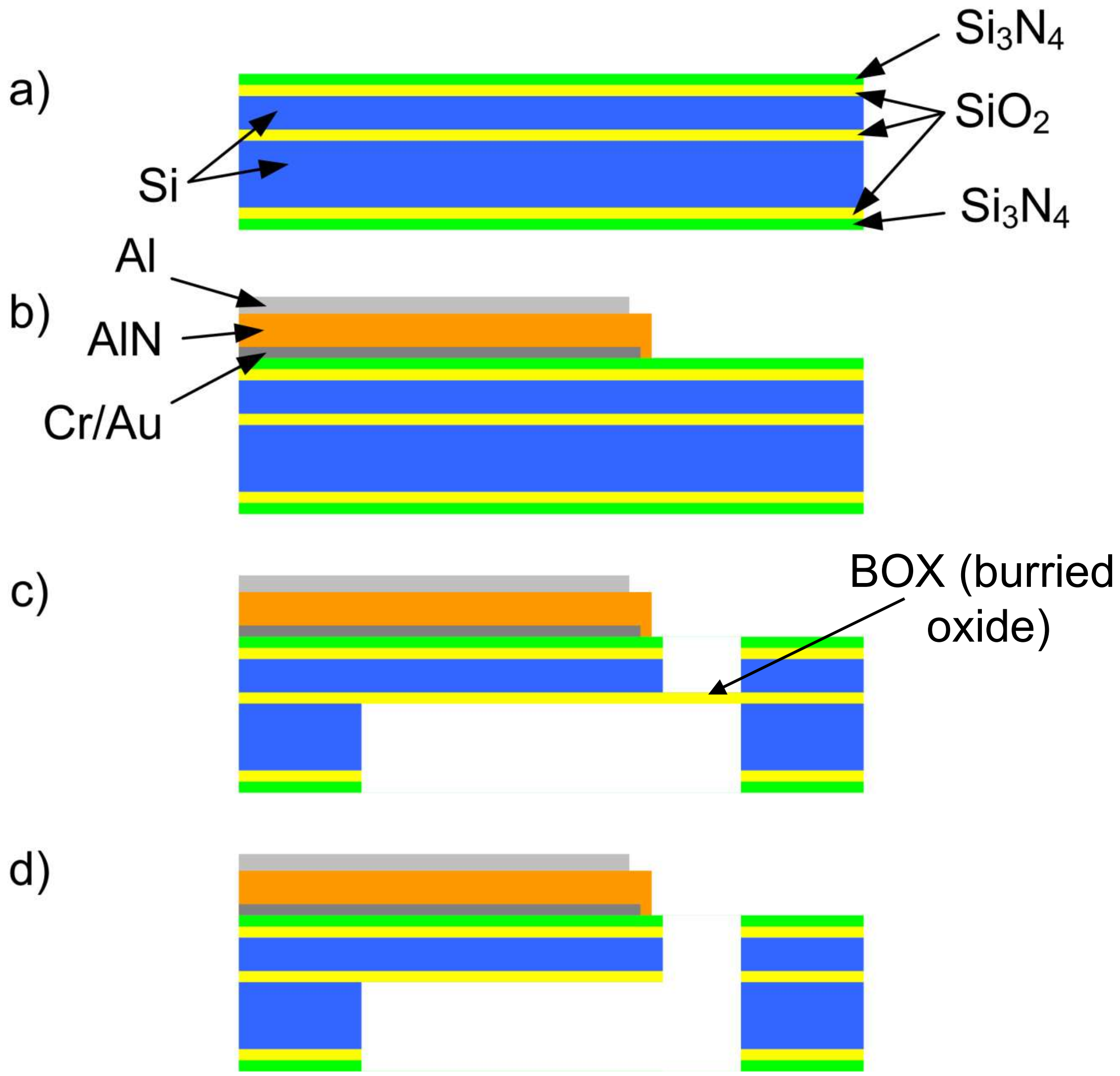
b) Deposition of Cr/Au electrode, piezoelectric AlN layer and Al top-electrode

- patterning of AlN with a lift-off process using titanium as sacrificial layer and 40% hydrofluoric acid (HF)

c) Patterning of cantilever and backside hole by DRIE etching process

d) Cantilever release by BOX (burried oxide) removing with 5% buffered HF acid

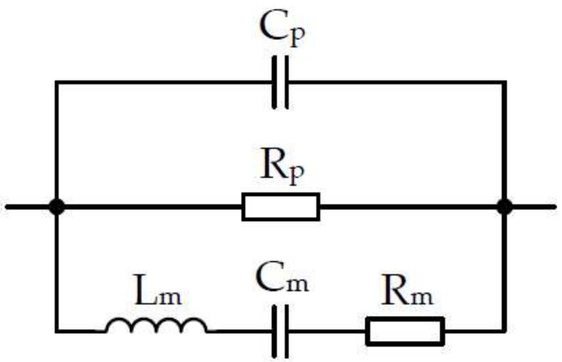
dicing, mounting, bonding,…..



M. Kucera et al., *Q-factor enhancement of a self-actuated self-sensing piezoelectric MEMS resonator applying a lock-in driven feedback loop*, **J. Micromech. Microeng. 23 (2013) 085009.**

Basic Device & Fluid Properties

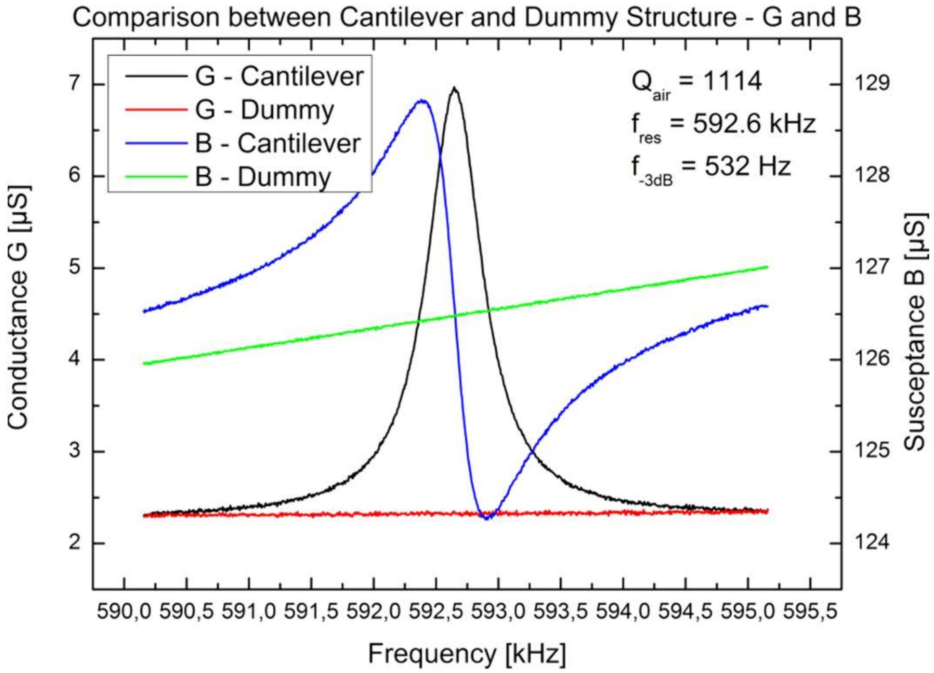
Modified Butterworth-Van Dyke equivalent circuit

