Smart Precision in Harsh Environments

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+ TU Delft, *U Twente, #TU Eindhoven

Overview

- Introduction/definitions
- Application areas
- Approaches
- Solutions
- Conclusions

What is harsh?

Any environment which impedes the normal operation.

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- Temperature: High T / Low T / Large ΔT

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- Mechanical loading
- High vacuum

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- Radiation (X)-UV, X-ray

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- Radiation (X)-UV, X-ray
- Harsh chemical environment
- Biological environments/Medical implants

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- Harsh chemical environment
- Biological environments/Medical implants
- Often: poor accessibility

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- Radiation (X)-UV, X-ray
- Harsh chemical environment
- Biological environments/Medical implants
- Often: poor accessibility
- etc.


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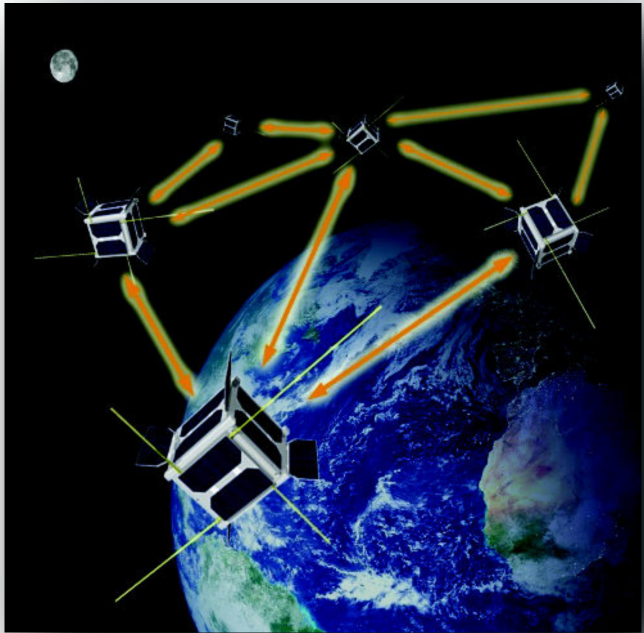
Harsh environmental applications

Applications I



Sensor Systems in Space

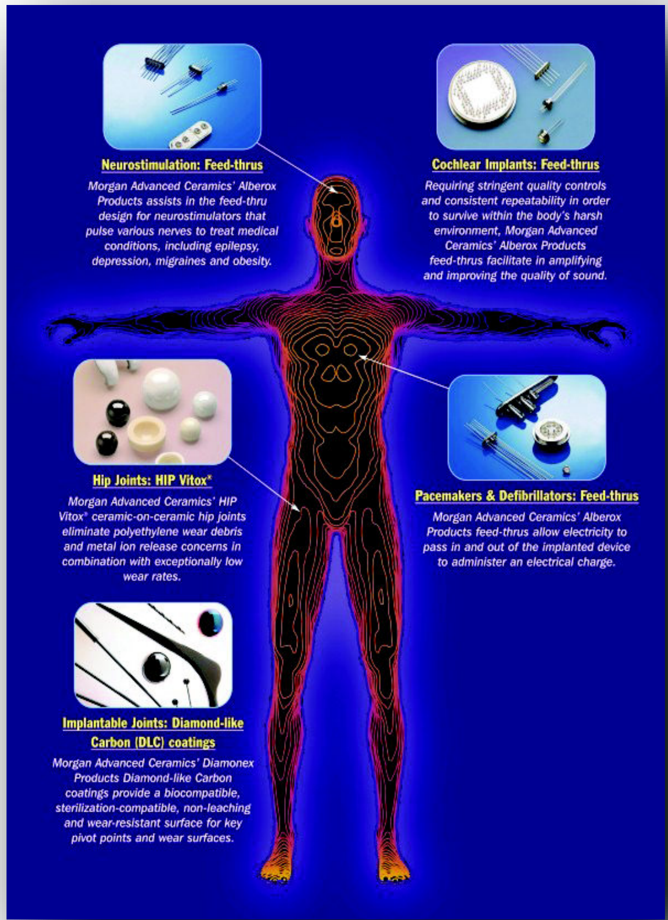
Sensor Systems in Wafer Stepper

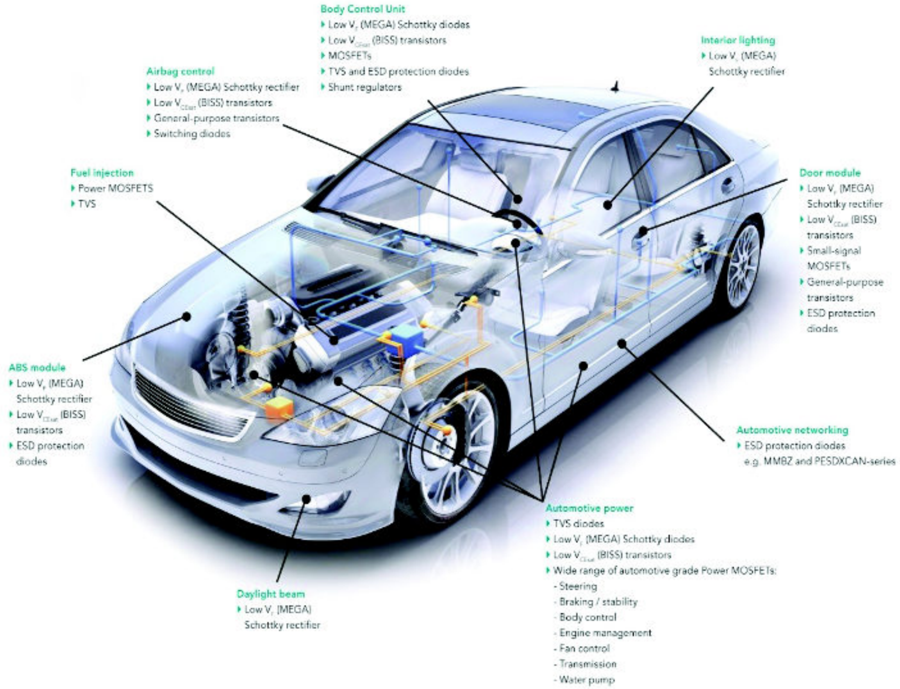
Applications II

Oil industry

Farming

Applications III





Hierarchy in compatibility with harsh environments

Some known harsh conditions					
	Chemical	Thermal	Mechanical	EM loading	Radiation
Materials	++	++	+		+
Technology	+	++	+		
Device Design		+	++	+	
Packaging	++	+	++	++	+
System		+	+	+	+
Levels at which conditions can be counteracted					

Compatibility with harsh environments: Examples

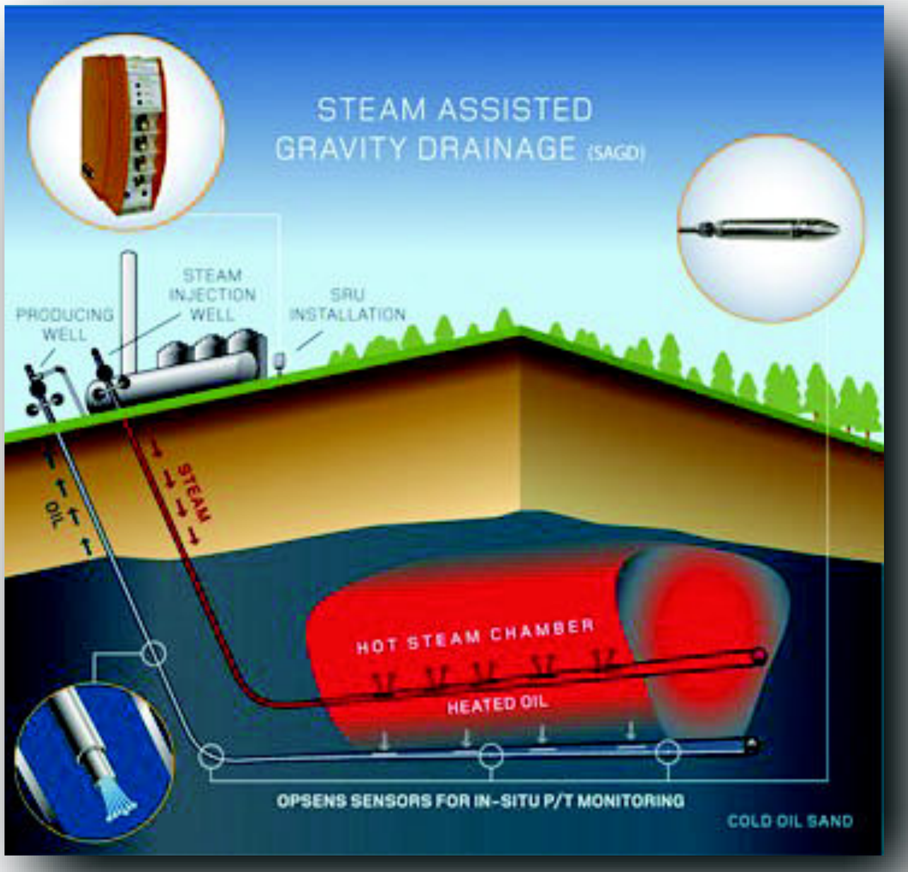
- Materials
  - Chemically inert
  - High glass or melting temperature
  - High fracture, yield strength and/or hardness
  - Dense materials to reduce device to exposure to radiation
- Technology
  - Fabrication method, conditions, annealing
  - Additional layers (e.g. to prevent delamination, increase resilience), additives
- Device design
  - Special zones to absorb mechanical/chemical loading or thermal cycling.
  - Choice of measurand (e.g. a derivative quantity)
- Packaging
  - Special zones to absorb mechanical/chemical loading or thermal cycling
  - Materials of package (e.g. chemically inert)
- System
  - Limited on-time
  - Judicious choice as to where to put the sensors.

