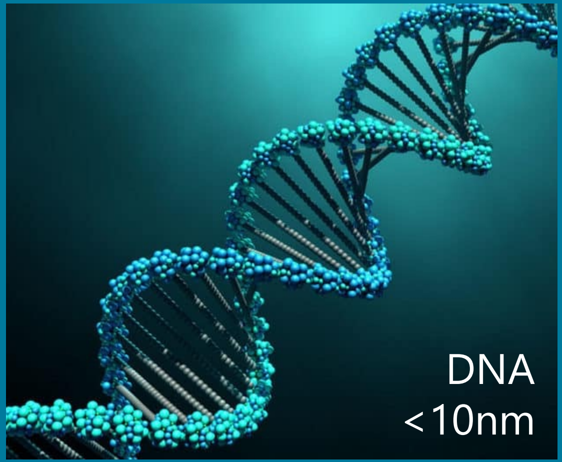
Zero AMP

30 years of xfab

Potential and Challenges of **NEMS** – *A Foundry View*



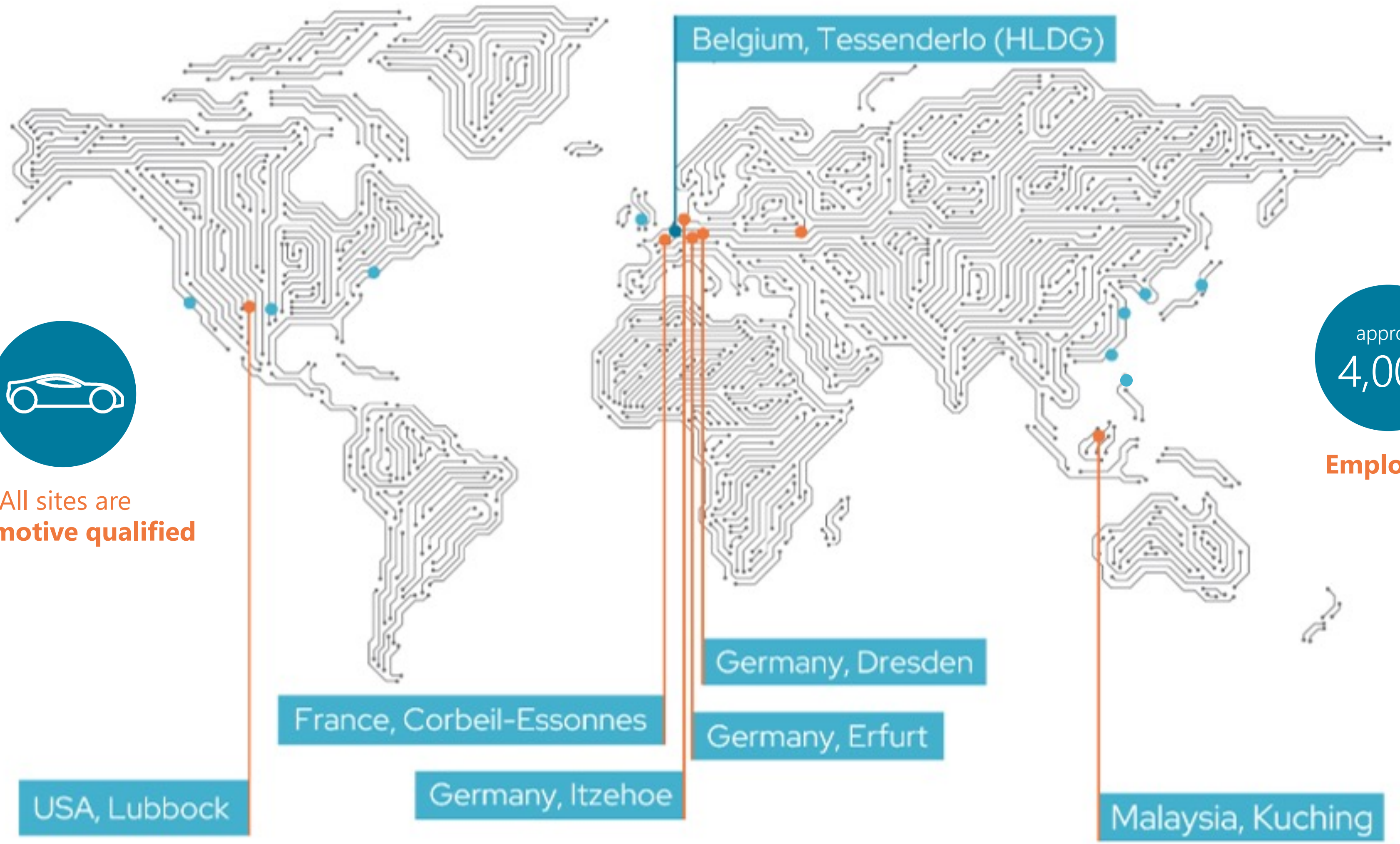
Dr. Stefan Ernst
Business & Strategy MEMS
Bristol, 30-June, 2022