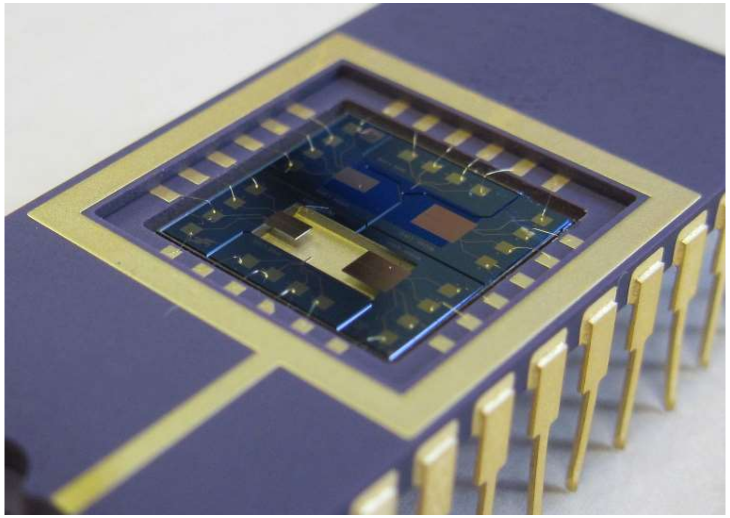


C_p … Parallel capacitance

R_p … Leakage resistance

R_m, L_m, C_m … Mechanical resonance

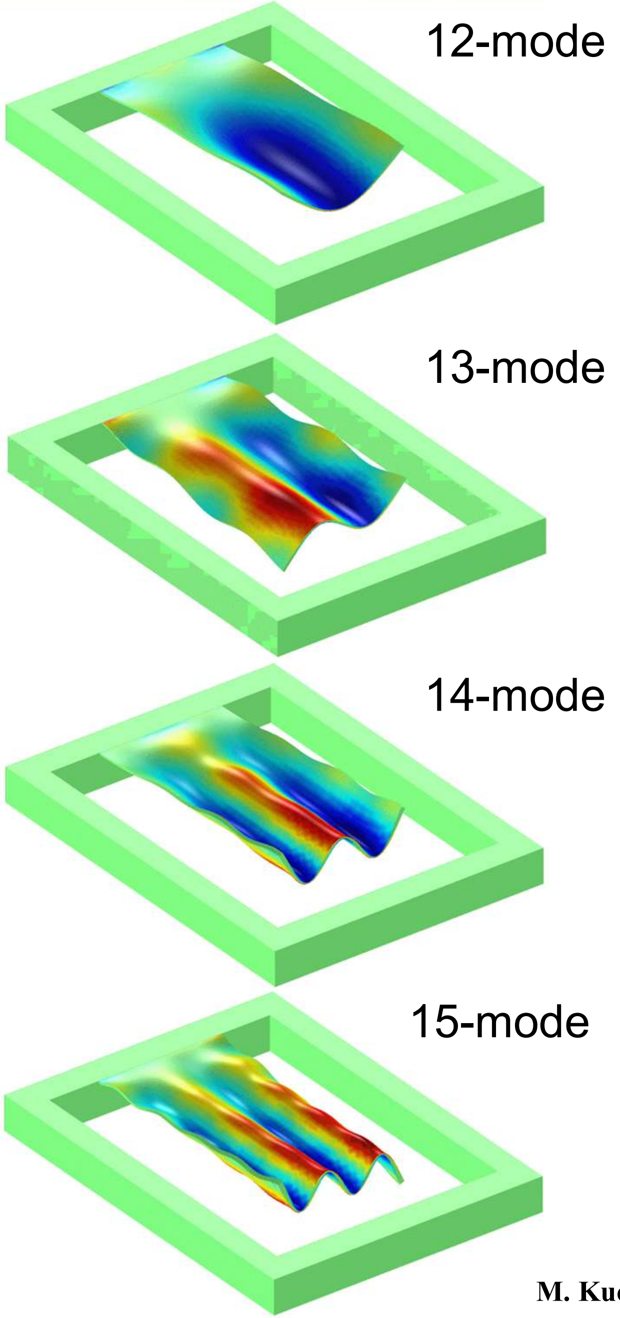




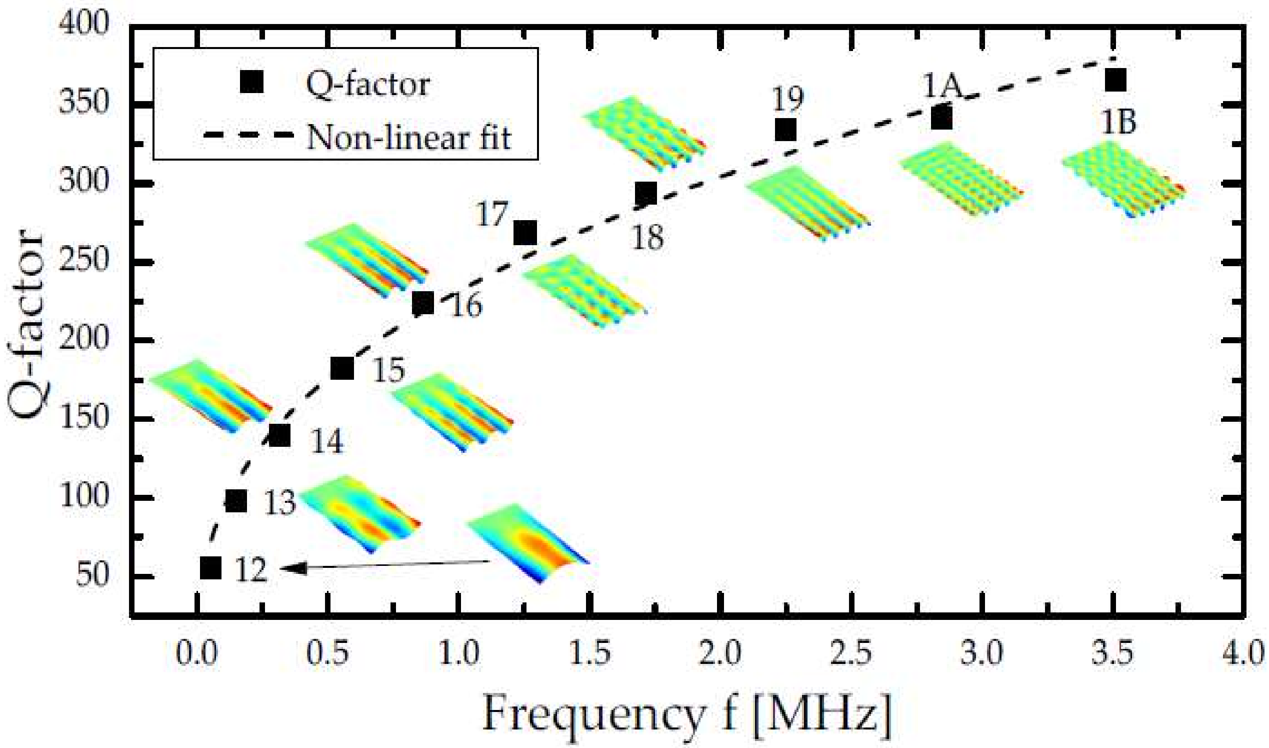
Fluid properties

Medium (–)	Density ρ (g/cm³)	Dynamic viscosity μ (cP)	$1/\sqrt{\rho\mu}$ $\left(\sqrt{\mathrm{cm}^3/(\mathrm{g}\times\mathrm{cP})}\right)$
Ethanol	0.7855	1.1175	1.0673
DI–H_2O	0.9907	1.0471	0.9818
Isopropanol	0.7812	2.1062	0.7796
D5	0.8354	4.9122	0.4936
N10	0.8476	17.235	0.2616
N35	0.8552	65.526	0.1336
N100	0.8627	238.82	0.0697

