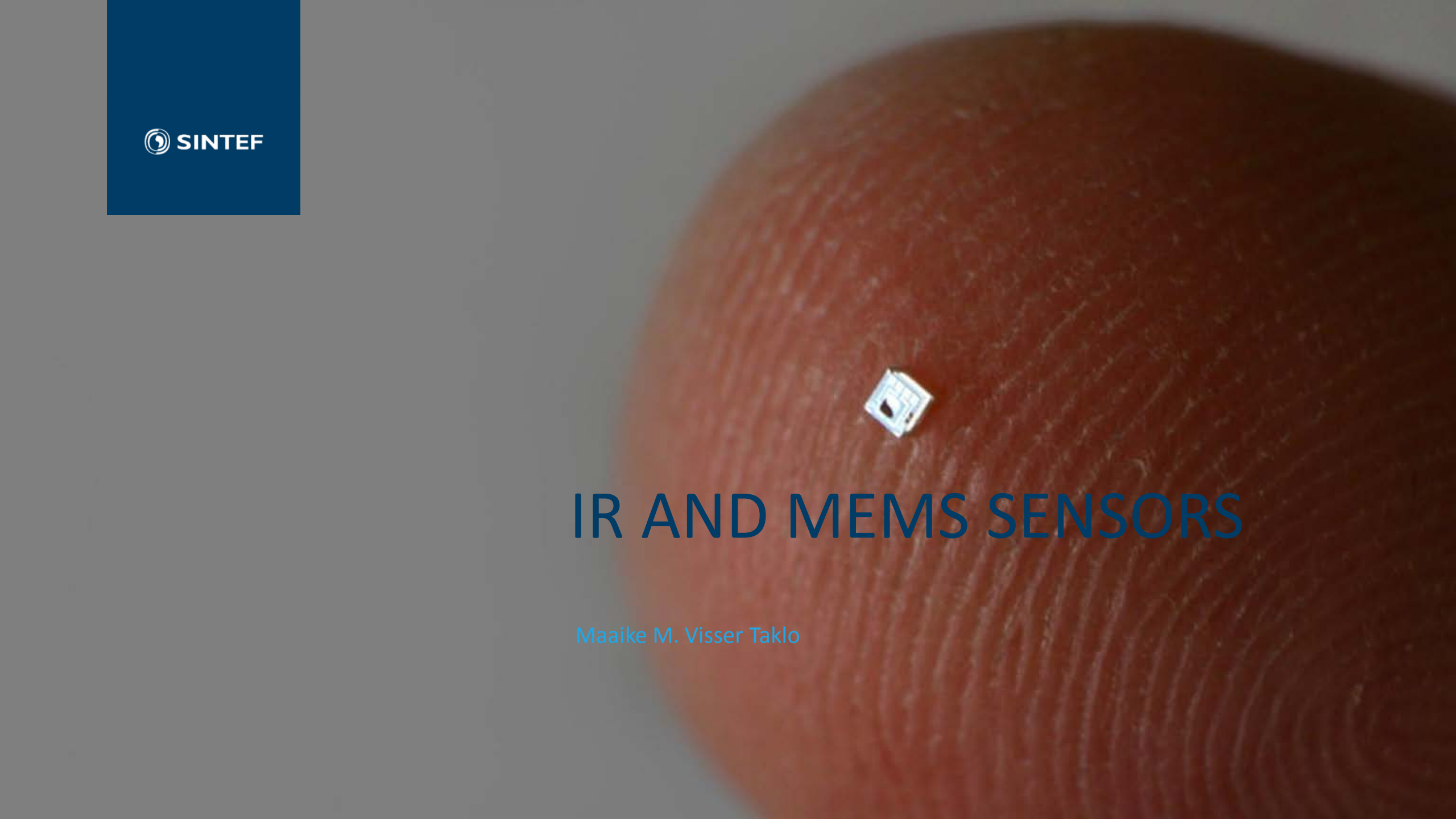

IR AND MEMS SENSORS

Maaike M. Visser Taklo

Outline

- History
  - From niche to mainstream
- New enabling technologies
- Examples of today's sensors
  - Mix of old and new technologies
- Future needs
  - More of the same, or new trends? Some perspectives for the future

SOME HISTORY

Where did we start?

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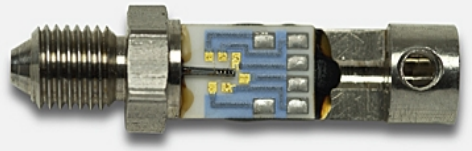
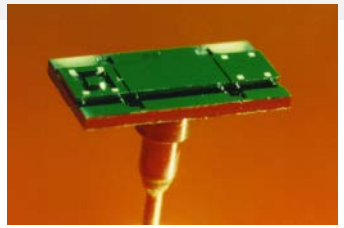
📖 P. Ohlckers and H. Jakobsen, Microelectronics Journal, vol. 29, pp. 587-600, Sep 1998.

Niche applications

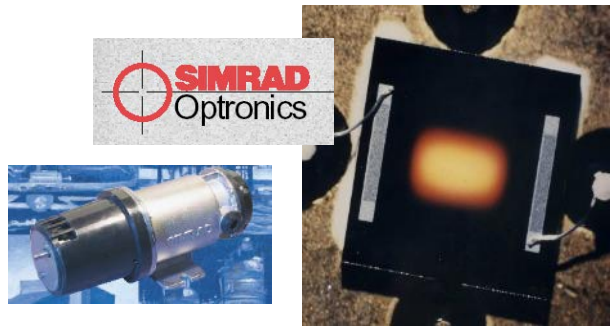


Various pressure sensors



📖 S. Moe et al., S&A 2000

- R&D in silicon sensors since 1961
  - The IC-development would become too low cost…
  - Piezoresistive based beams/membranes
  - Radiation sensors for high-end products
- Low and medium volume production since 1979
  - IR-emitter and pressure sensors among first MEMS products
  - Market primarily driven by the oil and gas industry



