

Smart Precision in Harsh Environments

Paddy French+, Gijs Krijnen* & Fred Roozeboom#

+ TU Delft, *U Twente, #TU Eindhoven

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Overview

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

What is harsh?

Any environment which impedes the normal operation.

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- Radiation (X)-UV, X-ray

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- Harsh chemical environment
- Biological environments/Medical implants

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- Biological environments/Medical implants
- Often: poor accessibility

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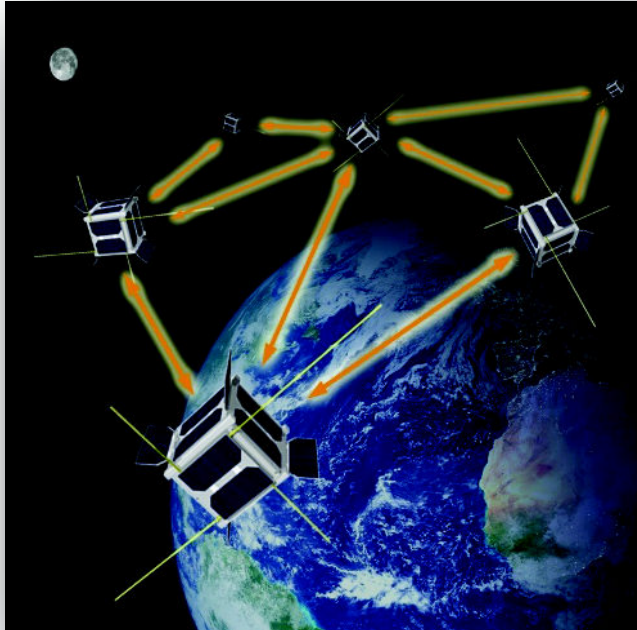
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- Radiation (X)-UV, X-ray
- Harsh chemical environment
- Biological environments/Medical implants
- Often: poor accessibility
- etc.

SPIHE

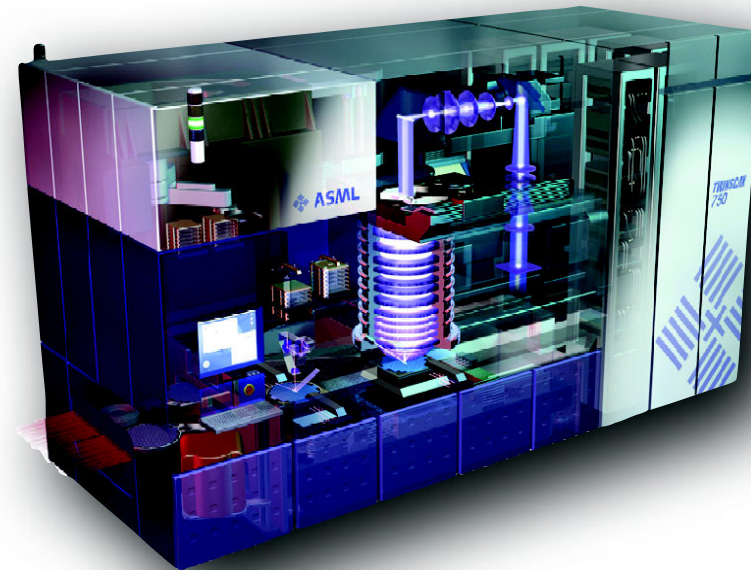


Harsh environmental applications

Applications I



Sensor Systems in Space



Sensor Systems in Wafer Stepper

Applications II



Oil industry

Farming



Applications III

Neurostimulation: Feed-thrus

Morgan Advanced Ceramics' Alberox Products assists in the feed-thru design for neurostimulators that pulse various nerves to treat medical conditions, including epilepsy, depression, migraines and obesity.

Cochlear Implants: Feed-thrus

Requiring stringent quality controls and consistent repeatability in order to survive within the body's harsh environment, Morgan Advanced Ceramics' Alberox Products feed-thrus facilitate in amplifying and improving the quality of sound.

Hip Joints: HIP Vitox®

Morgan Advanced Ceramics' HIP Vitox® ceramic-on-ceramic hip joints eliminate polyethylene wear debris and metal ion release concerns in combination with exceptionally low wear rates.

Pacemakers & Defibrillators: Feed-thrus

Morgan Advanced Ceramics' Alberox Products feed-thrus allow electricity to pass in and out of the implanted device to administer an electrical charge.

