Towards MEMS loudspeaker fabrication by using metallic glass thin films

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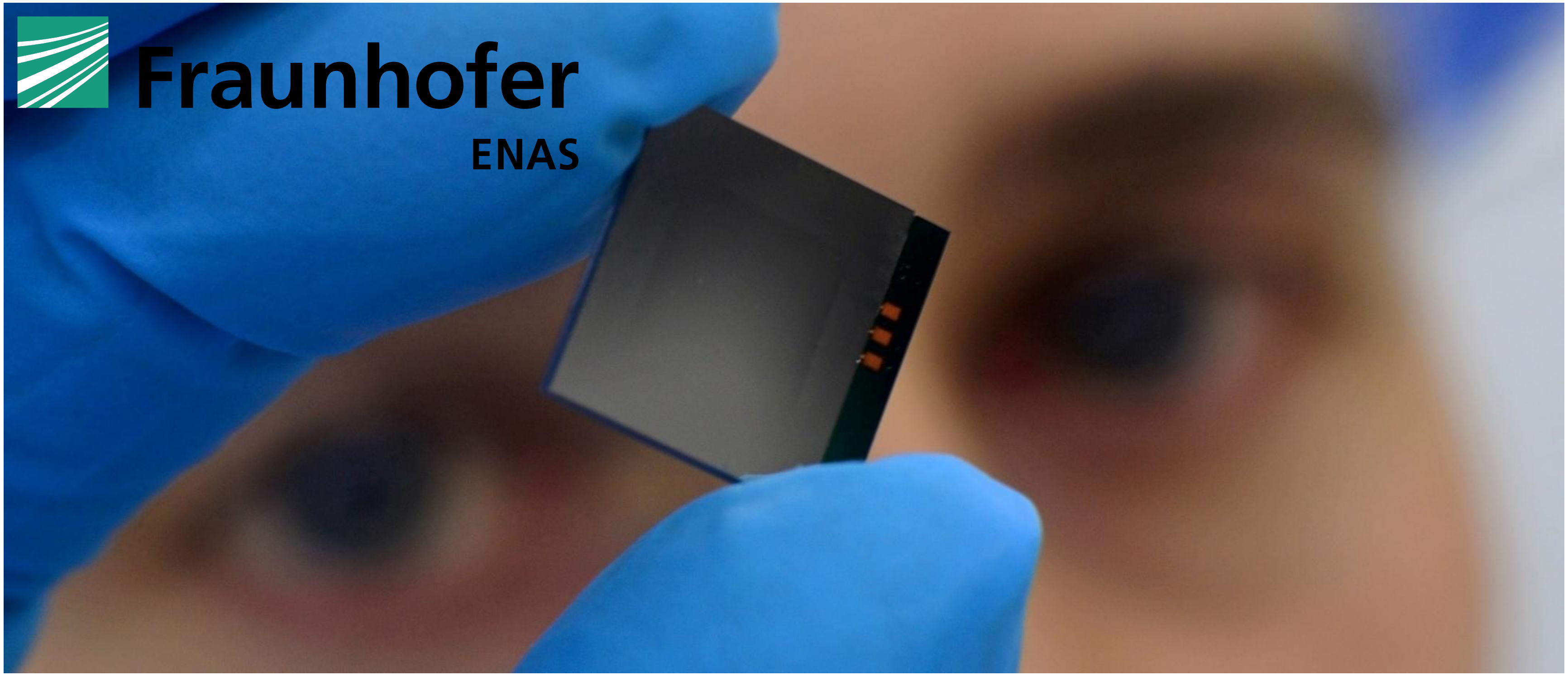
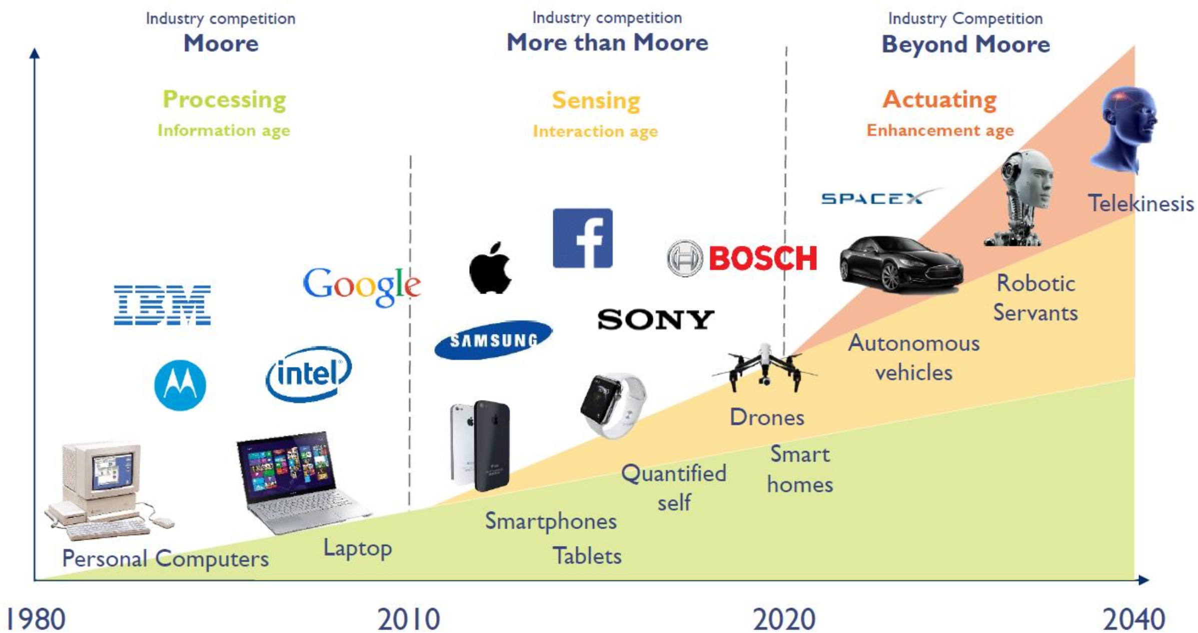