Study of the Multi Roof Tile-Shaped Vibration Mode

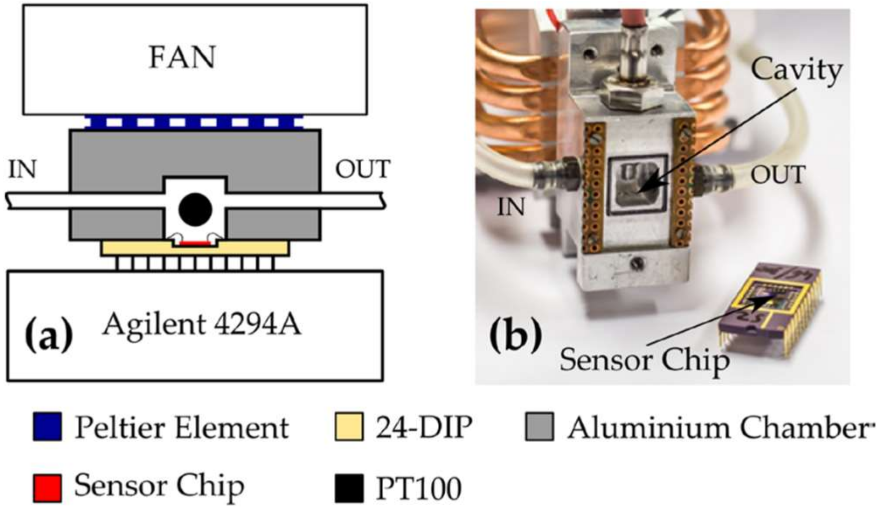


- New class of vibration modes
- Evolution of the *Q*-factor in DI-water



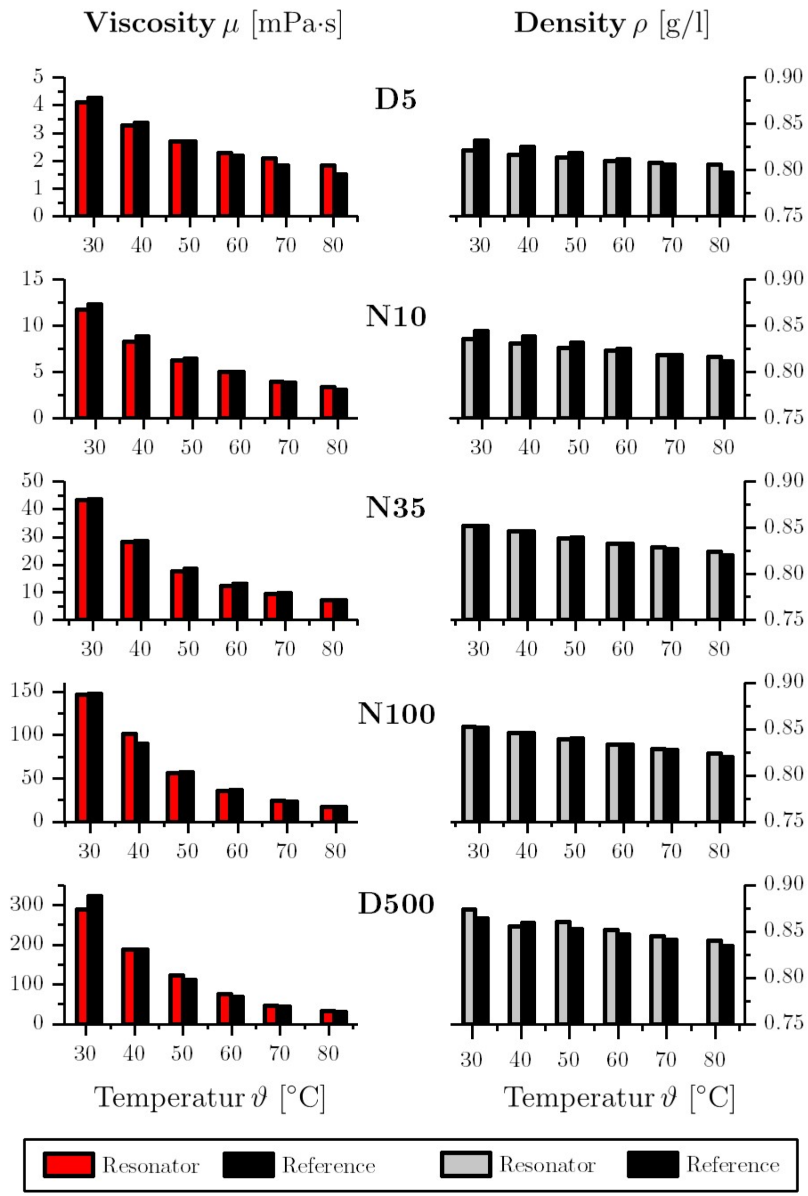
M. Kucera et al., Applied Physics Letters, Vol. 104, pp. 233501, 2014.

Benchmark to Commercial Equipment (Stabinger Viscometer)



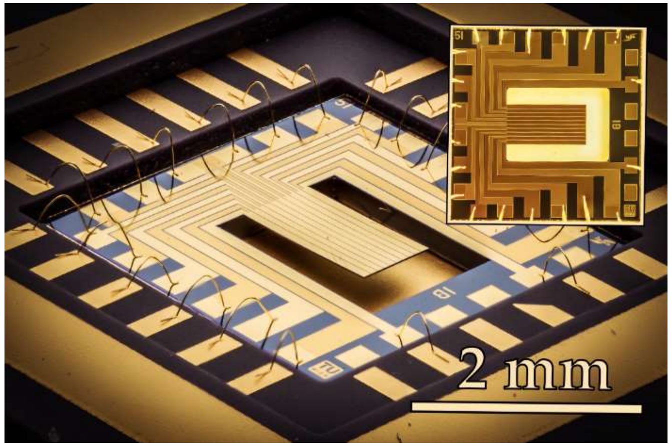
- **Temperature range**
  - 30 - 80°C
- **Viscosity range**
  - 2 - 300 mPa·s
- **Density and viscosity deviation**