X-FAB at a glance

6
Manufacturing facilities

All sites are **automotive qualified**

420
Customers in 4 key markets



100,000
Wafer starts per month*

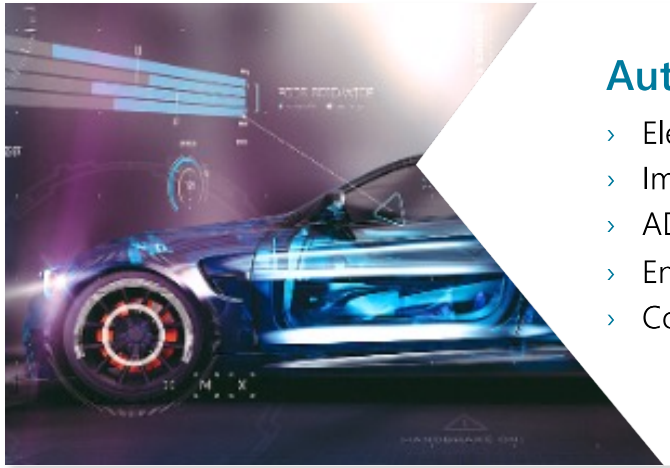
approx. 4,000
Employees

658 million $
Revenue 2021

Fabs/subsidiaries
Sales offices

*200mm equivalent

Serving the strongest growing end markets



Automotive

- Electrification
- Improved safety
- ADAS
- Environmental protection
- Connected cars and services

Industrial

- Power management
- Factory automation
- Intelligent drive and motor control
- Smart buildings and cities

Medical

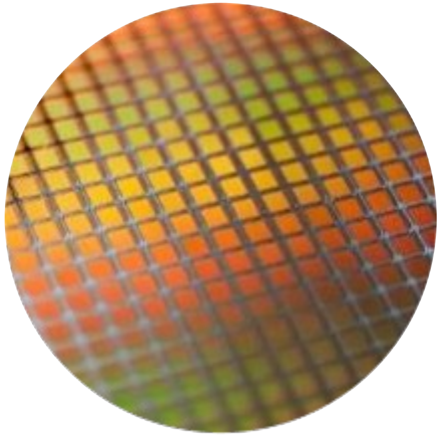
- Personal medical devices
- Medical equipment
- Lab-on-a-chip

Consumer, Communi-cations, Computer

- Smart home
- Connectivity
- Communication
- Appliances and HVAC

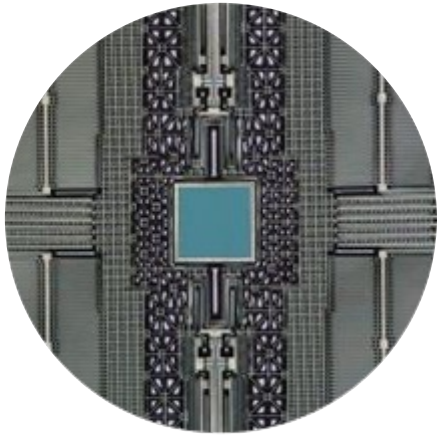
ADAS = Advanced Driver Assistance System, HVAC = Heating, Ventilation and Air Conditioning

