Trends and future challenges in designing and simulating high performance MEMS

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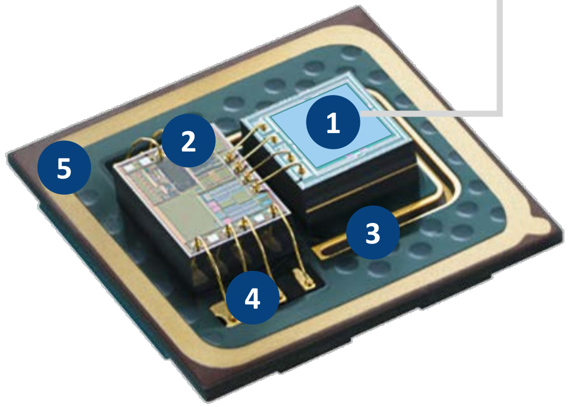
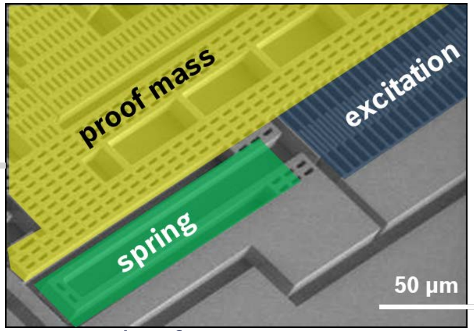
Outline

- What are MEMS?
- Which applications and future trends are pushing for performance?
- What are the resulting challenges in design and simulation?
- Conclusion

What are MEMS?

- **M**icro-**E**lectro-**M**echanical-**S**ystems are ***the senses*** of the artificial world
  - Typical setup of an inertial sensor (accelerometer / gyroscope)



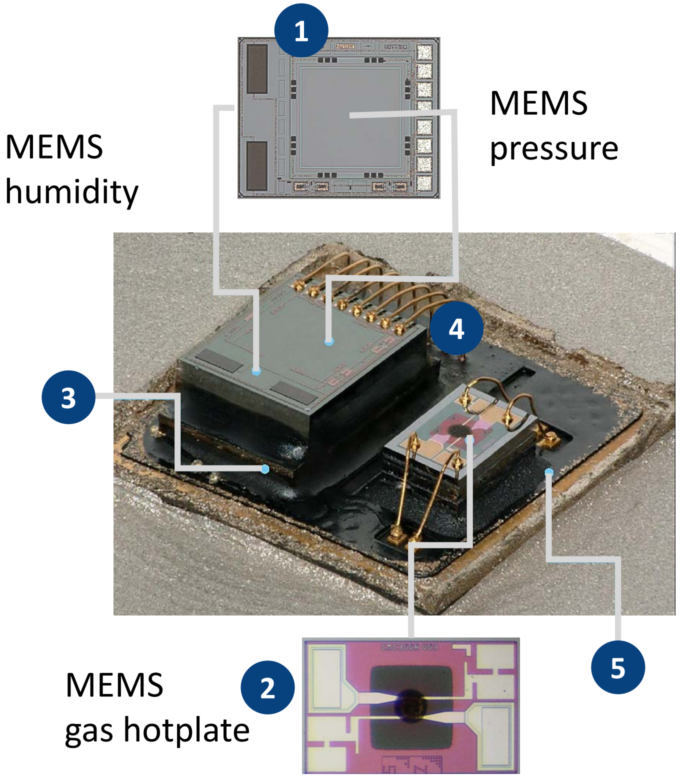


Example of a gyroscope

1. MEMS
2. ASIC
3. Decoupling unit
4. Bonding wires
5. Printed circuit board (PCB)

What are MEMS?

- **M**icro-**E**lectro-**M**echanical-**S**ystems are ***the senses*** of the artificial world
  - Sensor to detect gases and air quality (e.g. BME680)



1. MEMS 1
2. MEMS 2
3. ASIC
4. Bonding wires
5. Printed circuit board (PCB)

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What are MEMS?