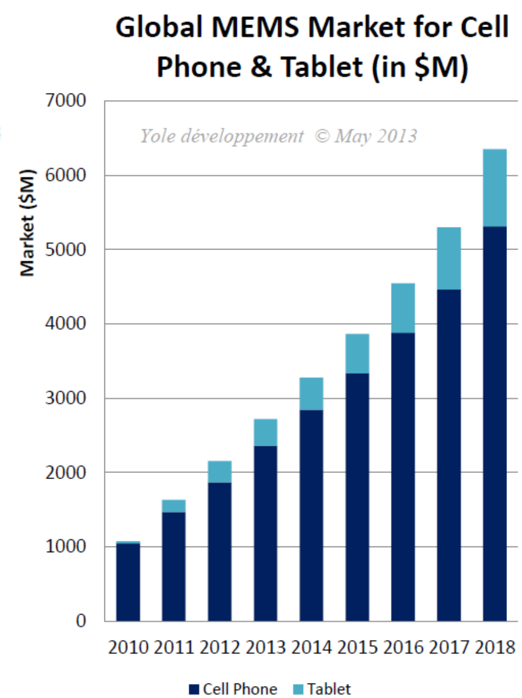
Outline

- MEMS market for mobile devices
- Introducing metallic glass as novel material for MEMS
- Fabrication of a MEMS loudspeaker technology demonstrator
  - Manufacturing of metallic glass membranes
  - MEMS-compatible integration of magnetic material
  - Waferbonding to micro coil wafer
- Summary and outlook

MEMS market for mobile devices

- Continuous growth of MEMS market over 20 years
- Market of mobile devices as one of today's key drivers
- MEMS enable key functionalities





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MEMS market for mobile devices

- New MEMS apps are about to come…

TODAY's smartphone board

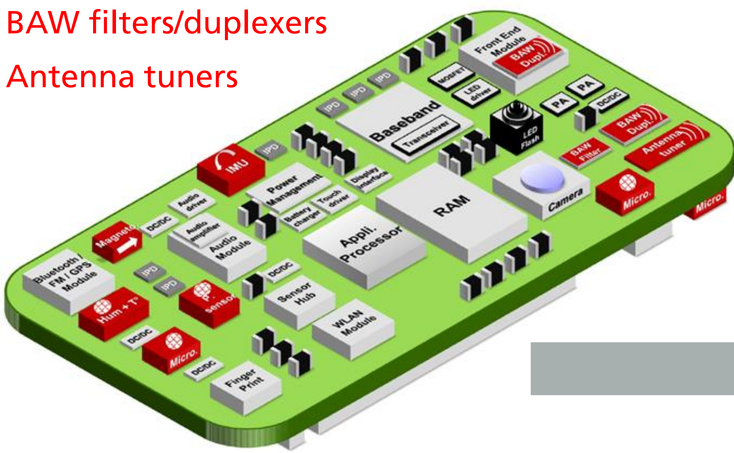
IMU combination

Magnetometer

Microphones

BAW filters/duplexers

Antenna tuners



2020

More microphones (>3)

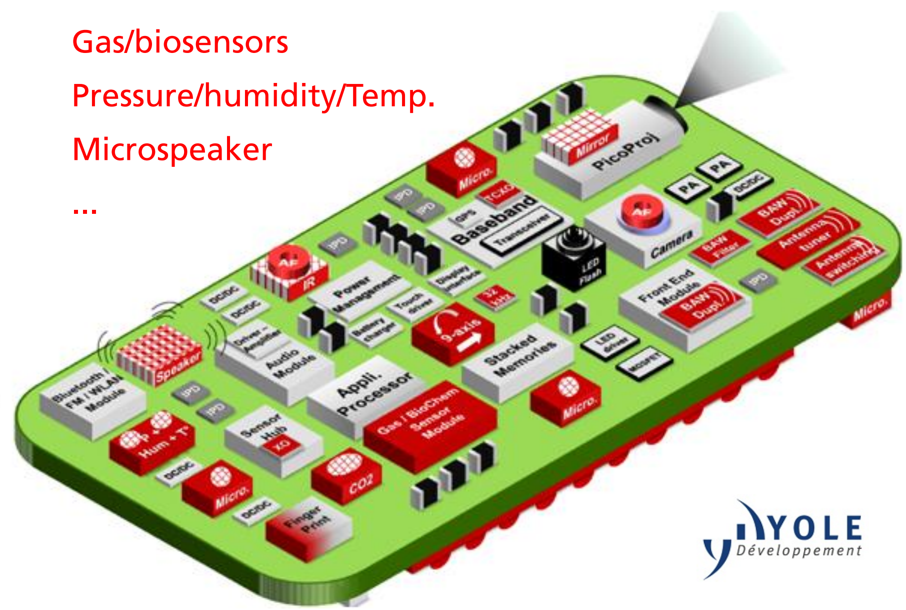
Autofocus

Gas/biosensors

Pressure/humidity/Temp.