Implantable Joints: Diamond-like Carbon (DLC) coatings

Morgan Advanced Ceramics' Diamonex Products Diamond-like Carbon coatings provide a biocompatible, sterilization-compatible, non-leaching and wear-resistant surface for key pivot points and wear surfaces.

Body Control Unit

- Low V_{max} (MEGA) Schottky diodes
- Low V_{max} (BISS) transistors
- MOSFETs
- TVS and ESD protection diodes
- Shunt regulators

Interior lighting

- Low V_{max} (MEGA) Schottky rectifier

Door module

- Low V_{max} (MEGA) Schottky rectifier
- Low V_{max} (BISS) transistors
- Small-signal MOSFETs
- General-purpose transistors
- ESD protection diodes

Automotive networking

- ESD protection diodes e.g. MMBZ and PESD5V0A-series

Automotive power

- TVS diodes
- Low V_{max} (MEGA) Schottky diodes
- Low V_{max} (BISS) transistors
- Wide range of automotive grade Power MOSFETs:
 - Steering
 - Braking / stability
 - Body control
 - Engine management
 - Fan control
 - Transmission
 - Water pump

Daylight beam

- Low V_{max} (MEGA) Schottky rectifier

Fuel injection

- Power MOSFETs
- TVS

Airbag control

- Low V_{max} (MEGA) Schottky rectifier
- Low V_{max} (BISS) transistors
- General-purpose transistors
- Switching diodes

ABS module

- Low V_{max} (MEGA) Schottky rectifier
- Low V_{max} (BISS) transistors
- ESD protection diodes

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

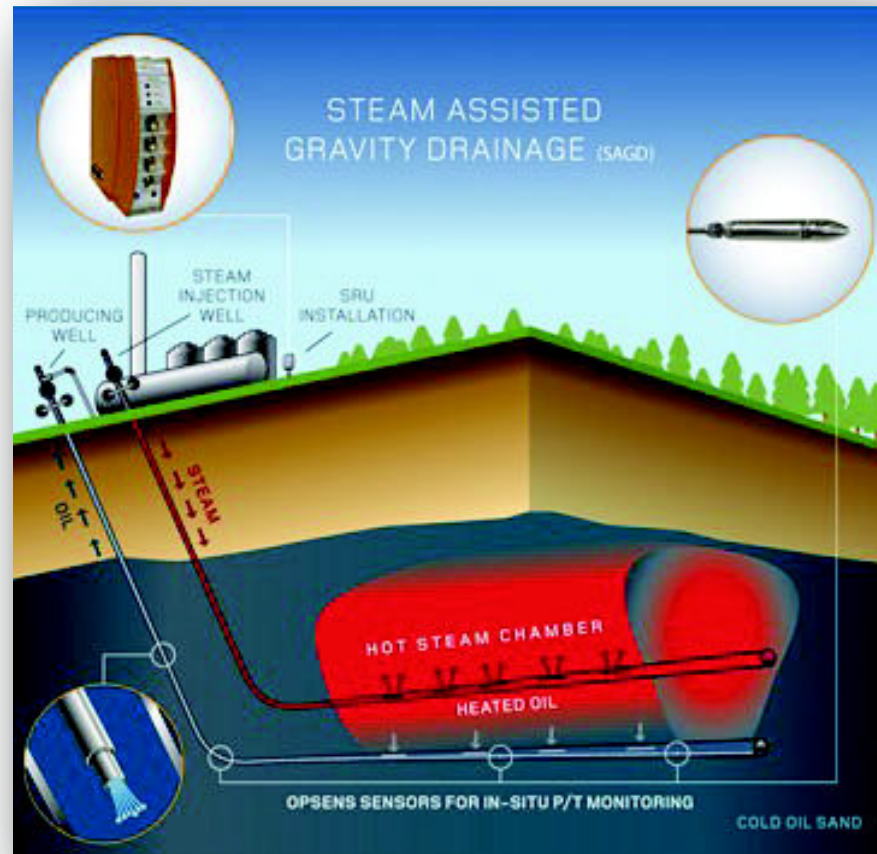
- **Materials**
 - Chemically inert
 - High glass or melting temperature
 - High fracture, yield strength and/or hardness
 - Dense materials to reduce device to exposure to radiation
- **Technology**
 - Fabrication method, conditions, annealing
 - Additional layers (e.g. to prevent delamination, increase 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