IR-emitter, for detection of hydrocarbons and CO_2

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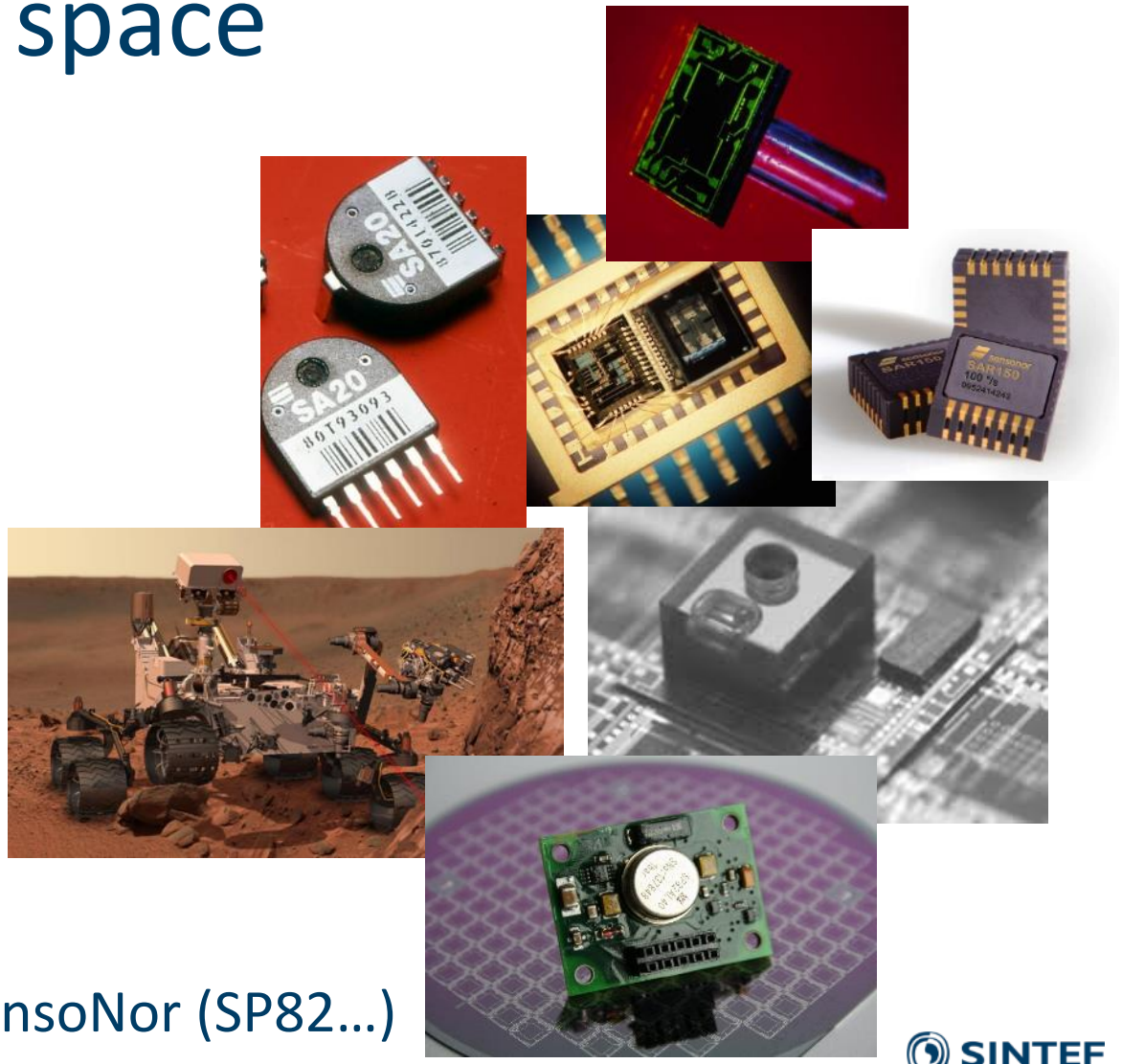
Automotive, aerospace, space

- 1965 AME founded
  - 1972 Accelerometer AE864, military application
  - 1980 AE880 Pressure sensor
- 1985 SensoNor spun off
  - 1992 SA20 Low cost accelerometer
  - 1998 SP13 Tire pressure sensor
  - 2003-2009 Infineon, TPMS
  - Now: STIM300 etc…
- 2002 Memscap acquired Capto, from SensoNor (SP82…)



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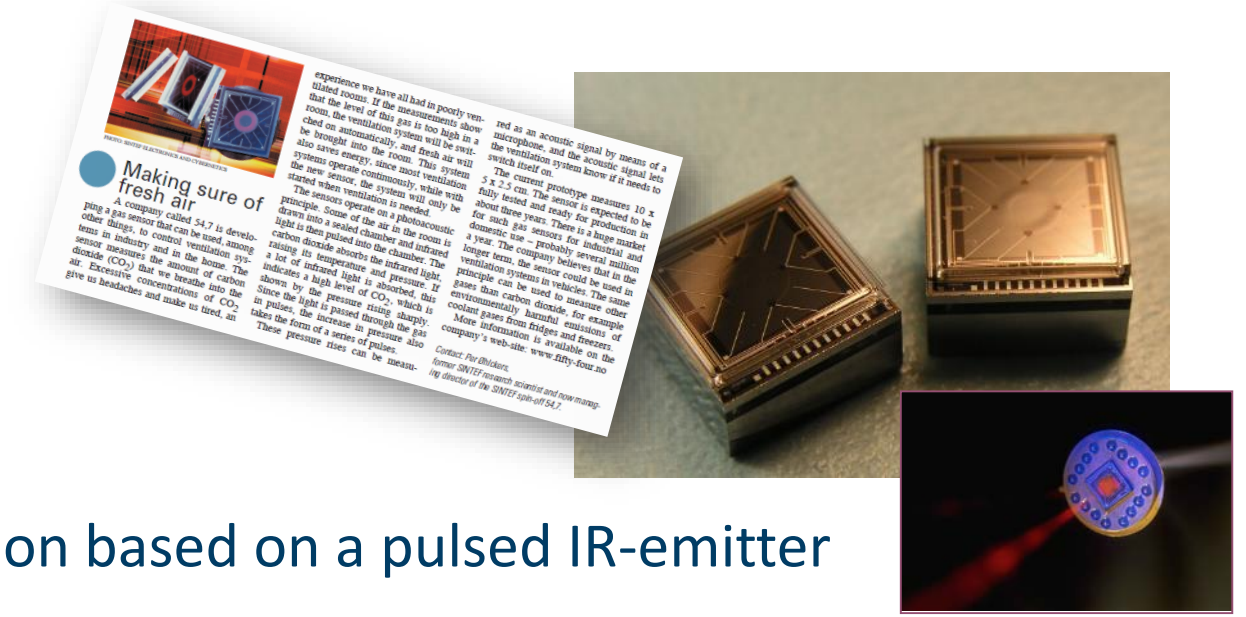
Design modifications introducing DRIE