Materials

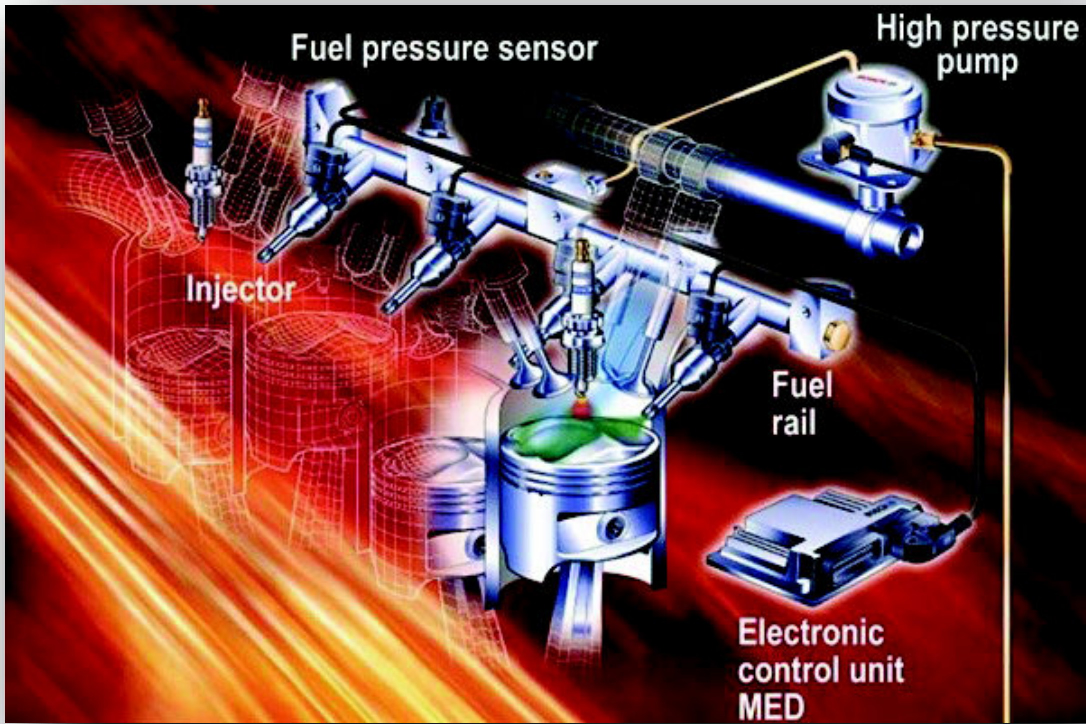
- SiC
  - High temperature
  - Chemically inert
- ALD (atomic layer deposition)
  - Pinhole free
- Polymers/parylene
  - Biocompatibility
- SOI
- Graphene
  - High temperature, medical implants
- Etc.

Oil industry

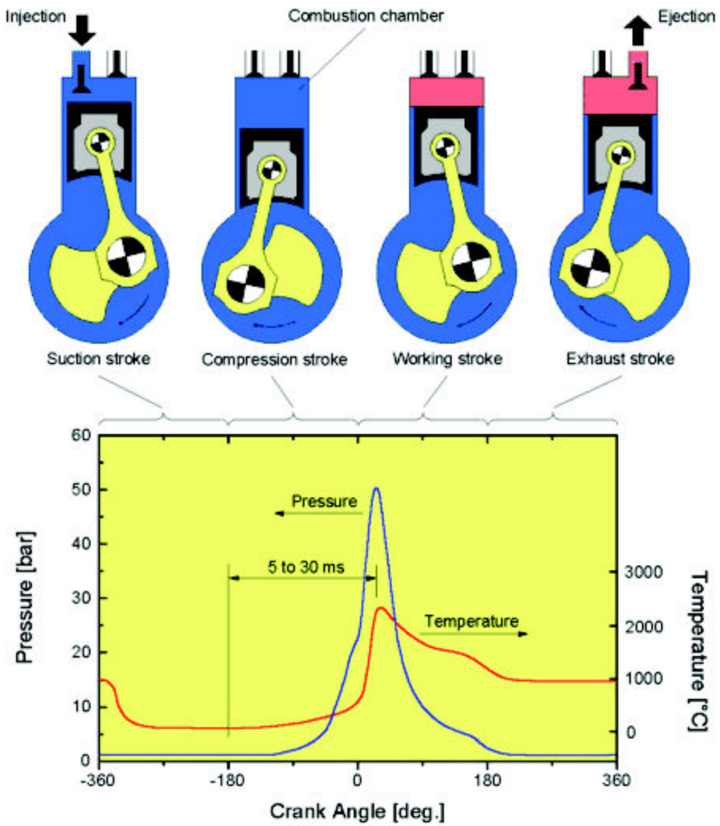
Temperature & pressure sensors



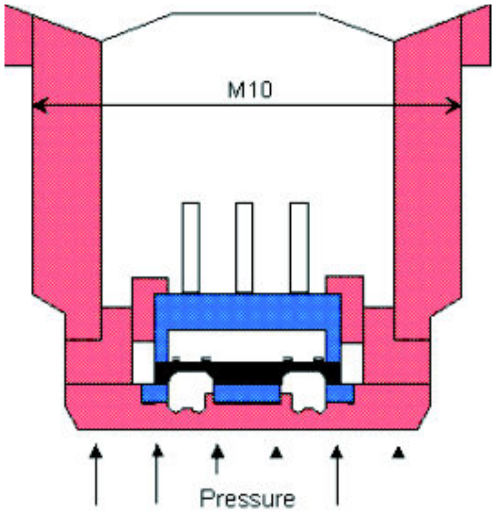
Automotive engine



High Temperature



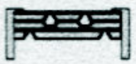
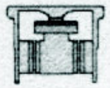
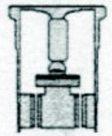
TU Berlin



SiCOI pressure sensor

Pressure sensors for high temperature

Price

Packaging / Chip-technology	Chip Direct Exposure 	Steel Membrane 	Steel Membrane with Transmissionelement 
Si	150°C	200°C - 250°C	450°C - 500°C
SOI	350°C	400°C - 450°C	650°C - 700°C
SiCOIN	500°C	550°C - 600°C	800°C - 850°C

Reliability, Life

GH Kroetz, MH Eickhoff & H Moeller - Daimler Benz

High temperature materials

Semiconductor	Bandgap (eV)	Electronic maximum operating temperature (°C)	Process maturity	Key technical issues and limitations
Si	1.1	150	Very high	• Not suitable for aggressive environments
SOI	1.1	300	High	• Not suitable for aggressive environments
GaAs	1.43	350	High	• Contact stability at high temperatures • Not suitable for aggressive environments
3C-SiC	2.39	600	Low	• Not available as bulk material
6H-SiC	3.02	700	Medium	• Bulk material quality • Ohmic contacts to p-type material
4H-SiC	3.26	750	Medium	• Bulk material quality • Ohmic contacts to p-type material
Group III-nitrides	1.89*-6.20**	>700	Very low	• Material quality, reproducibility • Ohmic contacts
Diamond	5.48	1100	Very low	• n-type doping • Material quality (only polycrystalline material available)

