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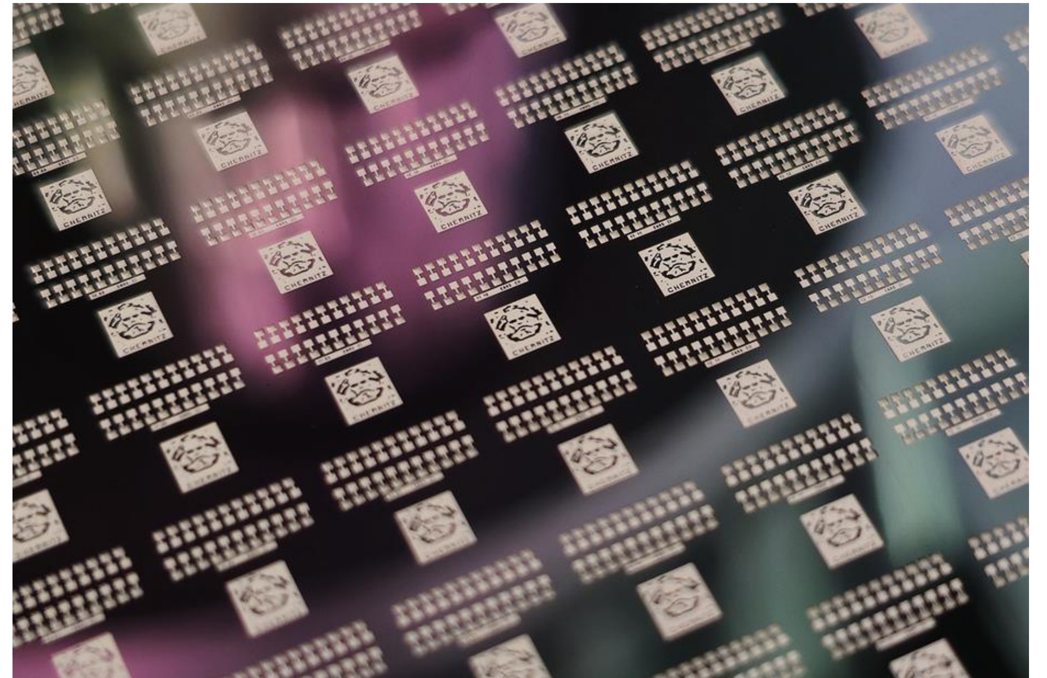
MEMS Characterization after Wafer Fabrication

Dr. Roman Forke

Motivation

Characterization of MEMS

- **Quality Control** - Ensure that chips on wafers meet specified parameters before they are diced
- **Process Optimization** - Provide feedback on the fabrication processes and help to identify means for improvement
- **Cost Efficiency** - Identify defective chips early in the production and reduce costs associated with assembly and packaging
- **Device Performance Analysis** - Evaluation of electrical and mechanical properties of devices for better understanding and to enable better design decisions
- **Parameter Testing** in laboratory environment
- Specify the **System Performance** to create data sheets for the devices



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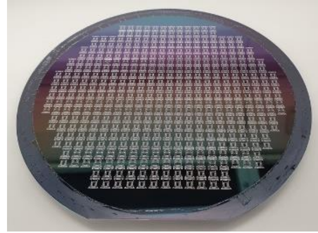
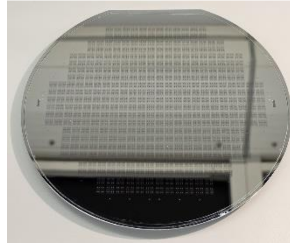
Typical characterization process after fabrication

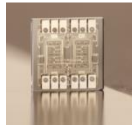
Characterization at wafer-level

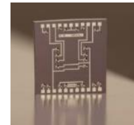


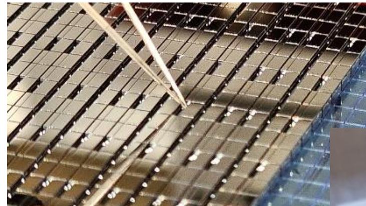


- Electrical parameters like capacitances, resistances
- Mechanical parameters like Eigenfrequencies, quality factors
- Optical parameters like coupling, loss, resonances
- Obtain information about process stability, unity over wafer (typical wafer profiles)
- Identify already first system parameters

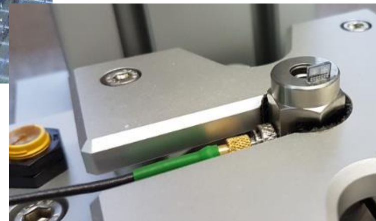
Chip-level



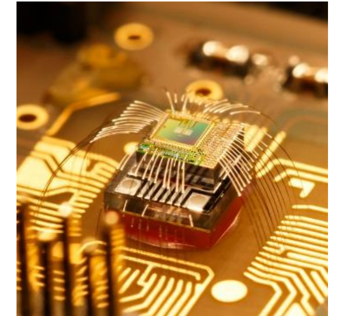




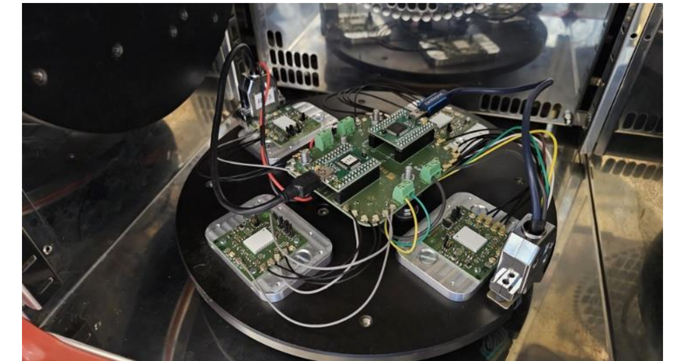
- Wafer diced to chips
- Same measurements as above possible
- Do parameters change after dicing (e.g. quality factor)?
- Additional characterization at e.g. shock tester



System-level



- MEMS and electronics set up together in packages or as chip on board (CoB)
- Different packages (ceramics, metal)
- Vibration test
- Shock test
- Tumble test
- Rate table test
- Temperature behavior



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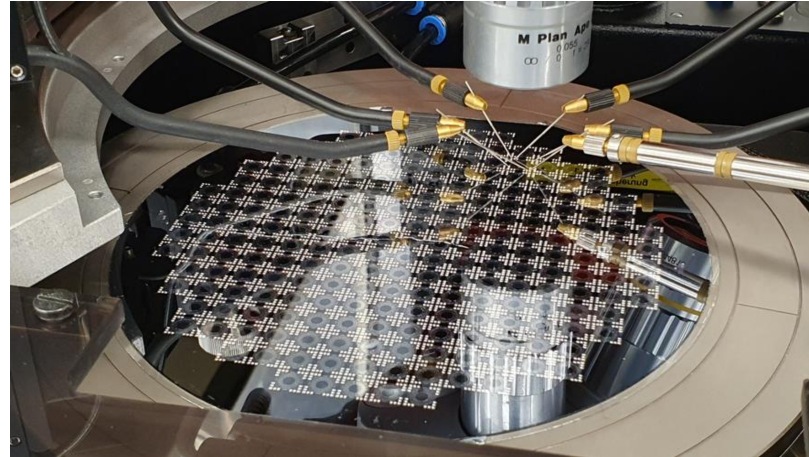
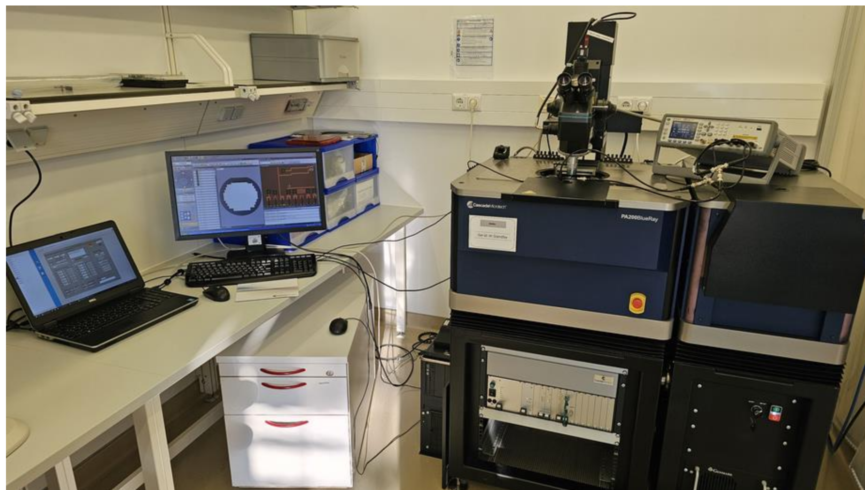
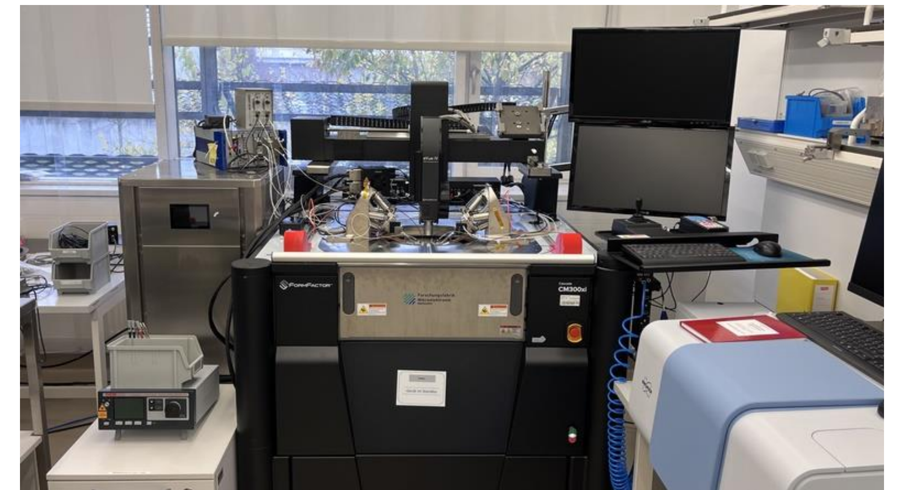
MEMS characterization at wafer-level

