Fraunhofer ISIT

Fraunhofer-Institut für
Siliziumtechnologie ISIT

Florian Ziegler, 14.09.2023, microtec nord 2023

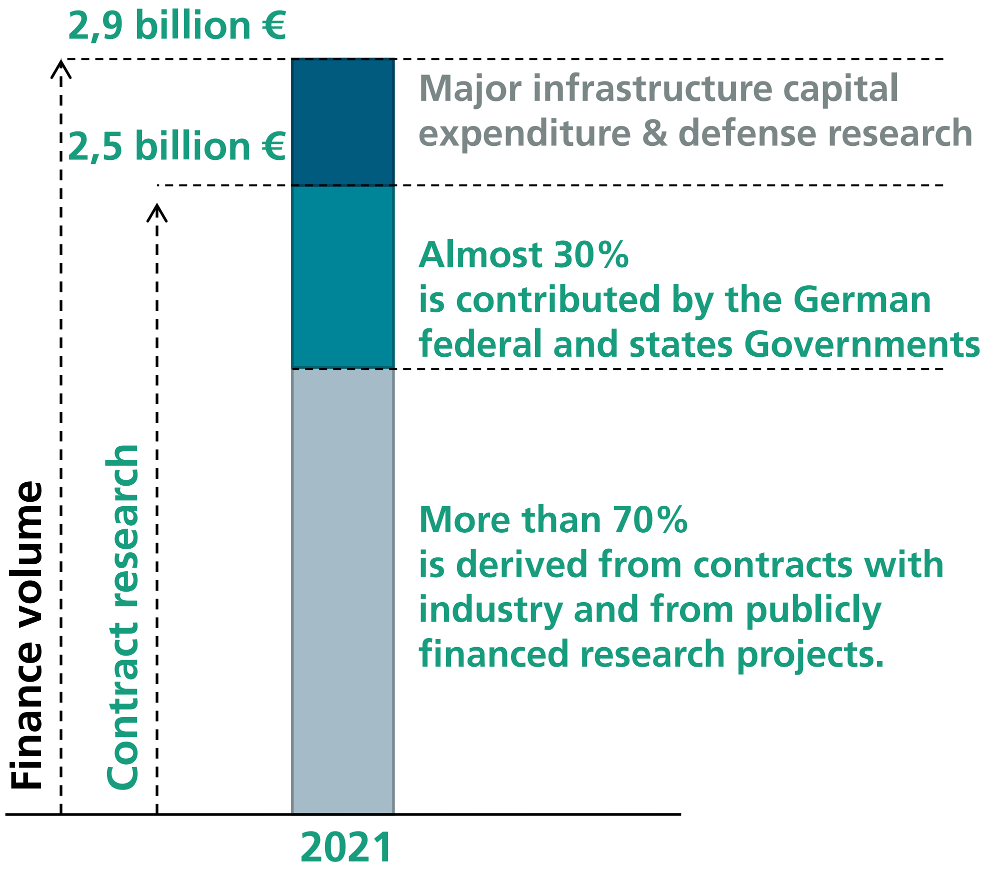
PowderMEMS - Technology for innovative MEMS

The Fraunhofer-Gesellschaft

Application-oriented research for the benefit of business and for the benefit of society

30 000
employees

76 institutes and research centers



  Public information

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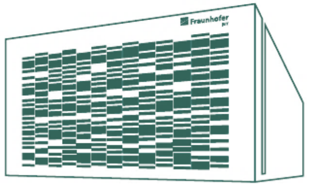
Fraunhofer ISIT - the Institute for Silicon Technology

Research and development center for power electronics and MEMS



In Itzehoe since 1996

Competence Center MEMS in Kiel (CAU)

Cooperation with Heide (FHW)

Prof. Dr. Holger Kapels
Acting Managing Director

Prof. Dr. Marco Liserre
Dep. Managing Director

160 employees
(+ 40 students)

Initial Investment:
125 million €

- 250 million € Industry
- 42 million € Cleanroom II
- 20 million € FMD*

Budget
27 million €

Certified according to
ISO 9001:2015

Location Partner

X-FAB MEMS FOUNDRY EXPERTS
VISHAY The DNA of tech.
IZET Innovationszentrum Itzehoe
CONDIAS CONDUCTIVE DIAMOND PRODUCTS

Spin-offs

CUSTOMCELLS® Ahead in cell innovation
CAMPTON Diagnostics
OQMENTED

FMD – Forschungsfabrik Mikroelektronik Deutschland

The heart of the institute: Our clean rooms and labs

Professional semiconductor production line for development and production for 200 mm wafers on 2500 m² clean room area

Professional MEMS production line for development and production for 200 mm wafers on 1000 m² clean room area

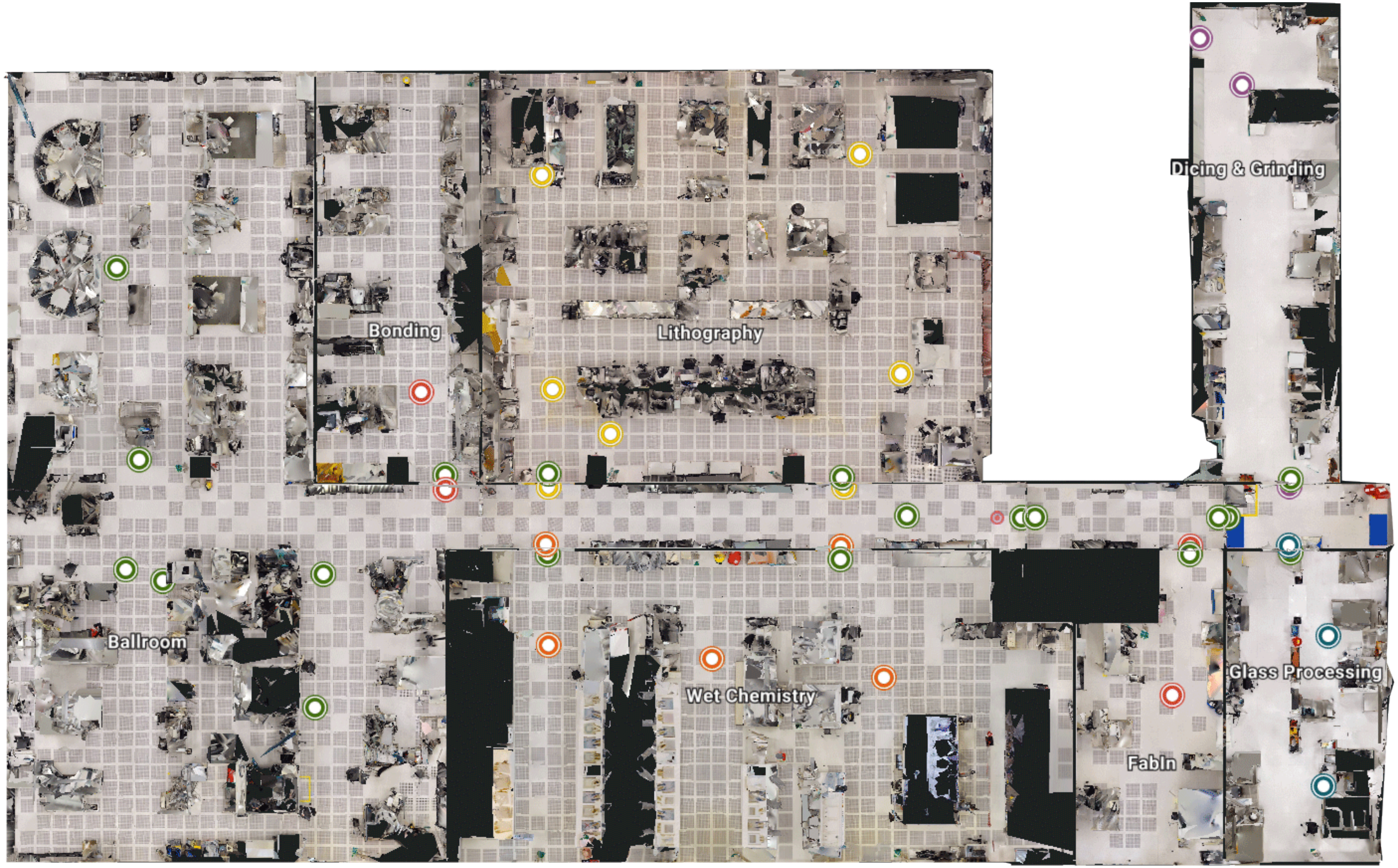
Chemical mechanical polishing (CMP), grinding and sawing on 300 m² clean room area

Various development and measurement laboratories on 900 m²

Development and pilot production line for lithium polymer accumulators

Our fab

s.fhg.de/isit360



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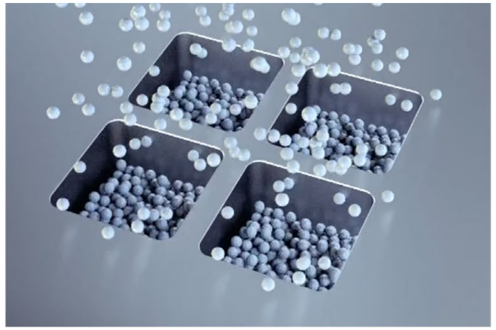
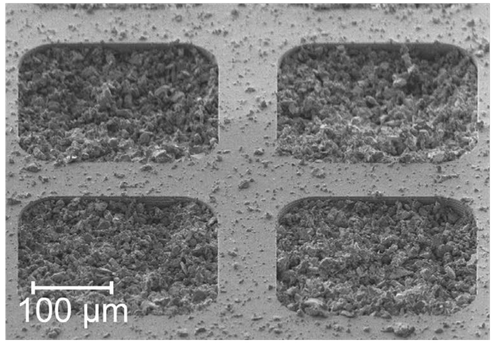
PowderMEMS

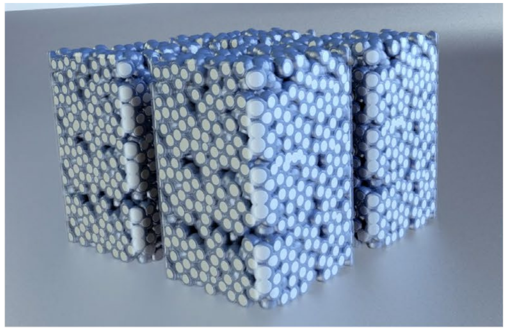
Wafer-level fabrication process for 3D functional microstructures

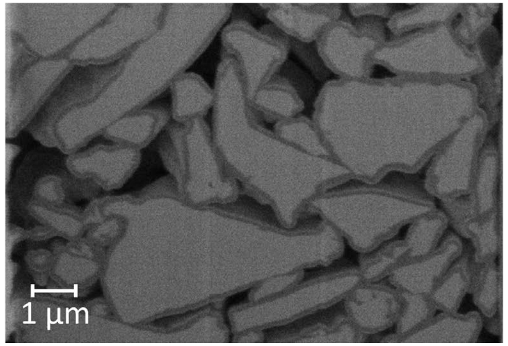
1. Dry filling of microcavities



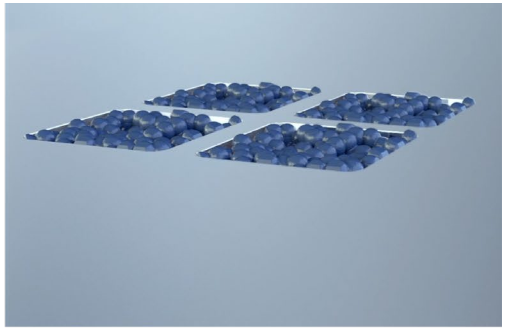


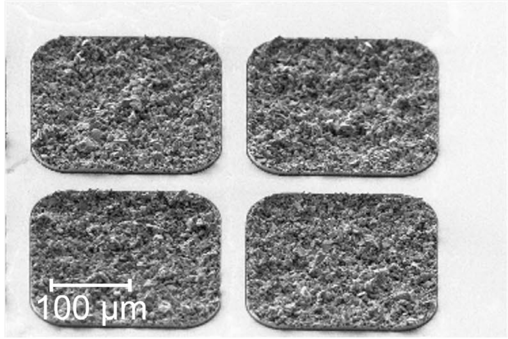
2. Solidification by atomic layer deposition