Technology portfolio



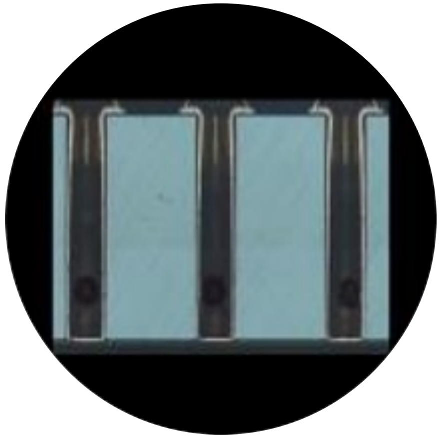
CMOS & SOI

13 process families with over 450 options



MEMS

MEMS with or without integrated CMOS



Heterogeneous integration

3D integration and wafer level package solutions

SiC & GaN

Processing technologies for WBG 6″ SiC & 8″ GaN-on-Si

CMOS & SOI offering

Large portfolio of process technologies & IP

X-FAB process portfolio and features

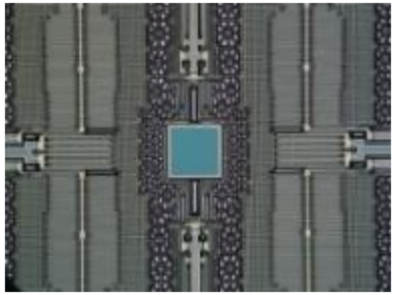
Technology node

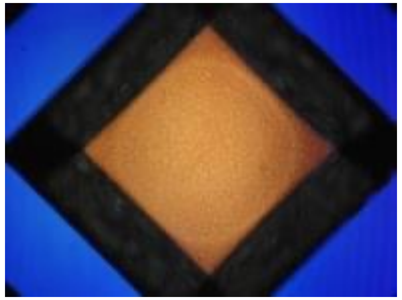
1.0 µm	Digital	Analog M/S	High Voltage	NVM		Opto	SOI	High Temp	MEMS
0.8 µm	Digital	Analog M/S	High Voltage	NVM		Opto			
0.6 µm	Digital	Analog M/S	High Voltage	NVM	RF	Opto	SOI	High Temp	MEMS
0.35 µm	Digital	Analog M/S	High Voltage	NVM	RF	Opto		High Temp	MEMS
0.25 µm	Digital	Analog M/S		NVM					
0.18 µm	Digital	Analog M/S	High Voltage	NVM	RF	Opto	SOI	High Temp	
0.13 µm	Digital	Analog M/S		NVM	RF		SOI		

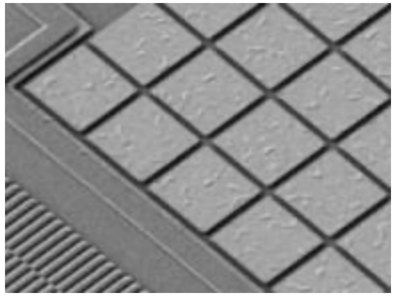
M/S = mixed-signal, NVM = non volatile memory, RF = radio frequency, SOI = silicon on insulator, MEMS = microelectromechanical systems, SiC = silicon carbide

MEMS Technology Pillars + Application view

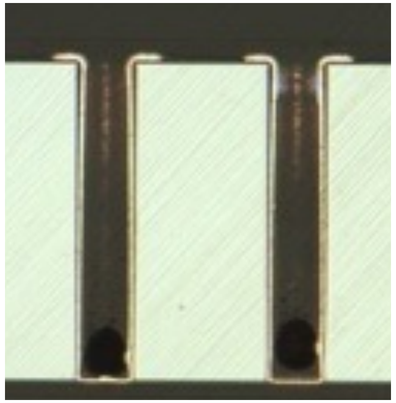
Sensors: Pressure, inertial, thermopile





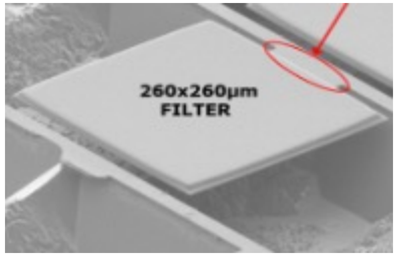


Functional surfaces & fluidic primitive devices

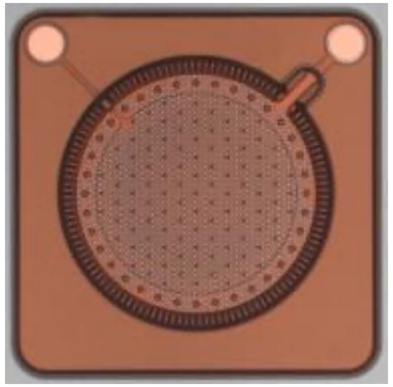


Wafer level integration and packaging

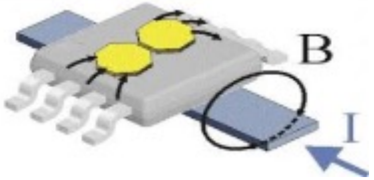
Thin-film Piezo-electric materials



Heterogeneous integration – Micro Transfer Printing (µTP)