*GaN **AlN

Matthias Ralf Werner and Wolfgang R. Fahrner, 2001

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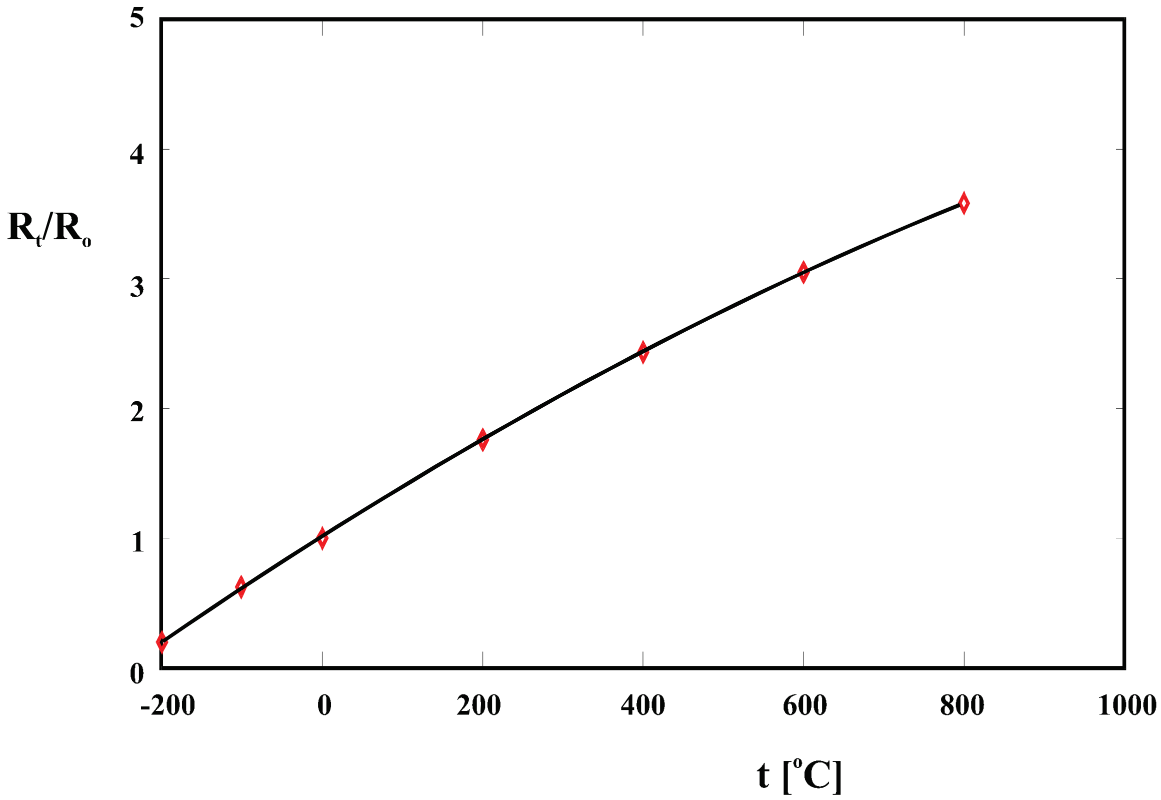
Platinum resistor



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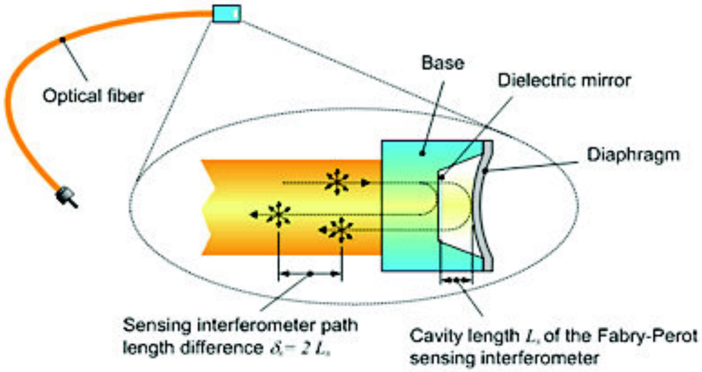
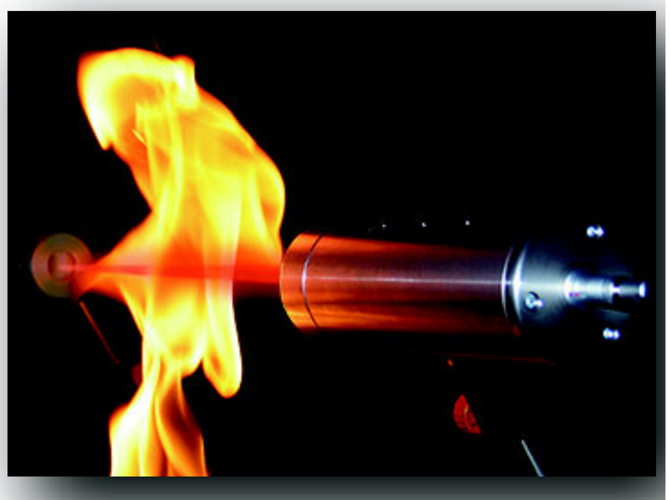
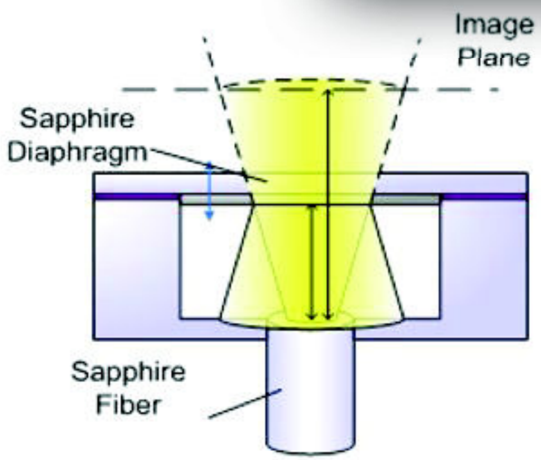
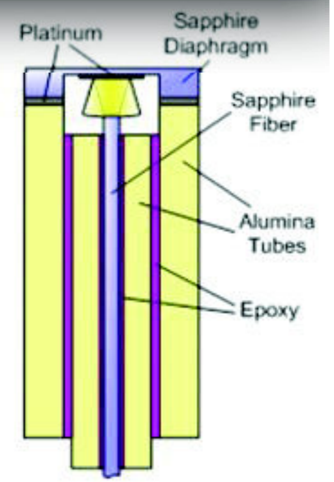
Optical approach