3. Substrate conditioning for post-processing



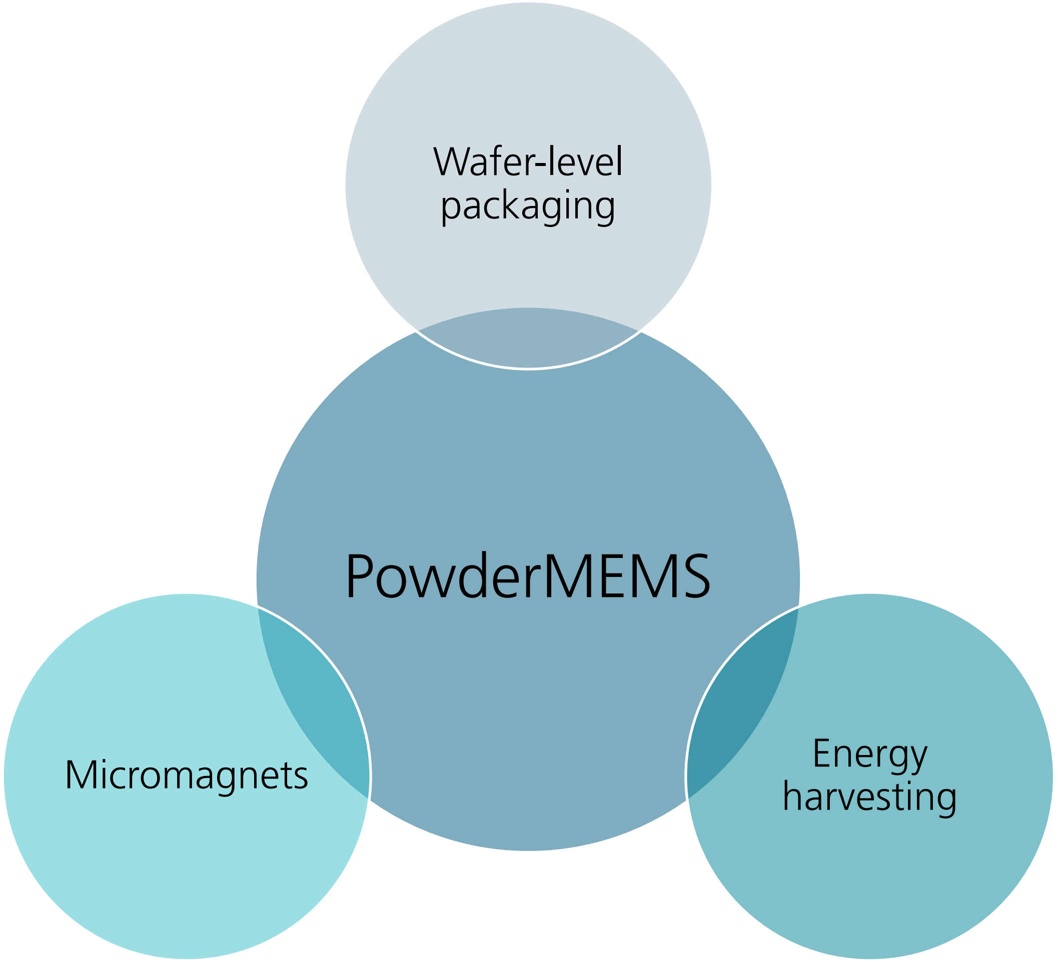


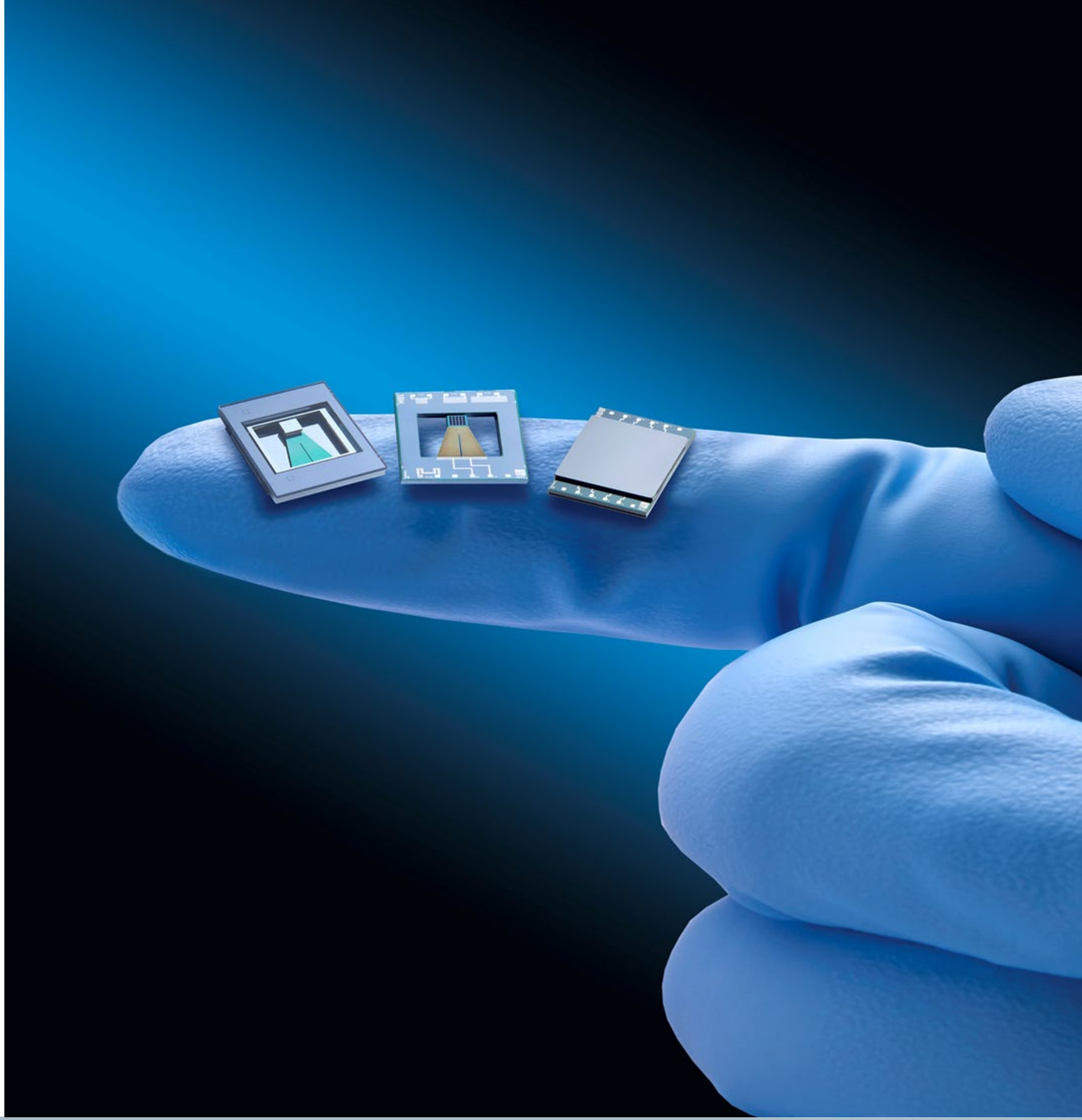
Unique set of properties:

- Production of miniaturized magnets possible:
  - Lateral dimensions: approx. 30 to 4000 µm
  - Depth approx. 30 to 1000 µm
- Precise wafer level integration
- Wide choice of powder material
- Low process temperature (75 to 300 °C)
- No organics or sintering involved
- BEOL compatible
- Integration before / after / within standard manufacturing flow possible

More details on the PowderMEMS manufacturing process:
https://doi.org/10.3390/mi13030398

PowderMEMS
Current areas of application





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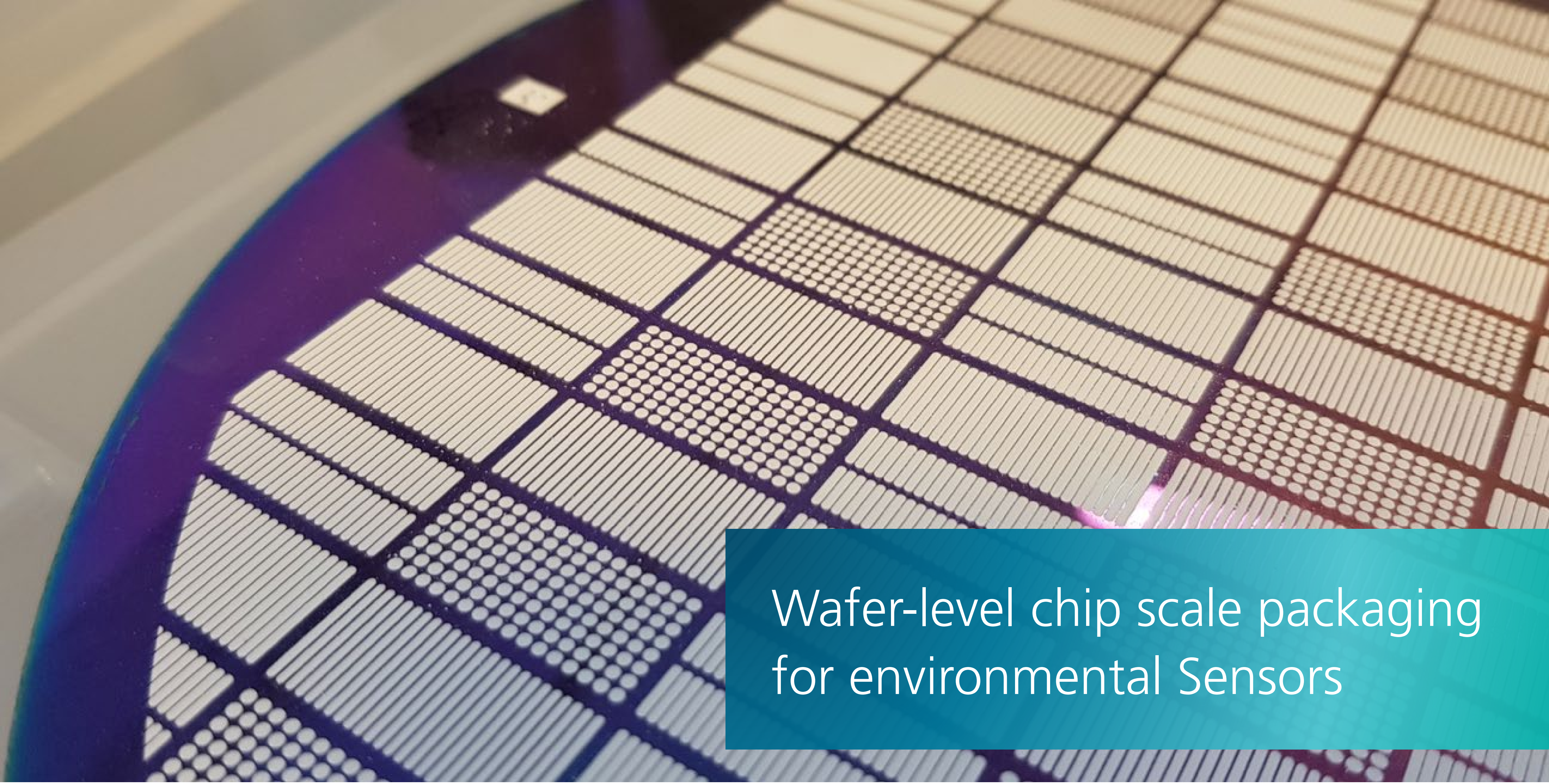
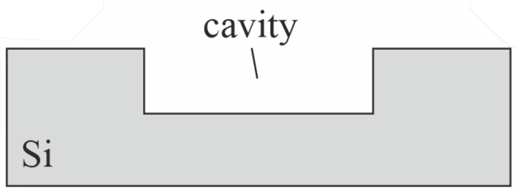