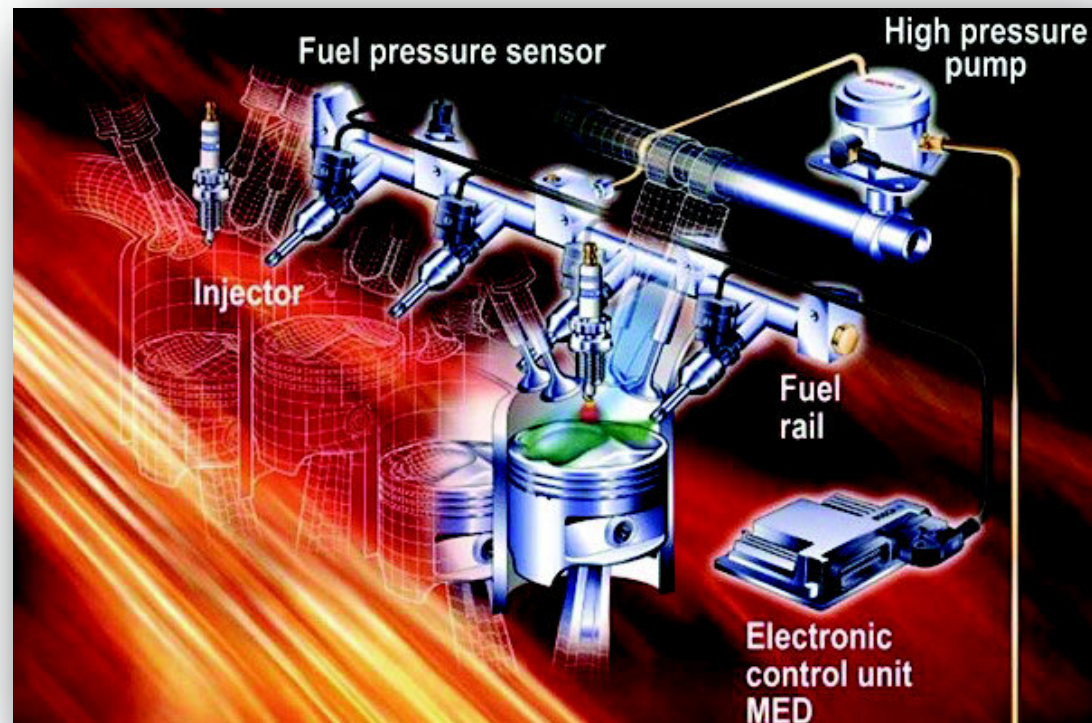
- SiC
 - High temperature
 - Chemically inert
- ALD (atomic layer deposition)
 - Pinhole free
- Polymers/parylene
 - Biocompatibility
- SOI
- Graphene
 - High temperature, medical implants
- Etc.

Oil industry

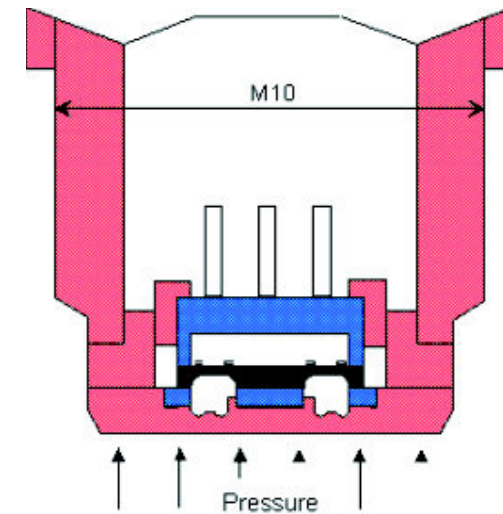
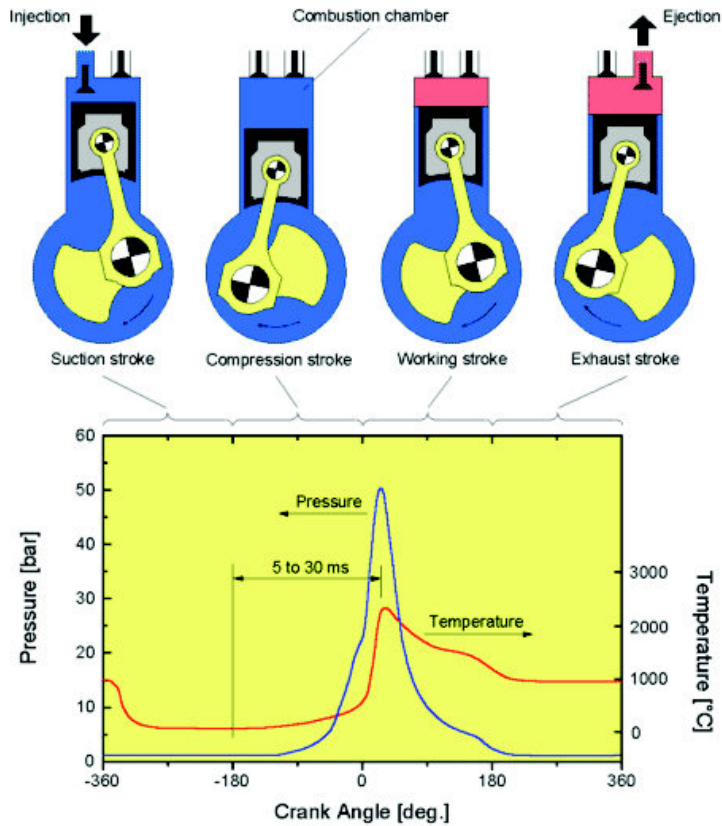
Temperature & pressure sensors