Wellbeing and health



- A selective gas sensor for CO_2 detection based on a pulsed IR-emitter and a miniature photoacoustic gas sensor
  - Gas filled cavity, temperature increase for absorbed light, change in amplitude measured

📖 O. Schulz et al., Eurosensors XIX 2005

- Memscap, blood pressure measurements
  - Simple design, originally from 1965
  - Redesigned for lower cost manufacturing

📖 O. Eriksen, Electromechanical transducer for stress, pressure and acceleration measurements, Norwegian Patent no. 115502. Submitted 1965, accepted 1969

📖 Ingelin Clausen et al., JMM 2012

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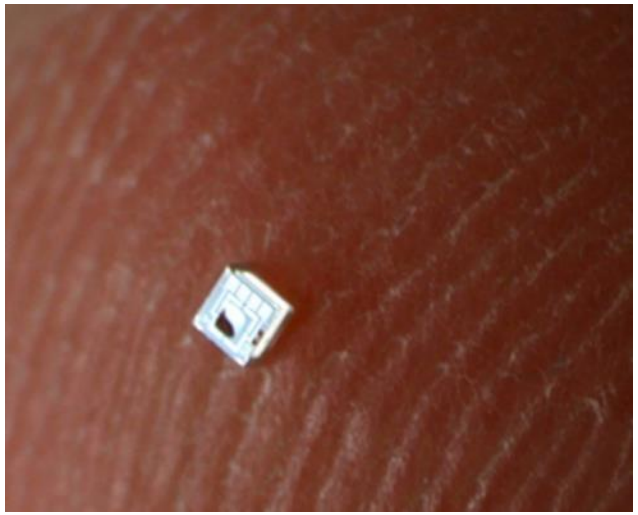
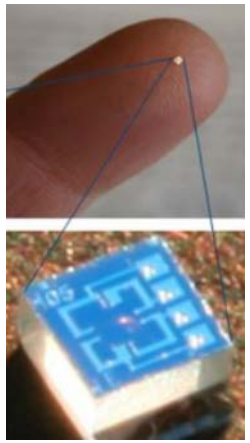
Shrunk to a minimum

- Pressure sensor for bladder examination
  - Can avoid life-threatening situations after spinal injuries
  - Clinical trials





📖 http://geminiresearchnews.com/2014/04/lifesaving-sensor-for-full-bladders/

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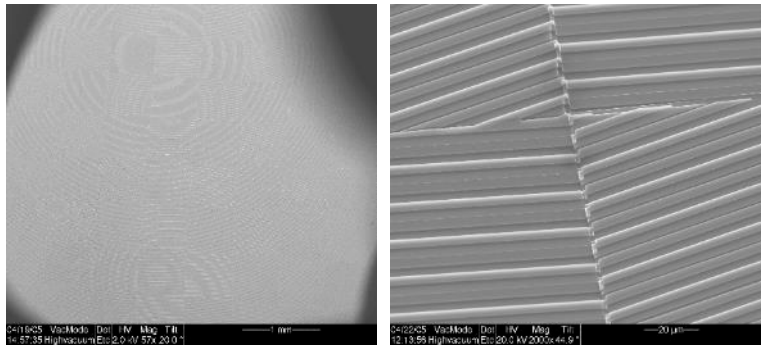
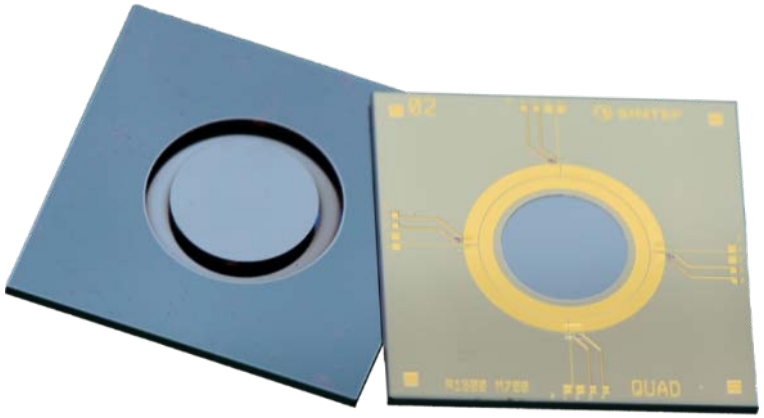
ENABLING TECHNOLOGIES

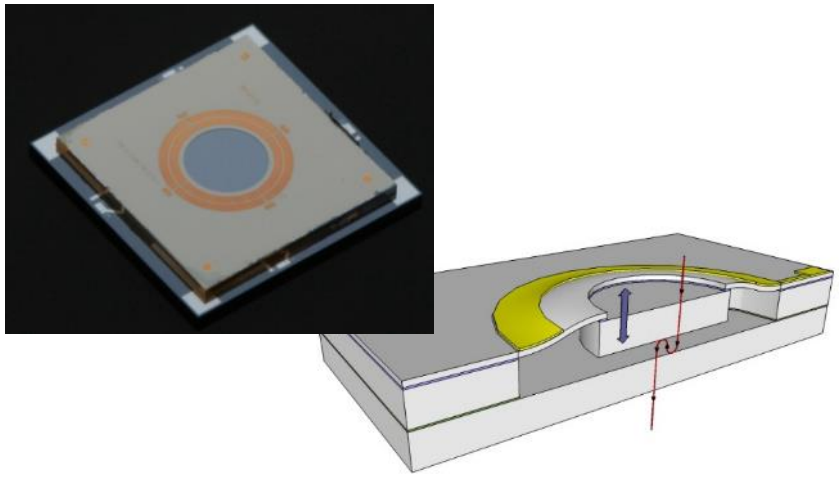
Solutions enabling steps closer to more widespread applications

MOEMS, optics and MEMS united

- Diffractive optical elements
- Tunable Fabry Perot structures
- Mirrors







📖 Thor Bakke and Ib-Rune Johansen, Optical MEMS and Nanophotonics conference 2012