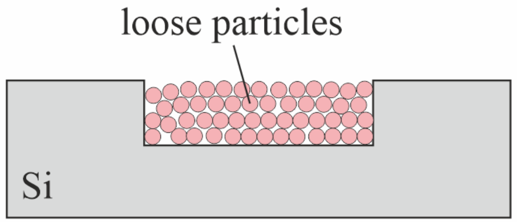
Wafer-level chip scale packaging for environmental Sensors

Wafer level packaging of porous caps for environmental Sensors

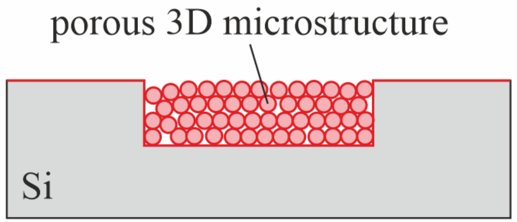
Processing with only two mask layers



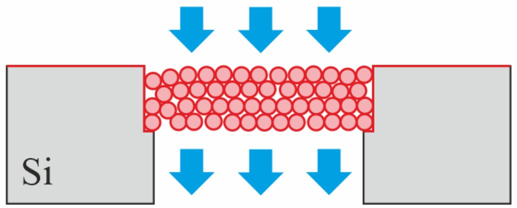
1 1st lithography and etching of cavities using DRIE.



2 Insertion of dry, µm-sized particles.

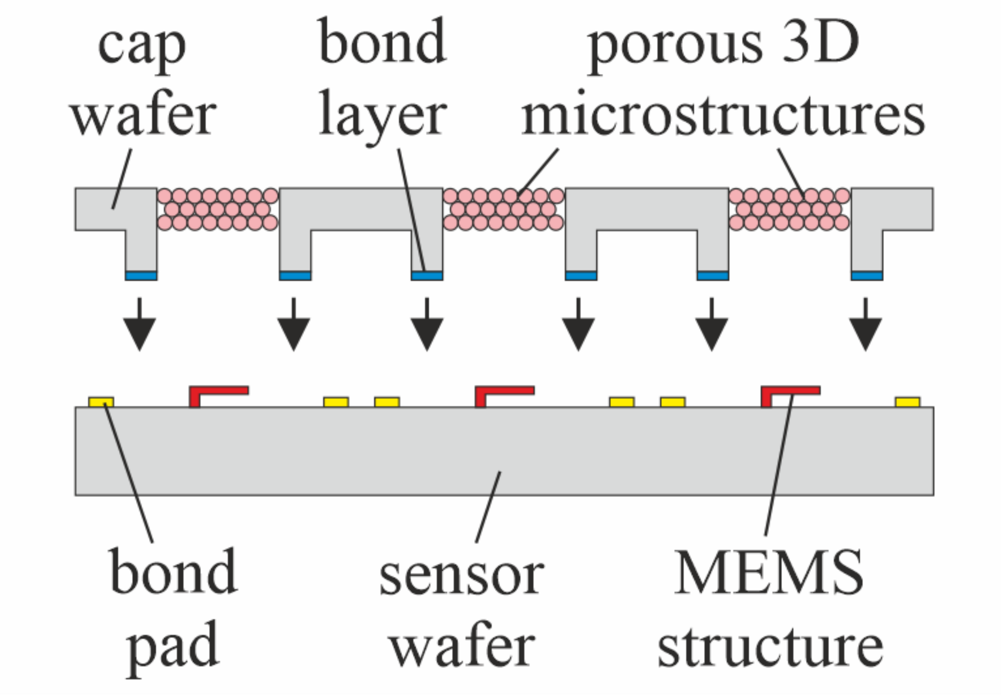


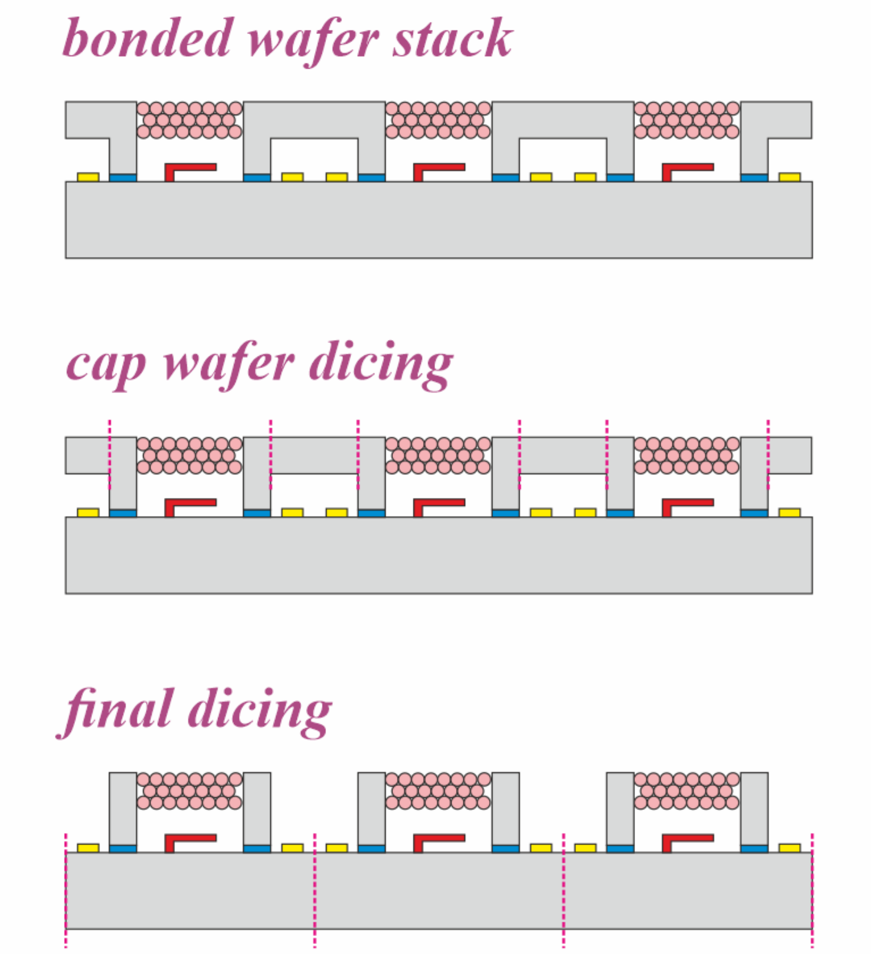
3 In-situ agglomeration of the loose particles by ALD.



4 2nd lithography on the backside and etching of the silicon by DRIE.

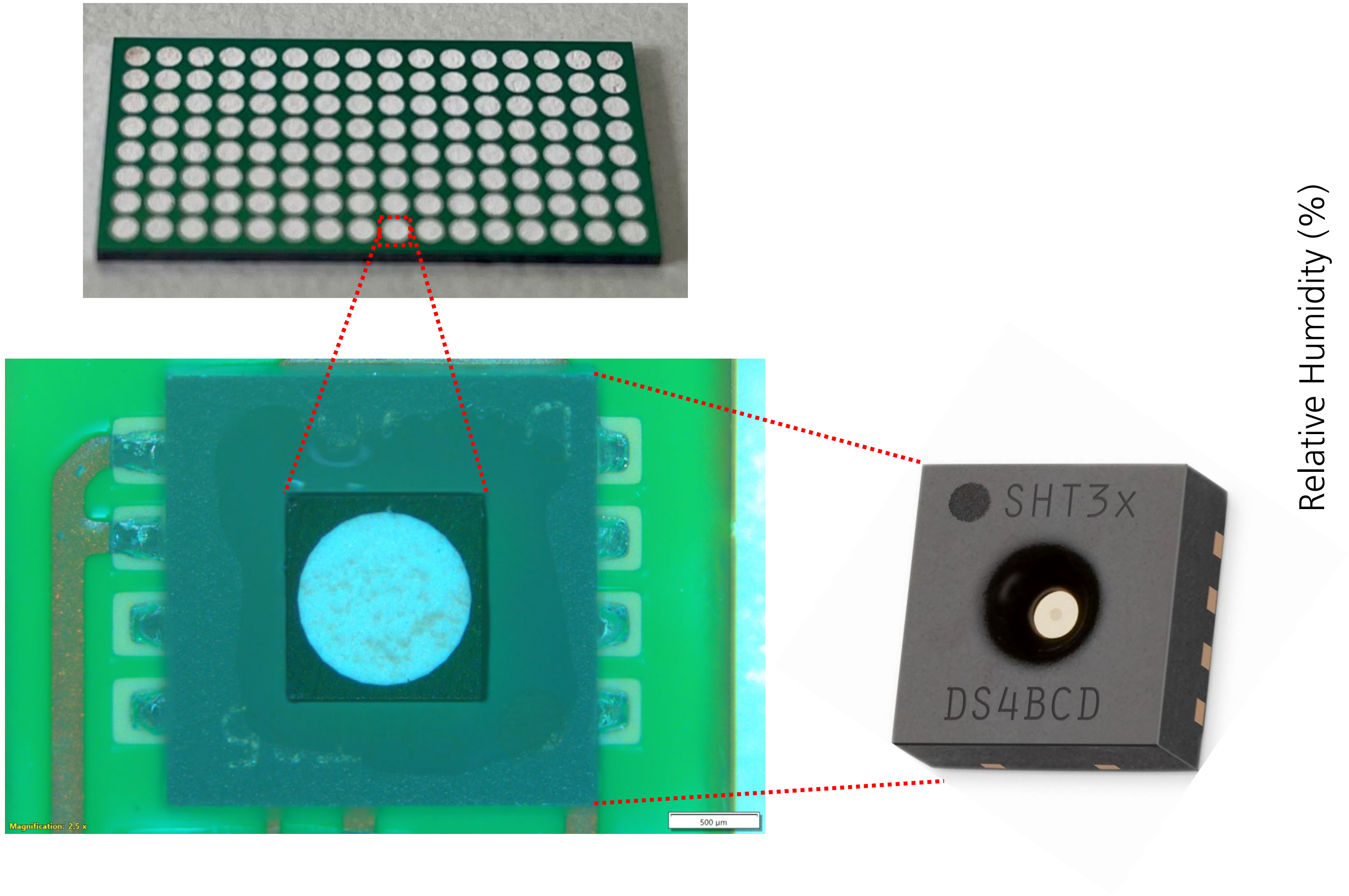
PowderMEMS WLCSP - connections on frontside or via TSV possible