Equipment - a selection, not limited to

- Wafer probers
- LCR meter
- Source meters
- Lock-In amplifiers
- Vibrometers
- …







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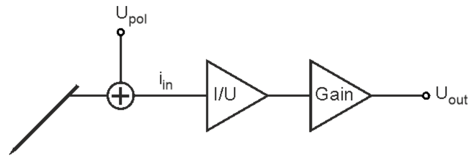
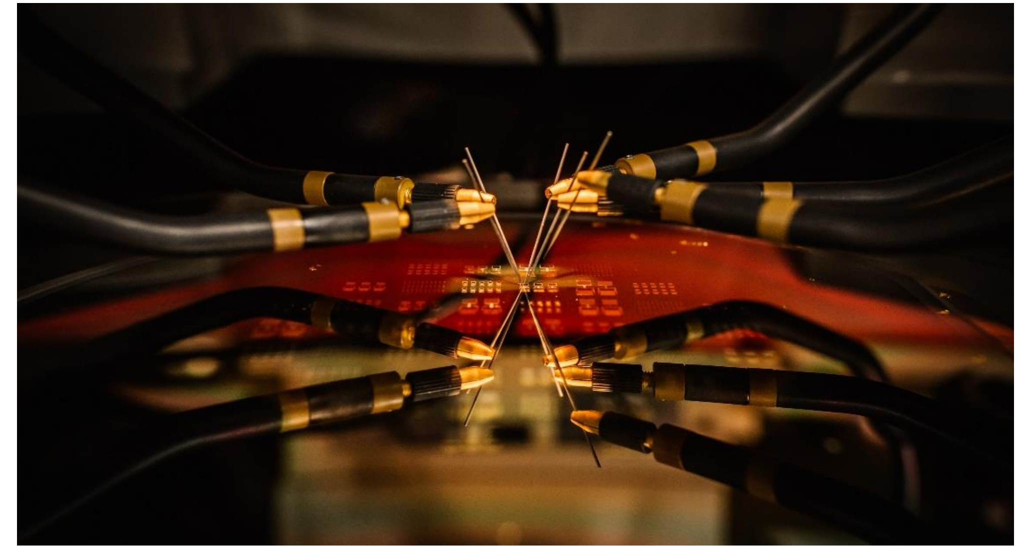
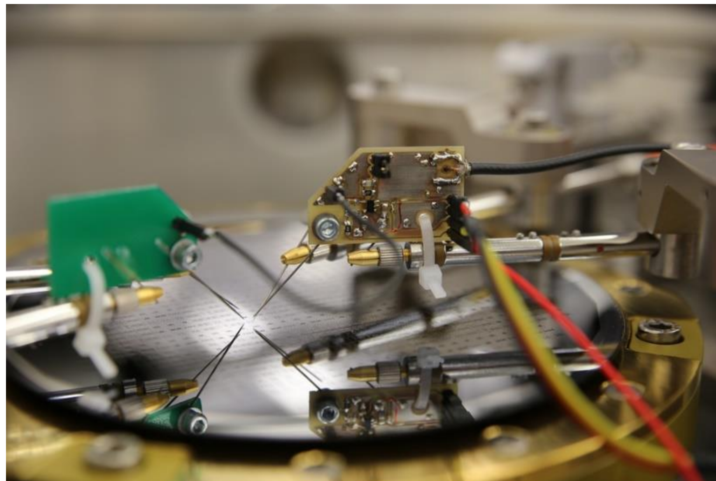
MEMS characterization at wafer-level

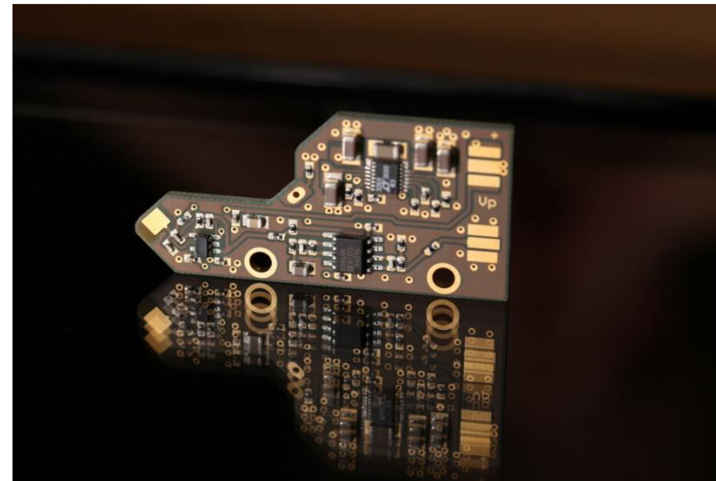
- Connection of MEMS with single manipulators (probe tips)
- Active probe to pick up small currents/charges
- Probe cards
- Active probe:



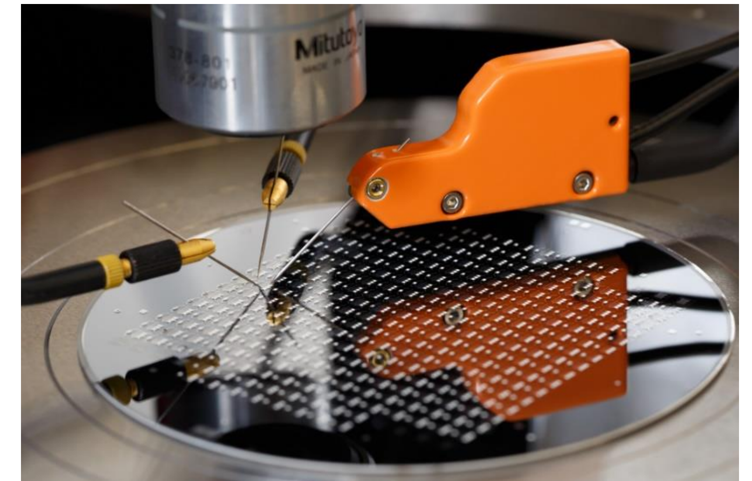




First tests with a prototype



Assembled PCB



Set up as active probe

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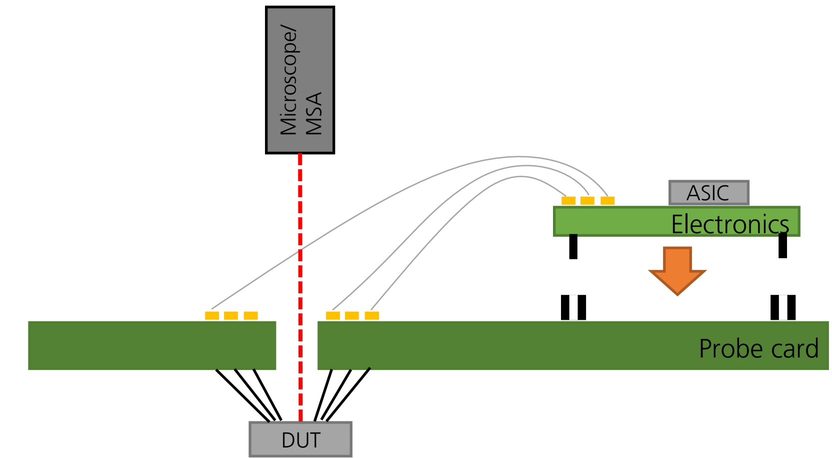
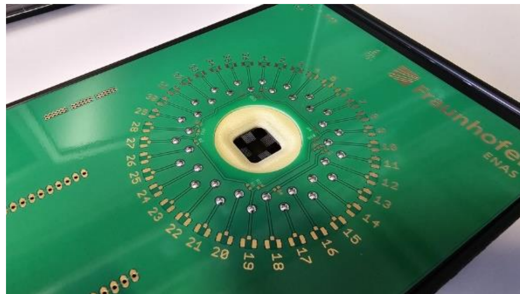
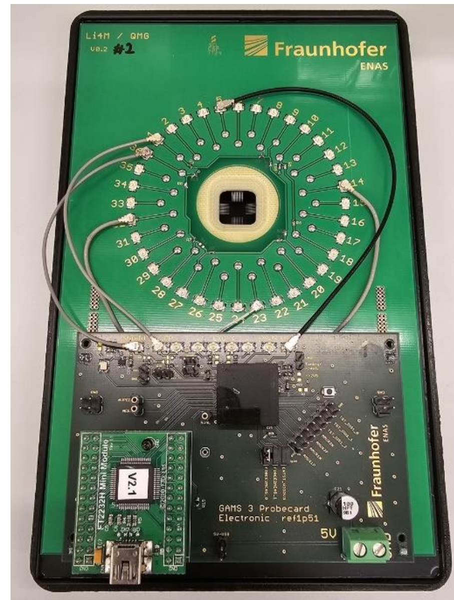
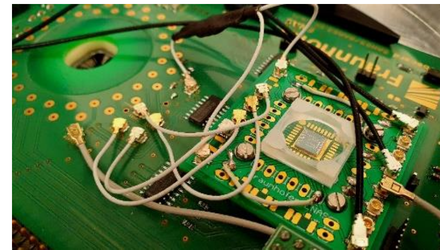
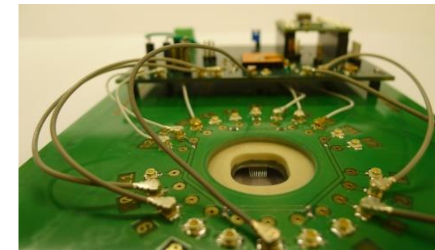
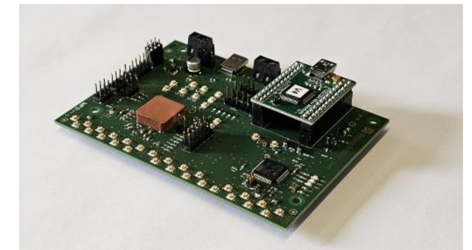
Modular probe card concept