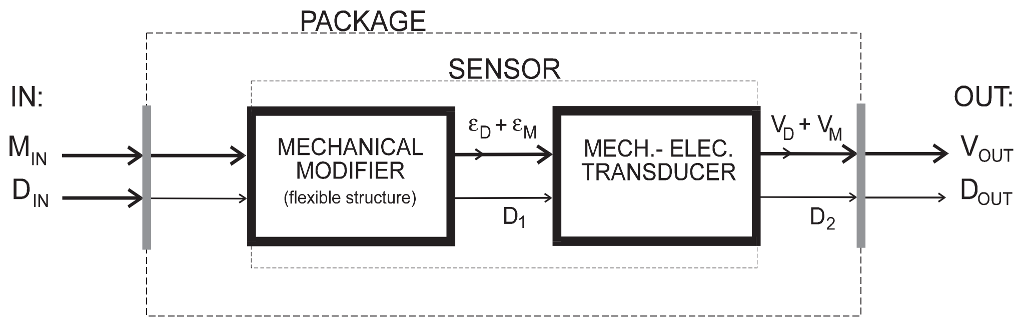




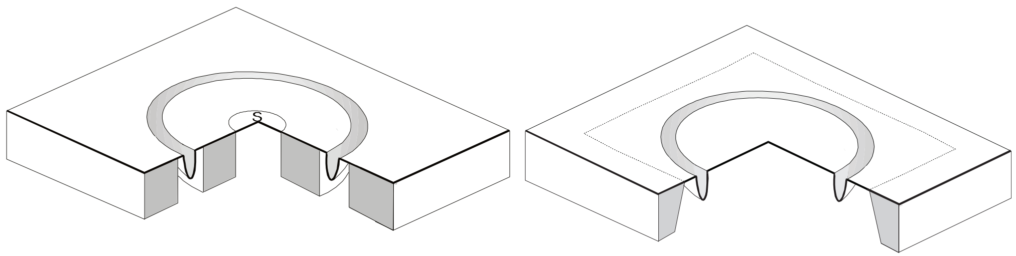


University of Florida

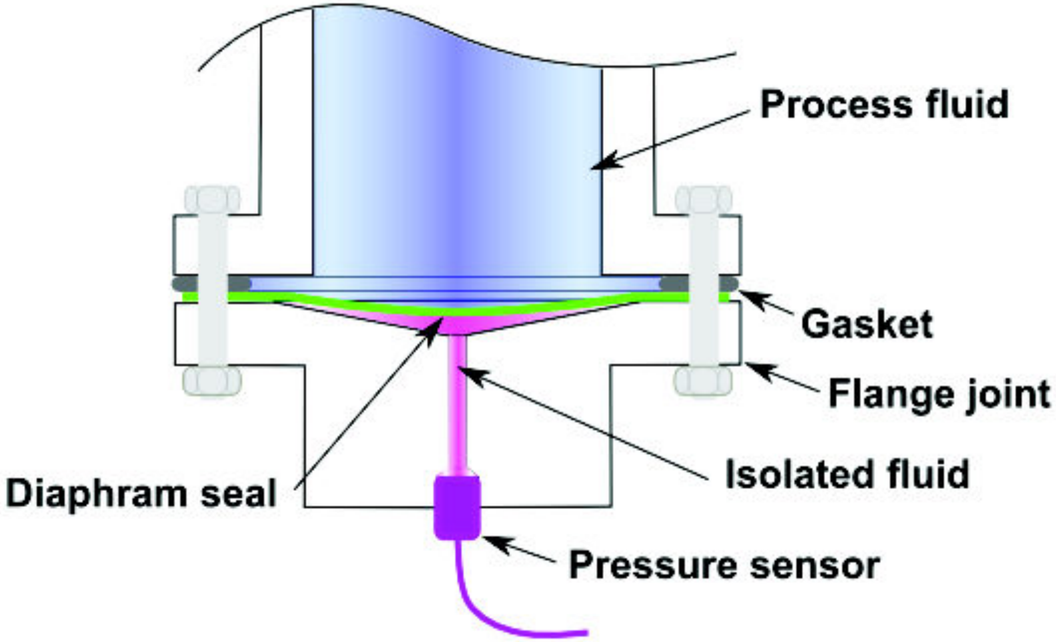
Design solution: On-Chip Crumple Zone



- PhD. Work of Vincent Spiering, 1994
- Package $\Rightarrow$ mechanical loading $\Rightarrow$ reduced sensor performance
- ID: make corrugated membranes to absorb mechanical stress



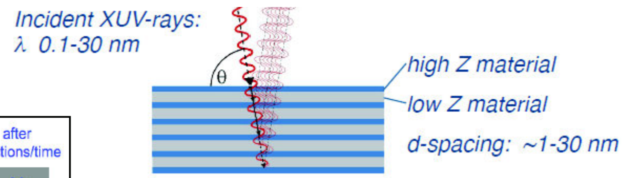
High pressure

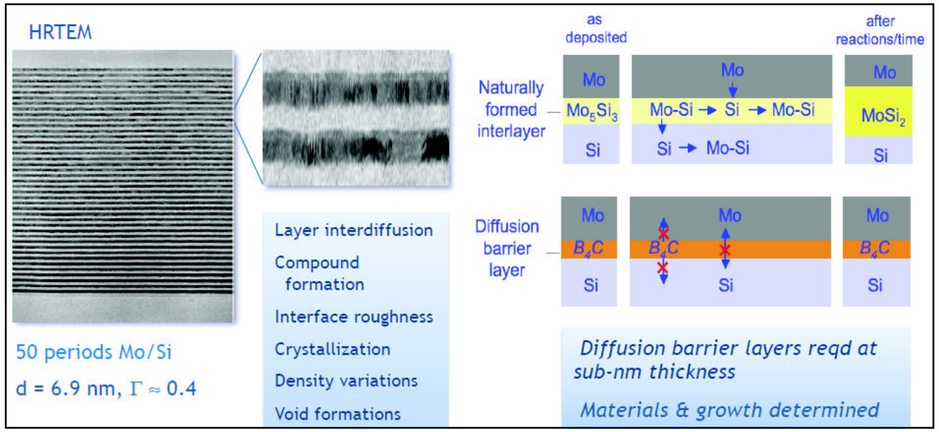


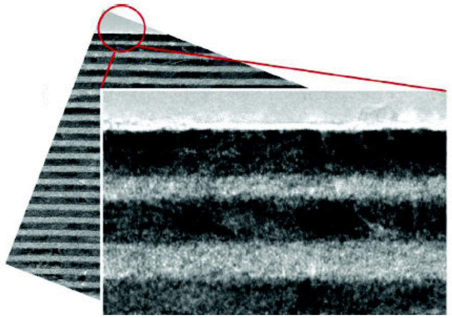
High radiation

Examples of ALD layers in harsh environment

- ALD-layers of Mo/Si mirrors for XUV reticules, etc.
- Ru-coated X-UV mirrors, etc.





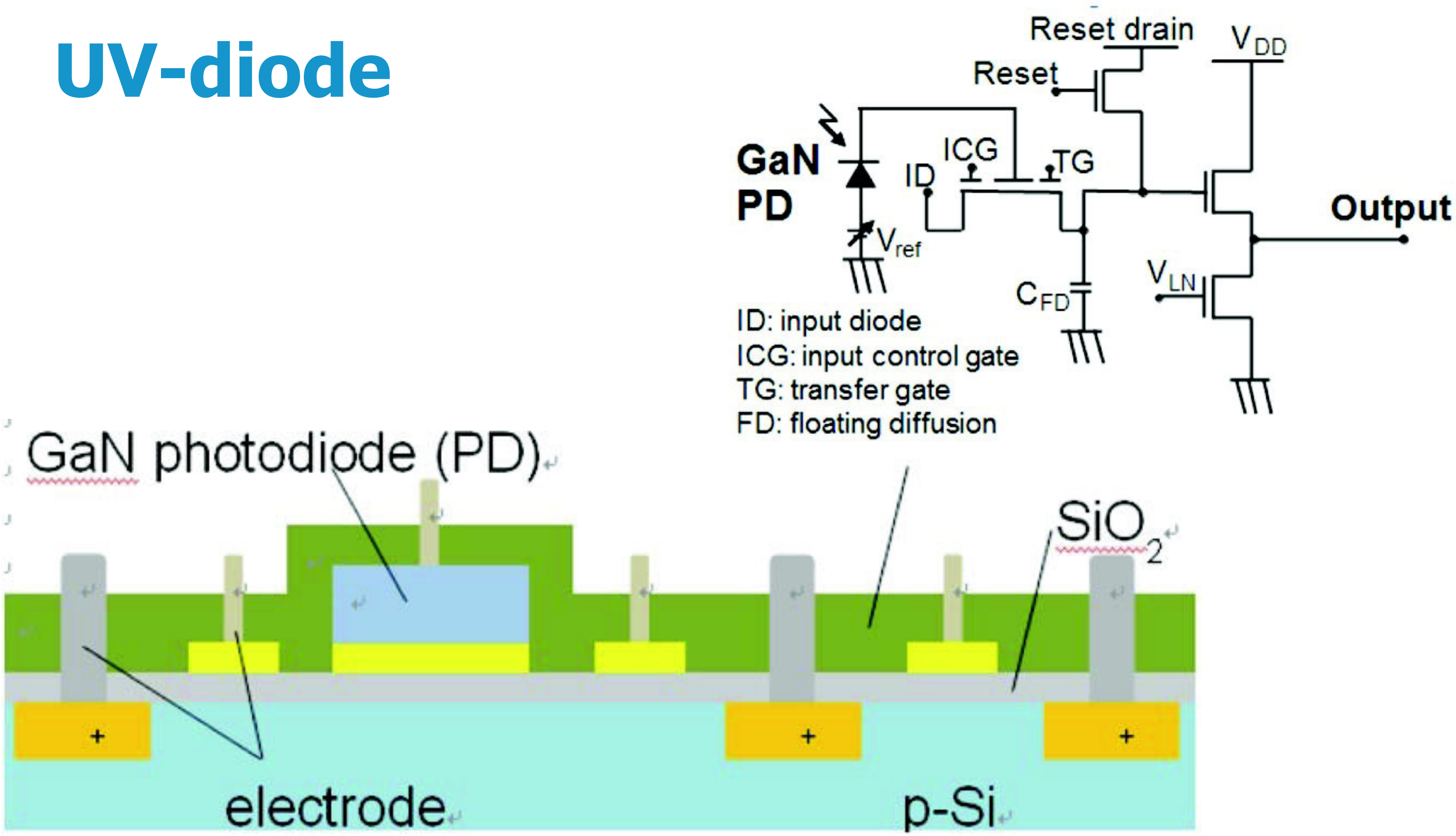


including diffusion barriers

Source: Fred Bijkerk

►Both 2D and 3D layers with ideal step coverage, pinhole-free, etc.