- **M**icro-**E**lectro-**M**echanical-**S**ystems in addition allow the artificial world to ***interact*** with the environment
  - Inkjets for printers
  - Scanning Micro mirrors
  - DLPs

Inkjet Printer

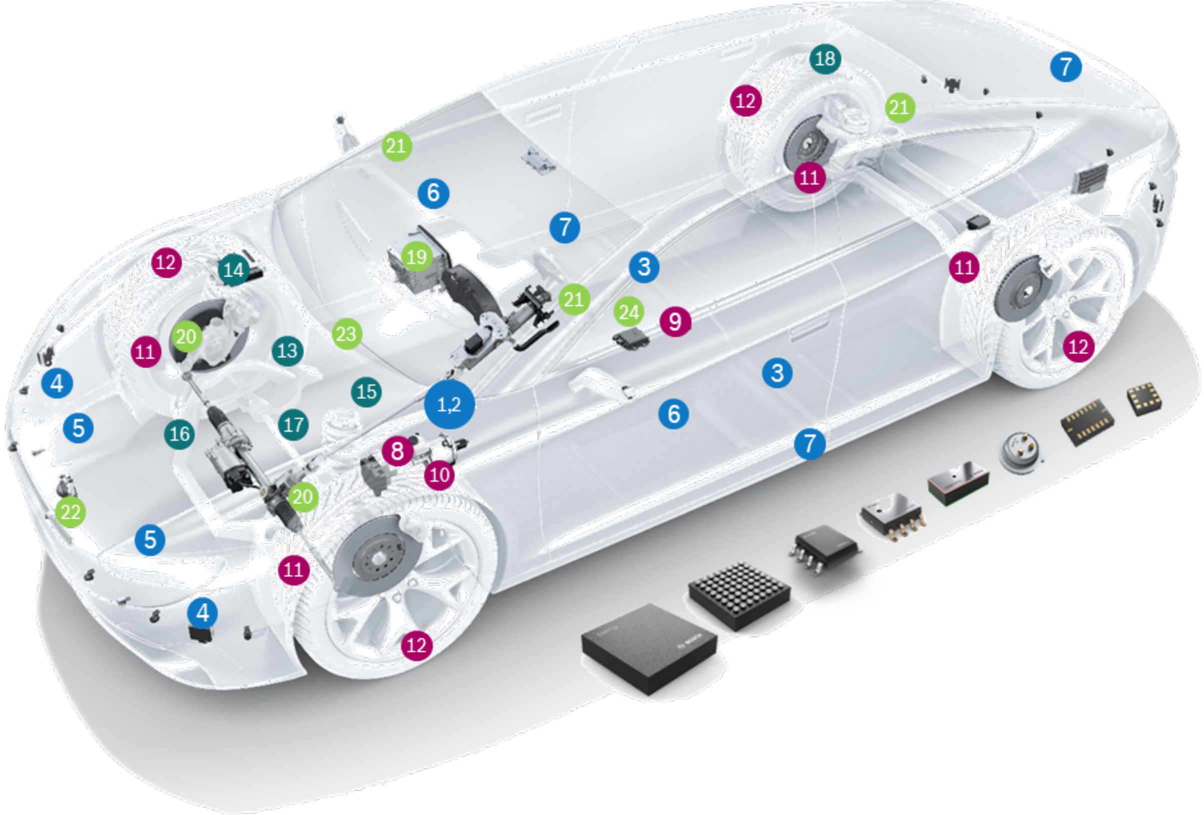
DLP micro mirror array

Smart glasses with µ-mirror based projection

MEMS are the key technology to connect the artificial world with its surroundings