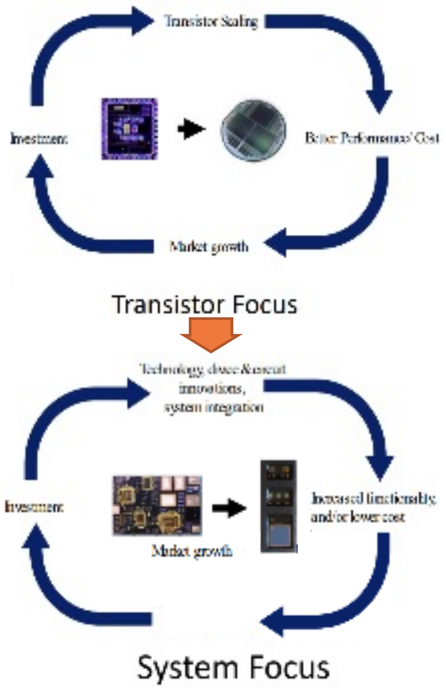


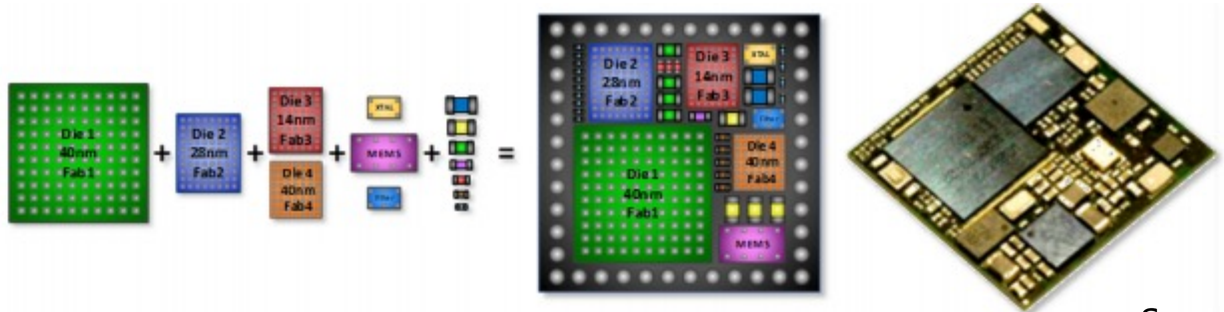
Customer specific processes



MtM Scaling. Heterogeneous Integration

- Semi industry experiences a paradigm shift from Moore's Law scaling to MtM evolution through **advances in system integration** in response to market applications
  - Mainly driven by High-Performance computing/data centers, IoT, Mobile, but also arrived in Medical/Health, Automotive and Production (c.f. HIR 2020 Edn.)
- **Heterogeneous Integration** (Source ITRS):
  - integration of separately manufactured components into a higher-level assembly (System in Package – SiP) that, in the aggregate, provides enhanced functionality and improved operating characteristics.
  - Components: any unit, whether individual die, MEMS device, passive component and assembled package or sub-system.
- **The Three Levels of Heterogeneous Integration**
  - Chip/Device Level – System Level – Software / Application Level. (J. Alvarez, Intel PSG CTO, February 20),

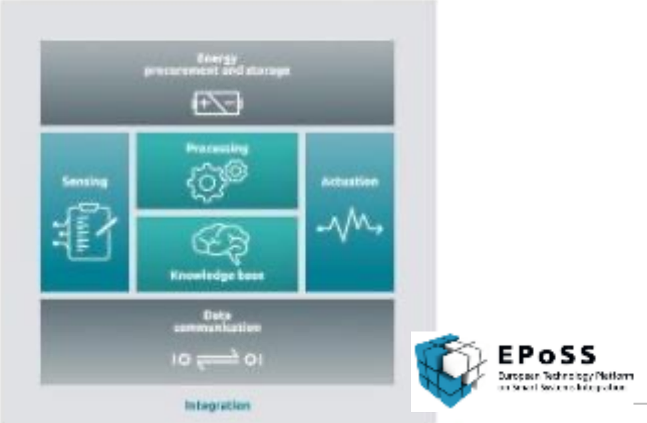




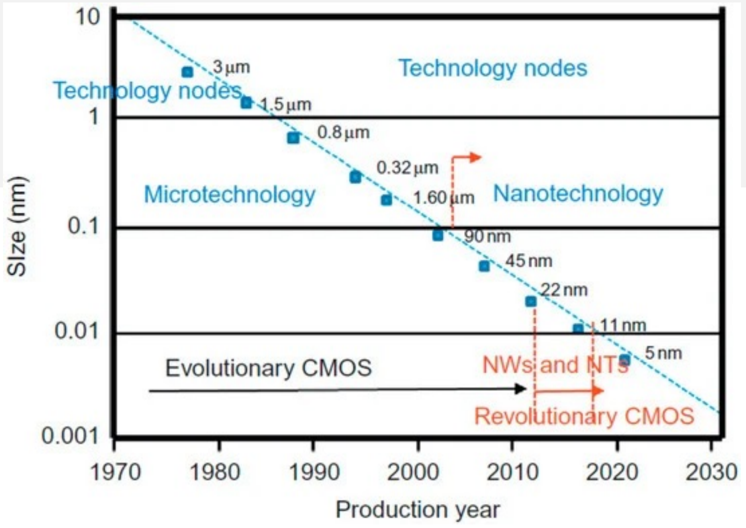
Die + Heterogeneous

System in Package (SiP)