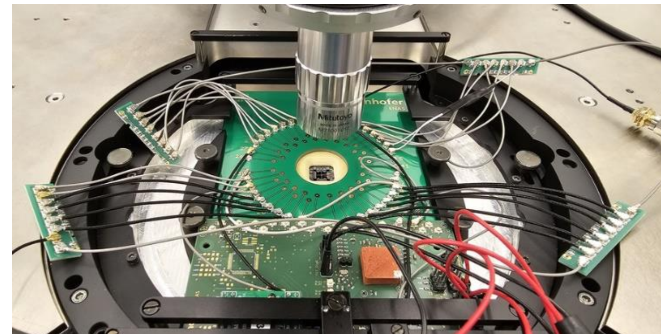
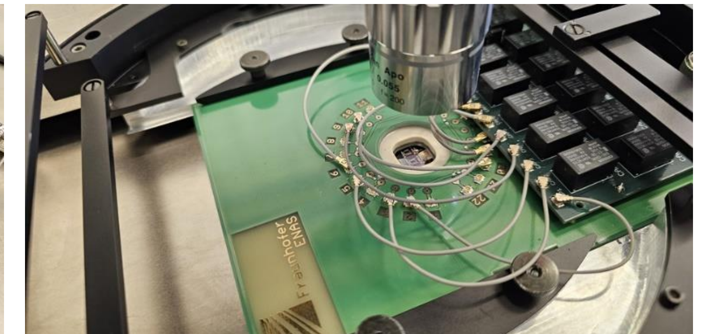
Why using a probe card?

- Characterization with multiple connections to the DUT
- Defined potentials for all components of the DUT
- Characterized values are more stable (defined parasitics, less drift)



Schematic of modular (active) probe card concept

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Modular probe card concept

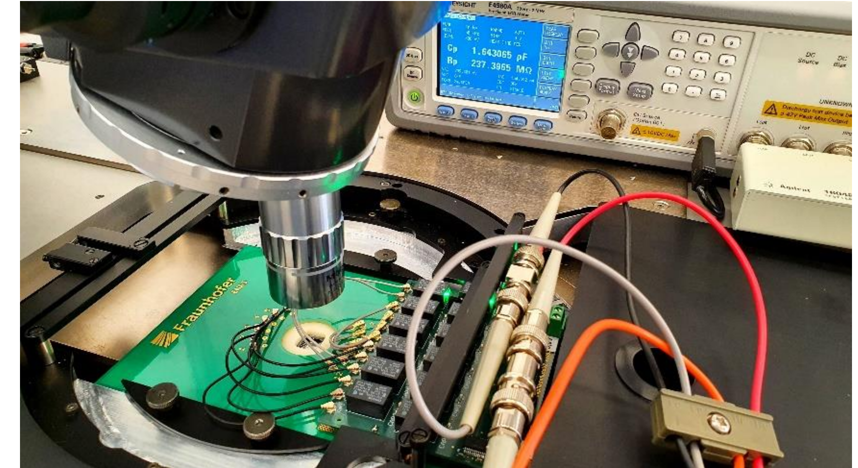
Switching matrix

- Electrical characterization of capacitances and resistances
- Flexible use with probe card or probe manipulators
- Variable configuration for fully automated measurement
- 18 very low-ohmic relays to measure 16 different ports (electrodes) against 2 different ports
- All electrodes of the MEMS at defined potential
- DC-bias voltage sweep to move MEMS structures and record C-V-curve
- 14 x 4 matrix under development

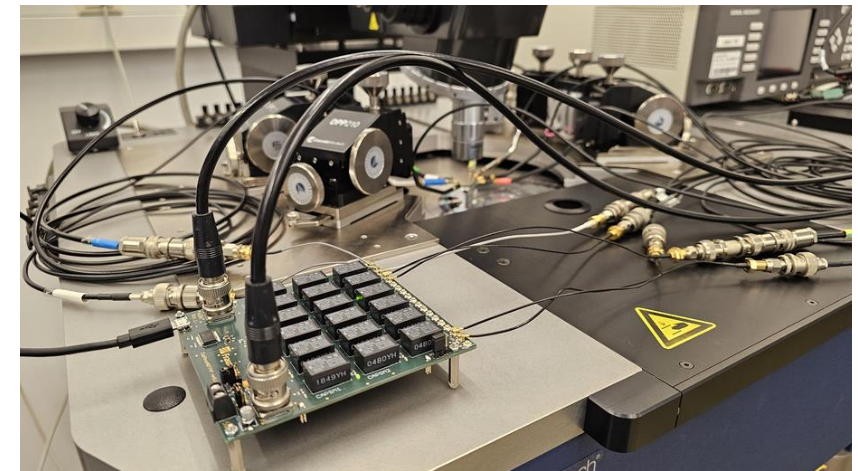
Measurement example:

	Drive Excitation Capacitance in pF																						
y\x	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	scala
1																							3.96
2																							3.92
3																							3.87
4																							3.83
5																							3.78
6																							3.74
7																							3.70
8																							3.65
9																							3.61
10																							3.56
11																							3.52

Wafermap of capacitance values for one electrode



Matrix electronics connected to LCR-meter and probe card



Matrix electronics used with manipulators

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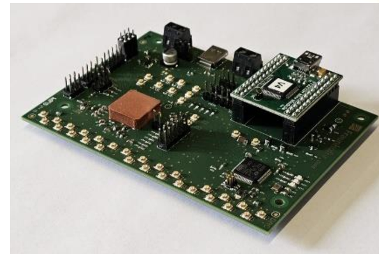
Modular probe card concept

Active probe card for gyroscope measurements

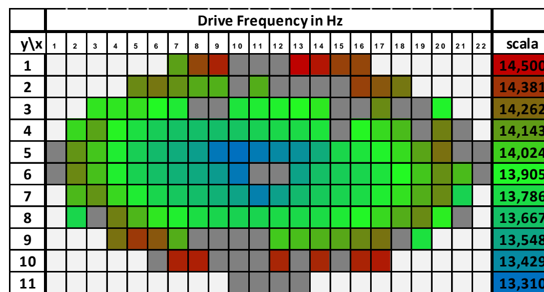
- Perform MEMS test with the corresponding ASIC
- Operate the MEMS gyroscope already at wafer-level
- Automated measurement of
  - Resonance frequency and quality factor
  - Excitation voltage
  - Mechanical Amplitude
  - Zero-Rate-Offset (ZRO) and mechanical quadrature (ZRQ) for the determination of the noise behavior



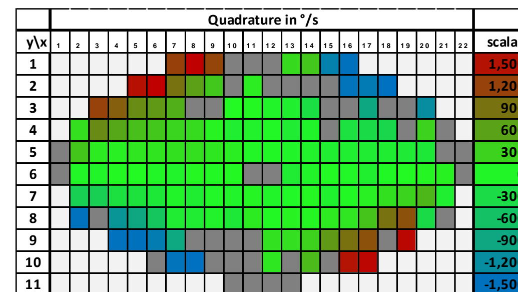
Latest version of APC electronics

Active probe card electronics

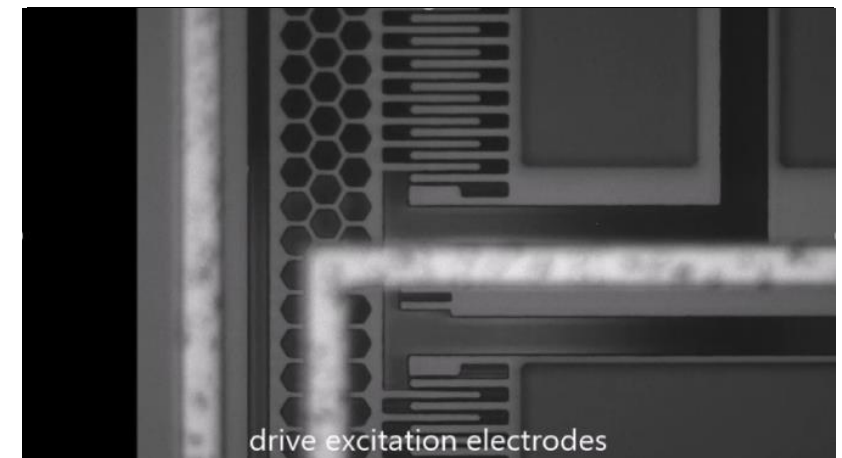
Measurement example:



Wafermap of drive frequency



Wafermap of quadrature error



Planar Motion Analysis of gyroscope elements

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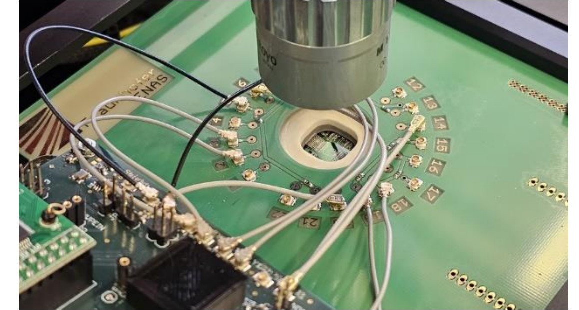
Modular probe card concept

Active probe card for gyroscope measurements



- Measurement example for quality-factors of wafer-level encapsulated MEMS gyroscopes

Drive Quality Factor — 06240701-02

Row	Design	Col:	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	I	01							47.919	83.869	87.983	80.588	85.590			84.243	86.173	87.361		50.542						
2	II	02								207.217	212.440		171.972	133.699		230.768	230.453	220.037	207.643	94.682						
3	III	03				51.060	100.070	164.197		248.167		268.440	269.041		264.809	273.237	272.879	275.679	272.517	236.223	135.044	82.501	43.514			
4	IIII	04				118.875	178.548	240.053	270.339	287.052	283.939	281.545		276.900	276.708			279.235	273.636	281.855		206.206				
5	I	05			66.138	184.627	237.731	289.413	289.634		281.940	280.562	279.621	277.774	279.178	277.270	278.960			287.526		280.519	182.067	53.509		
6	II	06			136.419	200.234	285.351	295.116		289.373	282.512	280.878	276.153	276.048	261.670	275.892	275.488	274.599	281.595		293.933	293.152	249.153	108.346		
7	I	07		58.994	180.212	255.882	292.781	314.353	293.161		283.272	277.631	276.702	275.657		274.533	275.995	276.729	283.055	290.527	296.323	296.619	285.165	169.248	55.667	
8	II	08		116.998	187.939	287.275		295.316	290.961		283.303	279.436		277.432	276.116		276.958			293.043			293.409	249.546	96.949	
9	III	09	44.874	142.309	223.879	289.625	288.939		288.564	290.195	287.922		280.734		276.453	280.357	283.135	286.892	290.758	292.795		292.232	292.563	281.560		36.835
10	IIII	10	43.648	136.111	249.219	281.162	281.081		282.616	286.540	288.838			286.455	286.460	285.389	287.384	290.626	290.756	275.524	291.837	291.414		277.632	155.390	30.319
11	I	11	27.575	104.174	261.262	266.037	280.567						290.580		290.783			275.443	290.409	287.672	288.926	288.712	289.728		146.165	20.660
12	II	12	25.763	93.157	257.133		279.971	278.767	280.068	281.436	283.755	287.804		292.705	213.575			290.253	282.608	285.980		287.931	288.064	279.458	144.062	23.246
13	I	13	33.302	118.335	259.788	281.688	281.708	277.909	279.401	280.110	284.401	287.444	289.103		291.701	291.873	292.413		281.655	286.560	286.657			283.597	186.226	40.952
14	II	14	35.002	133.839	228.685	277.039	273.400	279.383	280.014				285.564			291.678	290.189			286.346	286.157	287.807	254.543	277.076	156.394	
15	III	15		115.309	203.663	279.367	283.124	283.533	282.324		286.073	288.589	288.154		290.438	290.734	287.825	284.345	283.683	285.935	288.837	289.748	283.325	241.942	112.873	
16	IIII	16				258.036	286.931	287.753	285.998	286.760	289.410	290.371	286.949	290.229		292.745		287.655	286.320		291.507	290.187	282.794	201.005	56.815	
17	I	17			124.136	213.291		292.504		292.113	292.816	293.363	294.910		293.588	292.666	295.161	289.995		261.271	292.314	292.162	244.553	116.082		
18	II	18			59.921	178.737	226.466	279.624	280.746	293.756	291.832		294.640	290.329	295.271	297.014	294.858	292.550	288.541	291.769	289.909	286.224	195.436	58.377		
19	I	19				70.885		121.550	120.980	281.629	294.119	296.640	298.299		298.788	298.866	292.293	298.360		285.889	271.004	217.596	103.634			
20	II	20				7.166		6.452	130.855	281.591	289.343	292.787	289.886	292.475	295.519	293.671	295.942	294.511	286.504	236.583	144.331		46.545			
21	III	21								157.035		233.637	219.510	232.705	237.875	233.429	231.752	226.722	209.213	109.159						
22	IIII	22							45.826		88.909	95.057	95.428		102.602	98.035	92.137	88.901	72.671	50.264						

Scala	#	
6000	10	
40222		19
74444	22	
108667		17
142889	9	
177111		15
211333	23	
245556		60
279778	170	
314000		

Statistics

min:	6.452
max:	314.353
mean:	233.151
std:	83.137

Number Good Dies: **346**

statistics:				
	Design I:	**Design II:**	**Design III:**	**Design IIII:**
MIN	20.660	6.452	36.835	30.319
MAX	314.353	297.014	292.795	292.745
#	111	111	64	60
MEAN	230.524	238.725	235.138	225.576
+	+83829	+58289	+57657	+67169
−	-209864	-232273	-198303	-195257

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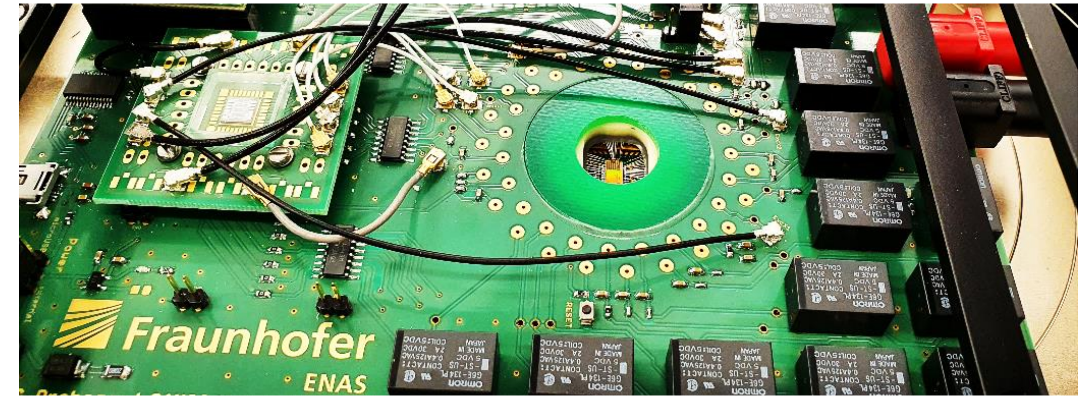
Modular probe card concept

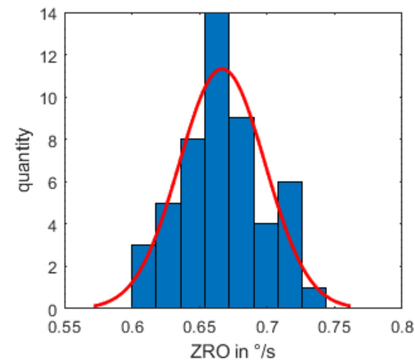
Probe card for ASIC characterization at wafer-level

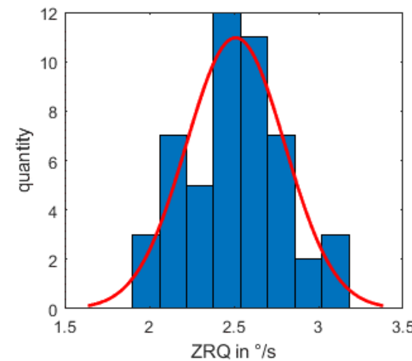
- Perform complete initial operation test of ASICs
- Interchangeable MEMS gyro on PCB
- Automated characterization of
  - Reference voltages
  - Current consumption
  - Start-up behavior of gyroscope device
  - Initial noise
  - Typical gyro parameters at zero rate input