Future trends pushing for performance

Automotive MEMS applications

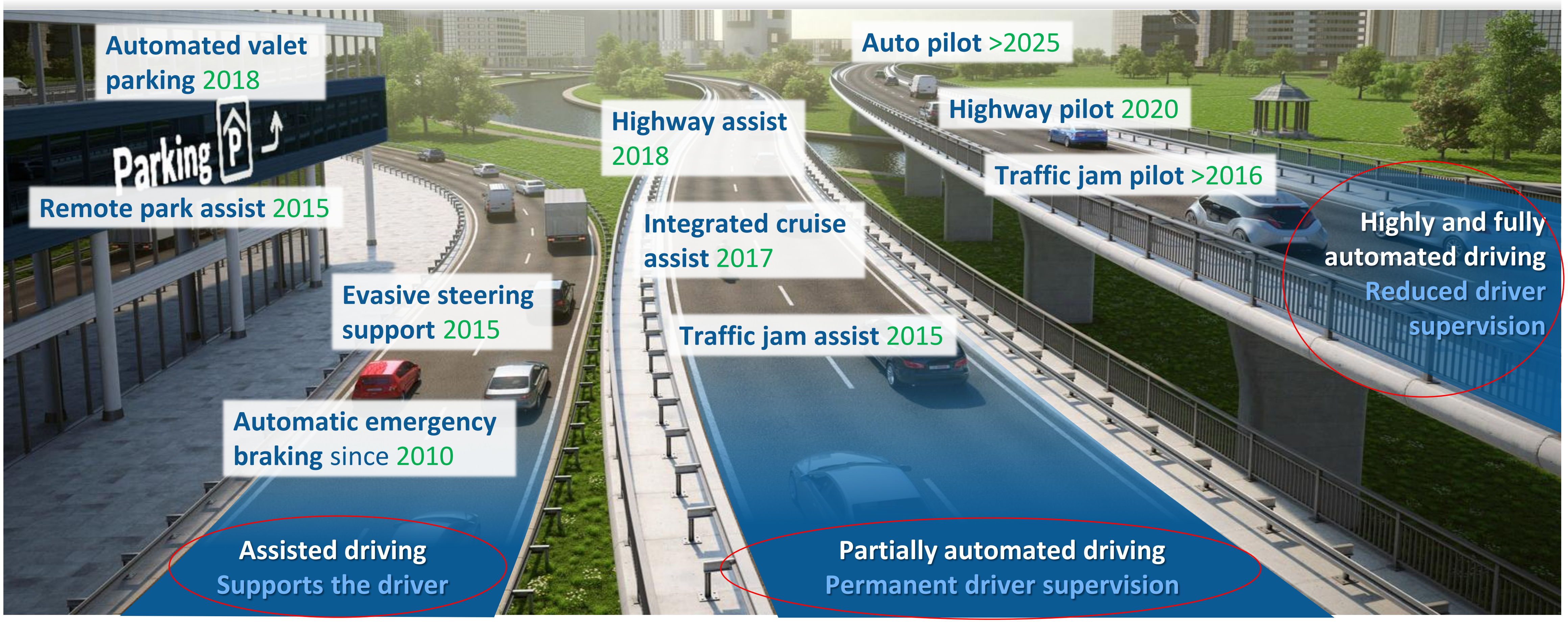


Passive Safety		
1	High G acceleration sensor for AB-ECU and eCall	
2	Rollover sensor for Airbag ECU	
3	Occupant weight senor or pressure sensor	
4	PTS – Pedestrian tube sensor	
5	UFS - Upfront sensor	
6	PPS - Peripheral pressure sensor	
7	PAS - Peripheral acceleration sensor	
Active Safety		
8	Inertial sensor für ESP, RSC, RoSe	
9	MM – Sensor cluster for ESP (accel + gyro)	
10	High pressure sensor for ESP	
11	Low G acceleration sensor for active suspension	
12	TPMS- Tire pressure monitoring system	
Power Train		
13	MAP – Manifold air pressure	
14	BAP – Barometric air pressure	
15	Medium Pressure for transmission	
16	Mass flow sensor	
17	High pressure sensor for fuel injection	
18	Tank pressure sensor	
Comfort Functions		
19	Inertial sensor for navigation	
20	Motor damping / noise cancellation	
21	Microphone	
22	Night vision	
23	Gas / air quality	
24	Alarm	

MEMS are widely used in modern cars for various functions
They improve our mobility – safety, comfort and economy