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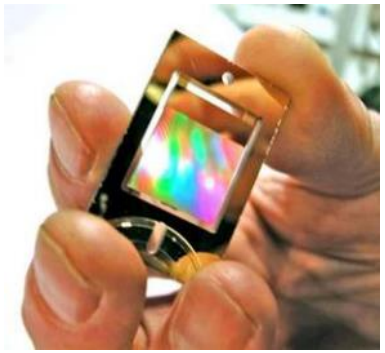
Industrial applications, light diffraction

Titech Visionsort

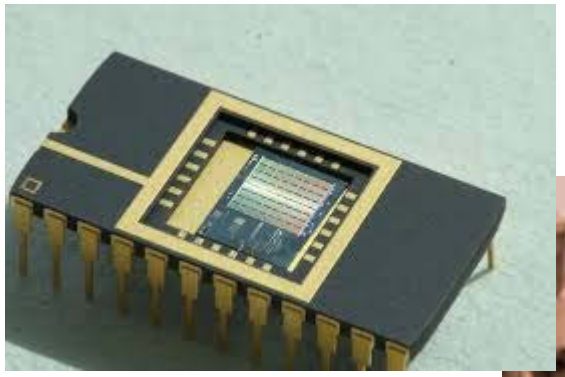
- Waste sorting

📖 www.sintef.com



GasSecure, a Dräger company

- Detect hydrocarbons



📖 www.gassecure.com

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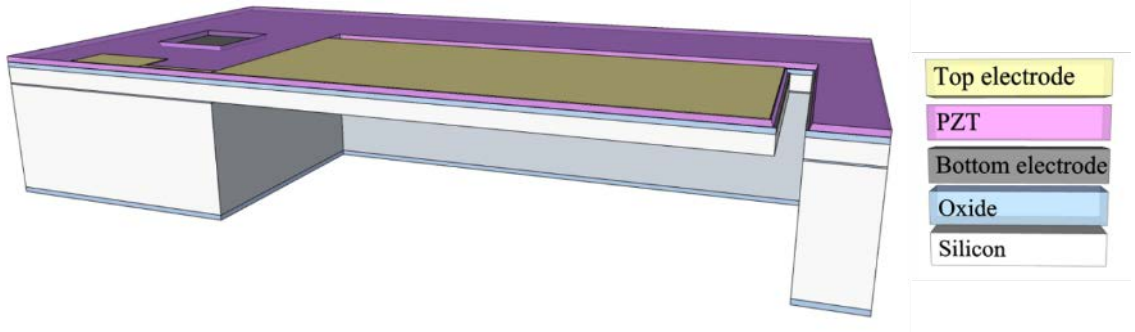
Piezoelectric material, PZT

- Innovative designs
- High volume manufacturing
  - Process integration
- Reliable performance in daily environment



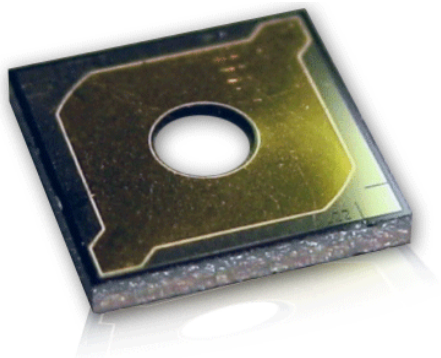
Chemical Solution Deposition

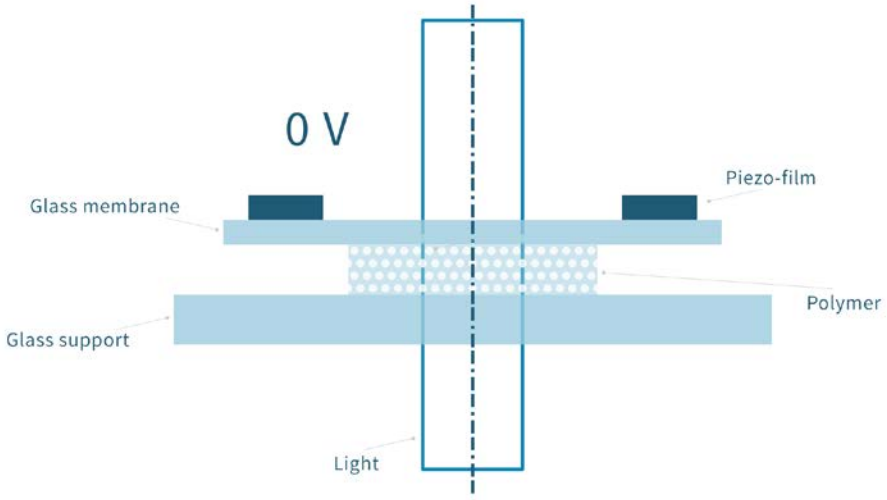
Pulsed laser deposition

Aotofocus lens

- SINTEF patent from 2006
- poLight is one of the pioneers in high volume piezoMEMS fabrication
  - High speed and ultra low power