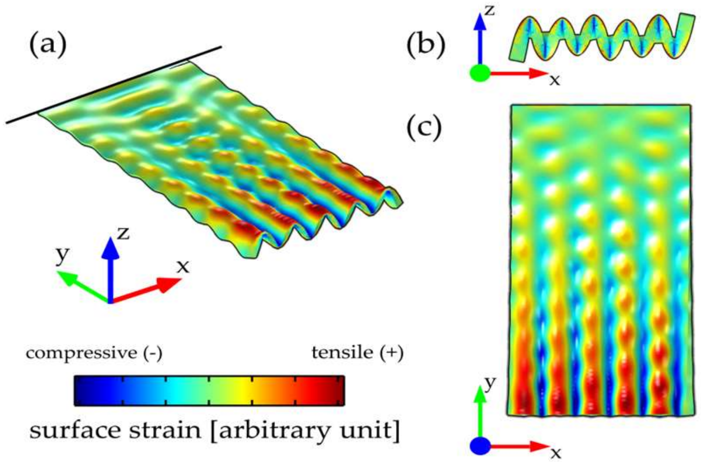
Temp. [°C]	30	40	50	60	70	80	avg.
ε_ρ [%]	0.94	0.65	0.54	0.30	0.25	0.66	**0.55**
ε_μ [%]	4.43	4.60	4.18	4.36	5.17	8.67	**4.26**

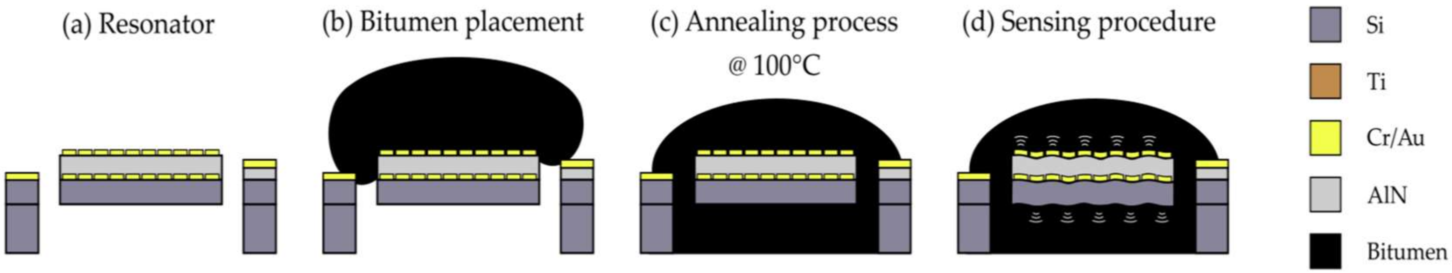


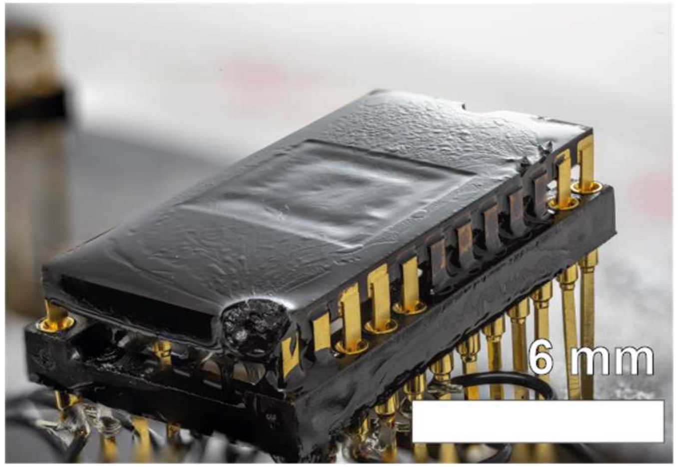
G. Pfusterschmied, et al., Journal of Micromechanics and Microengineering 25 (2015)

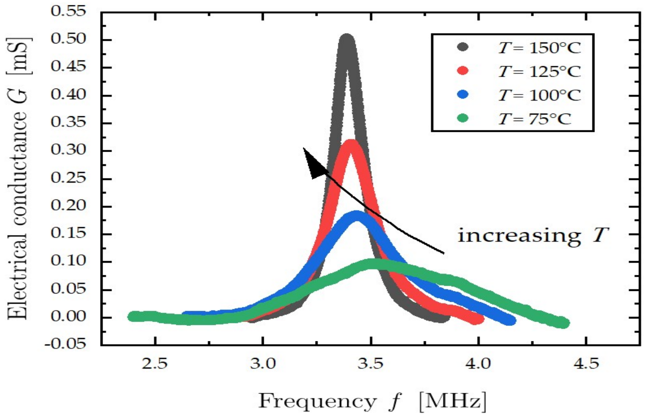
Measurements in Bitumen….up to ~ 60000 mPa·s!