Future trends pushing for performance

Automated driving – a revolution coming step by step



Future trends pushing for performance

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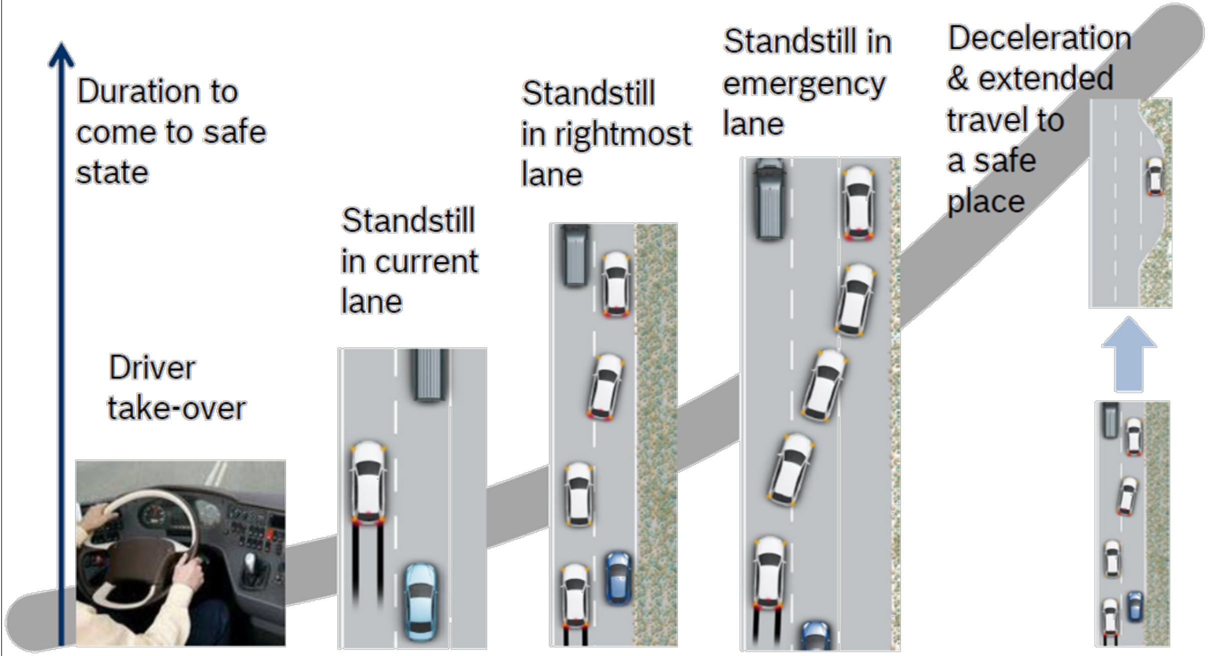
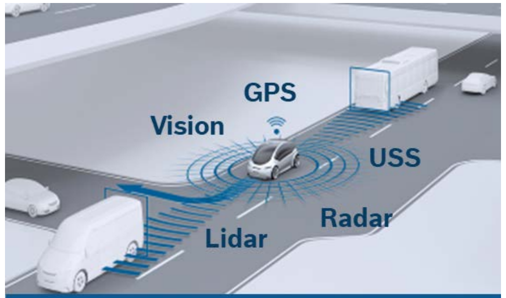
Automated driving – Increasing system complexity

Different scenarios for „safe stop strategies“

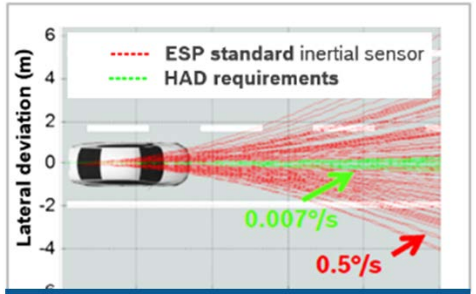




Sensor fusion for HAD

Beside a strong increase of demand on visual detection systems…

… the requirements on classical MEMS sensors e.g. gyroscopes is increasing



@ 100km/h: up to 4m error / 9s

The trend of highly automated driving (HAD) is leading to a tremendous performance push in classical inertial sensors such as gyroscopes and acceleration sensors

Future trends pushing for performance

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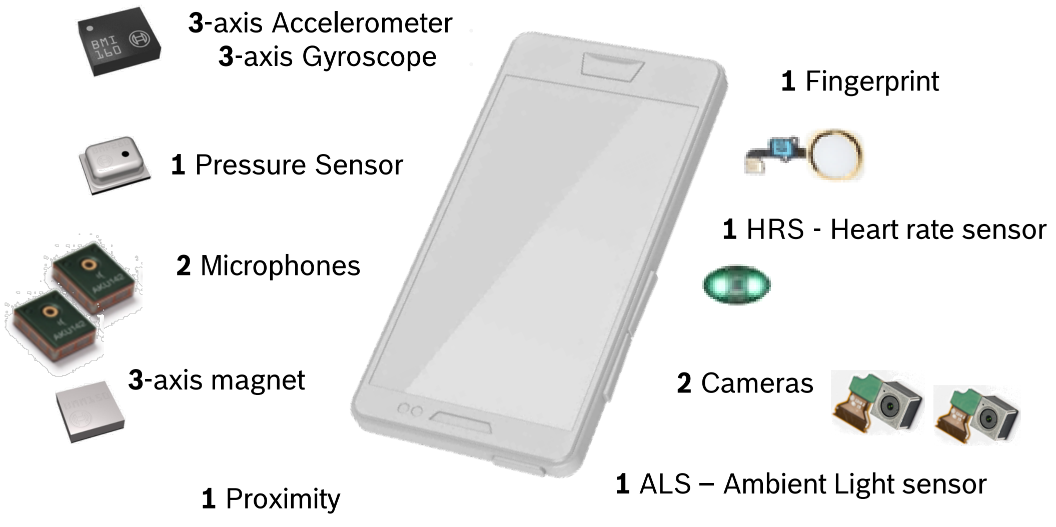
CE Application: Smartphone

2015
< 18 Sensors



2020
< 25 Sensors

Sensors open up new degrees of freedom for innovative features and APPs

Consumer applications and trends

Virtual and augmented reality devices require precise motion tracking to avoid „cyber thickness“ and allow acceptable user experience

Fitness tracker or body networks require ultra sensitive signal acquisitions to acquire necessary information (e.g. push up routines etc.)