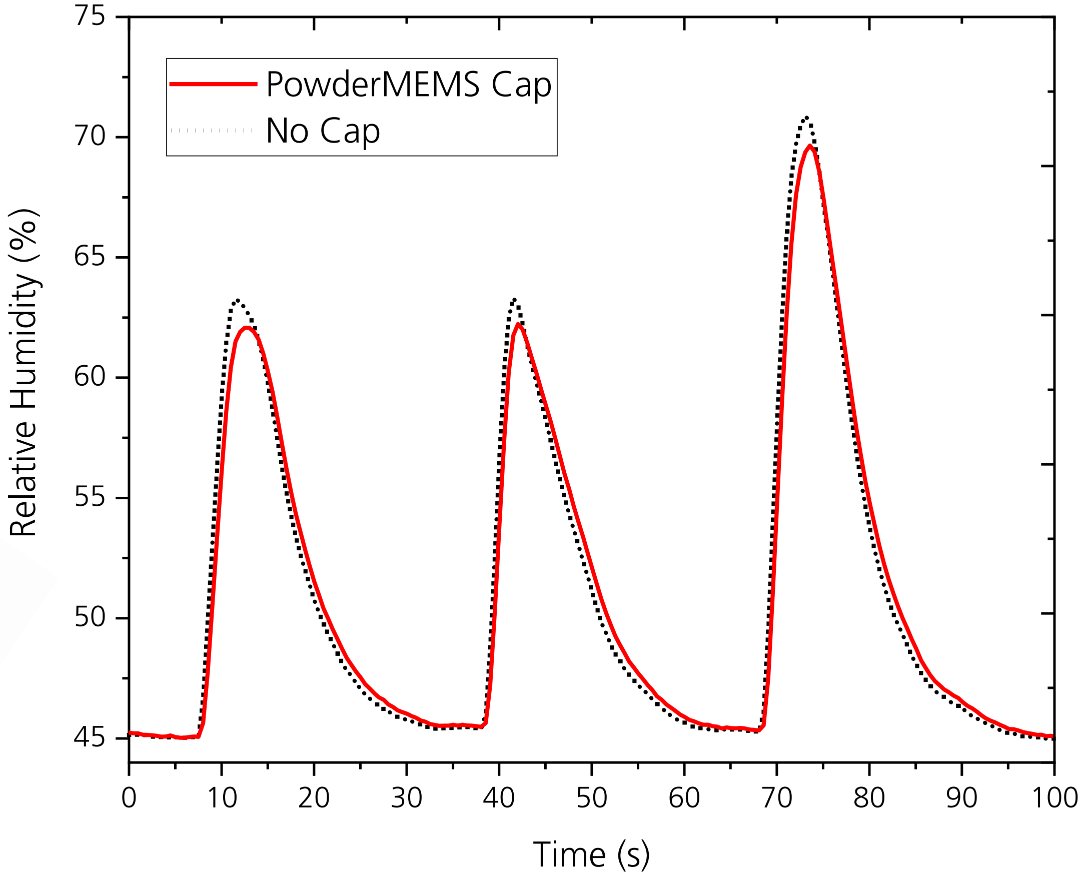




PowderMEMS cap does not reduce sensitivity

Demonstrator: humidity sensor SHT35 with PowderMEMS cap





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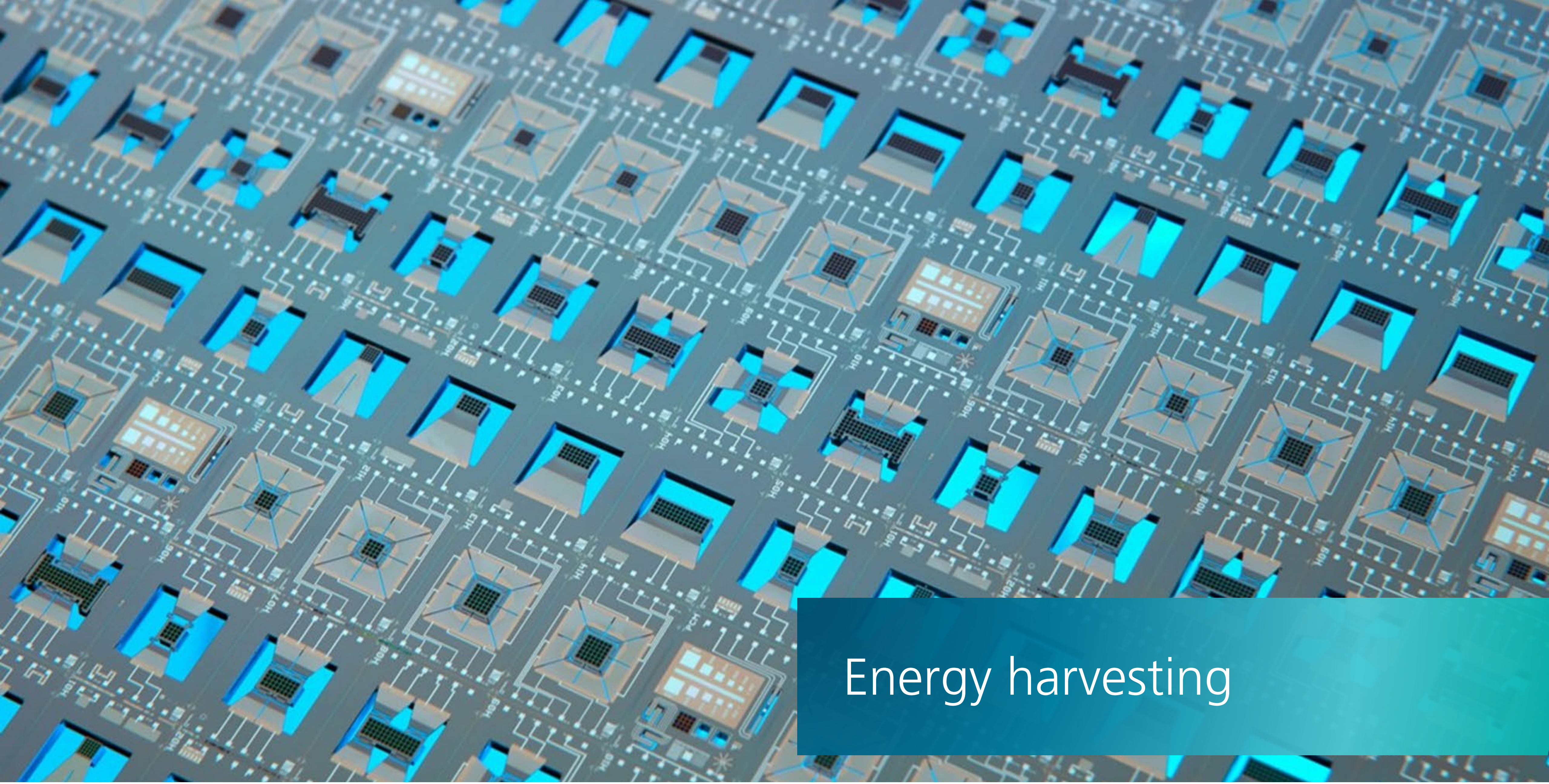
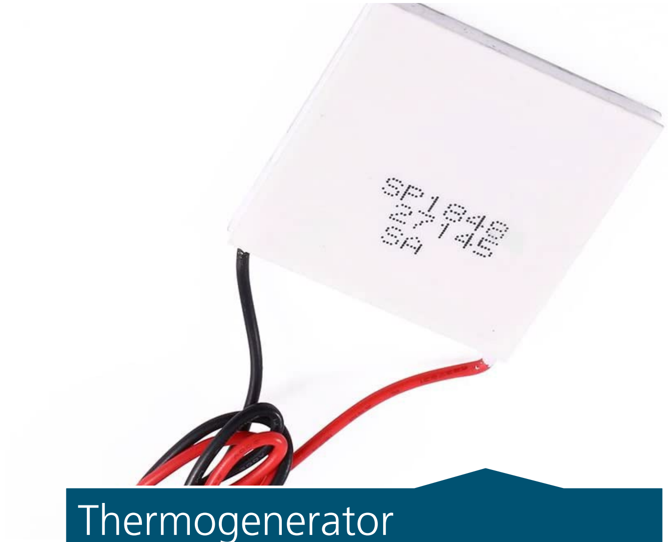


Energy harvesting

Energy Harvesting

A road to battery-free IoT devices

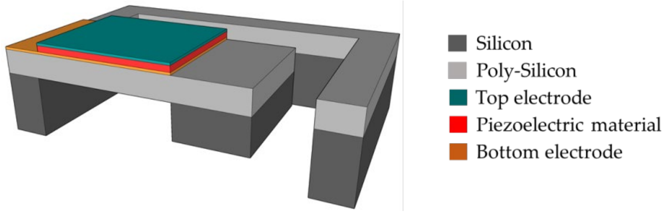


Thermogenerator

- Energy harvesting from thermal gradients.

Solar cells

- Energy harvesting light



Piezoelectric energy harvesting

- Harvests energy from vibration/shocks

Sweet spot:

- Non of the other sources available
- Hard to reach / costly to replace battery
- Size / costs matters

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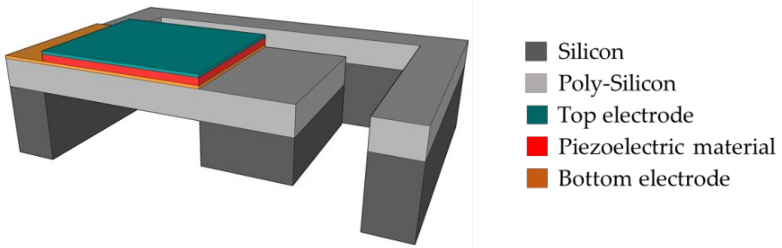
Energy Harvesting

What differentiates us?