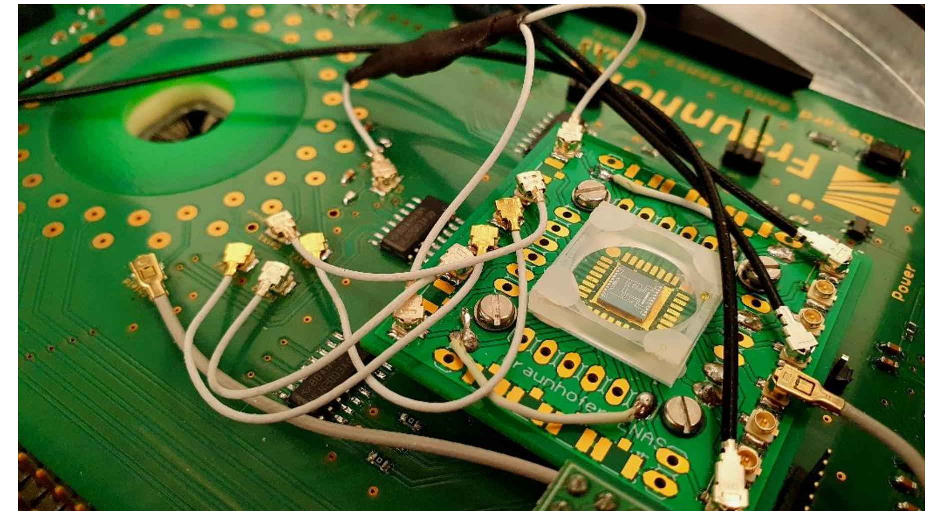
Probe card connected to an ASIC at wafer-level

Measurement example:





Statistical distribution of Zero-Rate-Offset and Quadrature Bias (ZRQ) for one MEMS and different ASIC dies



Connected Gyro MEMS element on probe card PCB

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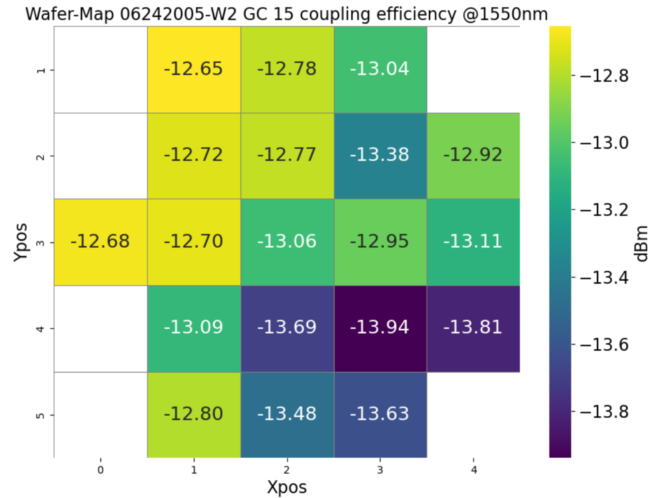
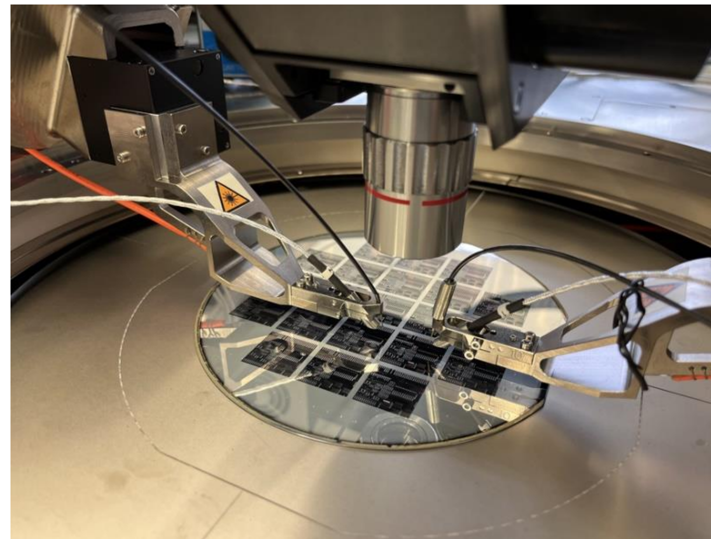
Silicon photonics wafer prober

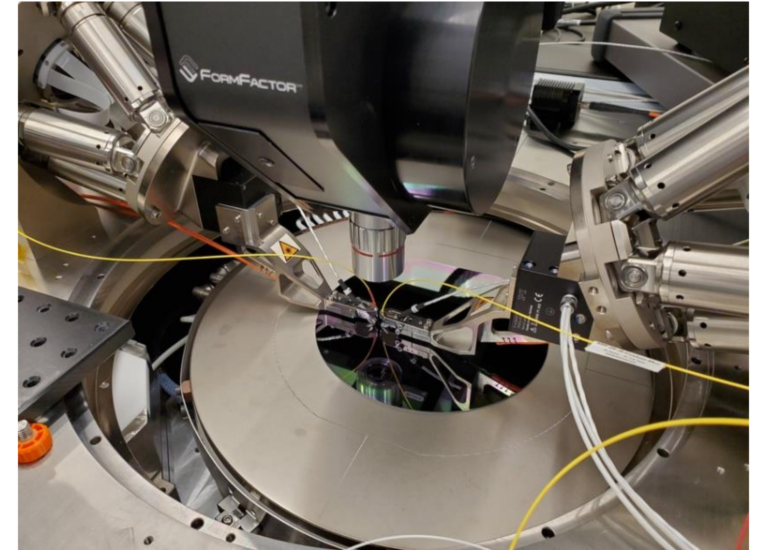
- Optical characterization of photonic integrated functions (PIF)
- Resonant frequencies of optical ring resonators
- Loss of wave guides
- Coupling efficiency of grating couplers

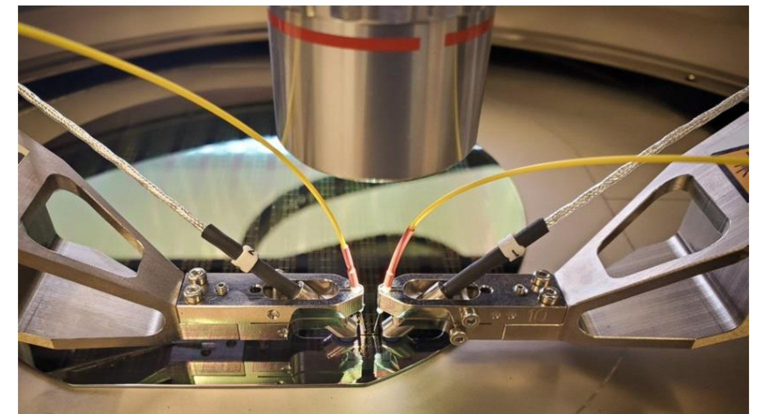
Measurement example:



Coupling efficiency of a grating coupler at 1550 nm







Setup with silicon photonics measurement system

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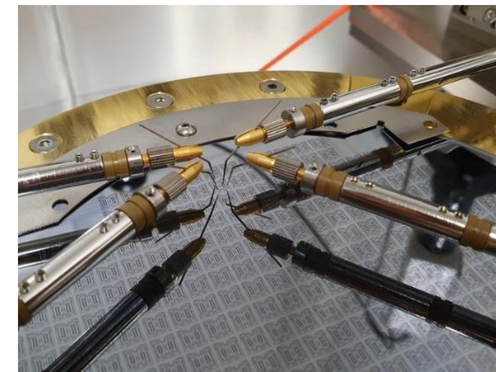
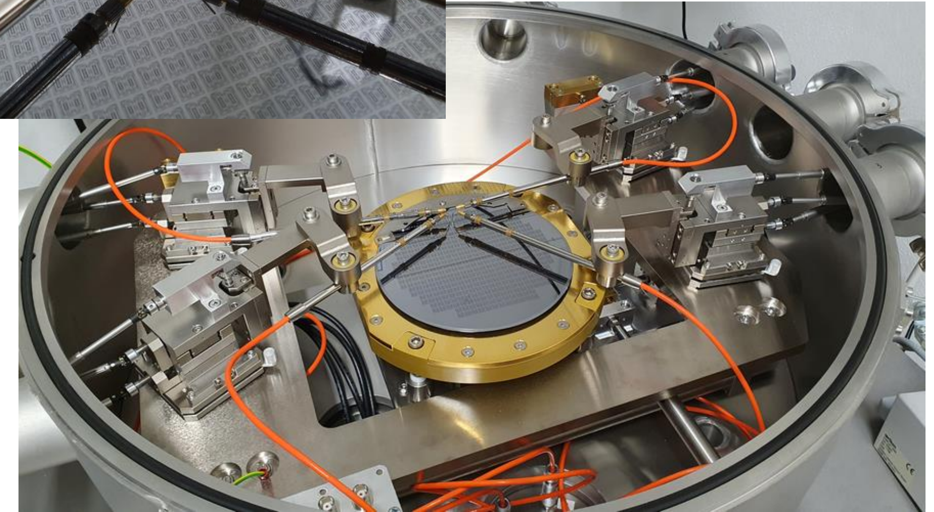
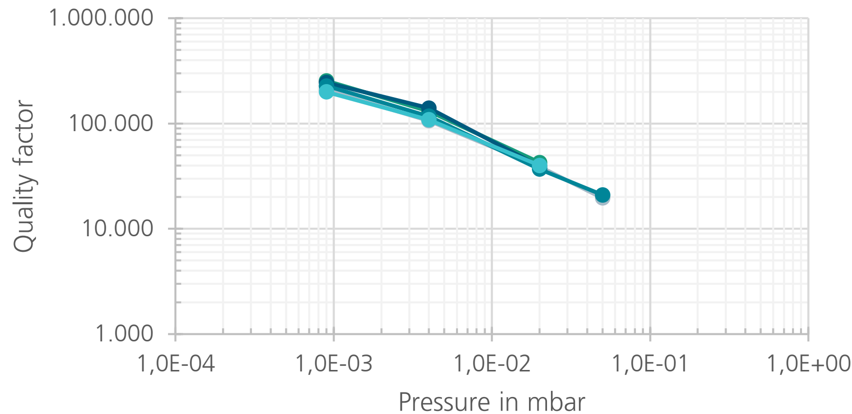
Vacuum chamber