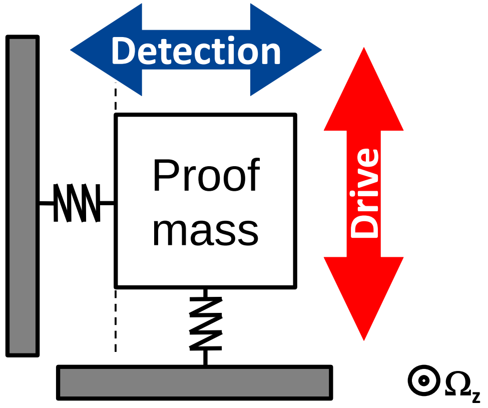
→ Low offset failures
→ Low sensitivity failures
→ High bandwidth

→ High signal to noise ratio
→ Low power consumption
→ Shock robust designs

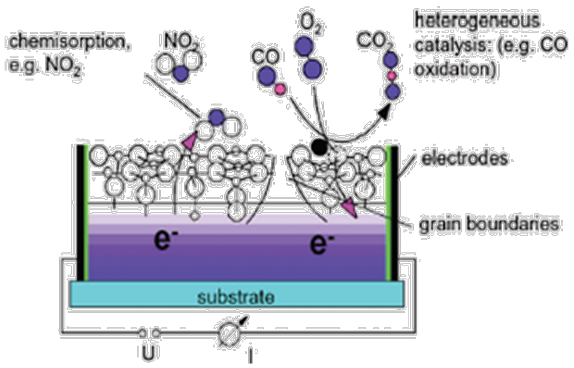
Various consumer applications pushing for higher accuracy and performance at lower current consumption.

Key Topics (1/3)

- To achieve current time to market (TTM) requirements, the accuracy of the design tools and simulation models must be precise enough to avoid additional sample phases („first time right") considering…
  - **Specific transducer principles (multi-physics)**



Micro mechanics of a **gyroscope** considering
- Electrostatic non linearity
- Mechanical non linearity
- Process tolerances and distributions
- etc.



Electrochemical reaction of a **gas sensor** considering
- Surface chemistry
- Ion and molecule movements and interactions
- etc.

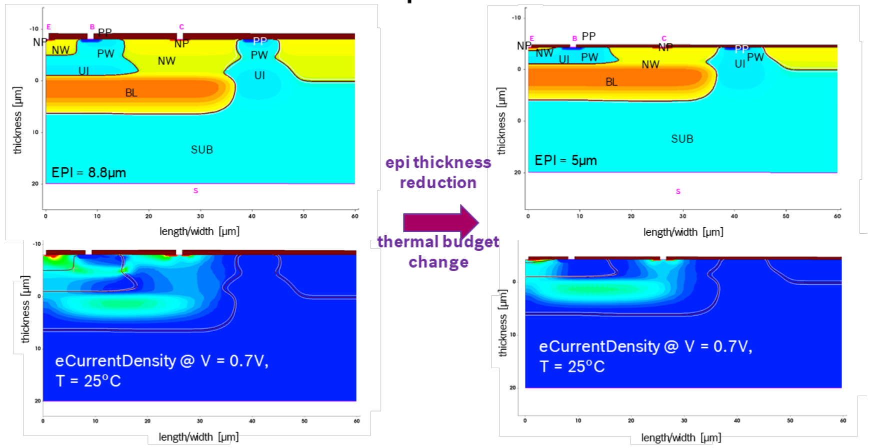
A deep understanding of the dedicated transducer principle with all possible side effects and relevant cross sensitivities must be known and considered in the design and the simulation model

Key Topics (2/3)

- To achieve current time to market (TTM) requirements, the accuracy of the design tools and simulation models must be precise enough to avoid additional sample phases („first time right“) considering…
  - **Process influences (process- & device simulation)**