Souce: ASE Group

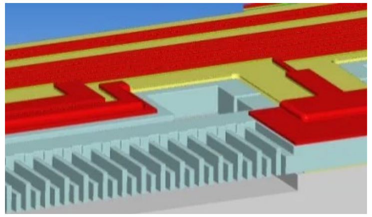


Why NEMS?

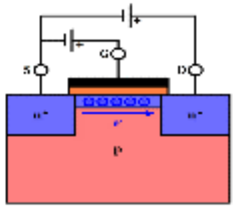


- integrating electrical and mechanical functionality on the nanoscale
- first demonstration of VLSI NEMS device by IBM in 2000: “MILLIPEDE”, array of AFM tips which can heat/sense a deformable substrate → memory device.

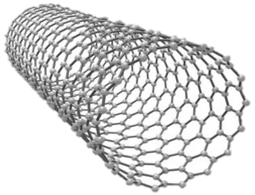
MEMS



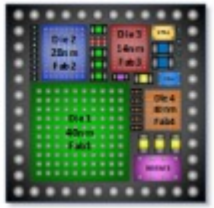
Mixed-Signal ASIC’s



Functional Materials



Advanced Packaging



Miniaturization

Enhanced opera-ting conditions

New Device Concepts

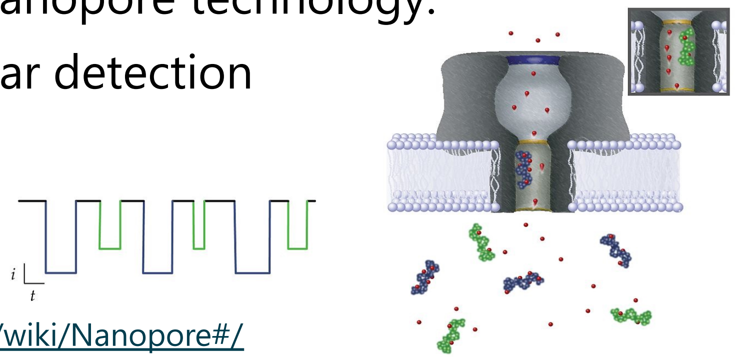
Heterogeneous Integration

NEMS / Nanotechnology

NEMS & Nanotechnolgy for Biomedical Applications

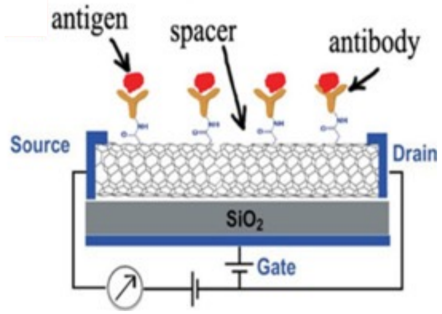
Nano-structured materials to detect biological features on molecular scale

- (Solid-State) Nanopore technology: single-molecular detection

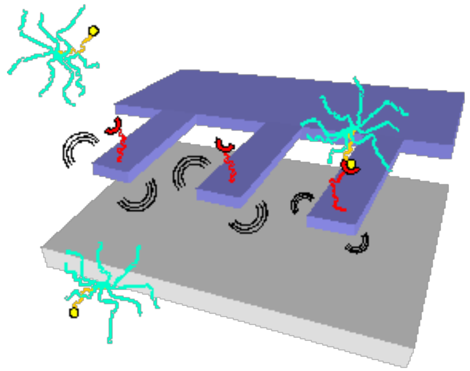


https://en.wikipedia.org/wiki/Nanopore#/

- Low-dimensional materials: enhanced biosensor performance
  - 2D: Graphene, TMC's etc
  - 1D: Carbon Nanotube (CNT)