General Challenges for vibrational MEMS Energy Harvester

- „High“ resonant frequency
- Resonant frequency fixed by design
- High quality factor – low power output out-off resonance



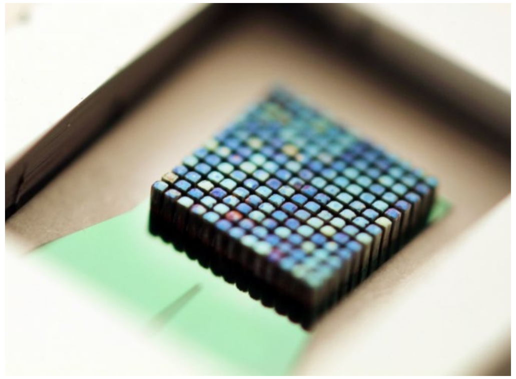
USP Fraunhofer ISIT magneto-mechanical MEMS Energy Harvester

- Integration of magnets: high magnetic coupling forces
- Integration of high-density materials, e.g. tungsten: increased mass compared to conventional Si

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

- Integration of AlScN:

$$FOM|\hat{E}_{max,out} \approx d_{31}g_{31} = \frac{d_{31}^2}{\varepsilon\varepsilon_r}$$



	AlN	AlScN
d_{31} (pm/V)	1,97	5,45
ε_r	10,5	16,9
FOM (10^{-12} m^3/J)	0,042	0,2

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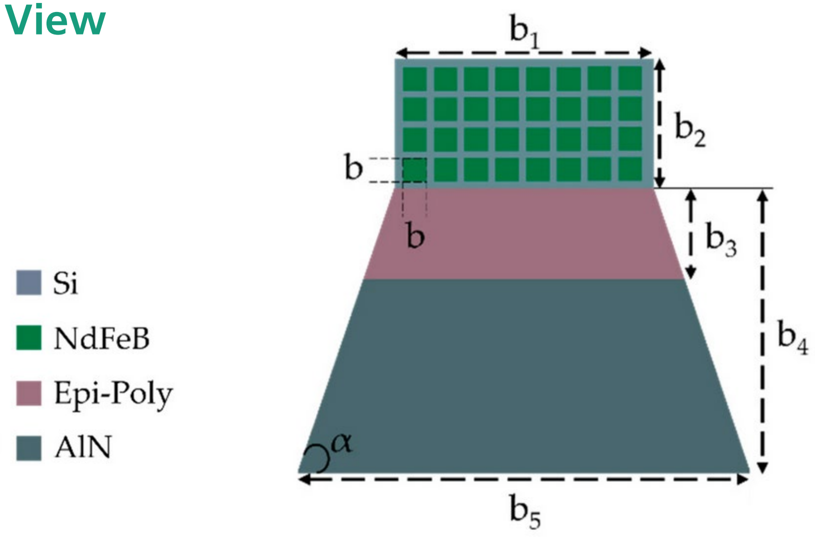
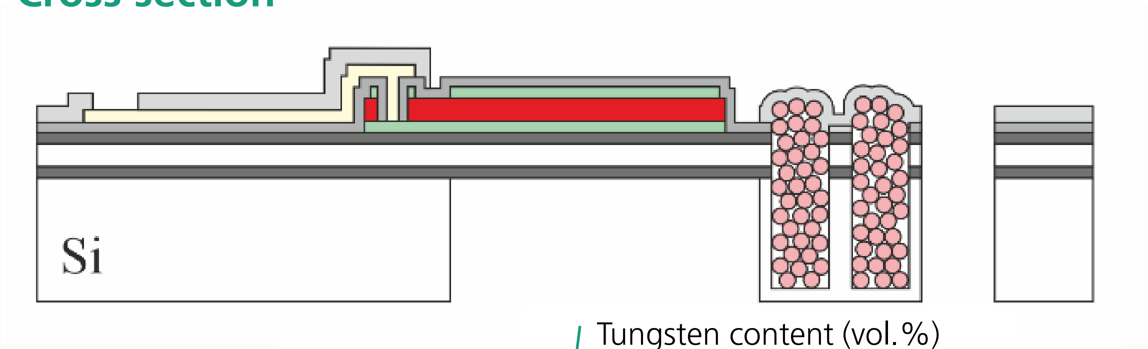
Versatile PowderMEMS energy harvesting platform

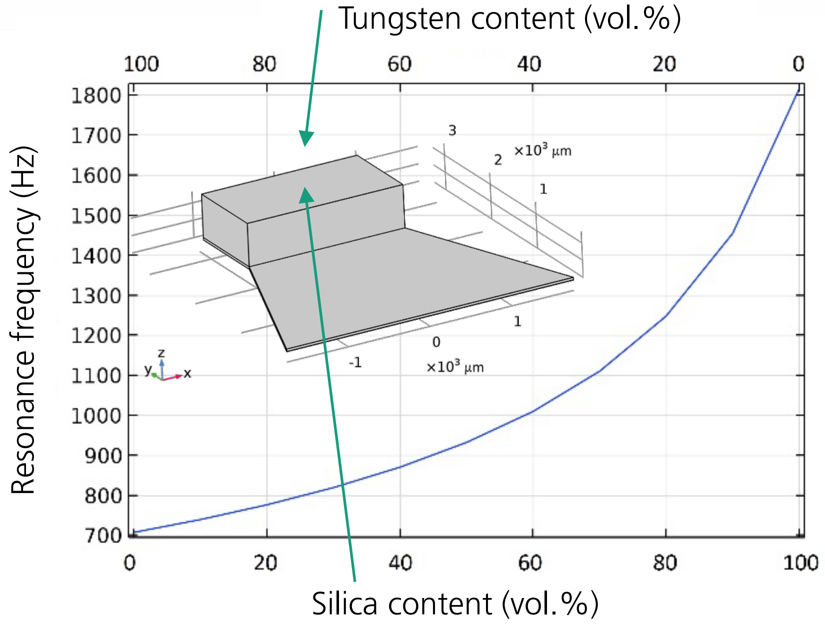
Tuning of mechanical properties in the same design

Top View



Cross section





Density (g/cm³)*	**2.33**	**3**	**8**
Powder material	Pure silicon	NdFeB	Tungsten
Resonance frequency (kHz)	1.41	1.24	0.77

* *For the seismic mass, powder filling factor 42%*

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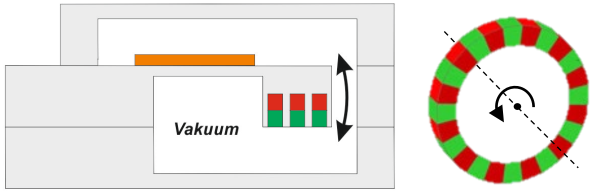
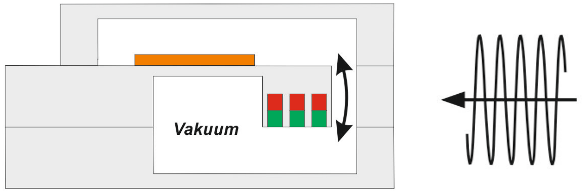
Harvester with integrated NdFeB micromagnet array

One MEMS device - Several applications

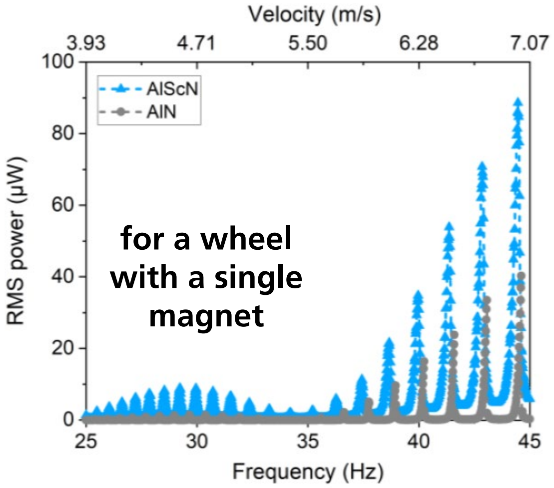
- Energy harvesting from rotating magnets at excitation frequencies far away from resonance.

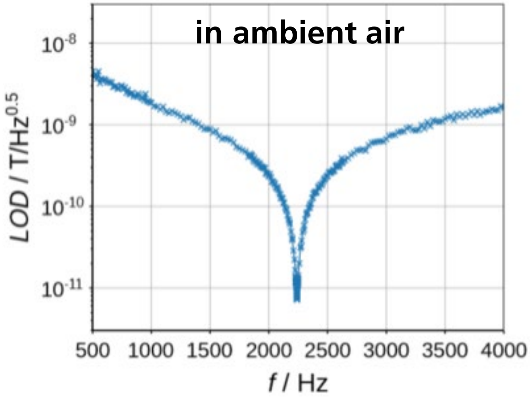


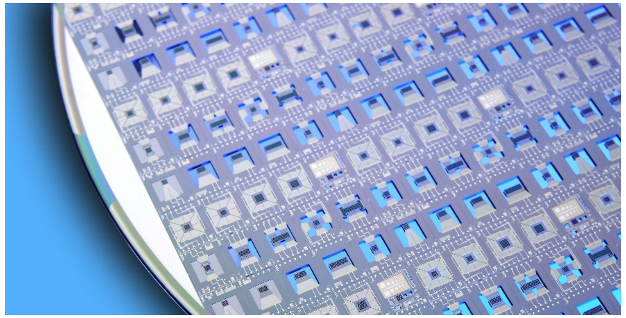
- Current sensing in resonance with exceptionally high sensitivity of 43,4 kV/T.

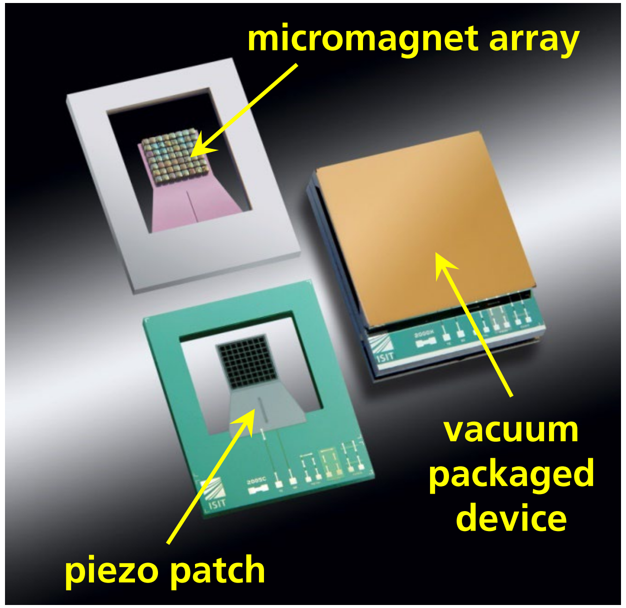


- Zero-power wake-up using one of the excitation schemes shown above.