Microspeaker

…



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MEMS market for mobile devices

- Market for mobile devices demands more than one billion microspeakers per year and is still growing

- Today's microspeakers are miniaturized versions of classic electrodynamic speakers consisting of:
  - Polymer membrane with attached coil
  - Permanent magnet
  - Housing
  - ➢ Not compatible with reflow soldering

- What is crucial for an electrodynamic MEMS-based microspeaker?
  - Elastic, temperature stable membrane
  - Integration of magnet

$$P_{acoustic} \propto d^4 f^4 x^2$$

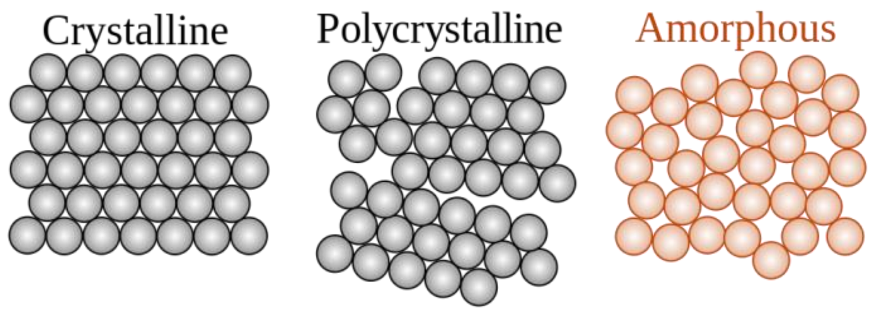
d – Membrane diameter

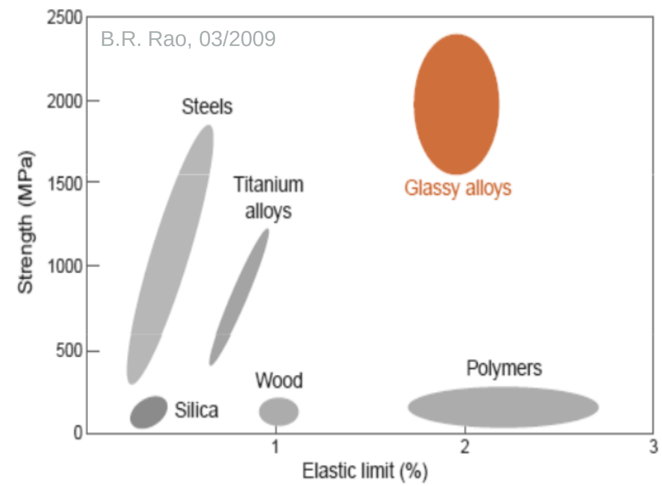
x – Membrane deflection

f – Frequency

Introduction to metallic glass

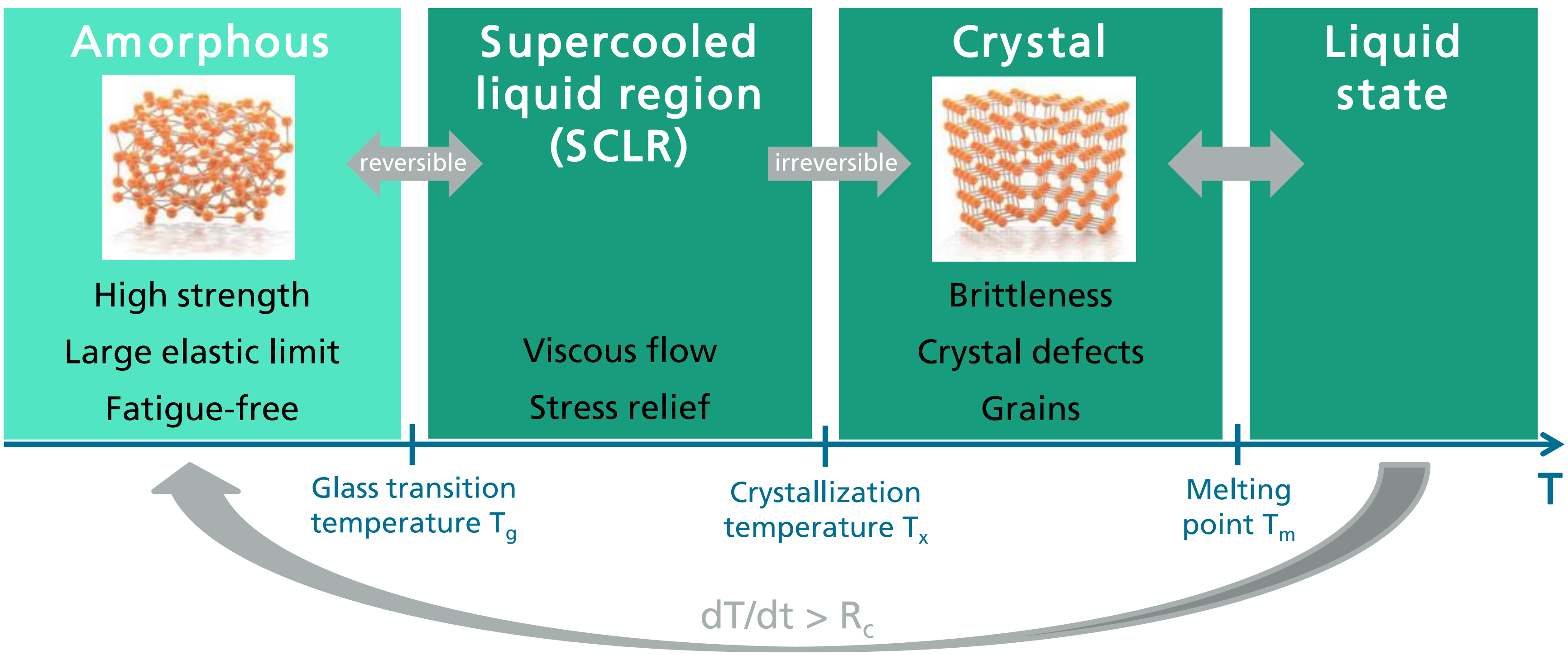
- <u>Metallic</u> alloy with disordered (amorphous) atomic structure like <u>glass</u>