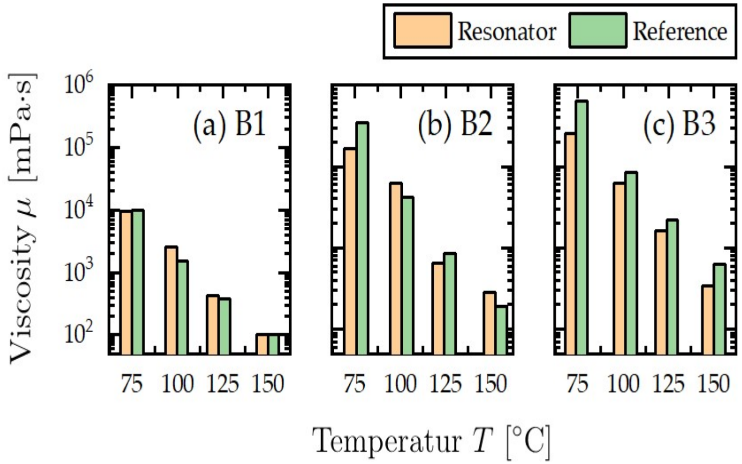








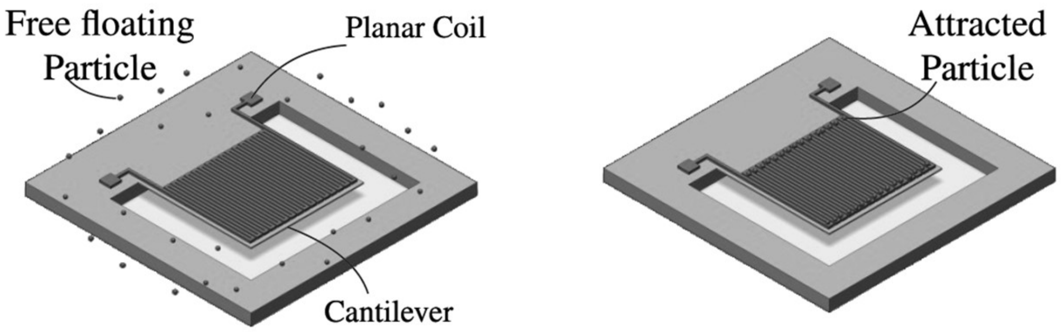


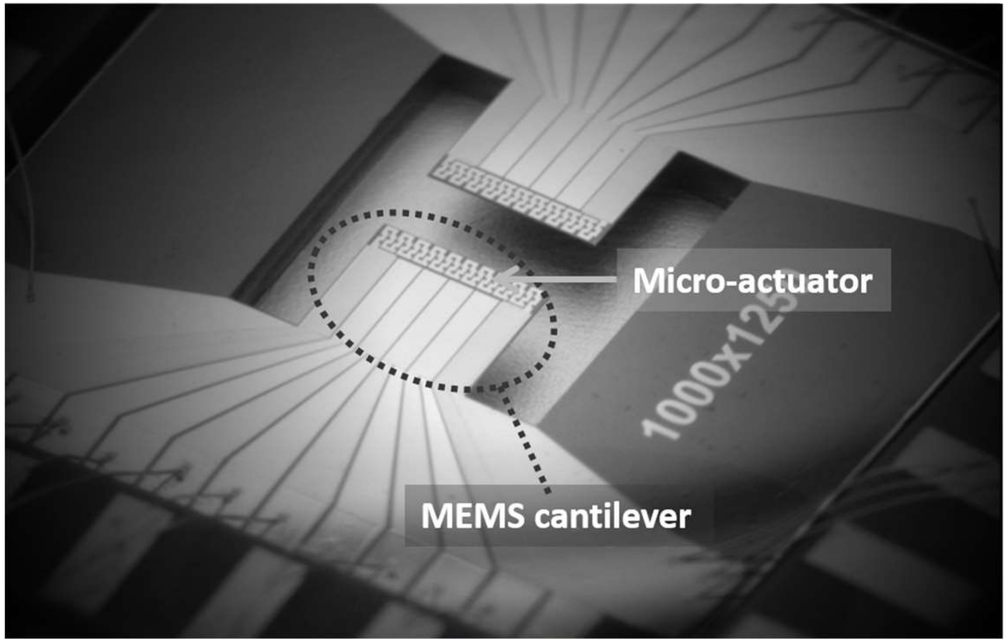


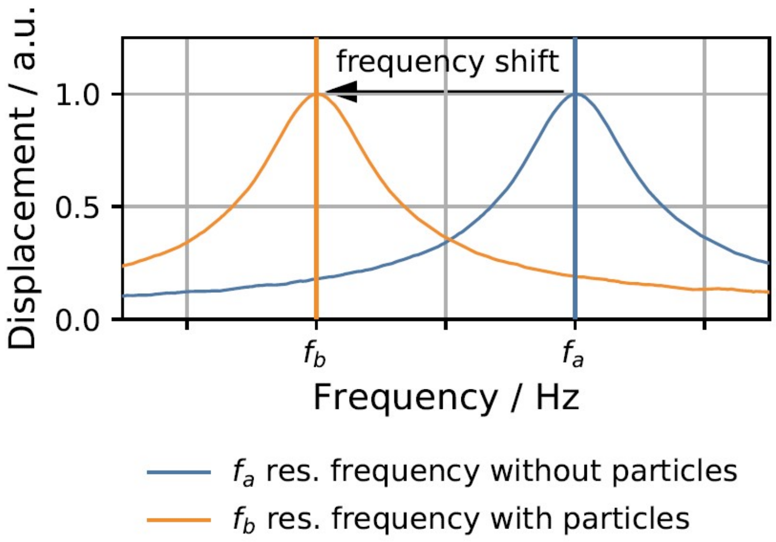
G. Pfusterschmied et al., MEMS Conference, Seoul, 2019.

Detection of Magnetic Particles in Water I

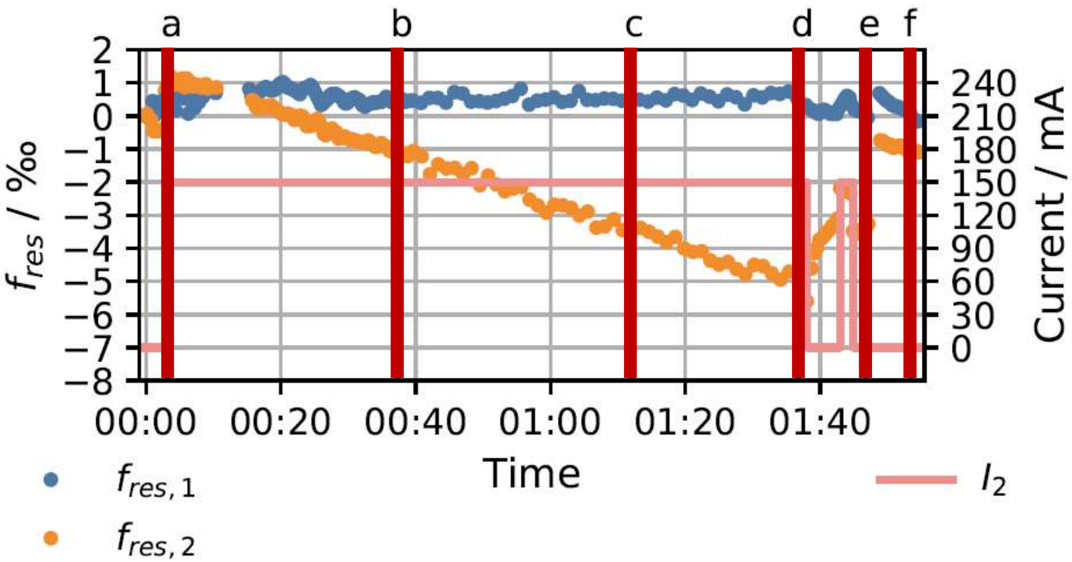
- Magnetic actuator → planar coil on resonator
- Attraction of magnetic particles
- Modell system: 250 nm iron-oxide particles dispersed in DI-Water