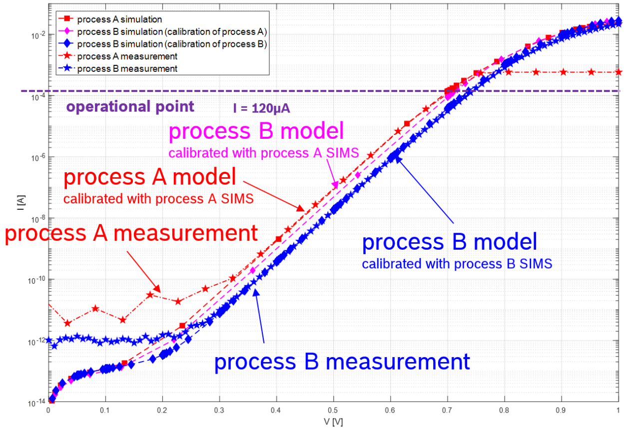
process A Diode

process B Diode



Process and device simulation of a **diode** considering

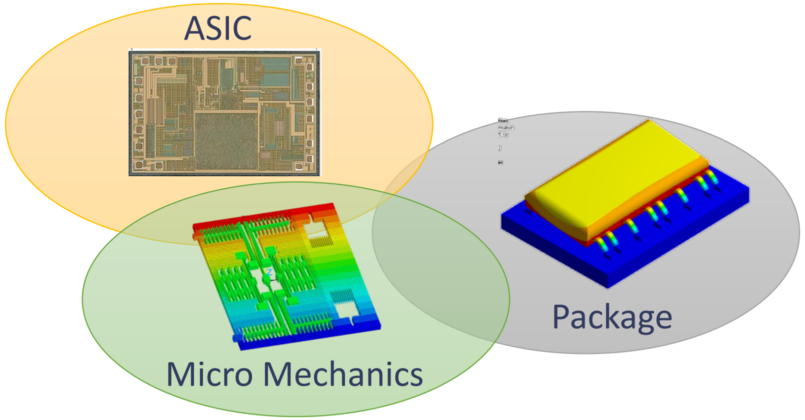
- Dopant
- Implant energy
- Process time
- Annealing steps
- etc.



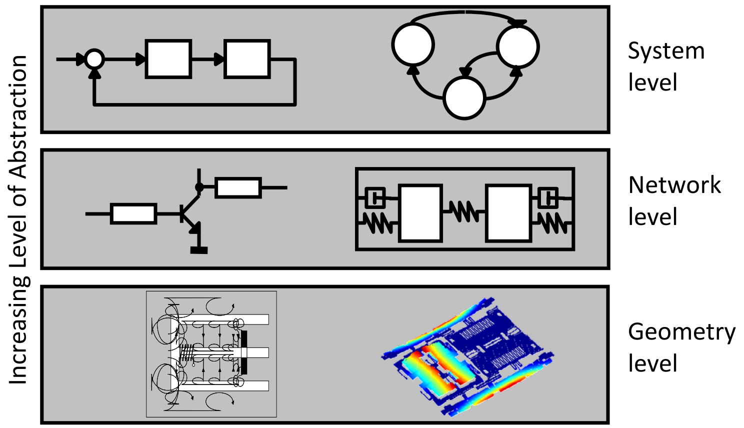
All relevant sensor influences and deviations must be considered to guarantee a robust MEMS design for series production
High performance can only be achieved with a deep understanding of even tiny process influences

Key Topics

- To achieve current time to market (TTM) requirements, the accuracy of the design tools and simulation models must be precise enough to avoid additional sample phases („first time right“) considering…
  - **Complex interaction of different domains (System Simulation)**



Complete **system model** considering
- Mechanical stress paths
- Parasites of MEMS
- Frontend (ASIC)
- Signal processing
- etc.

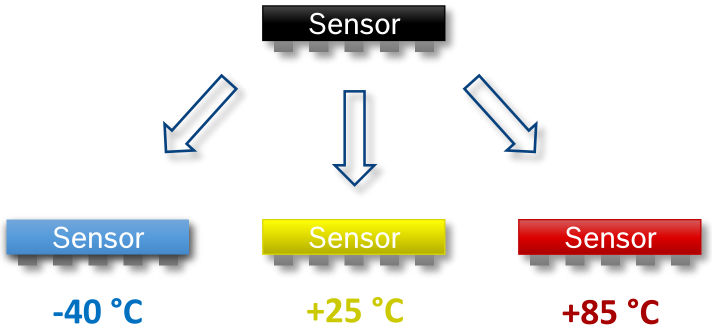


Achieving a reliable system model on a suitable abstraction level considering all relevant domain interactions is the key factor of success