- Properties:
  - No grain boundaries, crystal defects
  - Large elastic limit
  - High strength, corrosion resistance
  - Fatigue-free, isotropic
  - Supercooled liquid region
  - Depending on composition: electrical conductivity, magnetism

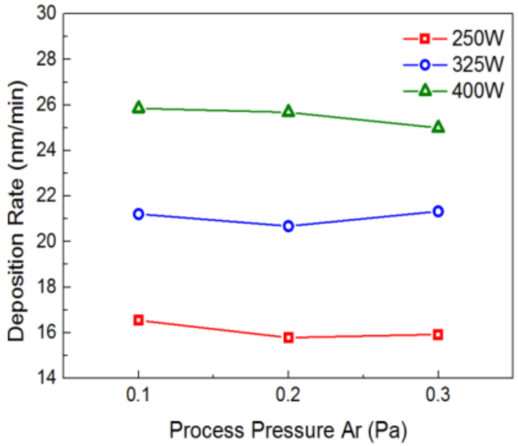
Introduction to metallic glass

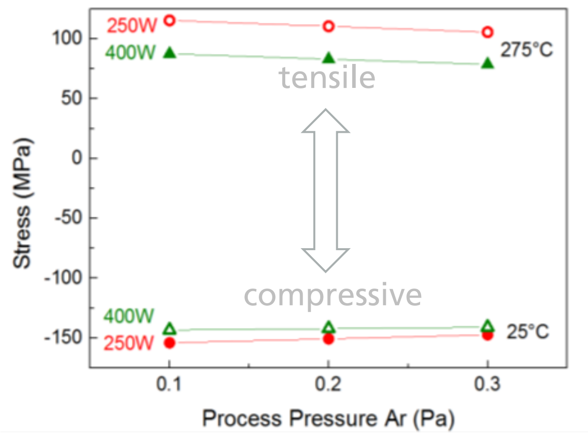


- Critical cooling rate R_c is determined by atomic composition (single-element metals do always crystallize, large differences in atomic sizes lead to low R_c)

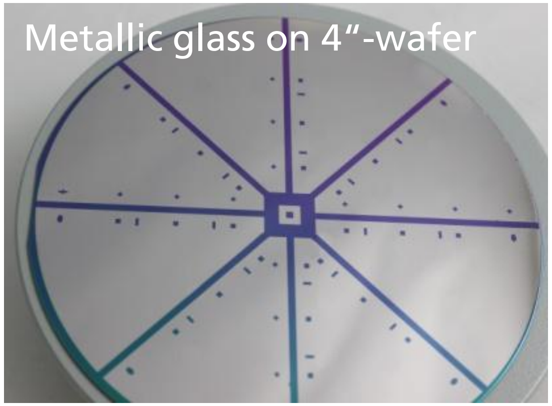
Introduction to metallic glass

- Sputtering using Pd-based alloy target
- Thickness of deposited films: 100 nm … 3 µm





	Pd-based Thin film metallic glass	*Polysilicon*
Young's Modulus	60...70 GPa	170 GPa
Elastic limit	2.0 %	0.7 %
Micro structure	Amorphous	Polycrystalline
Material fatigue	No	Yes
State	R&D	Standard



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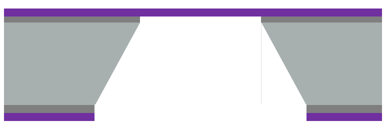
Manufacturing of metallic glass membranes

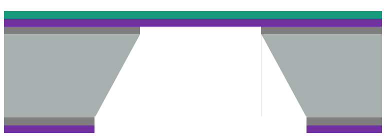
- Technology routine:

1) 4" Si wafer 300µmT

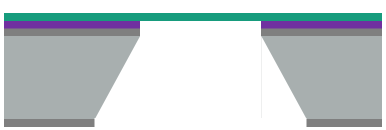
2) SiO_2 and SiN deposition



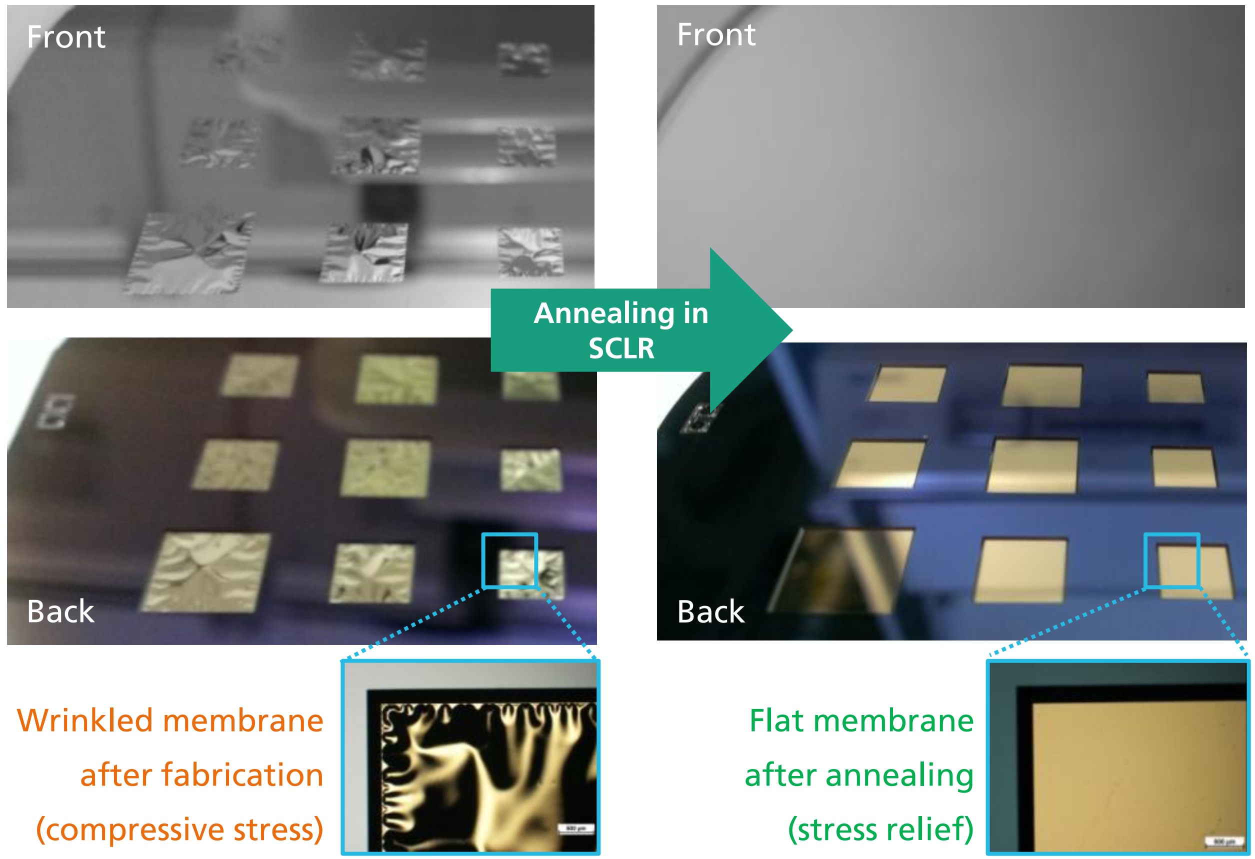
3) Si cavity wet etching



4) Metallic glass deposition

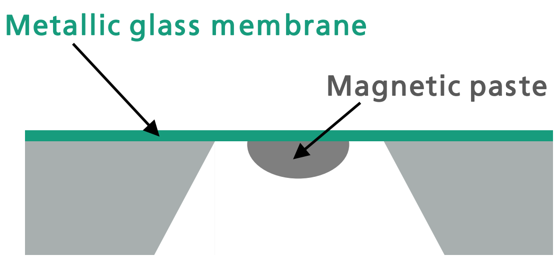


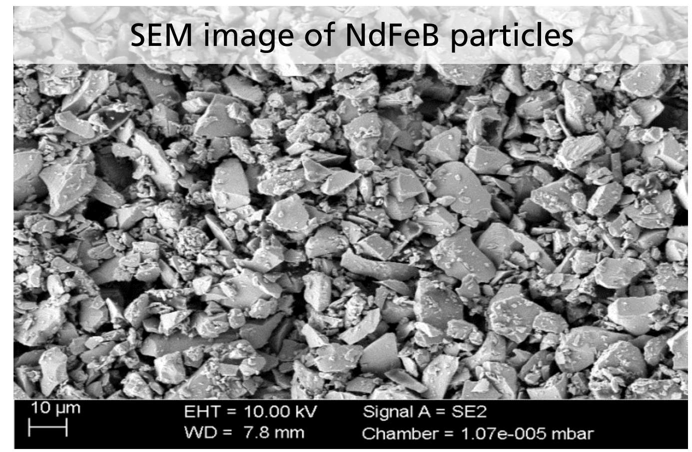
5) SiN dry etching



MEMS-compatible integration of magnetic material

- Epoxy-based paste with 70 wt% NdFeB particles
- Particle size around 10 µm
- Screen printing / dispensing at wafer-level
- On substrates or membranes applicable