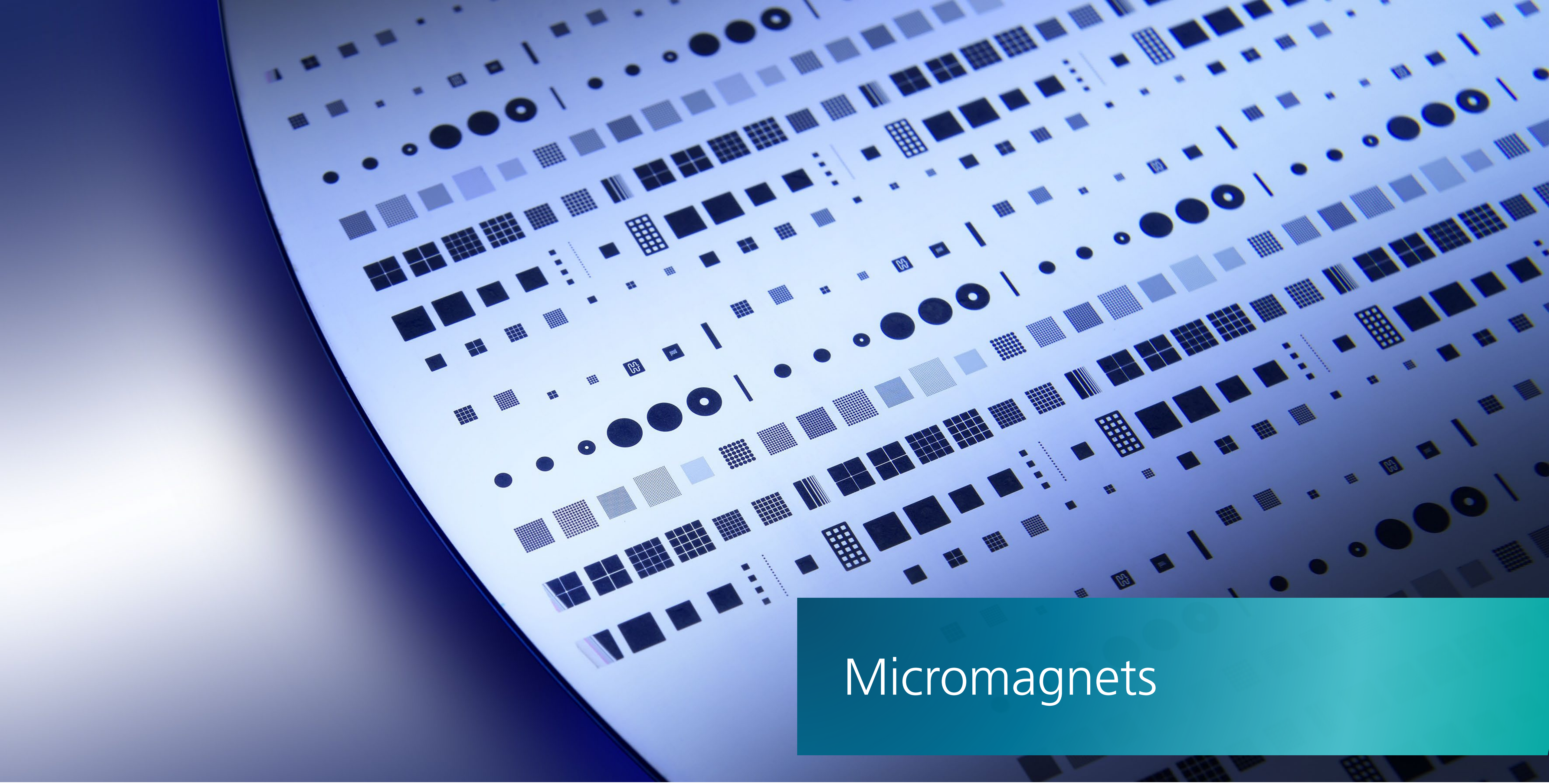








https://doi.org/10.3390/mi13060863
https://doi.org/10.1016/j.sna.2019.111560
https://doi.org/10.3390/mi13030407
https://doi.org/10.1109/ICM54990.2023.10101917

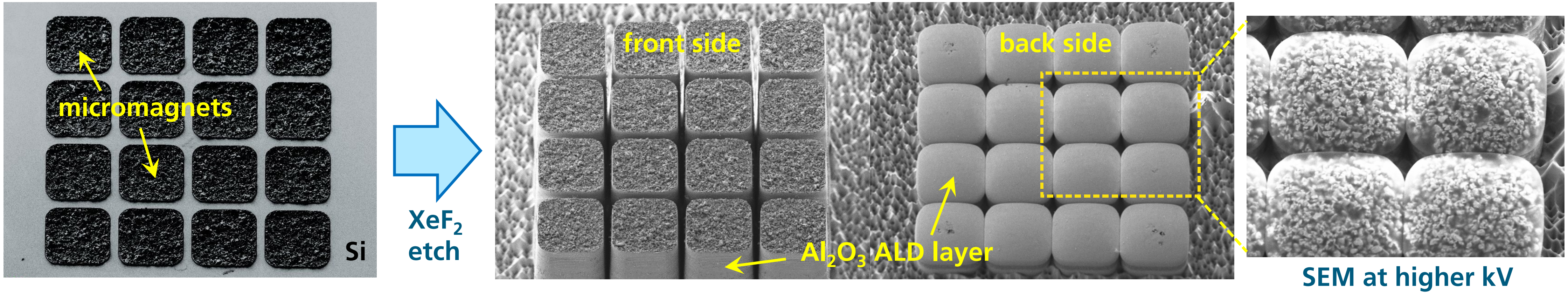


Micromagnets

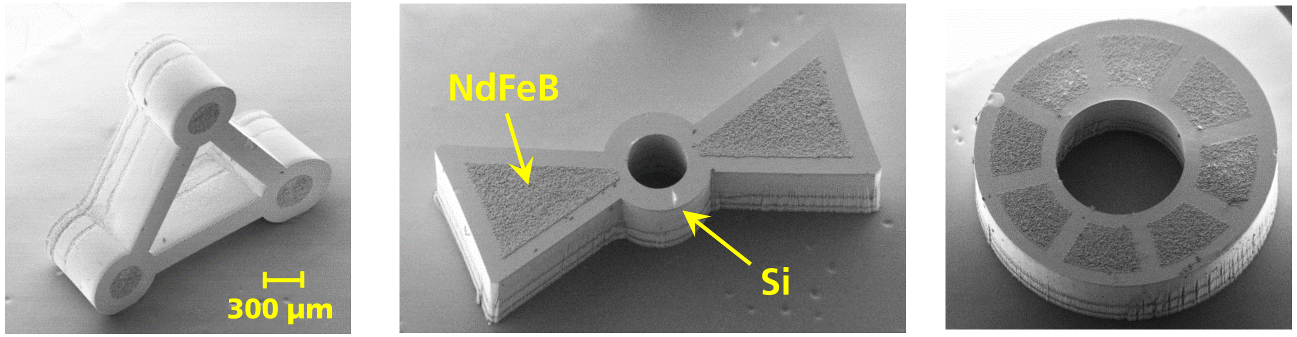
PowderMEMS enables integration of 3D hard and soft micromagnets

Custom shape, different materials and arrangements on wafer level

Morphology



Example: NdFeB magnets in silicon frame

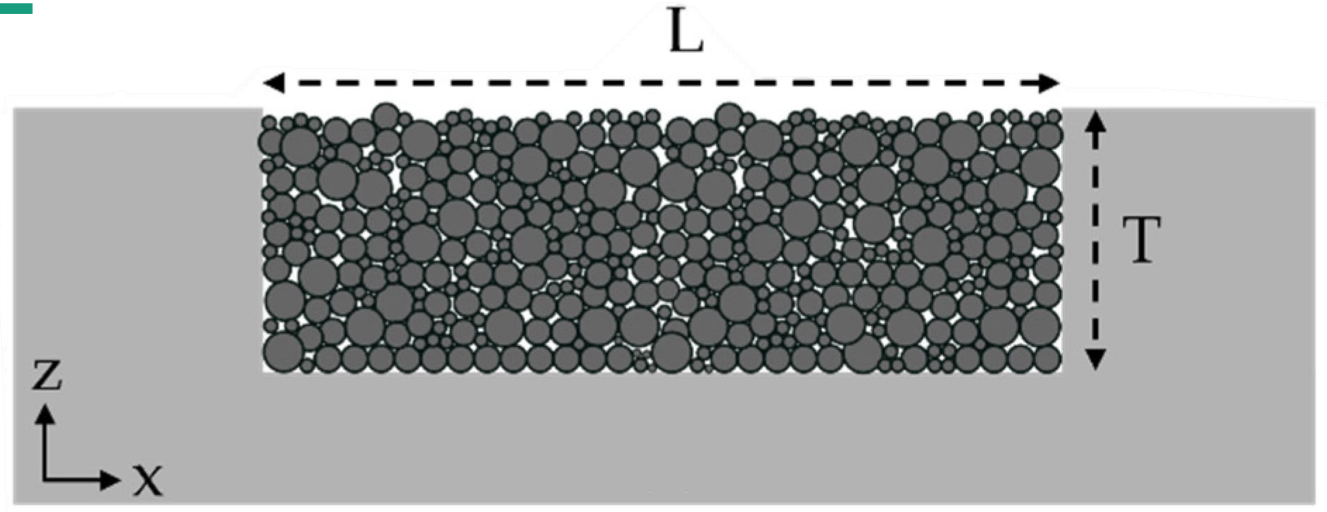


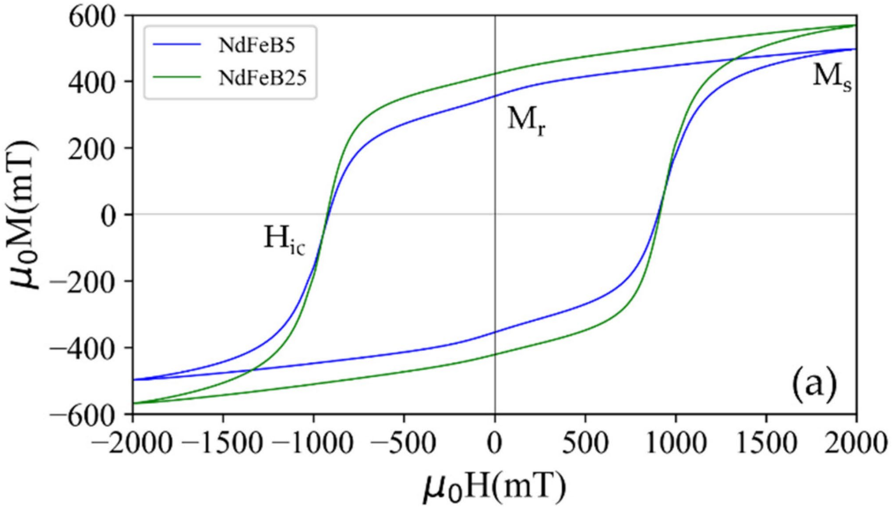
- Custom geometries and arrangements.
- Mechanically stable and easy to handle.
- Various materials, e. g. NdFeB, SmCo, Ferrite, Fe, etc.
- Particles are protected by ALD layer.
- Various substrates suitable, e. g. Si, glass, etc.

https://doi.org/10.1109/TRANSDUCERS.2019.8808804

Magnetic properties of hard magnetic PowderMEMS micromagnets

Example: two NdFeB powders with mean particle size $d_{50} = 5$ µm and $d_{50} = 25$ µm





Hysteresis loop in x-direction

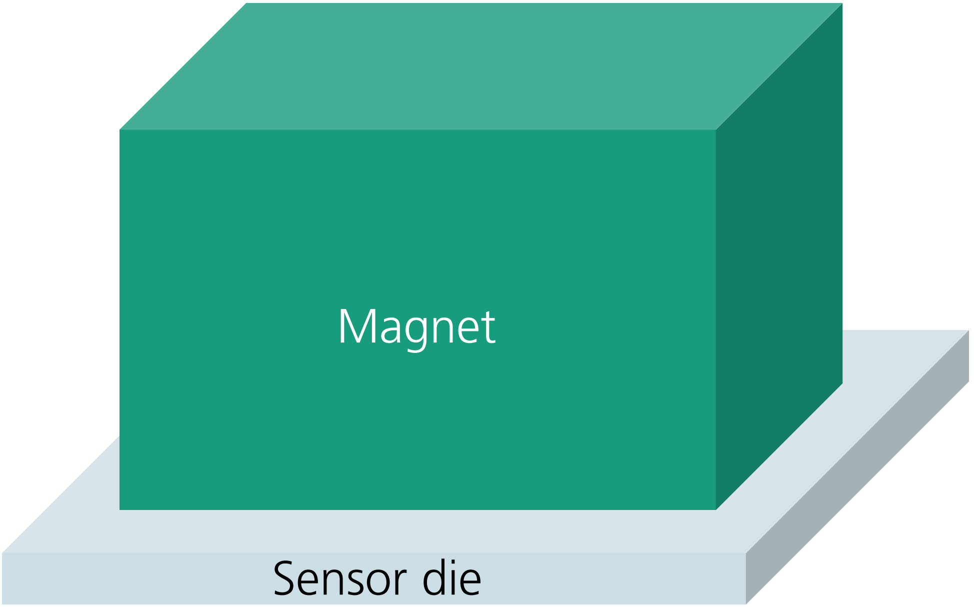
	$\mu_0 M_r$ (mT)		$\mu_0 H_{ic}$ (mT)		$\mu_0 M_s$ (mT)	
Direction	x	z	x	z	x	z
NdFeB5 (d_{50} = 5 µm)	355	309	915	910	497	464
NdFeB25 (d_{50} = 25 µm)	423	372	924	915	568	528