Automotive engine



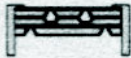
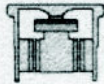
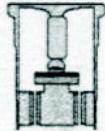
High Temperature



SiCOI pressure sensor

TU Berlin

Pressure sensors for high temperature

		Price		
Packaging	Chip Direct Exposure	Steel Membrane	Steel Membrane with Transmissionelement	
Chip-technology				
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	<ul style="list-style-type: none"> • Not suitable for aggressive environments
SOI	1.1	300	High	<ul style="list-style-type: none"> • Not suitable for aggressive environments
GaAs	1.43	350	High	<ul style="list-style-type: none"> • Contact stability at high temperatures • Not suitable for aggressive environments
3C-SiC	2.39	600	Low	<ul style="list-style-type: none"> • Not available as bulk material
6H-SiC	3.02	700	Medium	<ul style="list-style-type: none"> • Bulk material quality • Ohmic contacts to p-type material
4H-SiC	3.26	750	Medium	<ul style="list-style-type: none"> • Bulk material quality • Ohmic contacts to p-type material
Group III-nitrides	1.89 - 6.20**	>700	Very low	<ul style="list-style-type: none"> • Material quality, reproducibility • Ohmic contacts
Diamond	5.48	1100	Very low	<ul style="list-style-type: none"> • n-type doping • Material quality (only polycrystalline material available)