poLight





📖 http://polight.com/technology/how-does-it-work/

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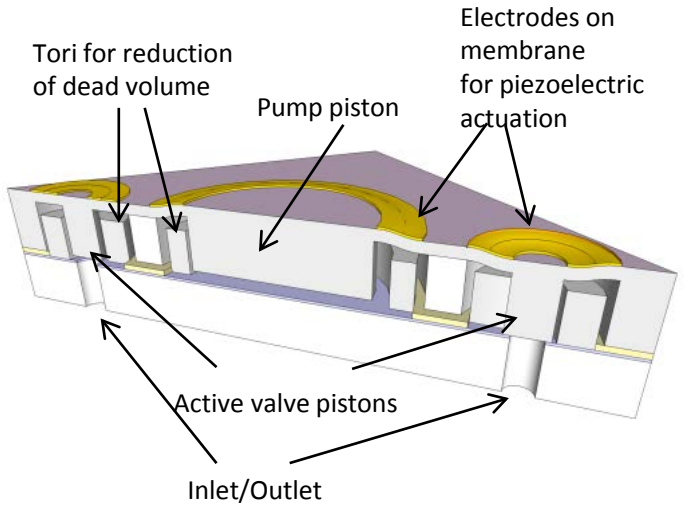
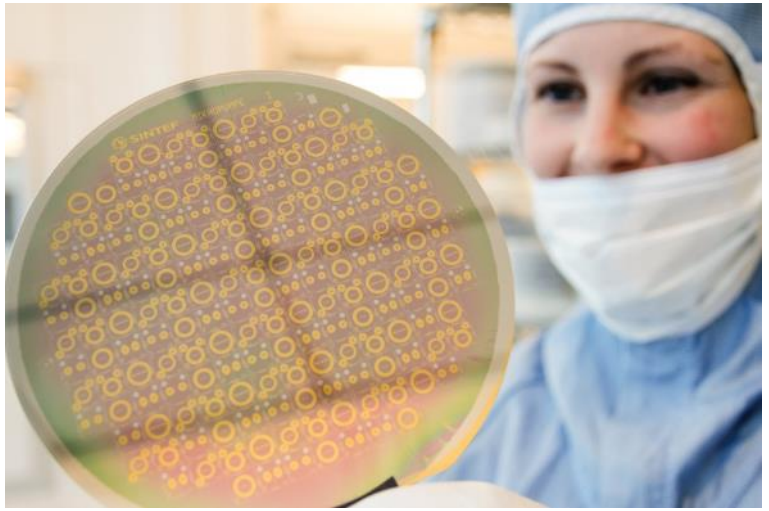
Micropumps



- For microfluid system activities



📖 Tofteberg, Hannah Rosquist; Bakke, Thor; Vogl, Andreas; Mielnik, Michal Marek; Østbø, Niels Peter. Micropump with active valves based on thin film PZT. piezoMEMS 2014; 2014-10-28 - 2014-10-29

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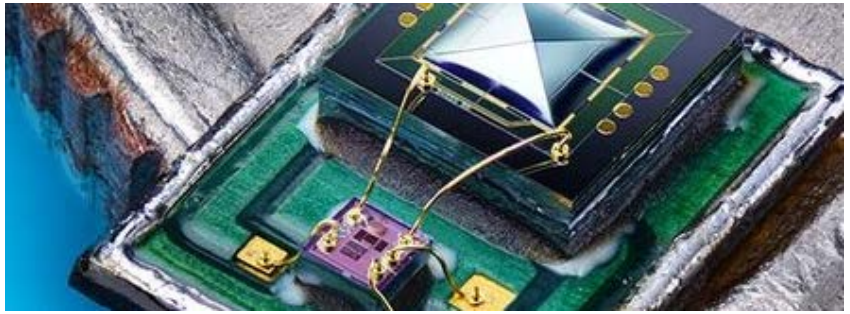
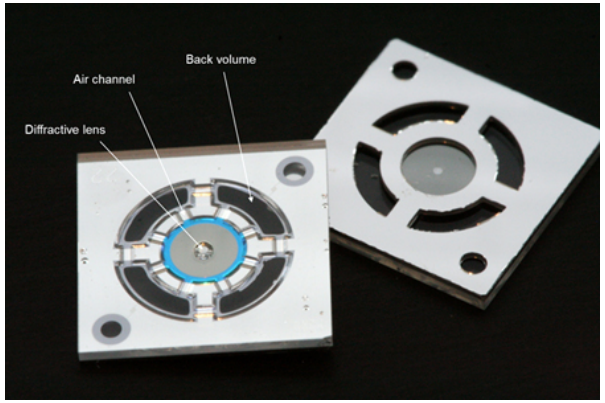
Microphones, a good one – and many

📖 www.memsjournal.com/2015/07/mems-microphones-emerging-technology-and-application-trends.html

- Trend: Request for very high signal-to-noise ratio
  - Challenge of arrays: Need matched sensitivity and phase
    - Arrays for noise cancellation/directionality
    - But also for gesture detection and as gyros, and …?
  - Vesper: Piezoelectric (AlN) rather than capacitive, SNR 68 dB
- Readout based on infrared optical technology
  - SNR 80 dB demonstrated
  - The sensor "sees" the sound
    - SINTEF, Norsonic, Norsk Elektrooptikk, Cisco, Forskningsrådet





📖 http://optics.org/news/4/7/9

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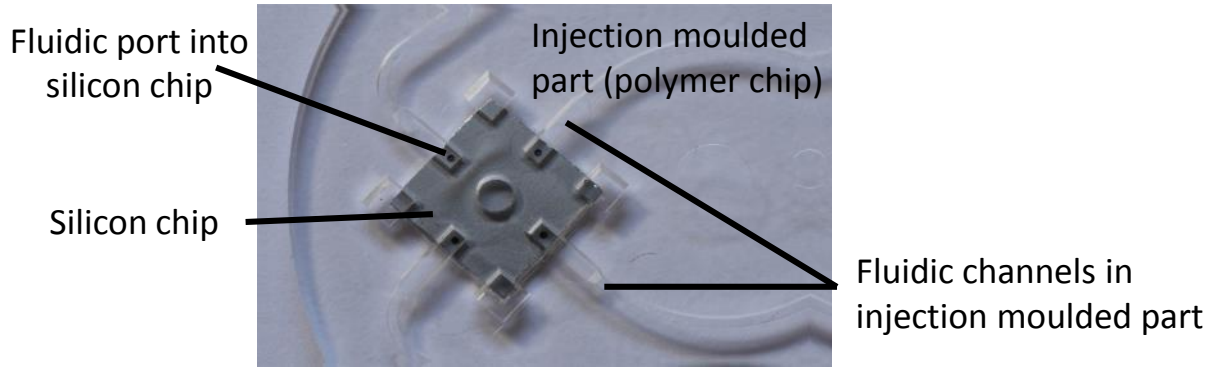
🕮 http://www.sintef.no/siste-nytt/forsker-pa-mikroplastens-morke-sider/

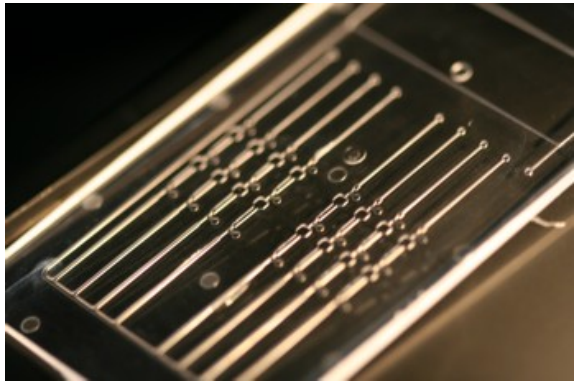
Cost reductions through polymers

- Not hermetic
- Not strong
- Not stable
- Even harmful…..
- But LOW COST
  - And flexible, formable, …