- More information on durability in open access publication https://doi.org/10.3390/mi13050742

PowderMEMS micromagnets - application in Hall and xMR sensors

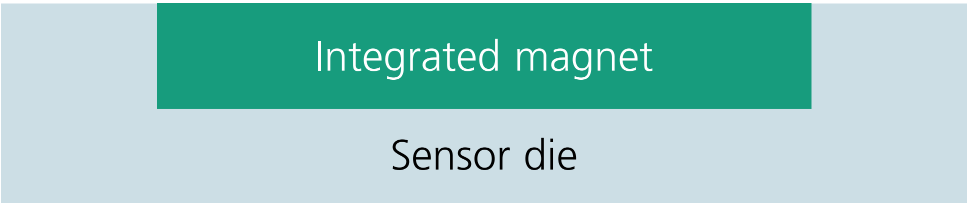
High miniaturization and cost-effective wafer-level integration

Conventional back-biased setup



- Discrete mounting of the magnet
- Relatively large magnet
- Magnet must be placed precisely according to its magnetization

Integrated PowderMEMS magnet for back or in-plane bias

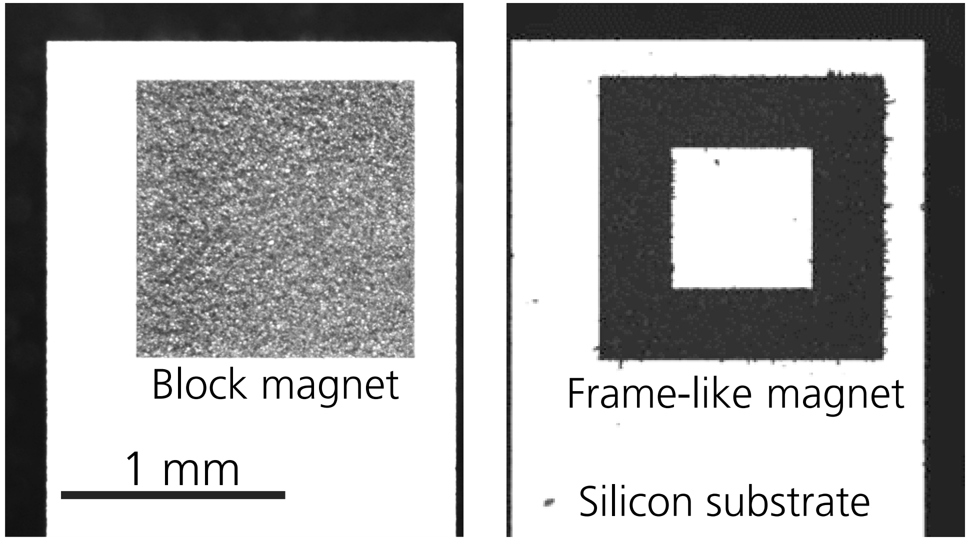


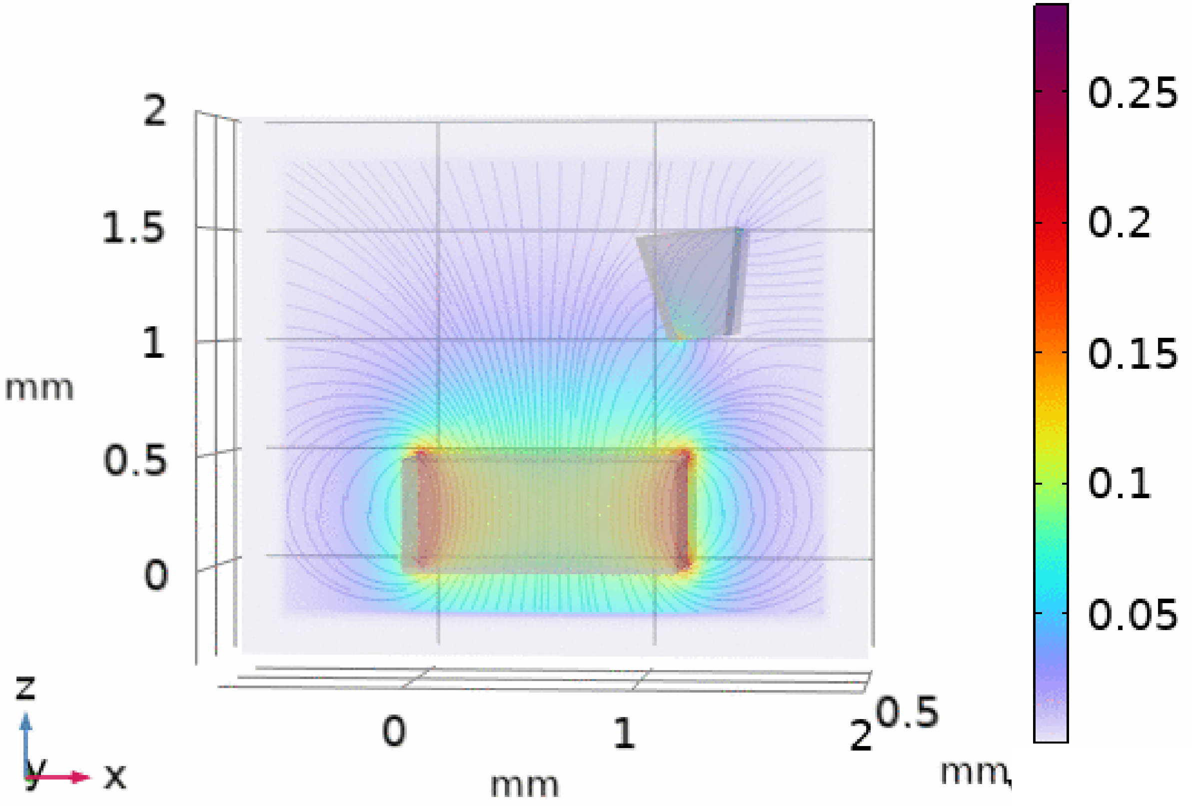
- Modification of existing Hall or xMR sensor designs
- Backside-integration saves wafer device area
- Wafer-level low-temperature process (75 °C to 300 °C)
- Flexible field shaping by custom magnet design
- Reduction of package size

Demonstrator: Integrated PowderMEMS micromagnets for magnetic sensors

Back biased 3D Hall sensor as proof of concept

- Rotation detection of gear wheel demonstrated with 3D Hall sensor and integrated PowderMEMS magnet
- PowderMEMS allows for magnetic field shaping
- Advantage of frame-like field shaping for back-bias:
  - Static field at sensor is close to zero
  - Higher sensitivity due to higher sensor gain





PowderMEMS NdFeB micromagnets integrated into the backside of a Hall sensor device wafer

 19.09.2023 Public information

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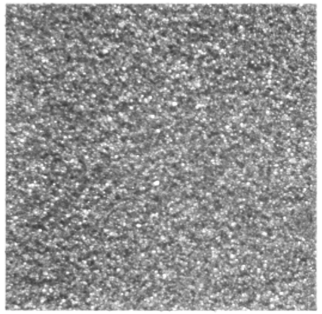
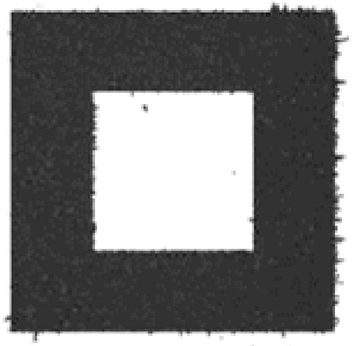
Demonstrator: Integrated PowderMEMS micromagnets for magnetic sensors

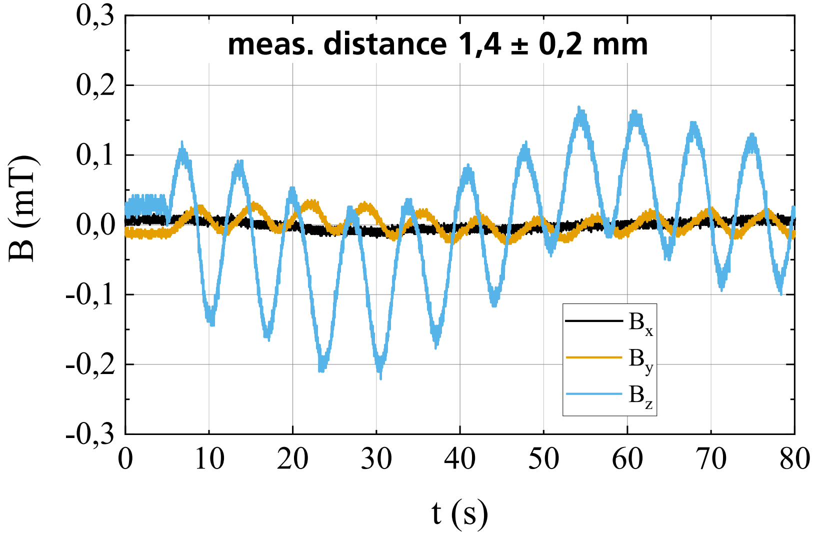
Back biased 3D Hall sensor as proof of concept