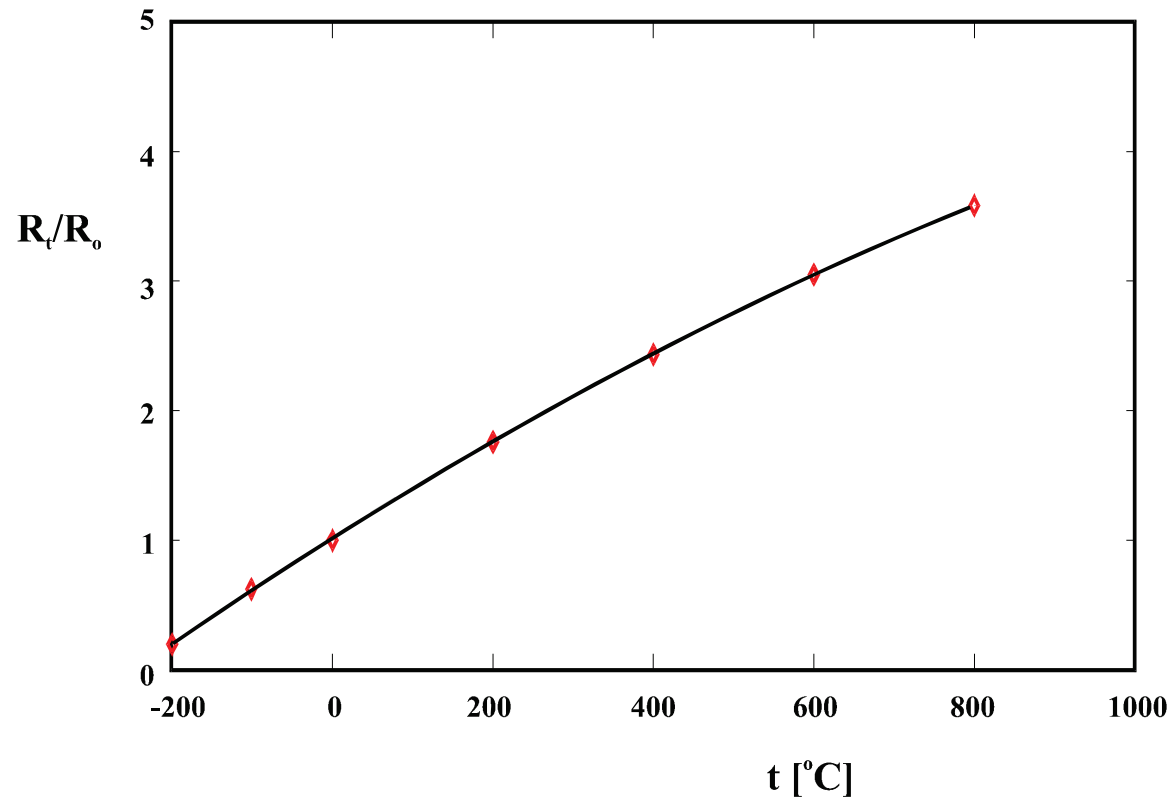
*GaN

**AlN

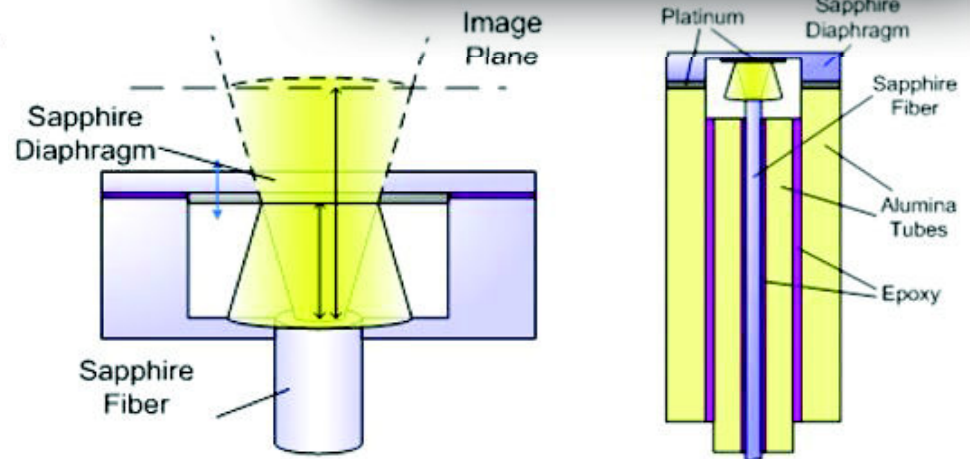
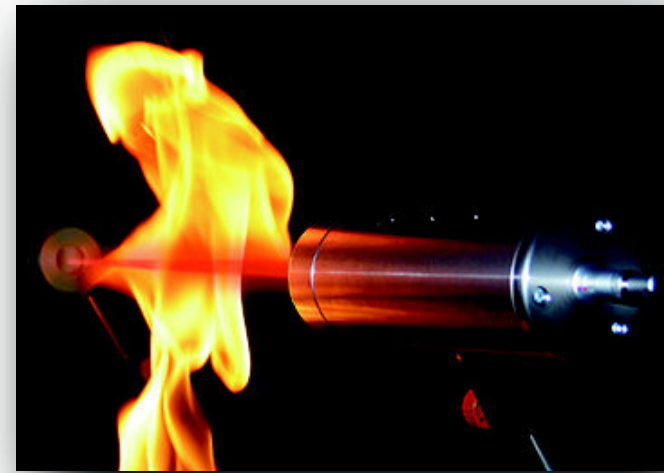
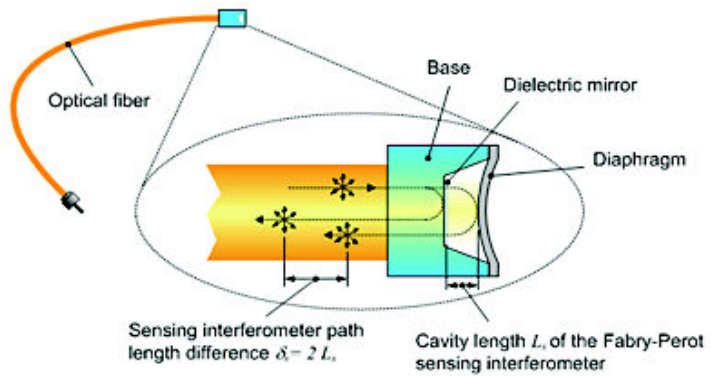
Matthias Ralf Werner and Wolfgang R. Fahrner, 2001