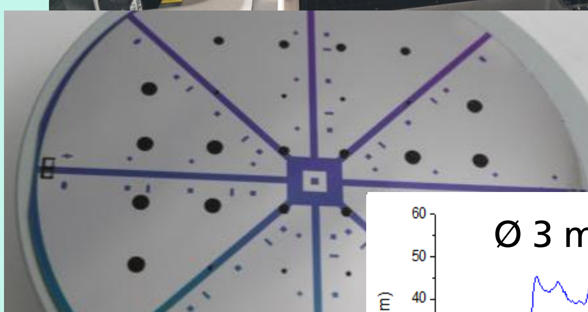


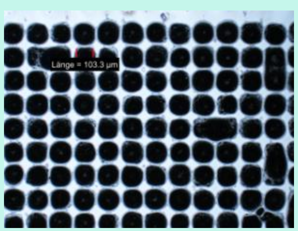


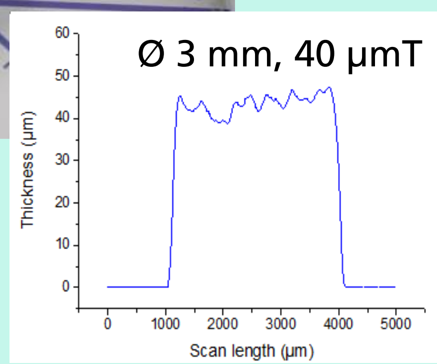
Deposition → Curing 120 °C, 30 min → Magnetization → Integrated permanent magnet