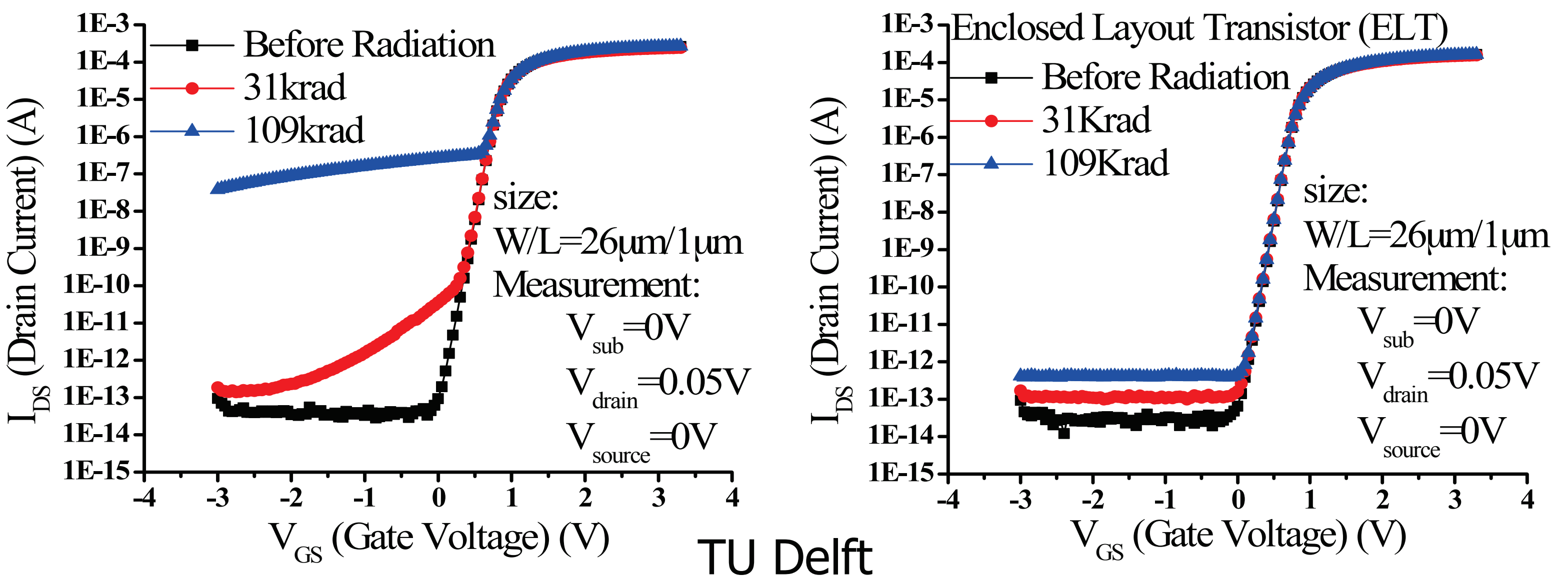
UV-diode



ChangYong Lee et. al. Toyohashi University of Technology

X-ray Radiation on MOSFETs

- No post-radiation threshold shift (due to thin gate oxide),
- Parasitic transistor formation induced leakage current increase around the layout edges,
- Post-irradiation interface trap generation induced leakage current increase.



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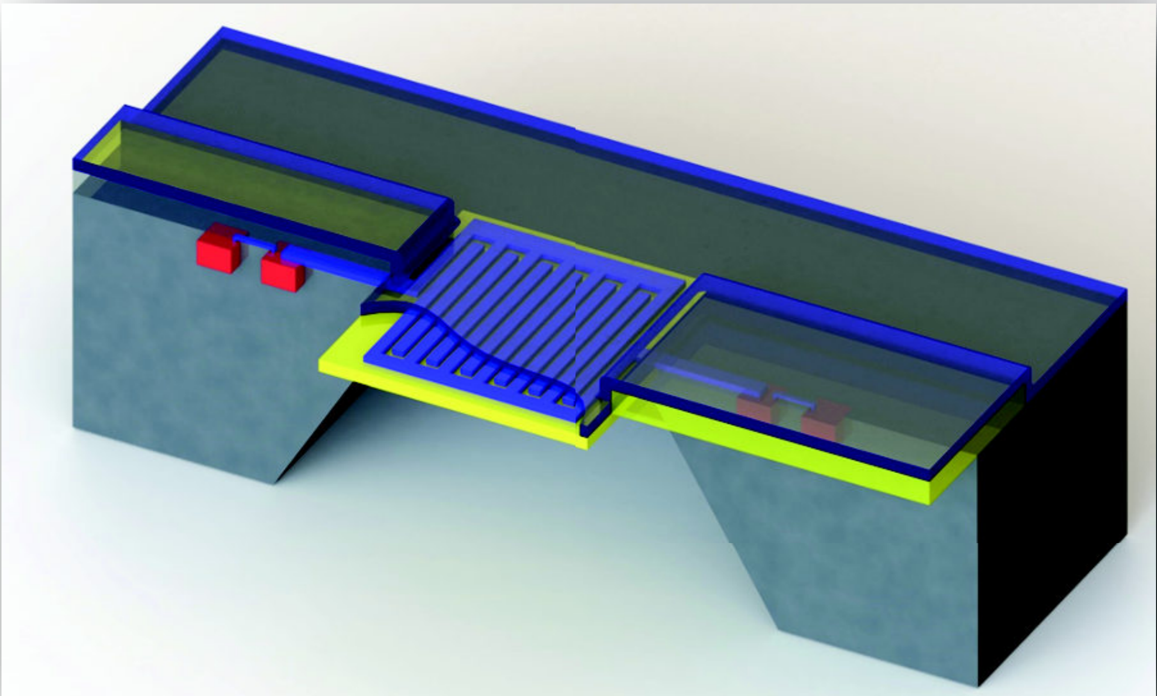
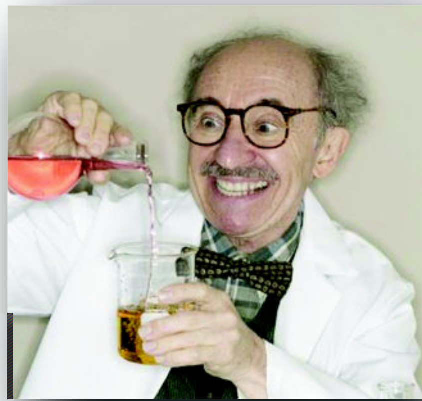
Harsh chemical