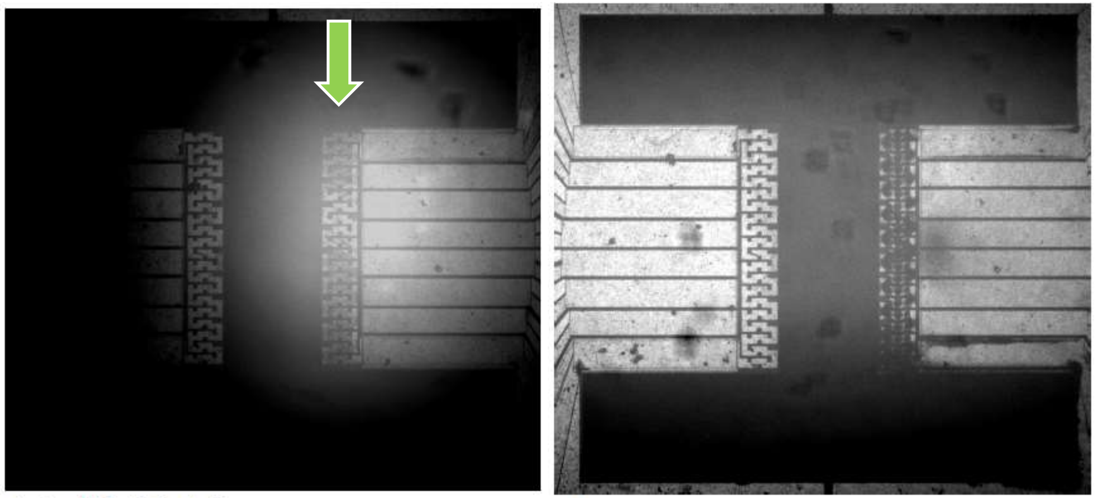




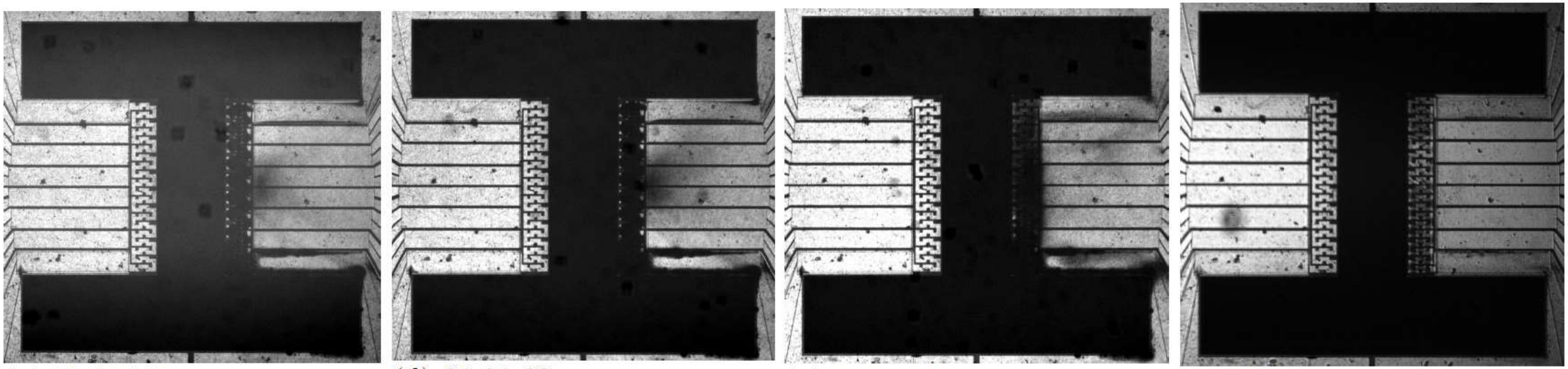


Detection of Magnetic Particles in Water II





(a) 00:03:15 (b) 00:07:04



(c) 00:20:12 (d) 01:21:39 (e) 01:50:59 (f) 01:53:16

F. Patocka, et al., Sensors&Actuators B, Vol. 299, p. 126957, 2019.

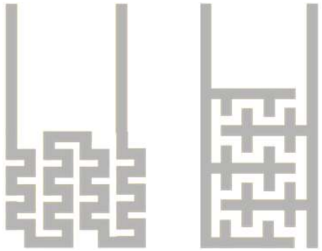
ACT research COMET

Detection of Dielectric Particles in Oil

- Electrostatic actuator
  → inhomogeneous electric field
- Attraction of dielectric particles

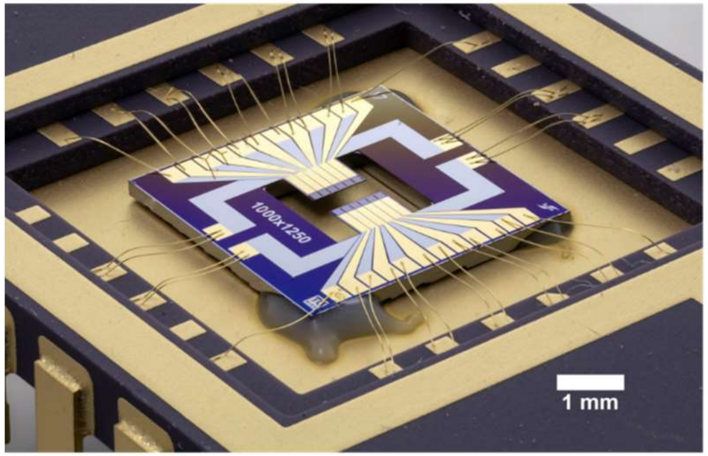
Magnetophoretic force

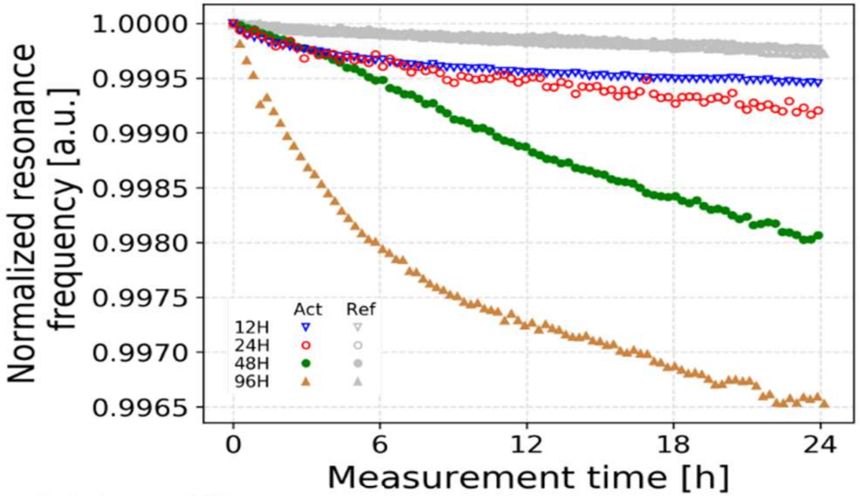
$$\mathbf{F}_{\mathrm{MAP}} \propto \nabla|\boldsymbol{H}|^2$$



Dielectrophoretic force

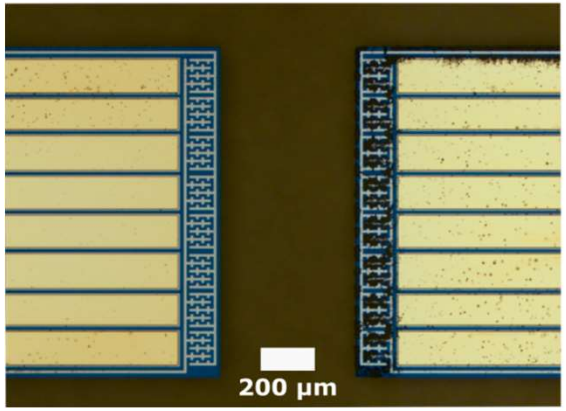
$$\mathbf{F}_{\mathrm{DEP}} \propto \nabla|\boldsymbol{E}|^2$$