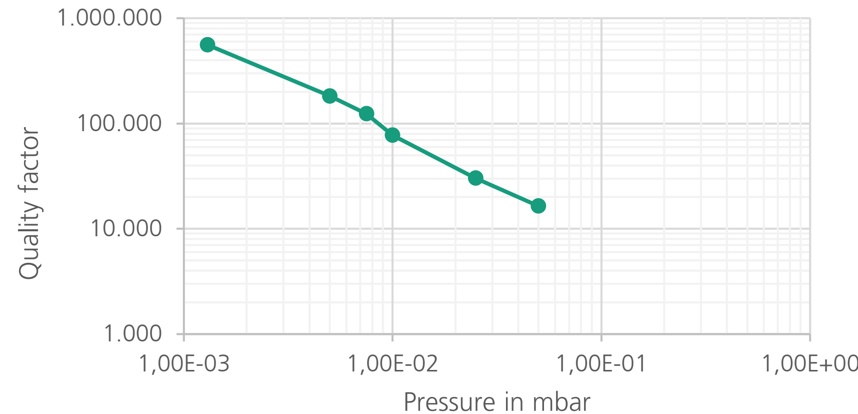
- Pressure range between 1 bar and 9E-4 mbar
- Leakage testing for wafer level encapsulated MEMS
  - ➢ Characterize MEMS to make sure that they are hermitically sealed
- Reference measurements for quality factor over pressure
  - Use semi-finished wafers
  - Use re-opened, capped MEMS dies



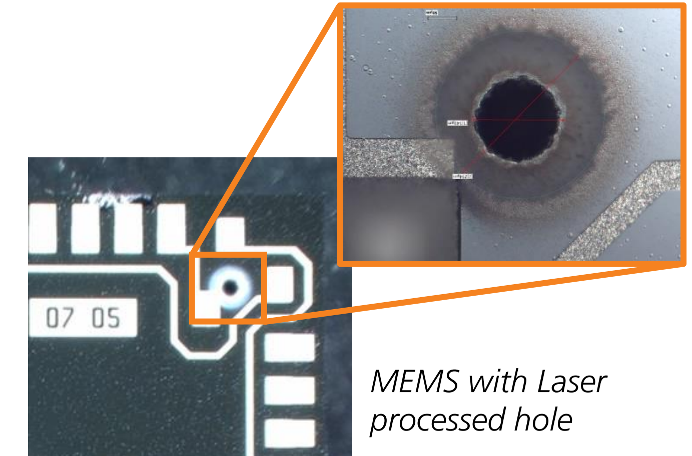




Pressure curve for semi-finished MEMS wafer



Pressure curve for re-opened single MEMS



MEMS with Laser processed hole

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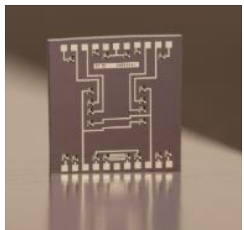
Wafer- and chip-level characterization

MSA 650 IRIS + HF2LI

- Micro system analyzer - MSA 650 IRIS
  - Infrared Laser-Doppler-Vibrometry
- Lock-In amplifier HF2LI
  - ➢ Closed loop MEMS resonator
  - ➢ Evaluate new control algorithms

- Analyze wafer-level encapsulated MEMS chips or wafers with
  - Glass-Si-glass
  - Full-Si



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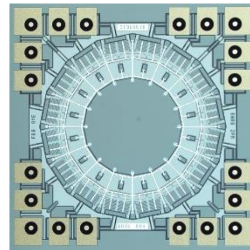
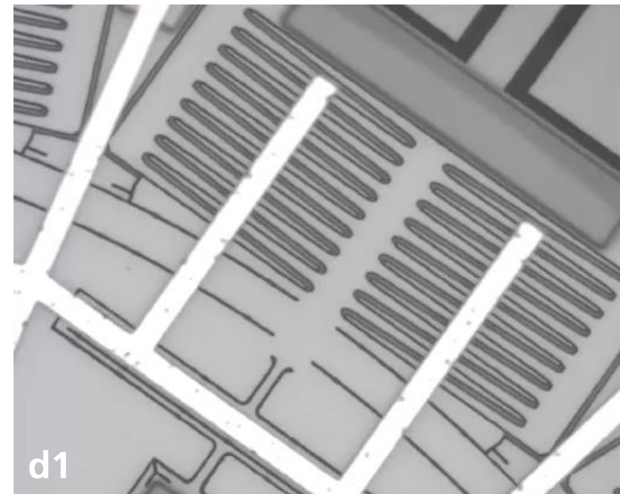
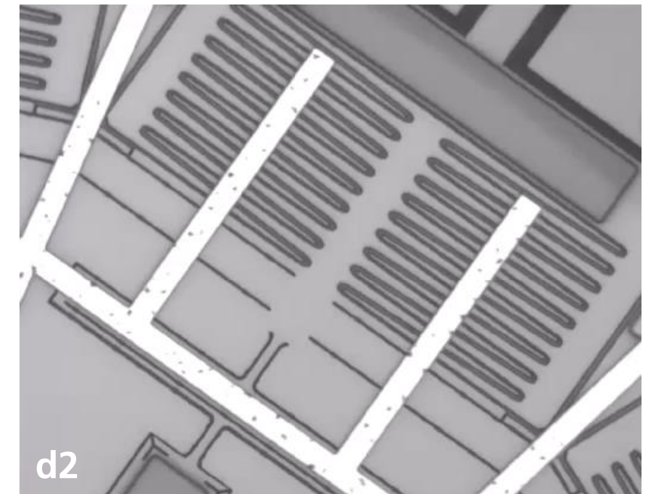
Characterization with the Micro System Analyzer

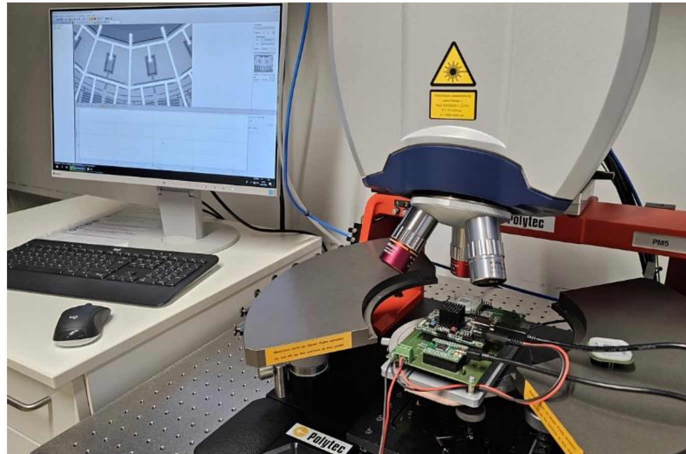
MEMS ring gyroscope in motion

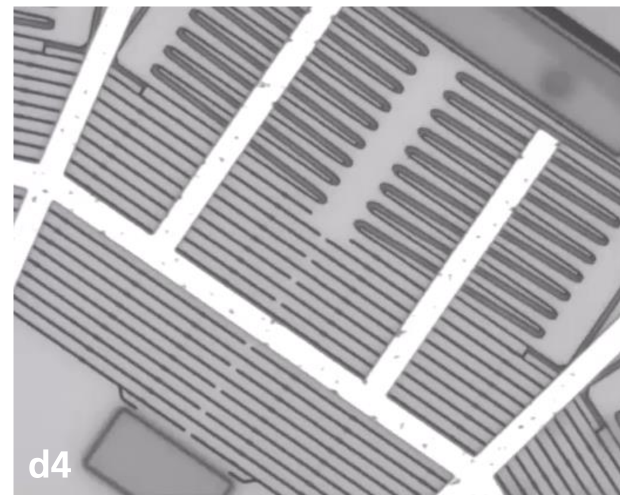
- 4 different MEMS designs d1…d4
- Closed drive control loop (FPGA electronics)
- Characterization of in-plane motion with Micro System Analyzer