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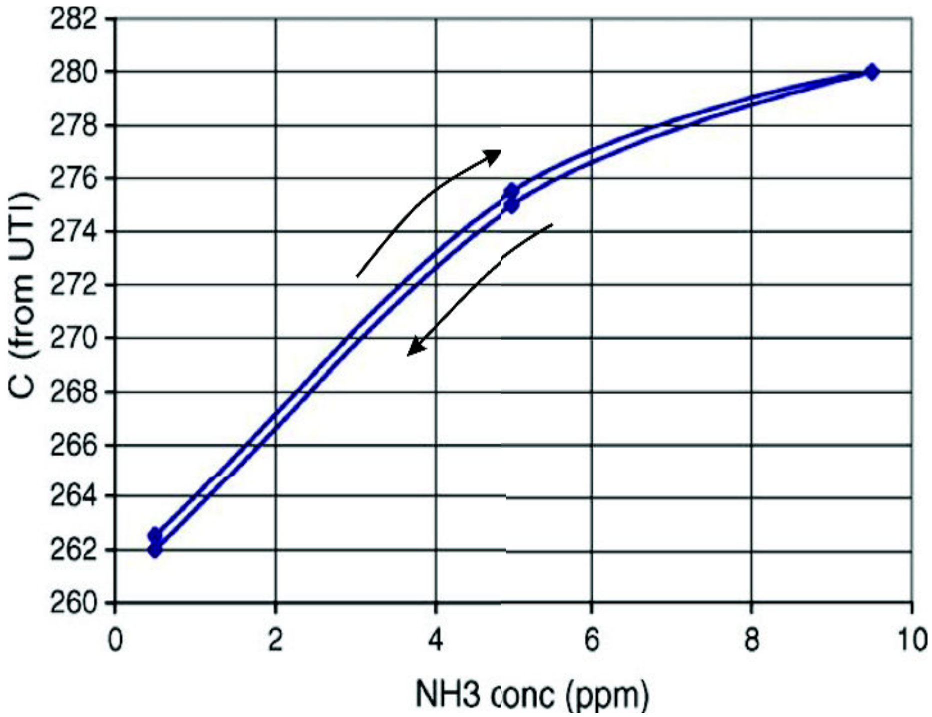
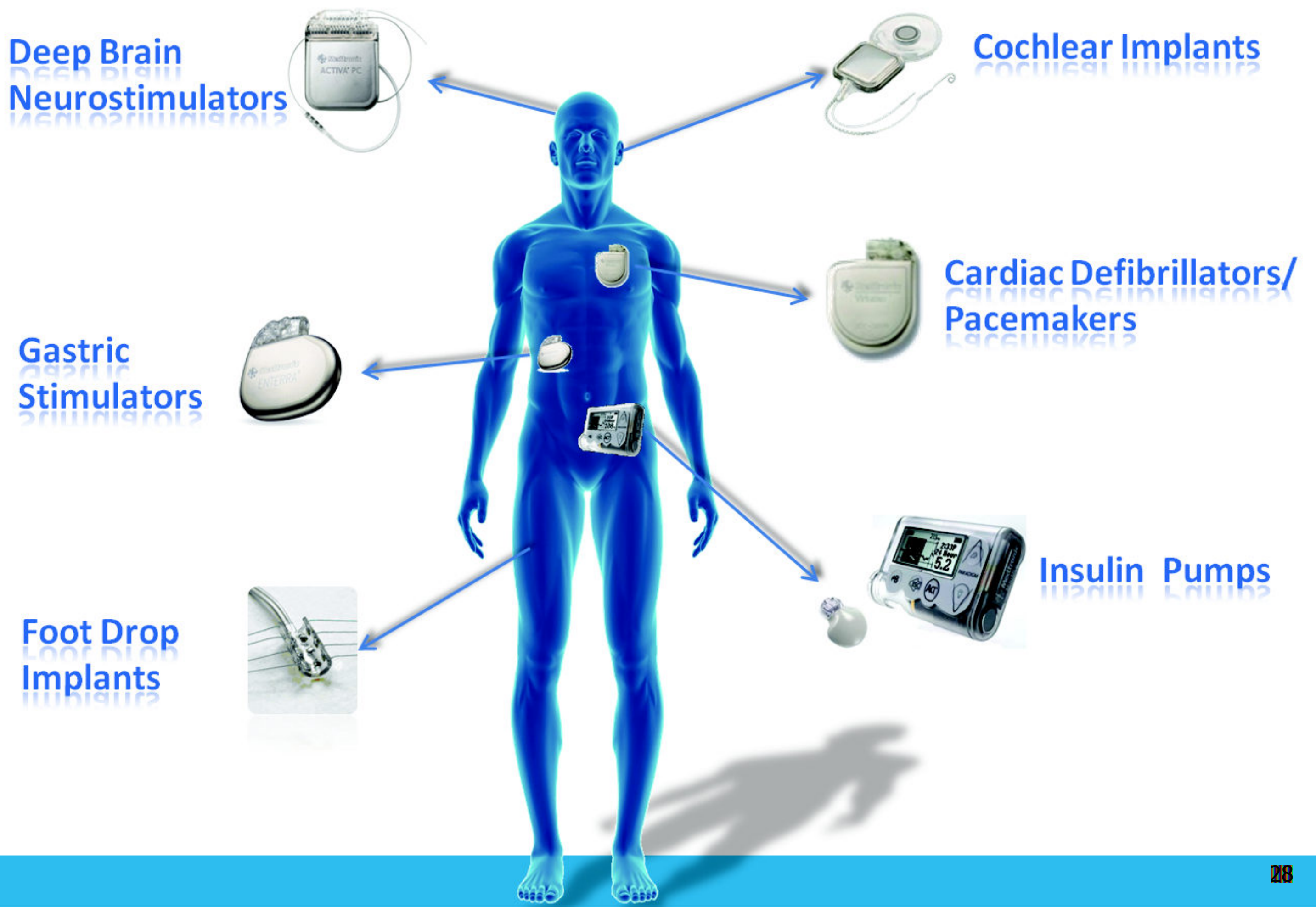
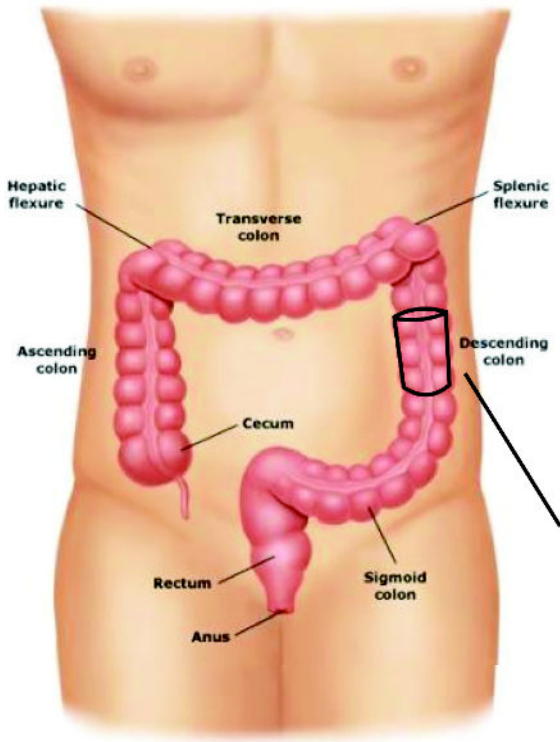
Ammonia sensor