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Platinum resistor

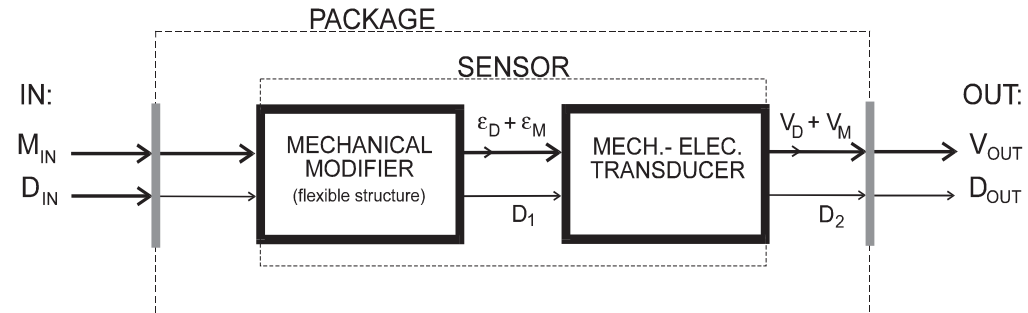


Optical approach

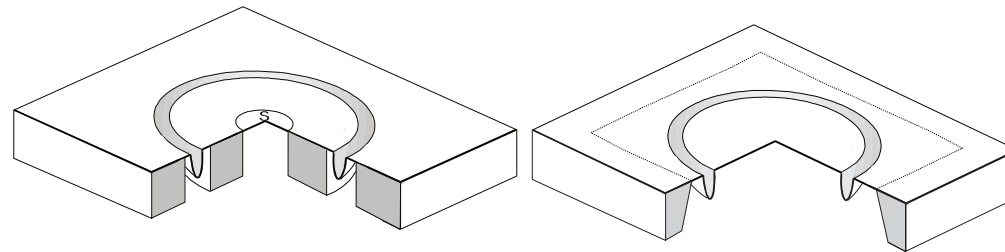


University of Florida

Design solution: On-Chip Crumple Zone



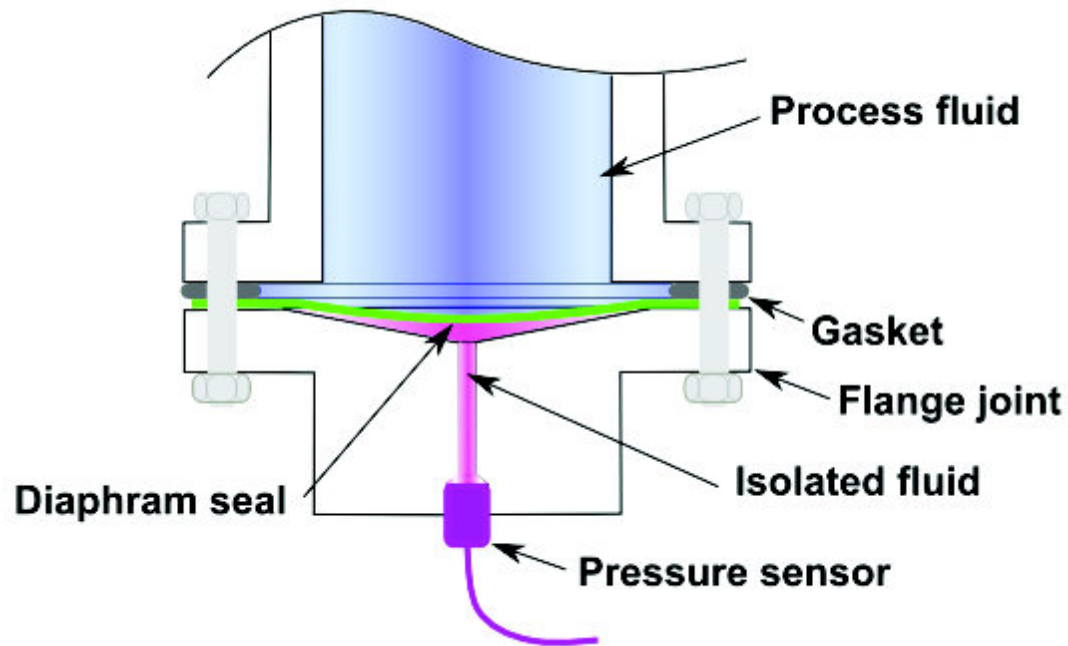
- PhD. Work of Vincent Spiering, 1994
- Package \Rightarrow mechanical loading \Rightarrow reduced sensor performance
- ID: make corrugated membranes to absorb mechanical stress