Valves, silicon integrated in polymer

- Direct integration of fluidic MEMS in polymer
  - By injection molding





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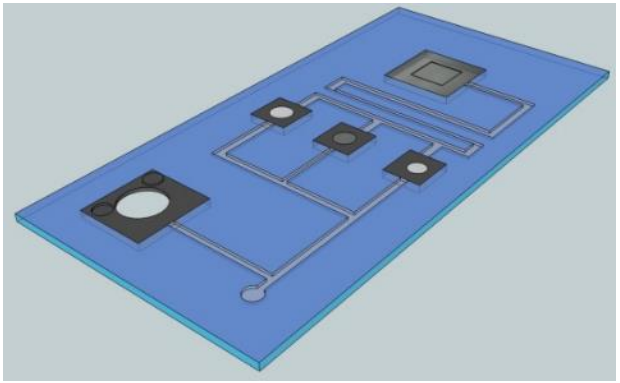
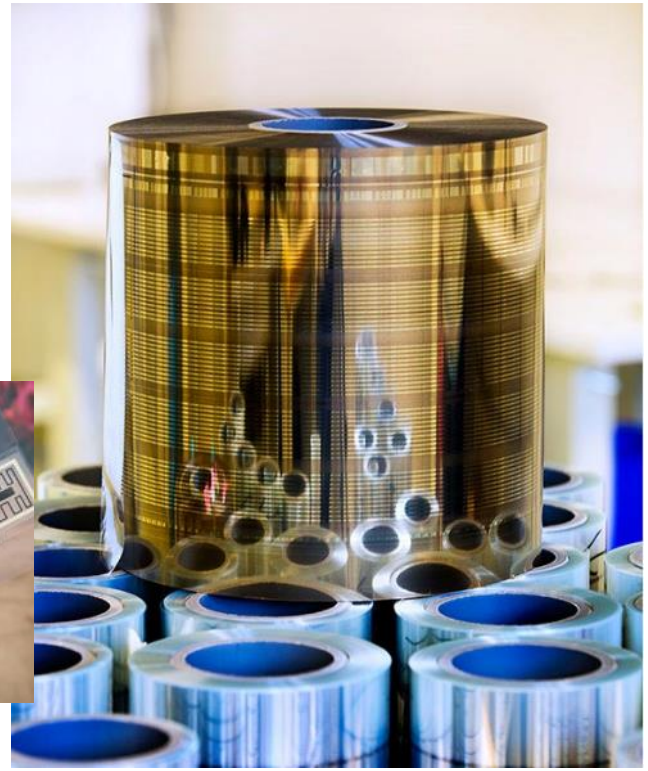


📖 MM Mielnik, T Tofteberg, E Andreassen, Chemical and Biological Microsystems Society 2013

Assembly of sensors to flex

- Hybrid integration, roll-to-roll
  - Smart tags with sensors, display, NFC, … food control, medicines
  - Similar challenges for assembly and interconnects



📖 http://thinfilm.no/technology-printed-electronics/

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THOUGHTS ABOUT THE FUTURE

Which niche device will be the next consumer product and which enabling process will bring us further?

Megatrends

"Scientifically automated amoral cars will be much safer than the average drunk/ tired/ old/ inexperienced/text messaging driver. Pick your choice."

📖 Yole, October 2016

- Assist ill/elderly at home

- Autonomous cars

1980s: Demonstrated
Now: Level 2, feet off
2025: Level 3, hands off
2030: Level 4, eyes off

📖 www.protradertoday.com/report/driverless-car-infrastructure/1527

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Spectroscopy, a candidate for upscaling

- Analysis of
  - The air we breath in
    - and breath out
  - The food we eat
    - Allergens
    - Quality and readiness
    - Toxicity
  - The ground we walk or drive on

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Mirrors/filters, cost reductions ongoing

- Reflect or remove light
  - Tunable and low cost
    in combination with MEMS
  - Photonic crystals for "super" mirrors
- Pico-projectors
  - For sharing phone experience

📖 http://www.ericpickersgill.com/removed

📖 http://www.lab4mems2.ite.waw.pl/overview.html

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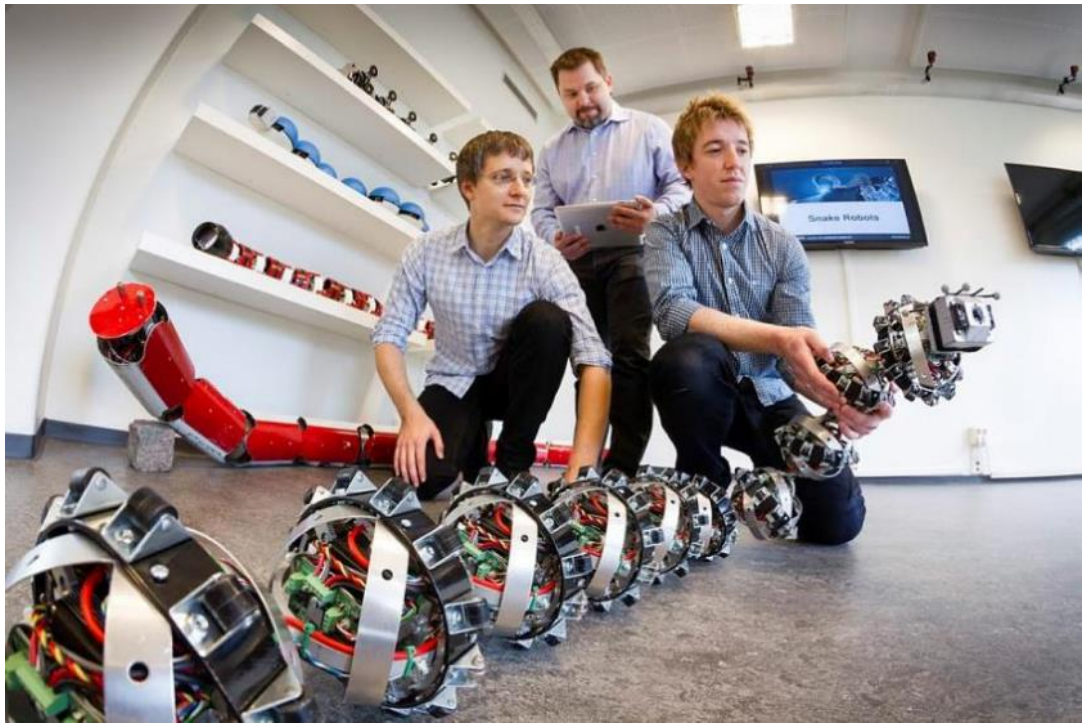
Pressure sensors, tactic sensors