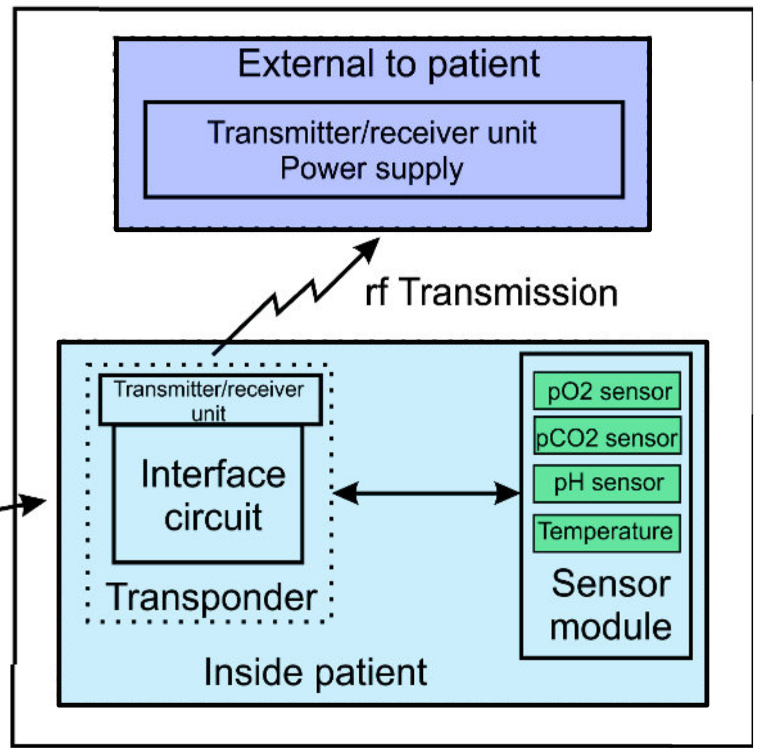


WIRELESS IMPLANTABLE MEDICAL DEVICES



In-vivo





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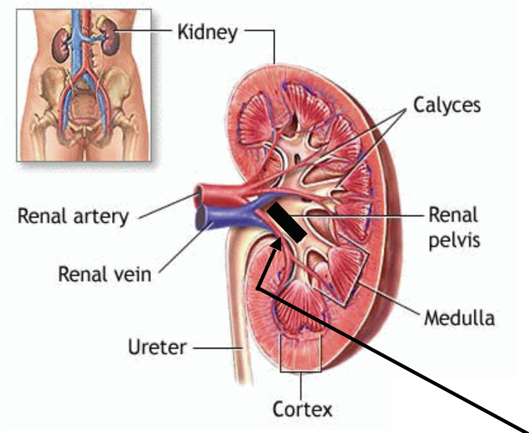
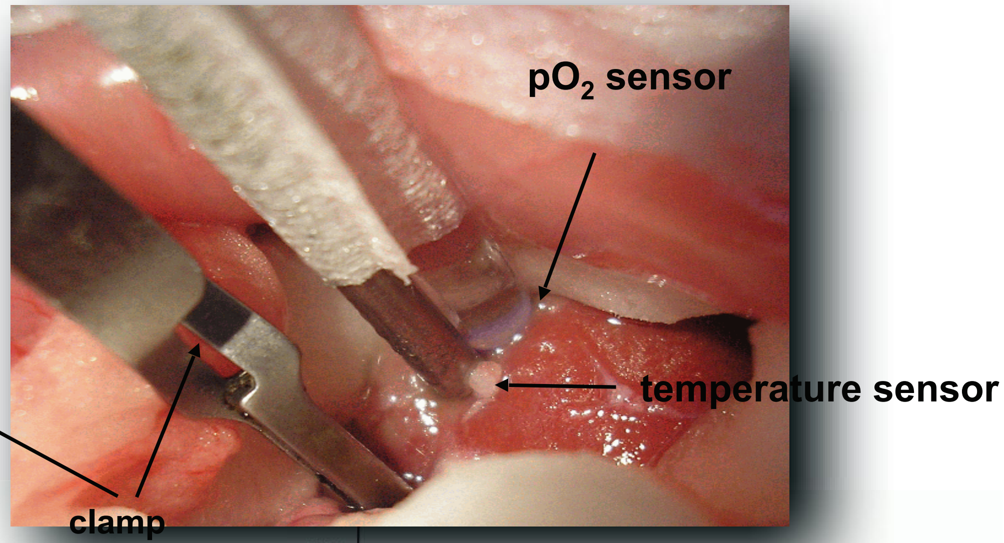
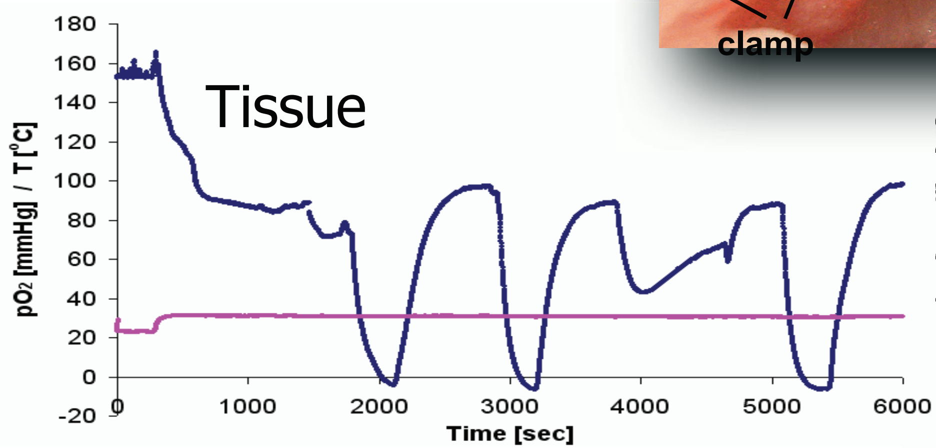
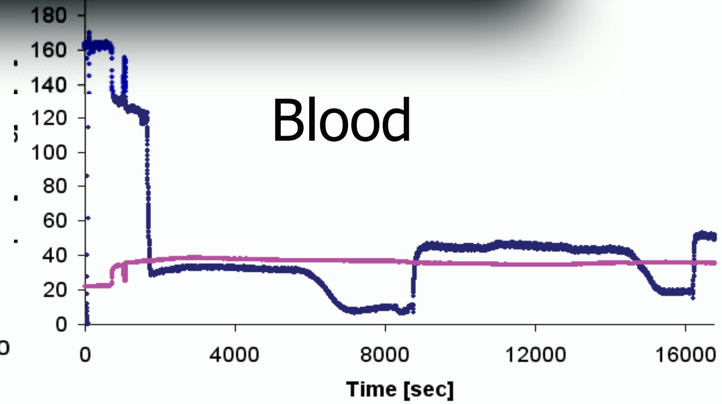
Oxygen measurements









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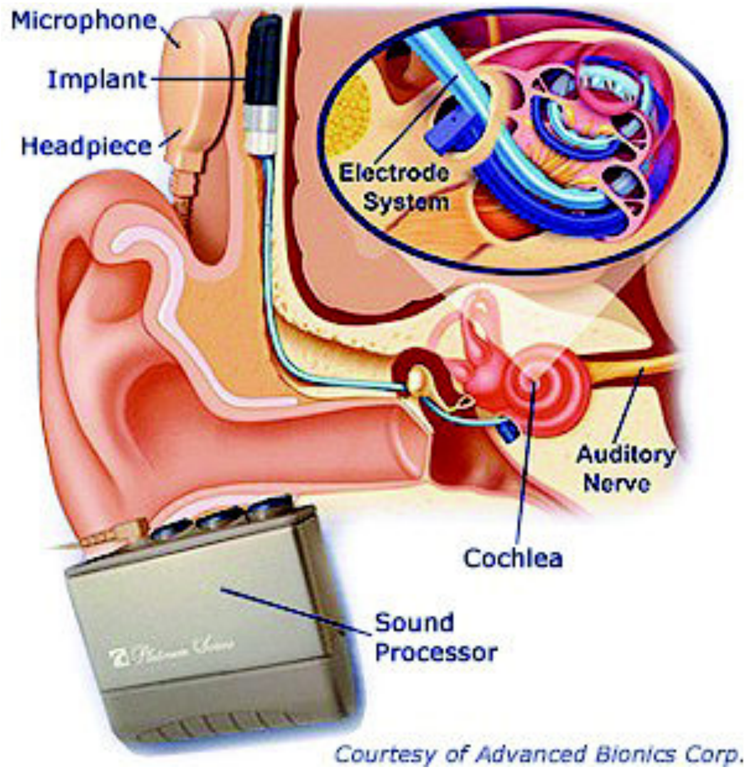
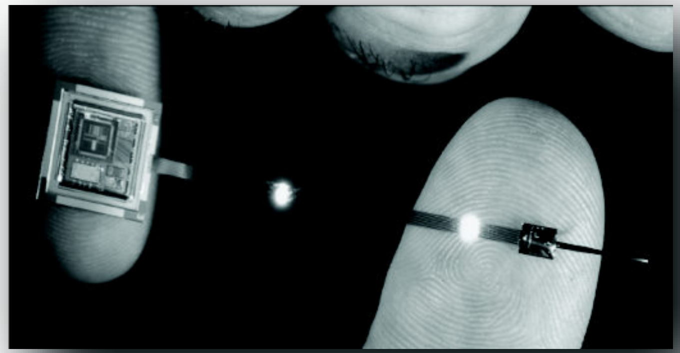
Cochlear implants (CIs)