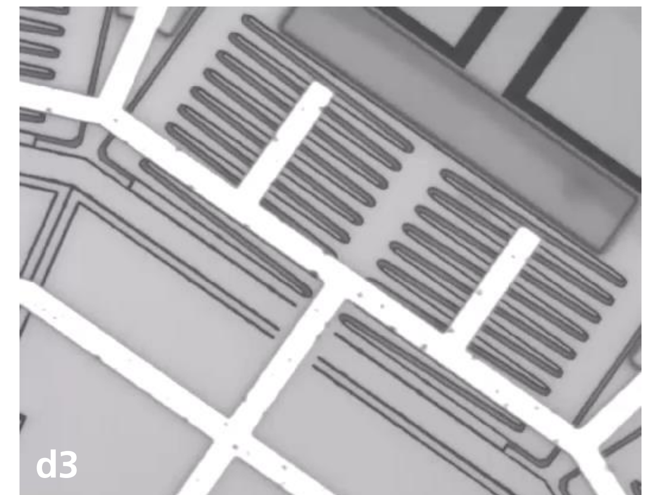












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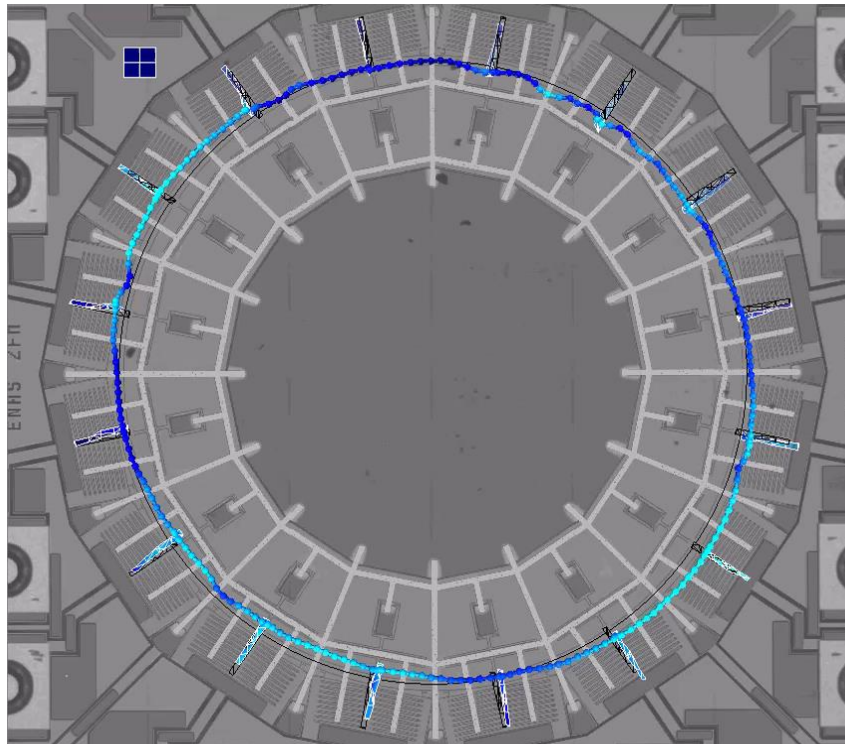
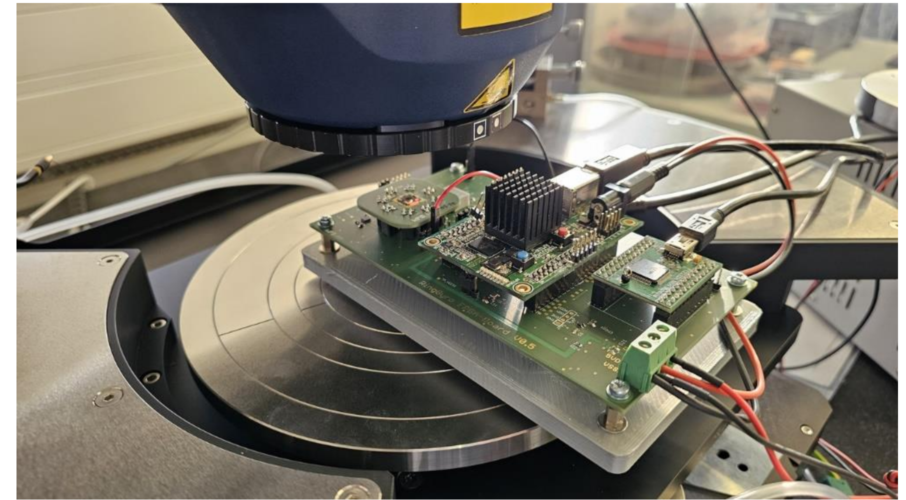
System test with 3D-vibrometer

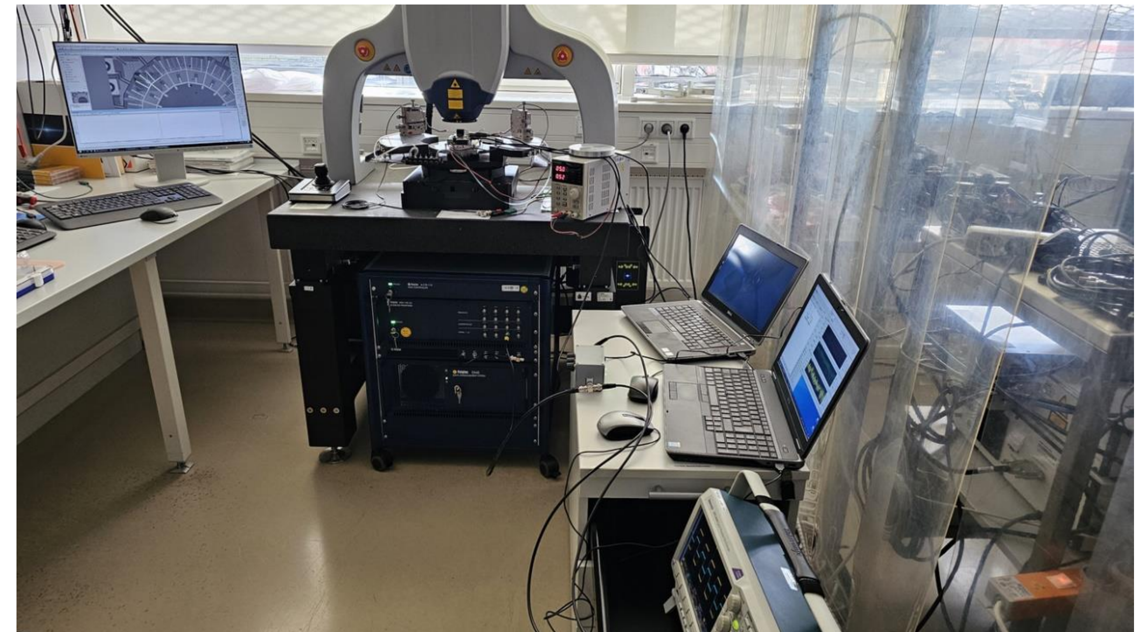
MSA 100 3D

- 3D inplane vibrometry of the first ring mode



Visualization of the ring motion





In the lab

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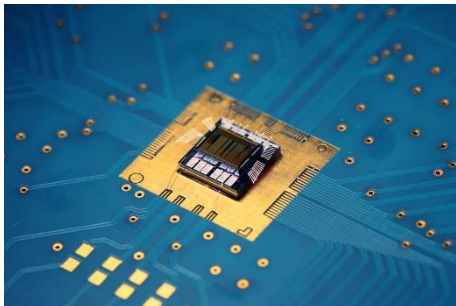
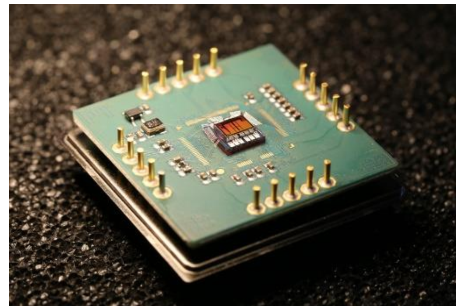
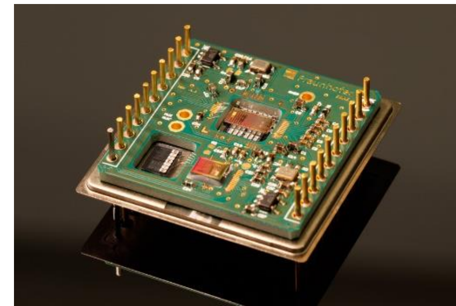
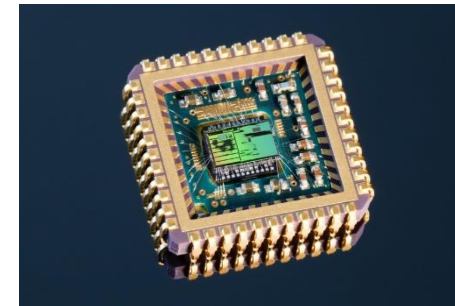
Characterization at system-level