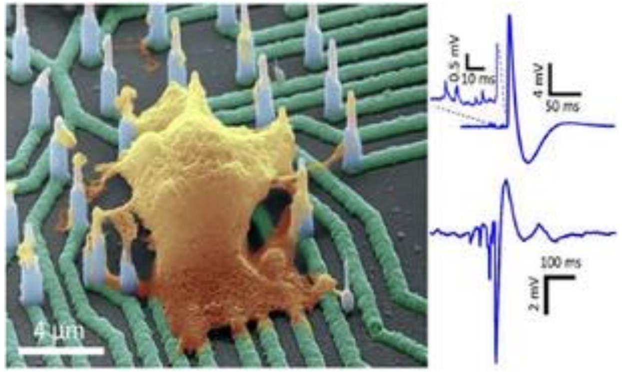


- BioNEMS: extend Chemical Force Microscopy (cantilever-based sensors) to bio-assays



http://nano.caltech.edu/research/nems-biosensors.html

- Nanoelectrode Arrays (NEAs): real-time dynamic analysis on different biological levels (cell, tissue, organ)

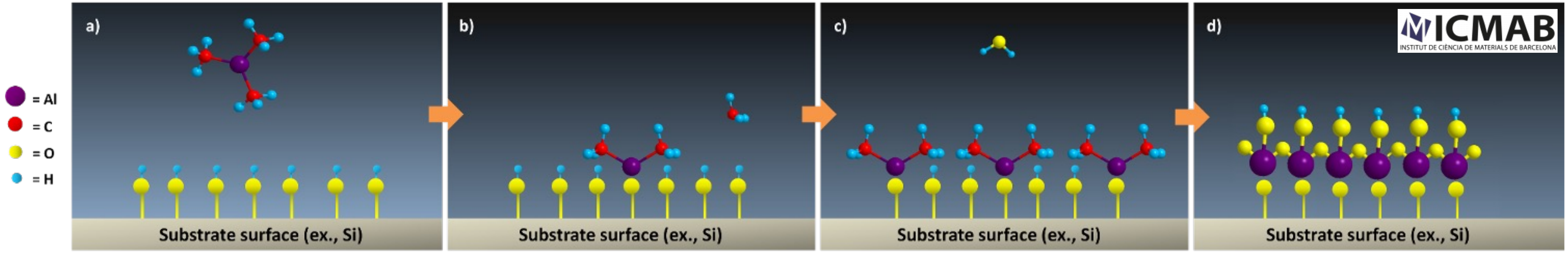


https://www.frontiersin.org/articles/10.3389/fchem.2020.573865/full

Atomic Layer Processing

- **Atomic Layer Deposition (ALD):** Chemical Vapour-phase Deposition method based on a sequence of (one ore more) self-limiting surface reactions, leading to conformal growth of individual monoatomic layers

Example of Al_2O_3 layers grown by trimethylaluminum (TMA) and H_2O



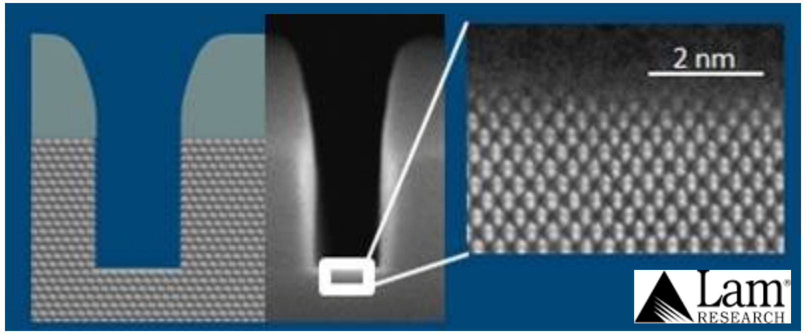
a) Pulse precursor A on activated surface.

b) Precursor A reacts with surface.

c) Reaction active till surface passivation . Purge with inert gas the remaining precursor. Pulse Precursor B to activate the new surface.

d) Precursor B has activated the surface. Ready to pulse precursor A again (start the cycle).

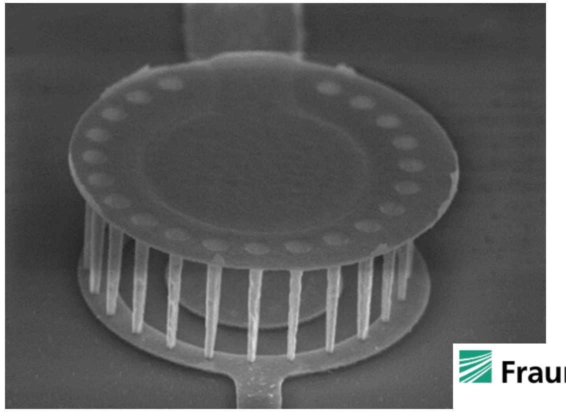
- **Atomic Layer Etching (ALE):** sequence alternating between self-limiting chemical modification steps which affect only the top atomic layers of the wafer, and etching steps which remove only the chemically-modified areas, allowing the removal of individual atomic layers