- Improved granularity of GPS in height
  - From avionics (height detection)
    to elderly (fall detection)
- Feedback to robots
  - From industry robots
    to service robots



📖 NTNU/SINTEF, snake robot Wheeko, Foto: Thor Nielsen

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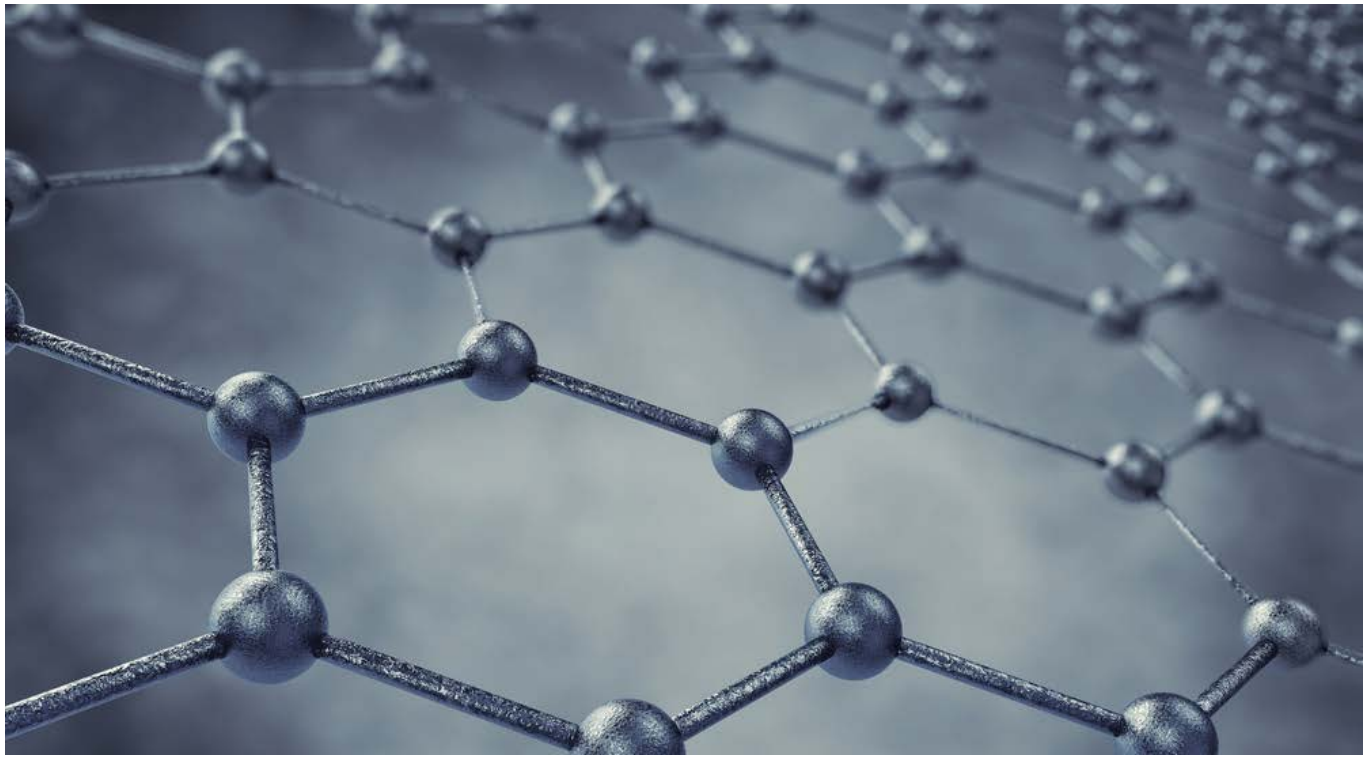
Enabling, but diverged, processes

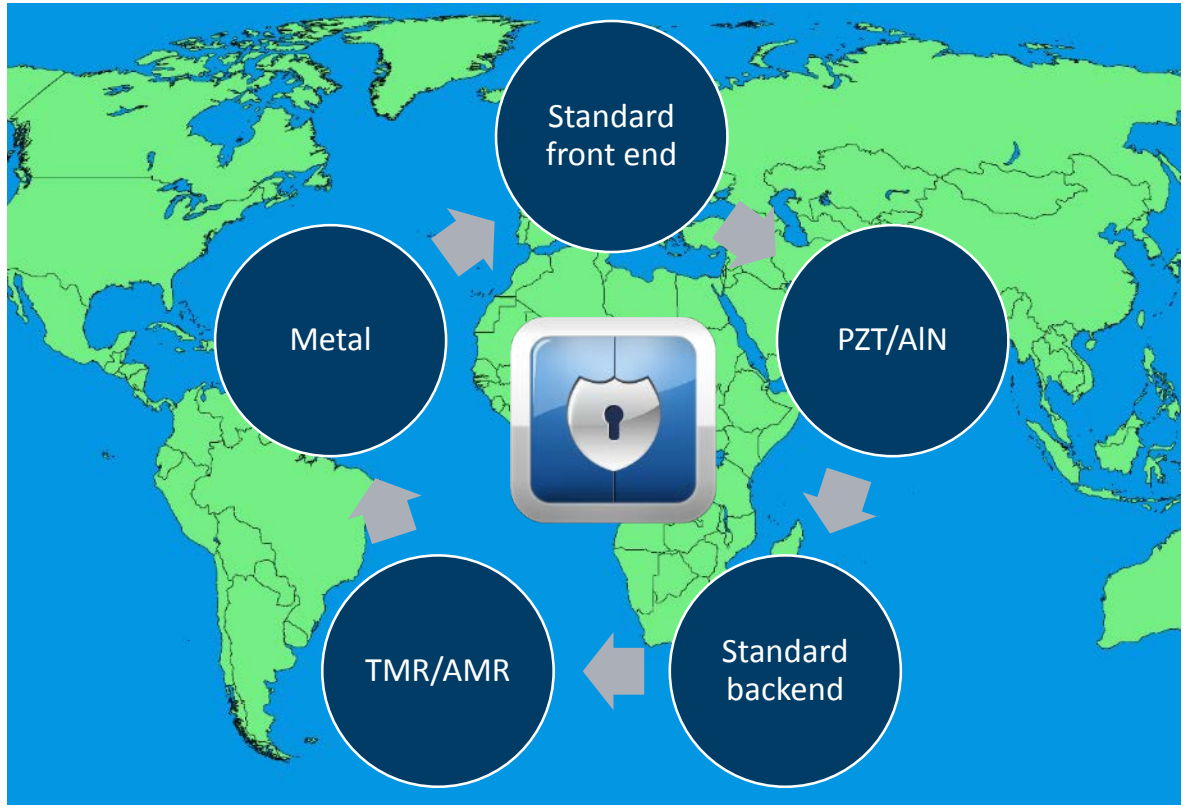
- Magnetic layers
- Piezoelectric layers
- Hydrogel layers
- Nanoparticle layers
- Graphene/CNTs