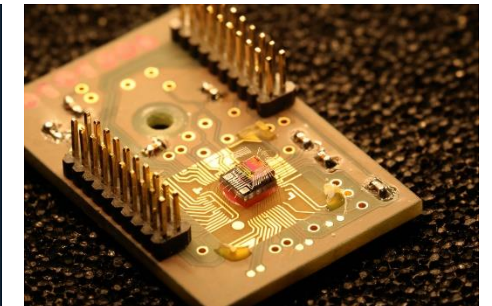
- Assembly of test systems
  - Chip-on-board (CoB)
  - Different packages (ceramic, metal)
- Determination of
  - Scale factors
  - Nonlinearities
  - Noise measurements
  - Calibration over temperature (with rate tables)
- Vibration testing
- Execution of shock tests











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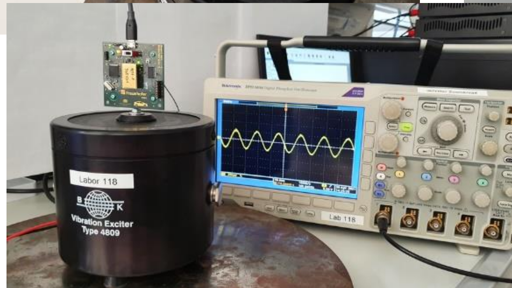
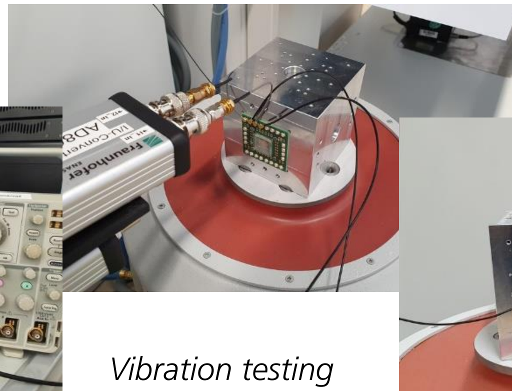
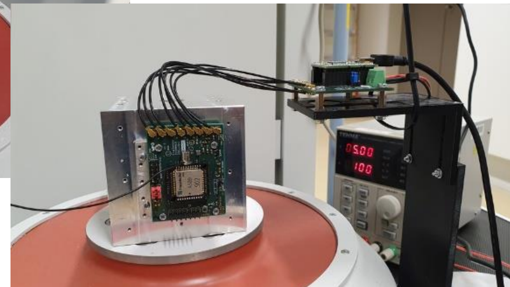
Characterization at system-level

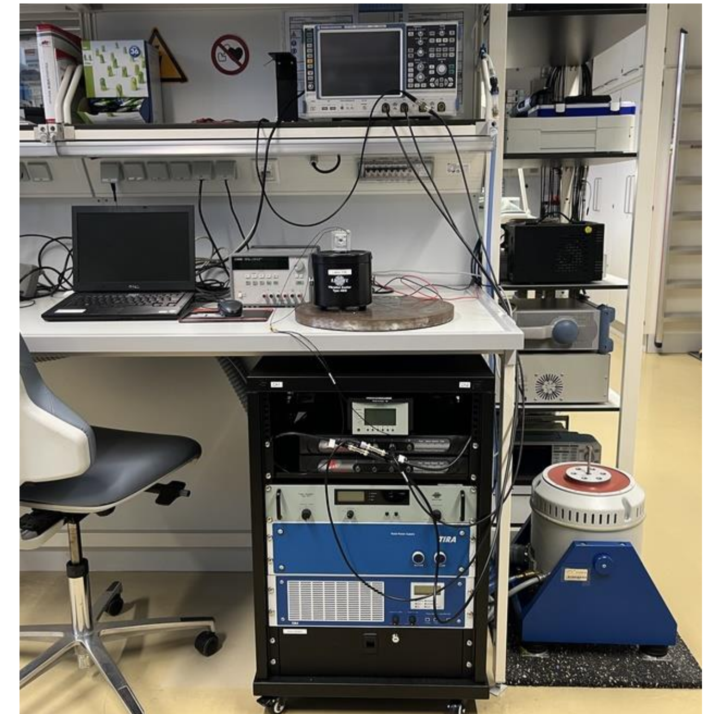
Vibration and shock

- Vibration test system for payloads up to 25 kg
- Table top vibration exciter
- Vibration control system
- Shock tester (up to 10,000 g)

Vibration testing

Shock tester



Vibration test setup

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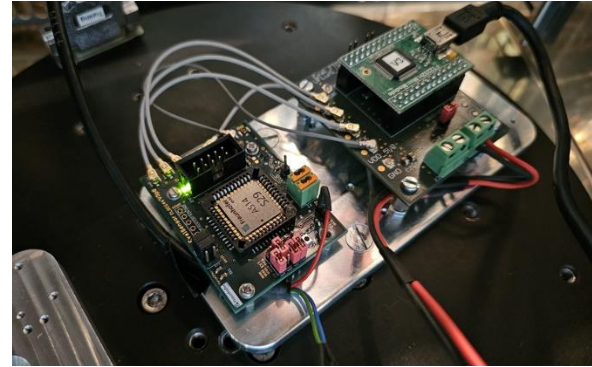
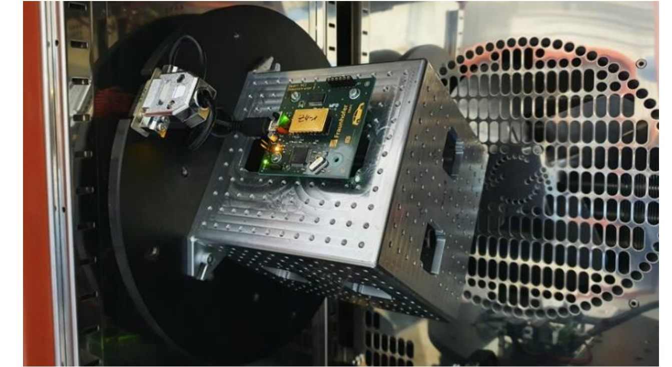
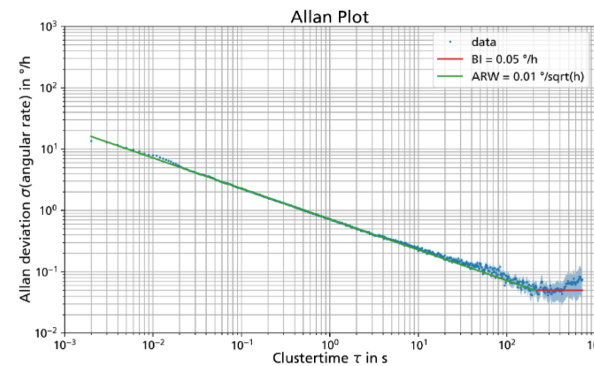
Characterization at system-level

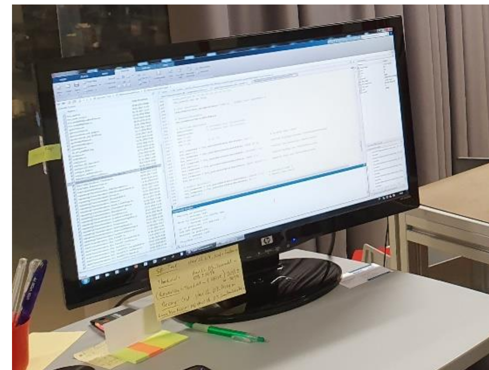
Angular rate, tumble test and noise measurement

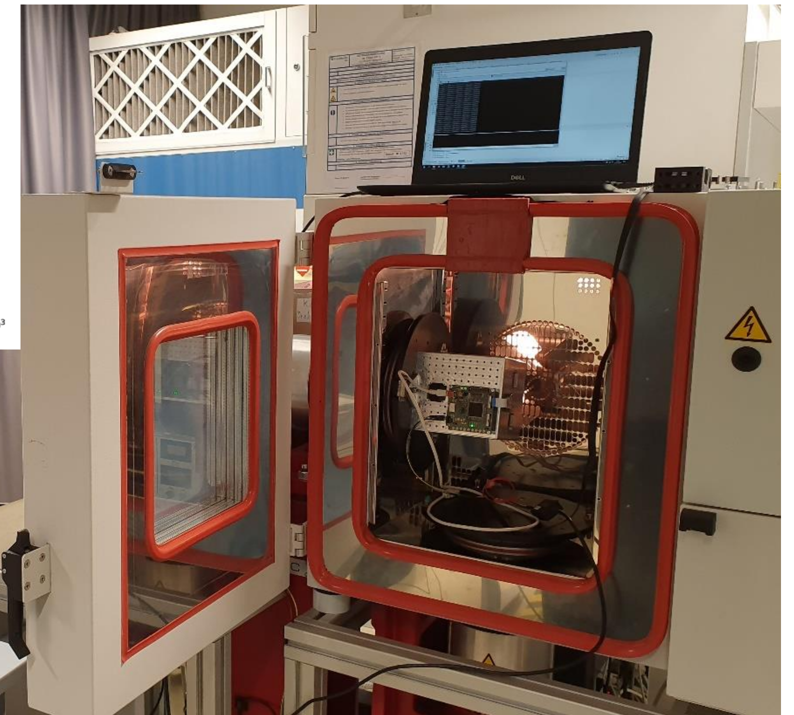
- Rate tables inside a temperature chamber (-60 °C to +125 °C)
- 2-axis rate table in procurement











Rate table with horizontal and vertical axes in temperature chamber

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Thank you for your attention!