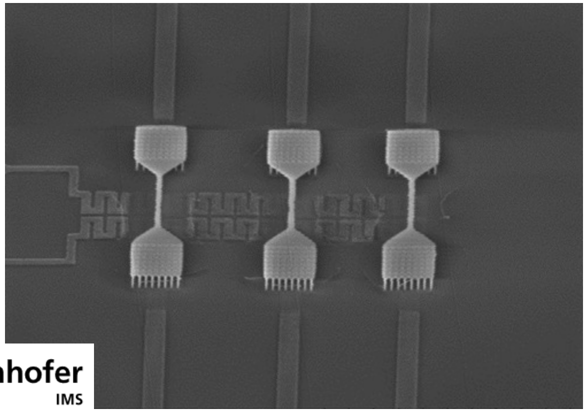
Atomic Layer Deposition - Examples

xfab

- Sacrificial Layer Technologies for creation of 3D NEMS



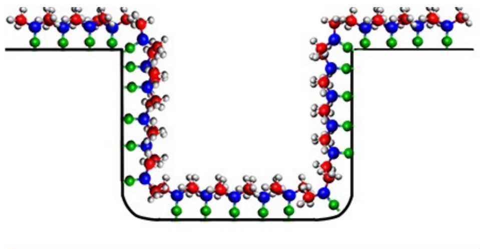
3D-Membrane
(capacitor, micro scale)



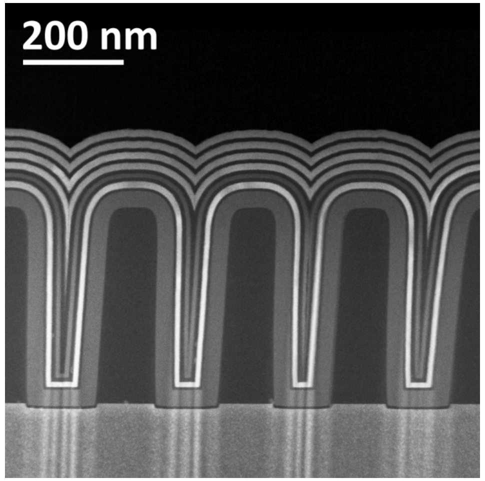
Fraunhofer IMS

Freestanding Nanowire
(heater, gas sensor)

- Conformal thin-layer deposition (passivation, functional layers

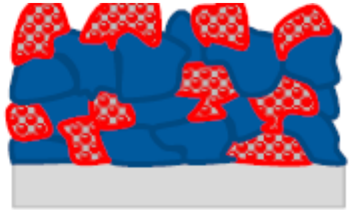


https://www.atomiclimits.com/imagebase/



- Nano-strctured materials

Nano laminate:
High specific number of Al_2O_3 and ZnO cycles, deposition of a close layer before starting with pulsing the second material



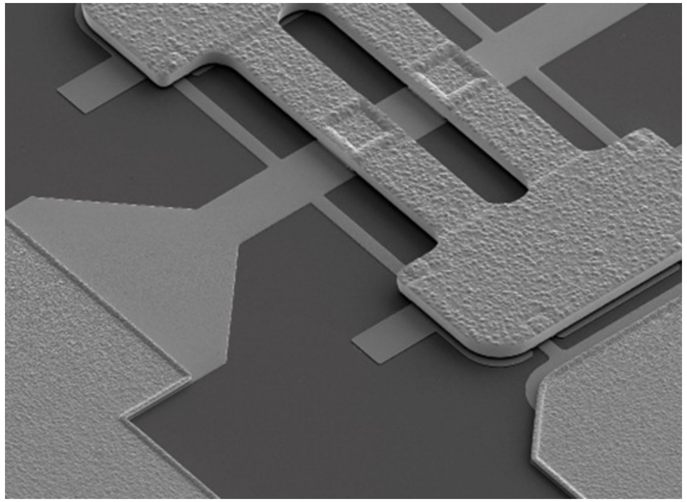
Homogenous mixture:
Low specific number of Al_2O_3 and ZnO cycles, just nucleation until starting with pulsing the second material

Fraunhofer IMS

NEM relays / switches

Advantages of MEMS/NEMS technology for switching application:

- Low leakage (IoT -> power gating: extend power source lifetime; low duty-cycle applications)
- Low power consumption
- reduced switching losses and parasitics, multiple frequencies on one chip (RF MEMS)
- Extended operating temperature range
  - CMOS operatonal up to 175°C -> M/NEMS can extend to 300°C and beyond
    - Reliability: high T over all mission profile
  - Batteries are temperature limited -> replace by super cap
- High voltage / high power capability: galvanic isolation
  - MEMS Driver, Level Shifter
- Scalable / CMOS integrable

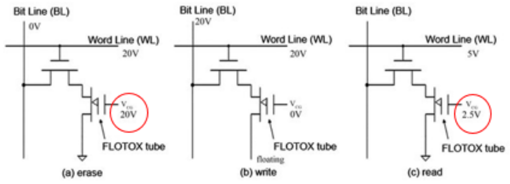


Source: Menlo Micro / EE World

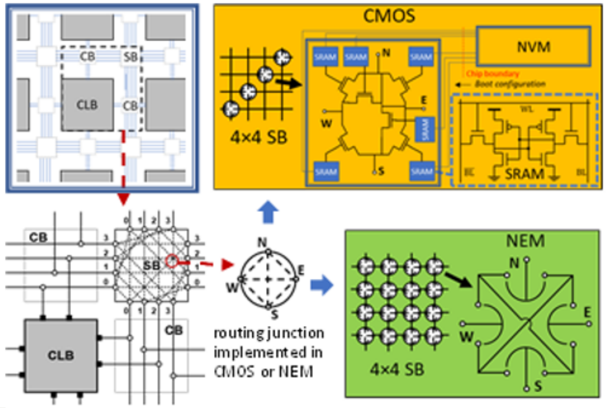
NEMS for digital / logic design

NEMS and their beneficial characteristics

- Design advantages over CMOS
  - Simpler memory design (one voltage for both reading and programming)
  - Logic and memory use the same technology – powerful platform for edge compute
    - Lower power usage for FPGA implementation of Artificial Neural Networks (ANN)
    - Greater flexibility and simplicity of FPGA switch box
    - “On the fly” ANN level adjustment – no remote memory



EEPROM memory read/write



Zero AMP
CONFIDENTIAL INFORMATION

MICROCHIP xfab AMO University of BRISTOL KTH csem SCIPROM

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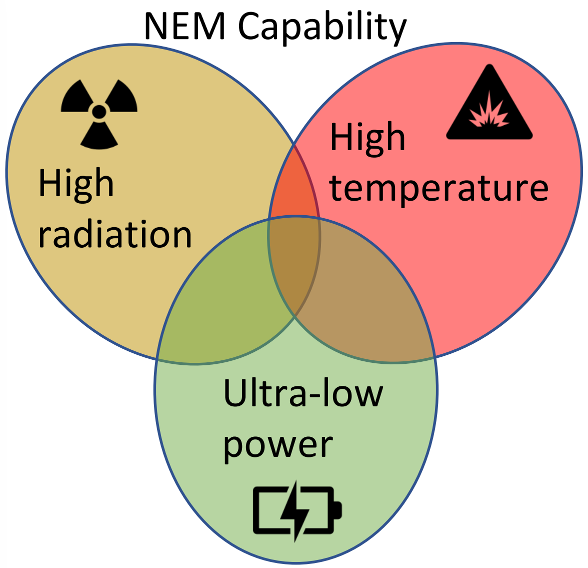

Zero AMP

Industrialization Challenges

In general *(and related to ZeroAMP)*

A) Process Technology: new Functional materials *(e.g., contact material & design)*

- Process maturity and compatibility / scalability
- Performance & Characteristics *(contact resistance, sticky vs. non-sticky contact, …)*
- Reliability *(Wear-out, # of cycles)*

  → **in-depth material characterization needed**

- Process integration

  last: High-T compatible metallization)

- Integration into existing manufacturing ecosystem;

  Cross Contamination management

- Process Control / Q-gates

Industrialization (cont'd)

In general *(and related to ZeroAMP)*

B) Application View:

› System Architecture *(Integration of memory or logics with drive / read-out capable with high T)*

› Ecosystem for system design and supply chain

C) Commercial Aspects

- Advantages of NEM-based technologies are very specific
  - niche applications challenge economy of scale
- High-volume applications (IoT) require economy of scale
  - significant invest, cost of ownership
- Cost of quality / yield

Conclusion

- NEMS constitute a promising technological approach for a number of applications
  - Efficiency gain for logic, power mgnt, RF, …
  - Extended operating areas unlock new applications
  - Enhanced sensor architectures
- Still at early stage
  - Challenges of industrialization
  - Time to shape the future:

    building a technology roadmap tailored to application needs

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 871740 (ZeroAMP).

Thank you.

www.xfab.com