Example – Radiometric effects in accelerometers

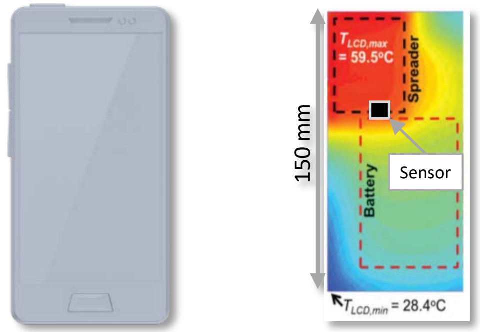
Homogeneous Temperature

- Intensively investigated[*1]
- Sensor characteristic dependent on CTE-mismatch
- Temperature trimming of sensor for compensation possible

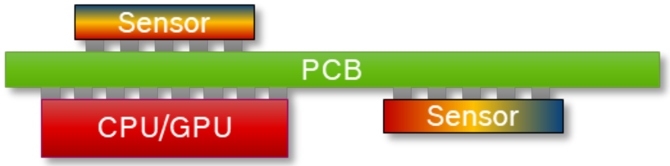


Temperature Gradient

- High integration density induces temp. gradients within the sensor[*2]



- Smartphone: $\frac{\Delta T}{\Delta x} \approx \frac{30\ \mathrm{K}}{150\ \mathrm{mm}} = 0.2\ \frac{\mathrm{K}}{\mathrm{mm}}$



*1 N. Yazdi, F. Ayazi, K. Najafi, Micromachined inertial sensors, Proceedings of the IEEE 86 (1998) 1640-1659.
*2 V. Chiriac, S. Molloy, J. Anderson, K. Goodson, A Figure of Merit for Smart Phone Thermal Management, Electronics COOLING (2015).

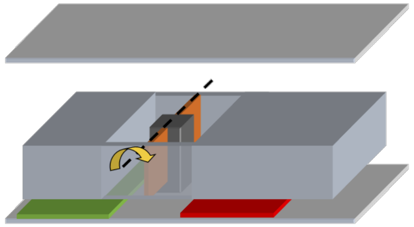
Challenges in design and simulation

Example – Radiometric effects in accelerometers

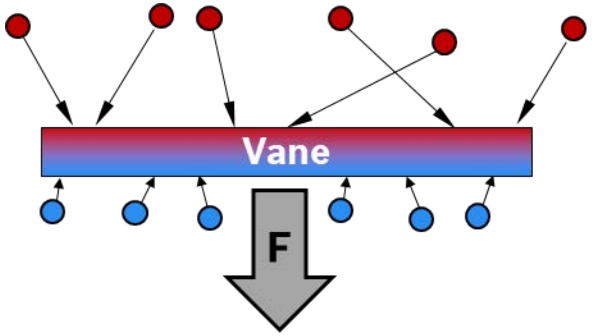
Published 2017 by
Dr. Cristian Nagel

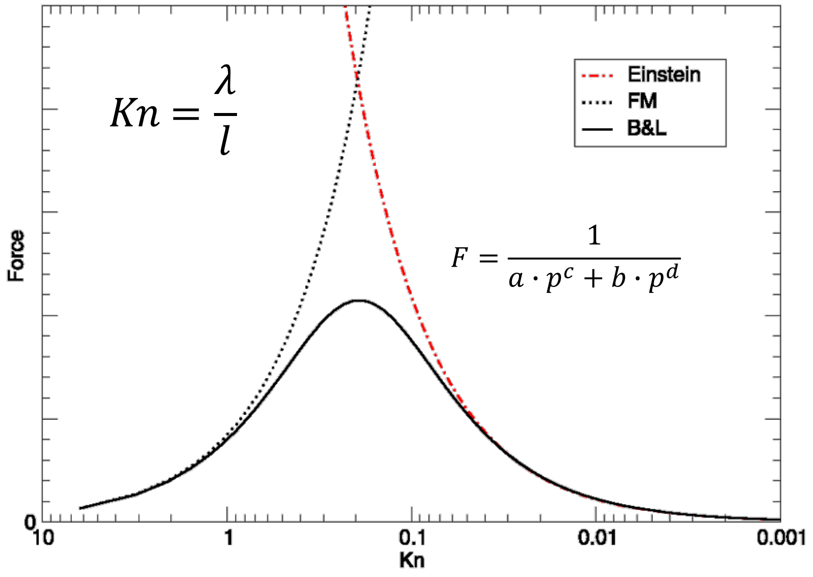
Temperature difference between both sides of single radiometer vanes

- Hotter gas molecules have higher momentum than cold gas molecules
- Net force:
  - Direction: from hot to cold
  - Shows bell shaped function
  - Dependent on gas species



µ-mechanical teeter totter of a z-channel accelerometer





Adapted from: Ketsdever, Andrew, et al., "Radiometric phenomena: From the 19th to the 21st century", Vacuum vol. 86, pp. 1644-1662, 2012.