MEMS-compatible integration of magnetic material

Screen printing

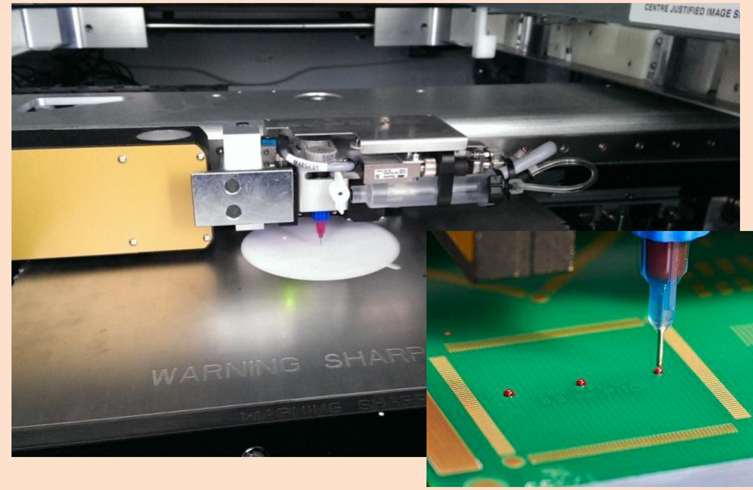


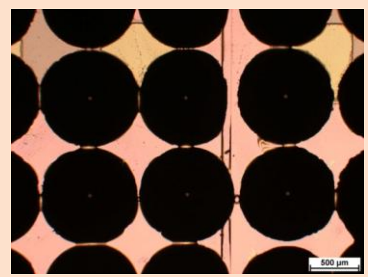


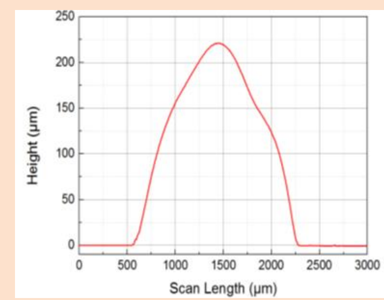


Ø 100 µm dots

Dispensing







Ø 1 mm
100…150 µmT

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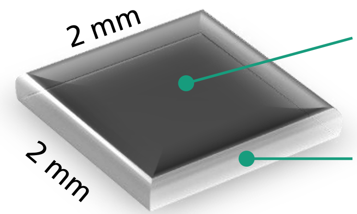
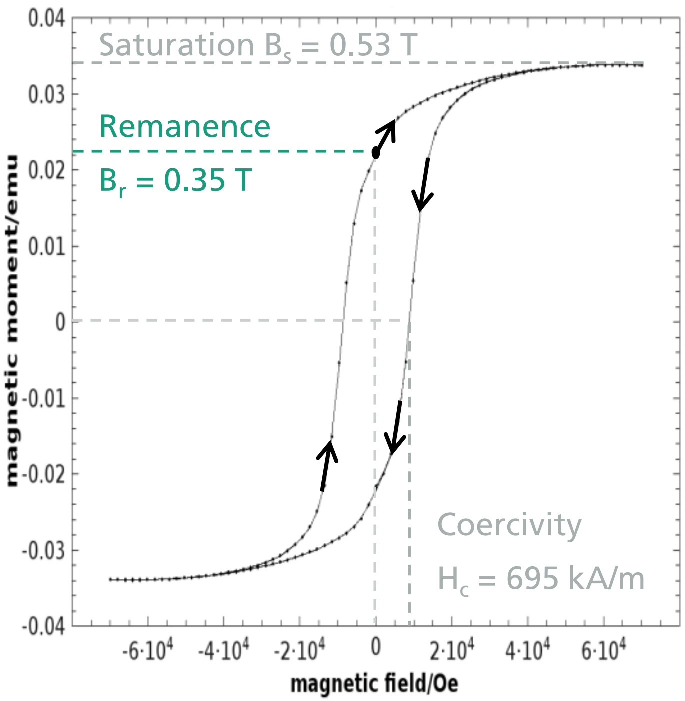
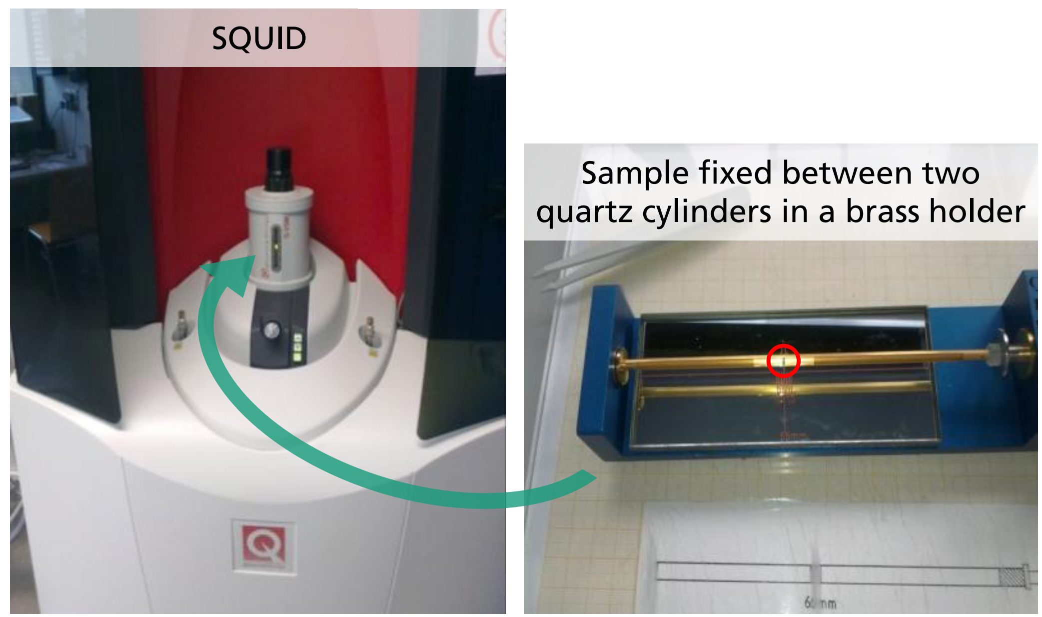
MEMS-compatible integration of magnetic material

- Magnetization of screen printed paste in strong magnetic field (~7 T)
- Recording hysteresis loop with SQUID
- Remanence of 0.35 T comparable to class Y35 ferrite magnets →







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Waferbonding to micro coil wafer

- Technology routine of coil wafer:

1) 4" Si wafer 500µmT

2) Si etching and oxidation

3) Ti/Cu seed deposition

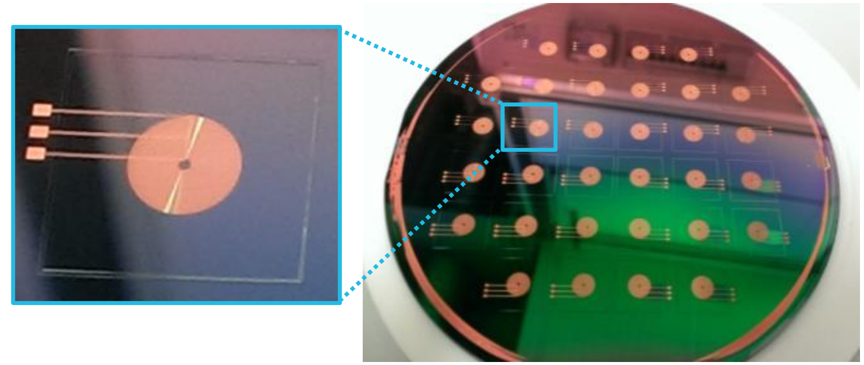
4) Pattern plating Cu and seed layer etching