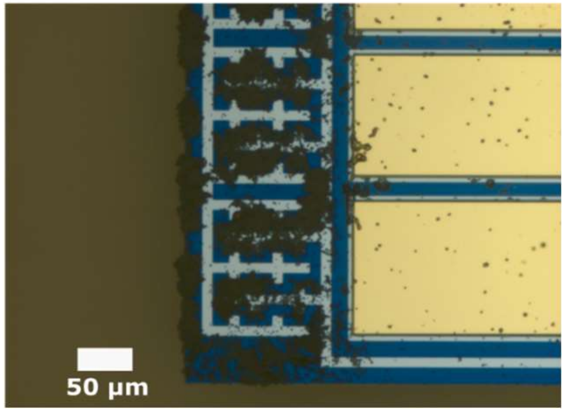


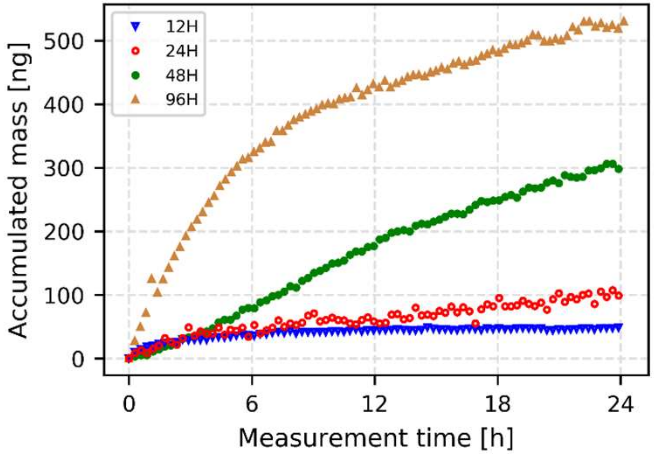
$$\left(\frac{f_r}{f_0}\right)^2 = \frac{m_{cl}}{\underbrace{(m_{cl}+m_{fl})}_{M}}\left(1-\frac{1}{2Q^2}\right)$$

96H



Detailed view on 96H

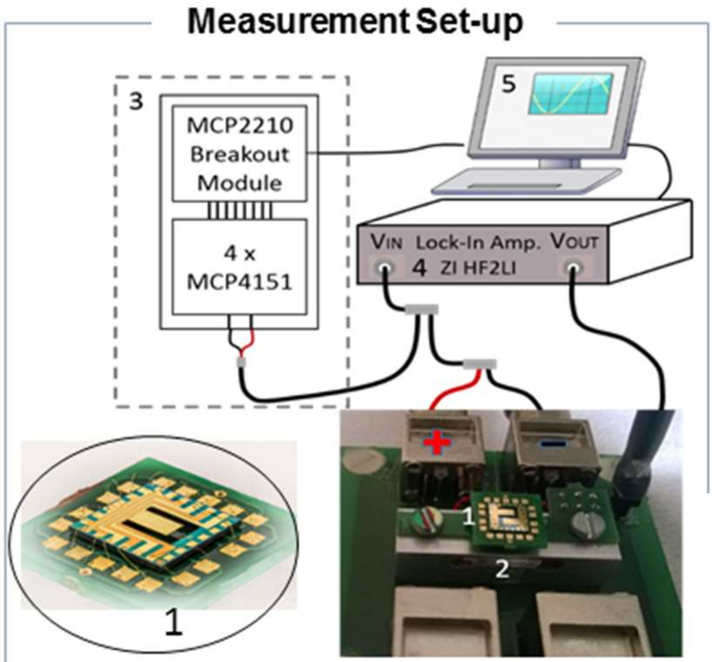




F. Patocka, et al., Sensors&Actuators A, Vol. 315, No. 112290, 2020.

Other PiezoMEMS we did….and worked (☺)

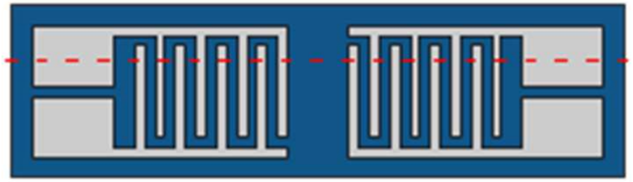
AlN/ScAlN vibrational energy harvesters

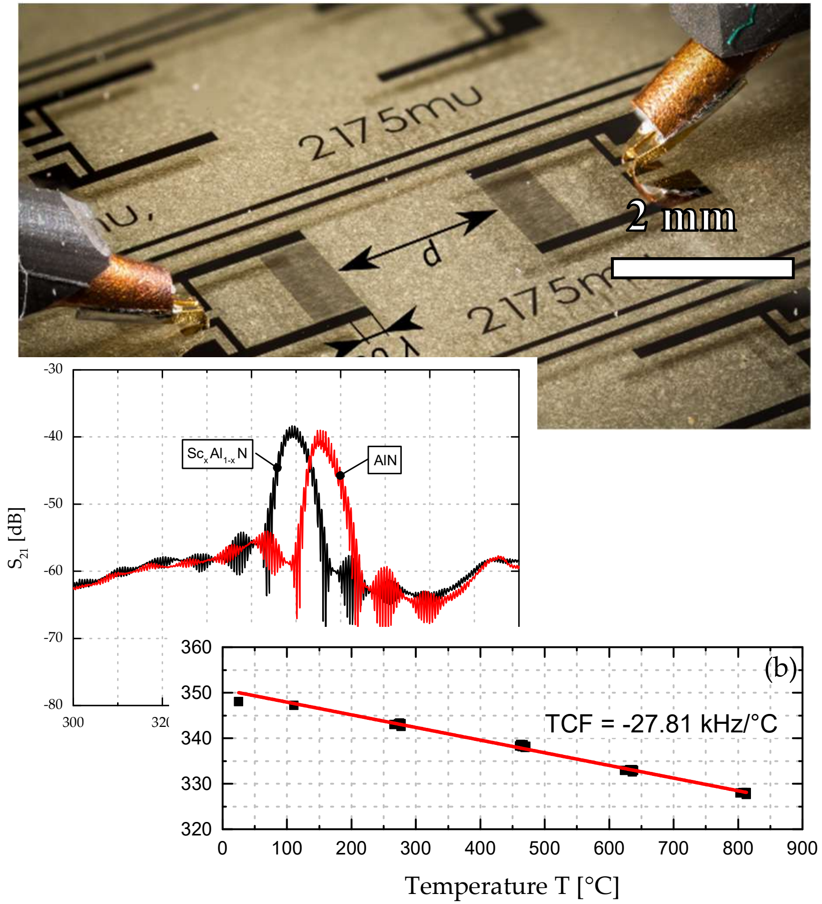


1: Cantilever & PCB
2: Shaker
3: Steckbrett mit 4x digitalen Potentiometer (max. 400 kΩ) & USB Controller
4: Zürich Instruments Lock-In Verstärker
5: PC mit LabView Implementierung.

P.M. Mayrhofer, et al., Journal of Microelectromechanical Systems, Vol. 26, No.1, 102-112, 2017.

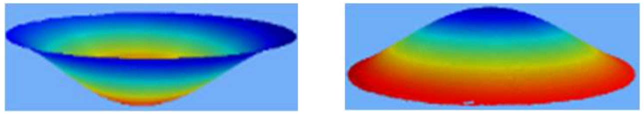
High temperature SAW devices up to 800°C