University of Twente

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High pressure

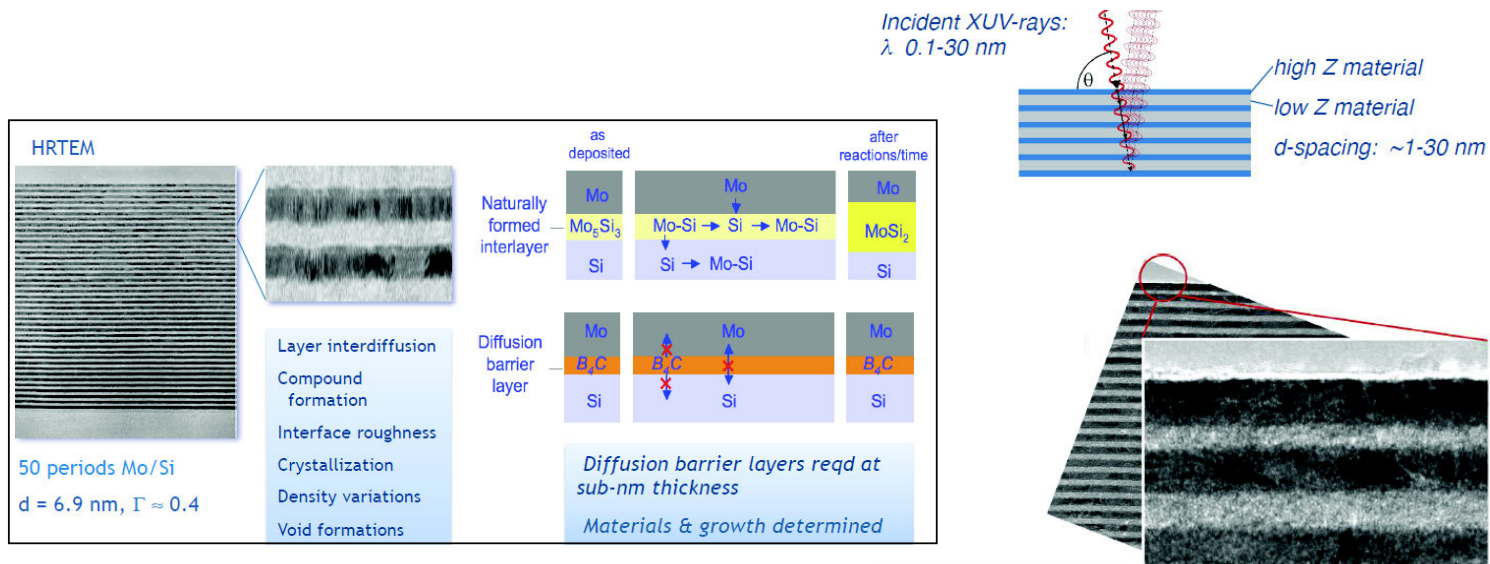


High radiation



Examples of ALD layers in harsh environment

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

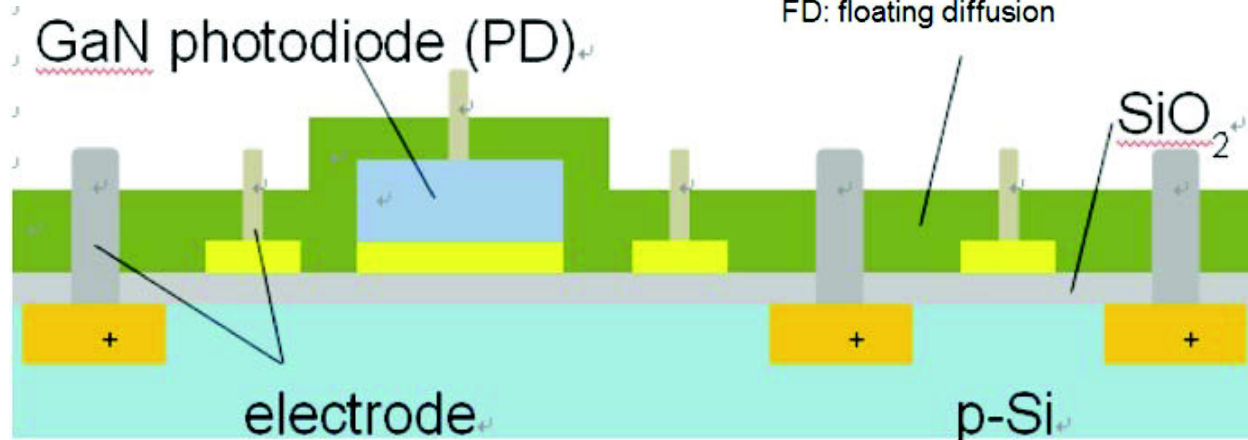
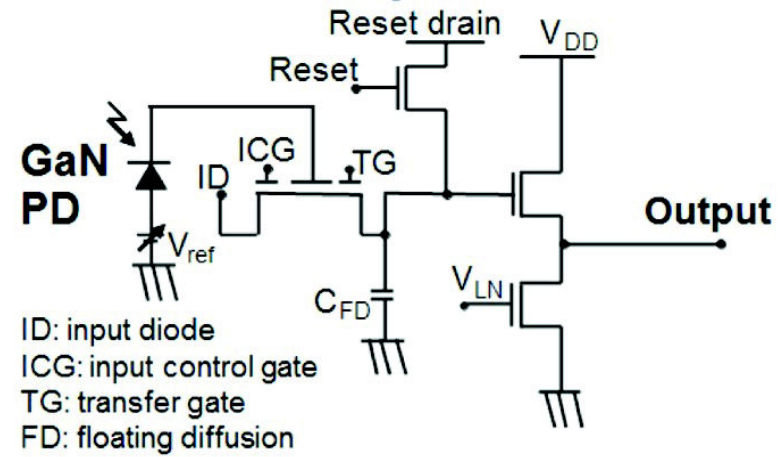