The radiometric induced force can tilt a teeter totter MEMS structure in an accelerometer resulting in an artificial output signal: TGO (Temperature Gradient Offset)

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Example – Radiometric effects in accelerometers

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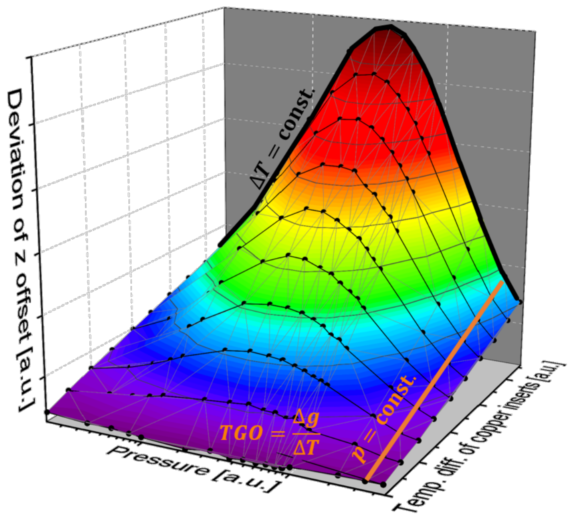
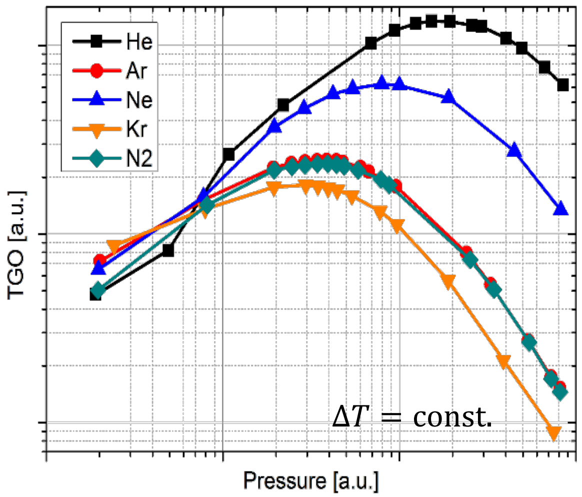
Influence factors (design parameters) for TGO:

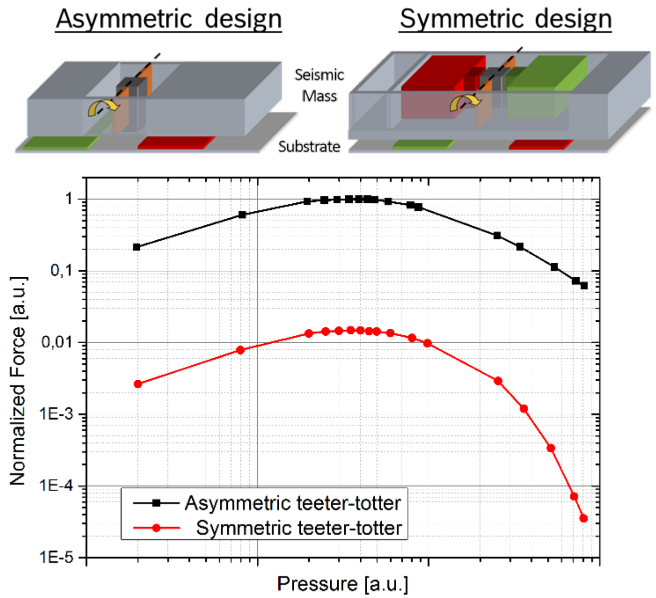
Cavern pressure:



Gas type:



Design of teeter totter:



Radiometric effect cannot be simulated using standard CFD (Fluid Dynamics) approaches. Simulations based on MD (Molecular Dynamics) cannot describe structures of several 100µm!

C. Nagel, T. Zoller, F. Ante, et al., Radiometric effects in MEMS accelerometers, 2017 IEEE SENSORS, 2017

Conclusion

- The markets and new use cases are pushing towards higher performance in MEMS at lower costs and current consumption

- To achieve the required accuracies new phenomena and physical effects must be taken into account

- The requirements on the simulation models increases parallel to the increase of product performance and accuracy

- To comply with the increasing demands on simulations and model accuracy new strategies towards „enhanced ROM“ and „HPC-based“ simulations must be developed

Thank you

Dr. Mirko Hofmann
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