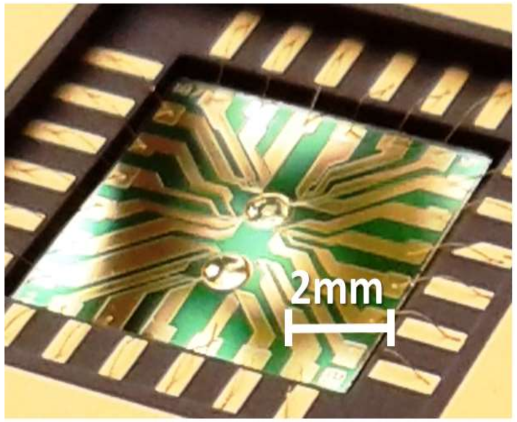


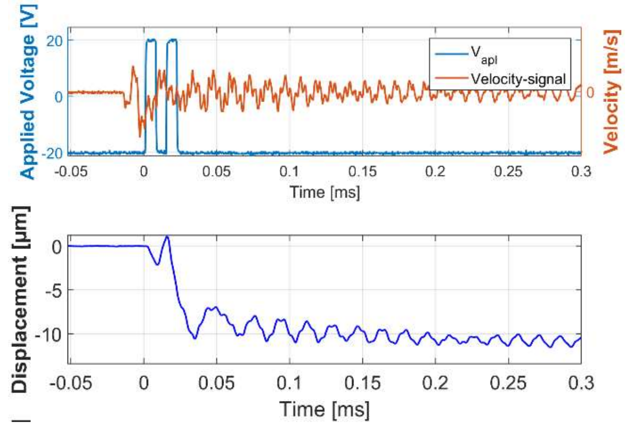


M. Gillinger et al., APL, Vol. 108, pp. 231601, 2016.

Buckled membranes with AlN actuator for switching

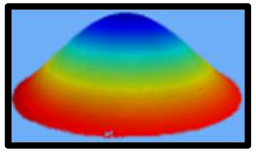


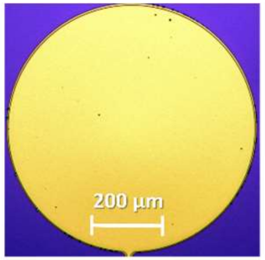


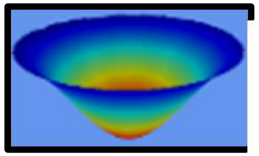


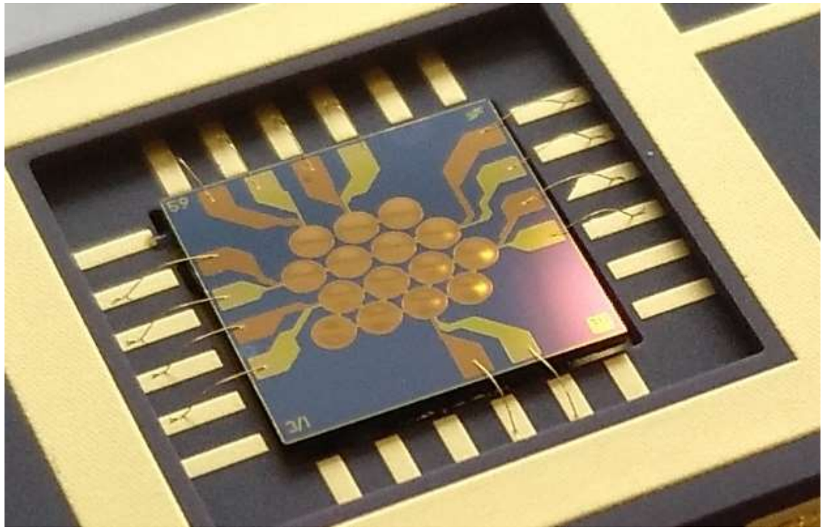
M. Dorfmeister et al., S&A A, Vol. 282, pp. 259-268, 2018.

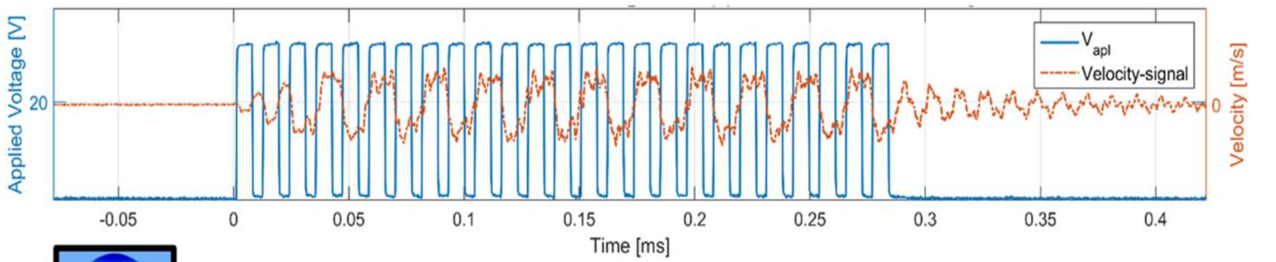
Acoustic MEMS: Piezoelectric Micromachined Ultrasonic Transducers (PMUT)

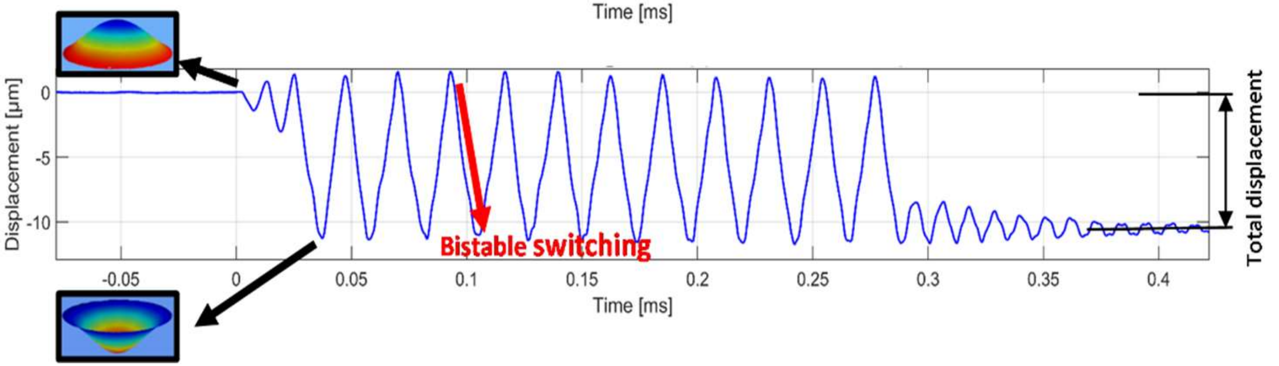


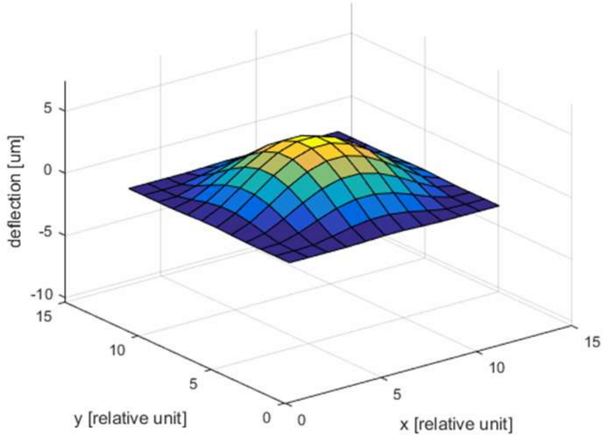












Acoustic performance:

- SPL@56mm= 97.5 dB (jackhammer)
- SPL@0.5m = 78.46 dB
- SPL@2m = 66.42 dB (loud TV)

Loud, broadband signal

M. Schneider et al., JMEMS, Vol. 29, No. 5, pp. 948-953, 2020.

My thanks go to ….. my team

…. and YOU
for your attention!

Questions?