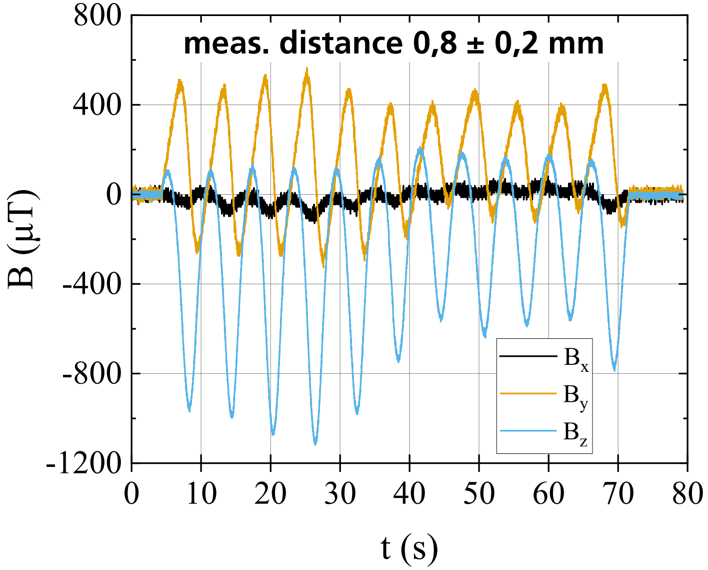


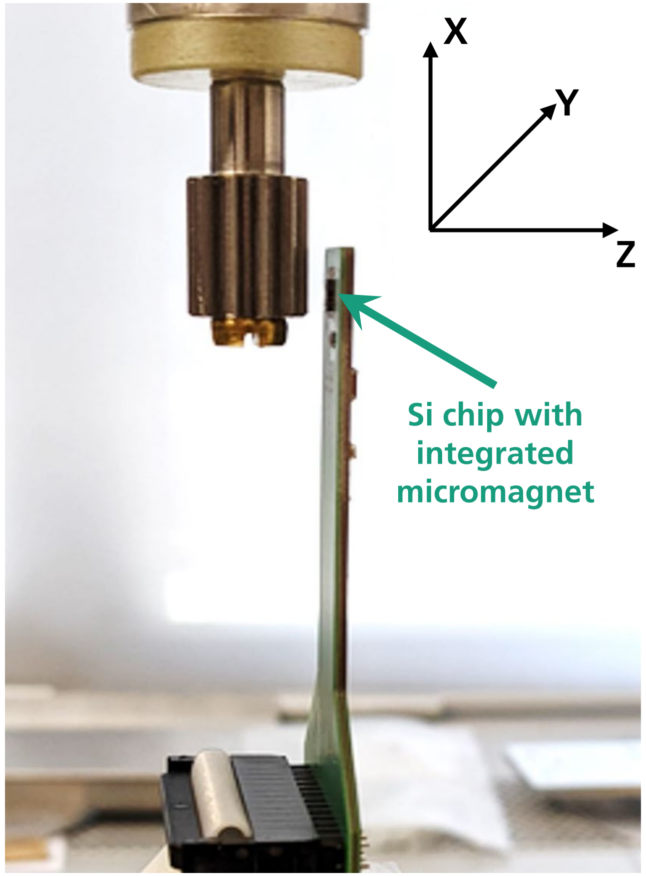
block magnet



frame-like magnet







https://doi.org/10.3390/mi13020235

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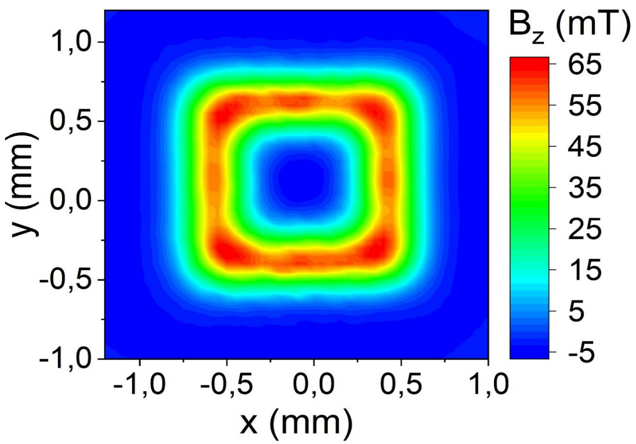
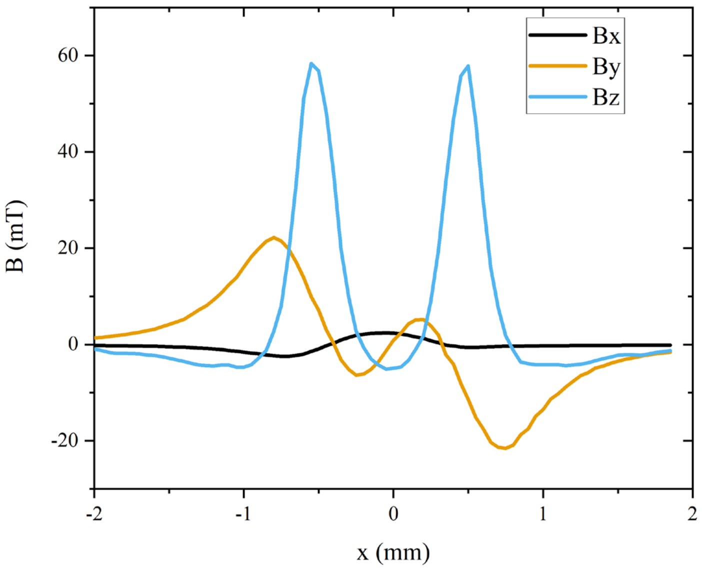
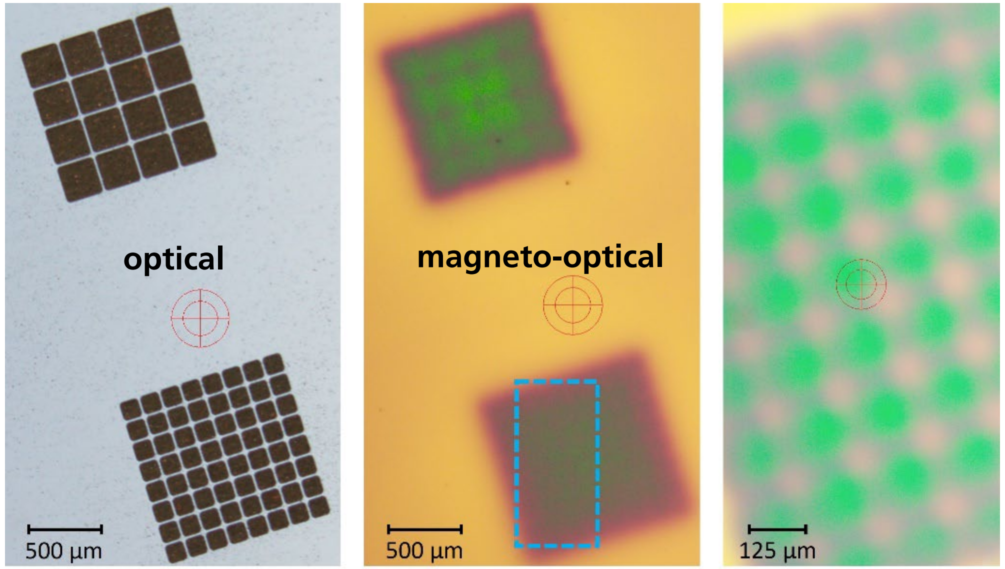
Wafer-level inspection tools available at Fraunhofer ISIT

Qualitive and Quantitative testing equipment

- Vibrating scanning magnetometer for B-H loop determination on chip level.
- Magneto-optical microscope for fast qualitative inspections and semi-quantitative determination of B_z on wafer-level.

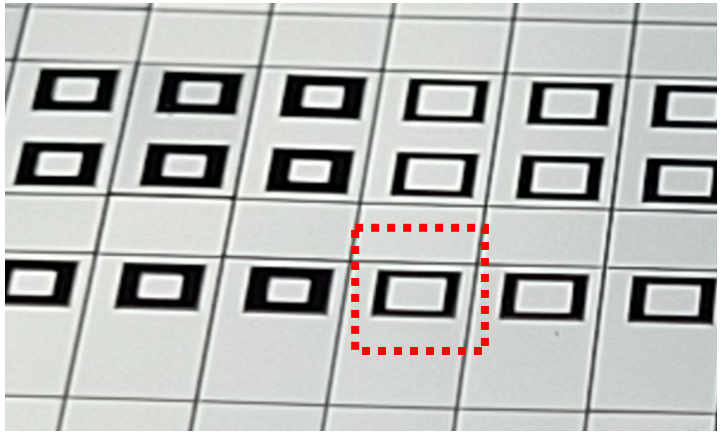






- Developed within Fraunhofer: Hall-sensor-based tool with automatic positioning for fast quantitative 3D measurements on wafer-level.

Line and 3D measurements of a frame-type magnet at a distance of 360 µm.



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Fraunhofer ISIT

Group Agglomerated Microsystems

Head of Group

Dr. Björn Gojdka

Technology

Dr. Thomas Lisec, Finn Klingbeil,
Mani Teja Bodduluri

Simulations

Dr. Niels Clausen

Non-Magnetic application

Dr. Ole Behrmann, Julia Cipo

Energy Harvester

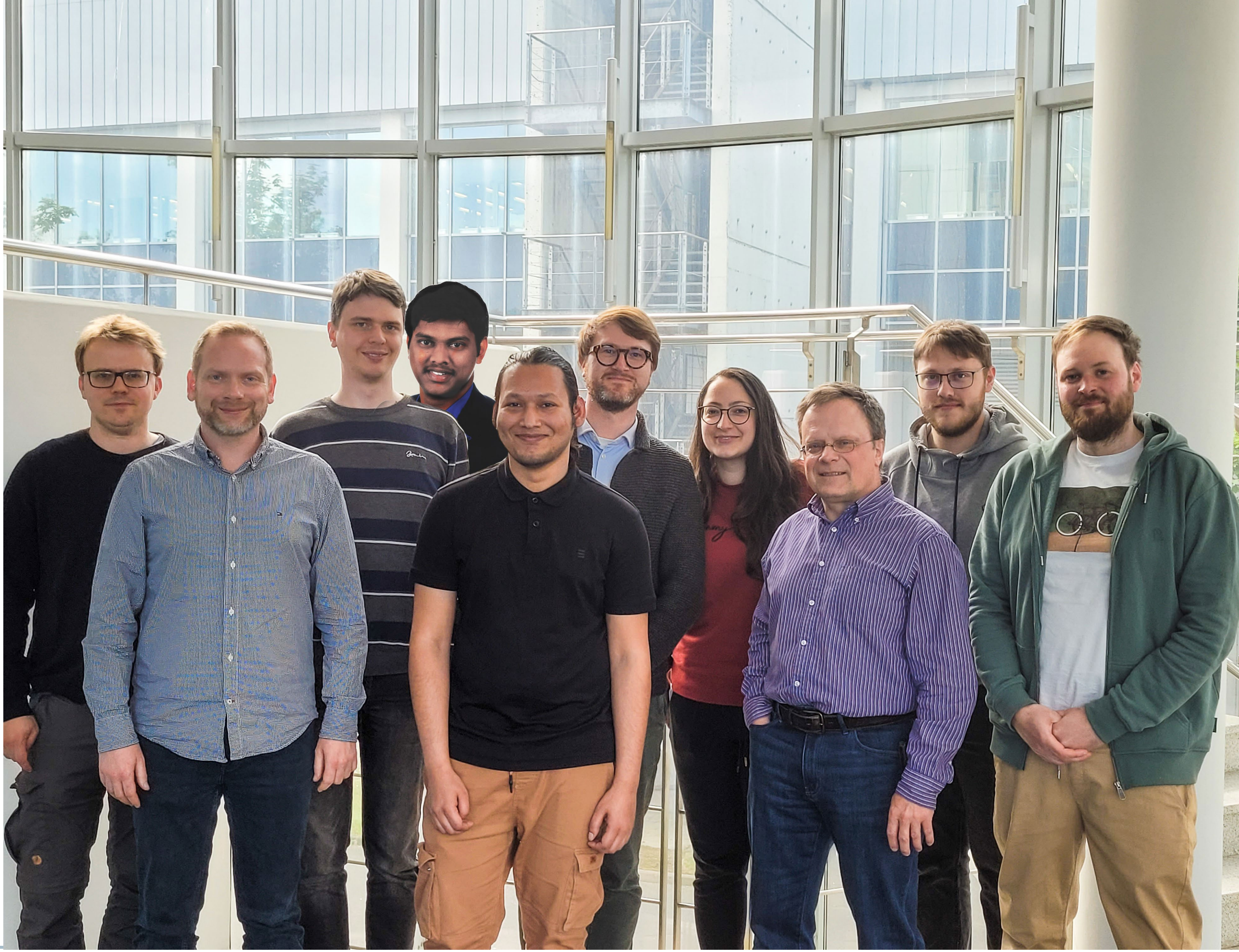
Dr. Torben Dankwort, Minhaz Ahmed

Integrated Micromagnets

Florian Ziegler

Students

Philipp Hickisch, Tina Höppner,
André Lange-Clary, Niklas Kyoushi



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Fraunhofer-Institut für Siliziumtechnologie ISIT

Thank you for your attention!

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