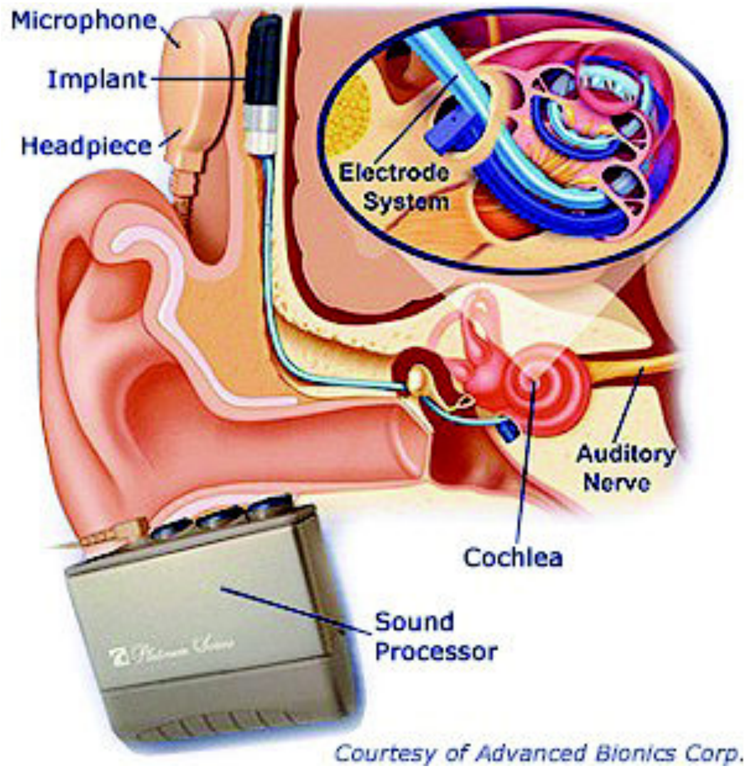




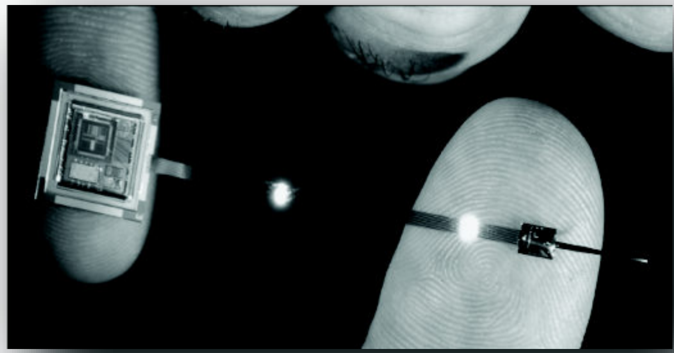
Source: A 32-Site 4-Channel High-Density Electrode Array for a Cochlear Prosthesis, Pamela T. Bhatti, Kensall D. Wise

Electrode for the Cochlear Implant. TUD & LUMC

Cochlear implants (CIs)



Electrode for the Cochlear Implant. TUD & LUMC



Source: A 32-Site 4-Channel High-Density Electrode Array for a Cochlear Prosthesis, Pamela T. Bhatti, Kensall D. Wise

- Challenges:
  - Small
  - 230 channels
  - > 20V into a 1V IC
  - 126dB DR
  - Low power

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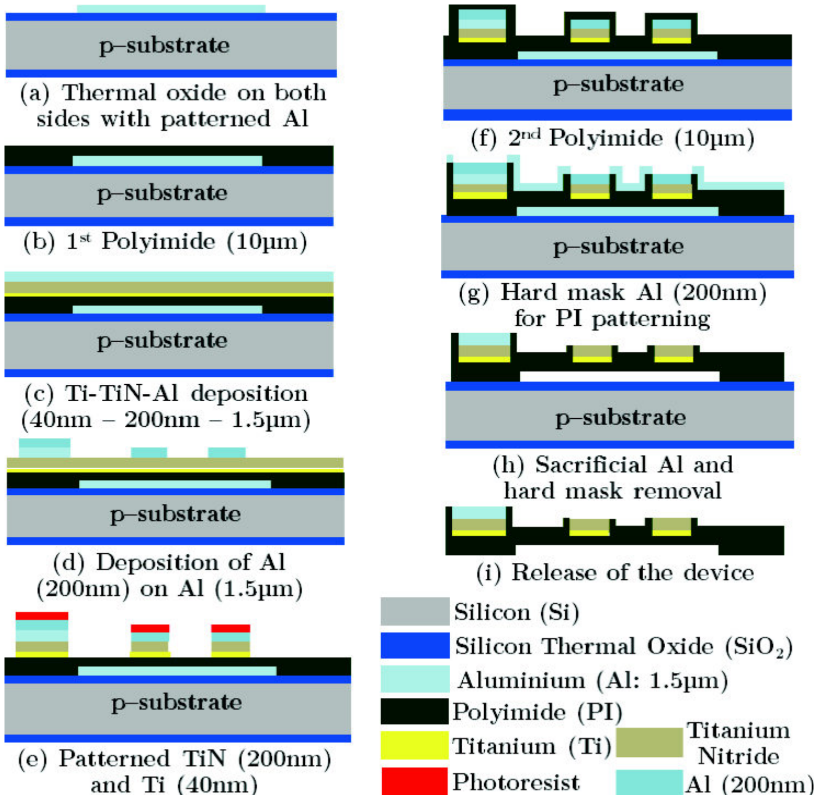
New generation cochlear implant

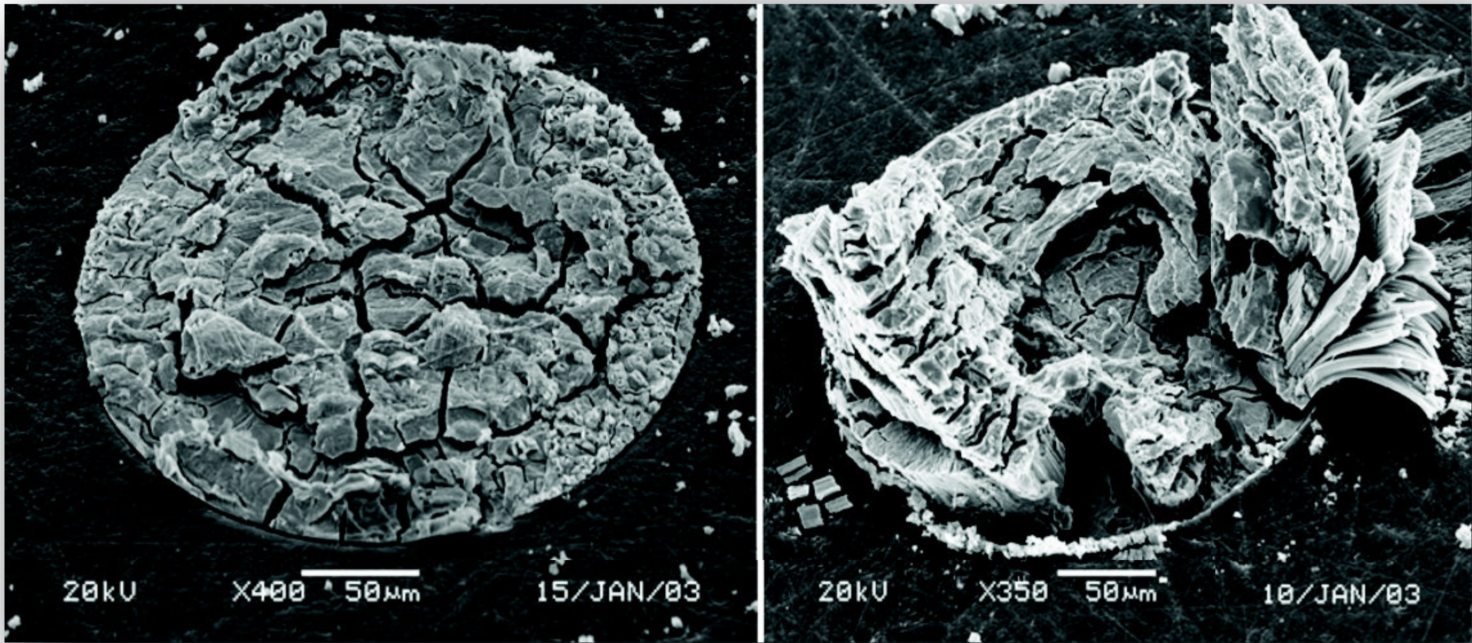


Electrode for the Cochlear Implant.

TUD & LUMC

Delft University of Technology

Sputtered platinum after extended exposure to a salt solution



Key research fields and scientific challenges

1. Materials, technology and packaging
2. Sensors and actuators
3. Systems aspects
4. Maintaining precision in harsh environments

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Smart Precision in Harsh Environments

- SPIHE
- STW perspectief proposal writing
- 15% cash / 30% total required from industry
- Round 2015, starting 2017 if granted
- We look for interested companies
- Contacts:
  - p.j.french@tudelft.nl
  - gijs.krijnen@utwente.nl

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Conclusions

- Expanding applications mean increasing exposure to harsh environments.
- This can be addressed in many ways including materials, packaging and design.
- The challenge is not only to survive and operate in these environments, but also to maintain reliability and precision.