📖 http://www.extremetech.com/wp-content/uploads/2013/08/graphene-metal-hexagons.jpg

An ecosystem needed

- Design (institutes/universities)
- Control of wafer compatibility
- Secure shipping/processing of wafers
- High throughput @ high quality
- Or - the winner takes it all?
  - Apple, Alphabet/Google, Qualcomm/NXP, AMS, TSMC?



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The gap between 1980s and 2030?

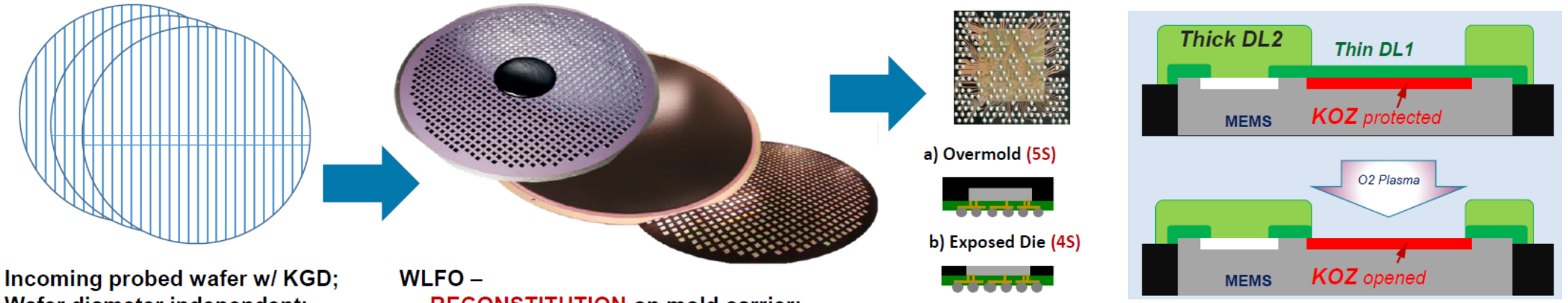
- Manufacturability and cost
  - Robustness of design and in production
- Computing power
- Reliability

📖 http://www.formtrends.com/driver-less-car-design-sleepwalking-into-the-future

Packaged in polymers, sensors merged

📖 S. Kröhnnert and A. Cardoso, Chemnitzer Seminar 2016 - NANIUM

- How to reduce cost by hybrid integration, computing at the EDGE
- MEMS in Fan-out wafer level packaging (Keep Out Zones)



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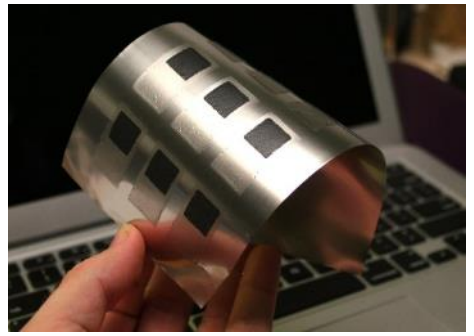
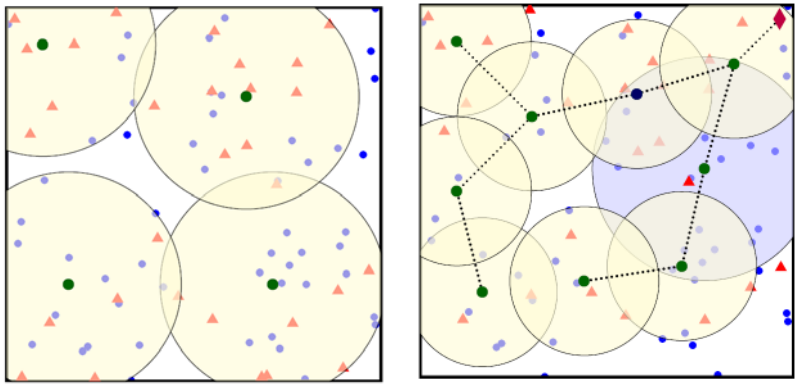
Small energies for small things

- Energy harvesting is the most elegant
- But - batteries are still used
  - Utilized so efficiently that they last the lifetime of the devices
    - Even for years of operation
  - Can be printed and be environmentally friendly
    - Products that only need to last some months
- Batteries in large wireless sensor networks
  - A perfect challenge for mathematical optimization

📖 Imprint Energy, zinc-based rather than lithium-based printed batteries





📖 Marc Sevaux, seminar @SINTEF 2016

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Summary

- Development has been, and is (?), from niche to consumer markets
- New enabling technologies keep coming and move us further
  - Integration becomes more challenging
  - Reliability gets less predictable
- Polymers solve cost issues, but adds reliability issues
  - Merging of sensors will come
  - Energy consumption can be made smarter

Acknowledgements

- Input was received from several SINTEF colleagues, in particular
  - Andreas Vogl, Erik Andreassen, Ingelin Clausen, Matthieu Lacolle, Michal M. Mielnik, and Sigurd T. Moe

- We would like to thank all the funding sources involved in the project examples shown

Technology for a better society