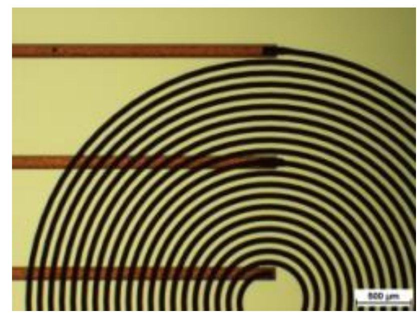
5) PE-CVD SiO_2

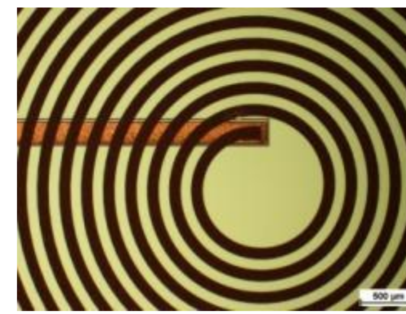
6) SiO2 etching

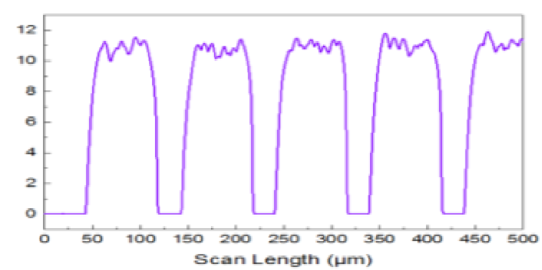
7) Ti/Cu seed deposition

8) Pattern plating Cu and seed layer etching









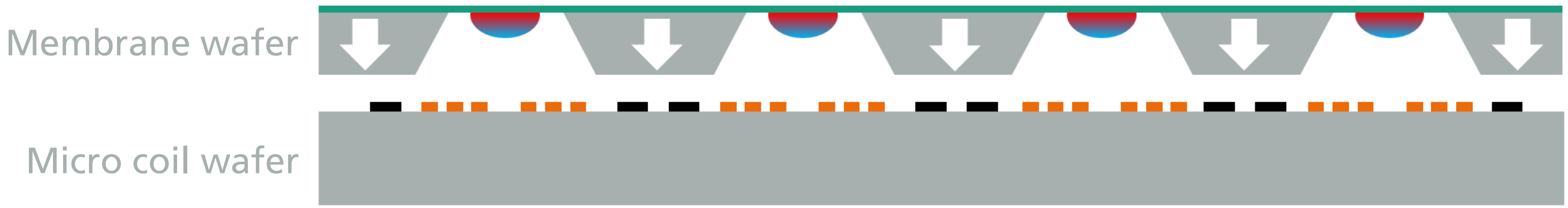
Line/space: ~50/50 µm

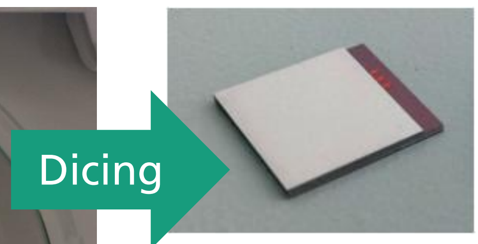
Thickness: ~10 µm

Turns: 10, 20

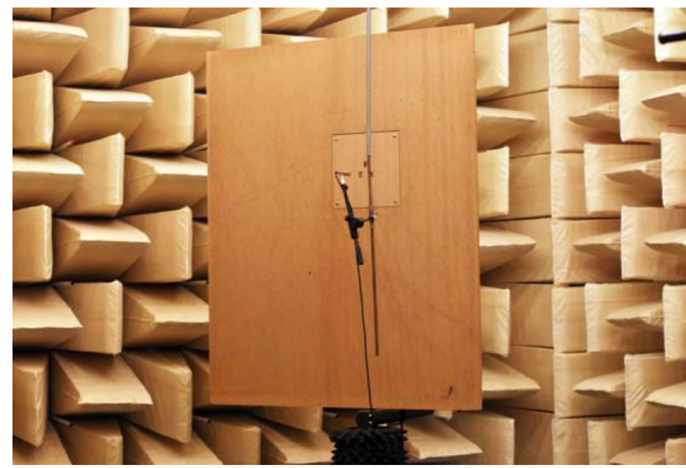
Waferbonding to micro coil wafer

- Assembly of membrane wafer (with dispensed magnets) and micro coil wafer by SU8 waferbonding at 150°C





12 x 12 x 0.8 mm



- Acoustic characterization: SPL 50 dB at 10 cm, 15 kHz

Summary and outlook

- More MEMS apps are expected in mobile devices during the next years

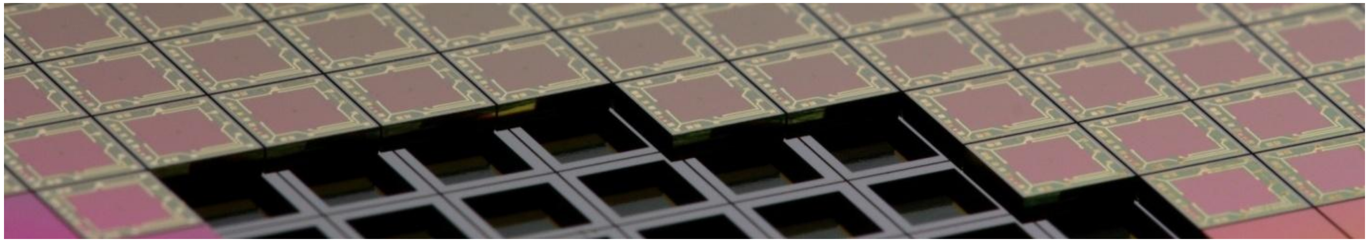
- New technologies available at Fraunhofer ENAS:
  - Sputter deposition of thin-film metallic glasses
  - MEMS-compatible integration of magnetic material by screen printing and dispensing

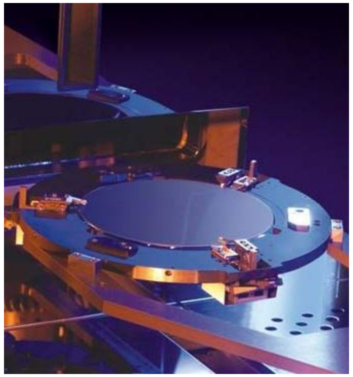
- Metallic glass is promising wherever large elastic deformations are needed in MEMS (especially in case of many cycles)

- Integrated magnetic material can be used to fabricate MEMS-based electrodynamic actuators/sensors

- Outlook: redesign of MEMS loudspeaker, replace Poly-Si membrane in MEMS microphones with metallic glass, ... → project partners are highly welcome

Thank you for your kind attention!





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