including diffusion barriers

Source: Fred Bijkerk

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

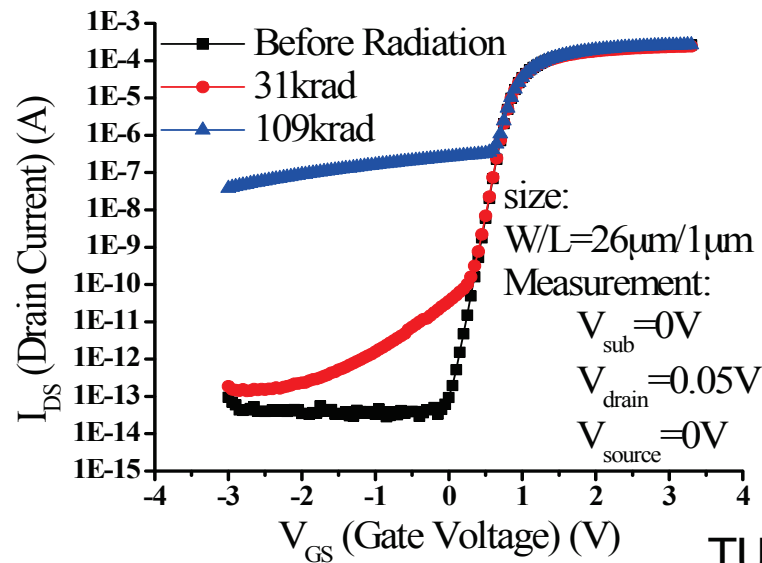
UV-diode



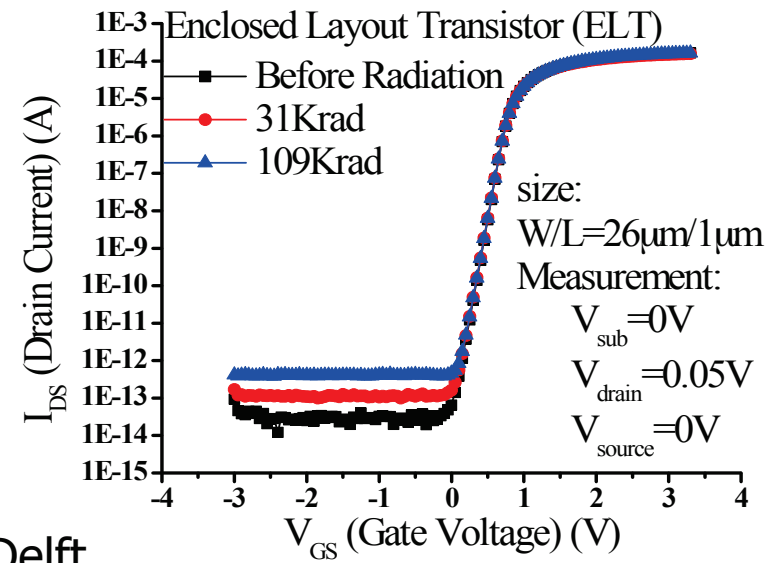
ChangYong Lee et. al. Toyohashi University of Technology

X-ray Radiation on MOSFETs

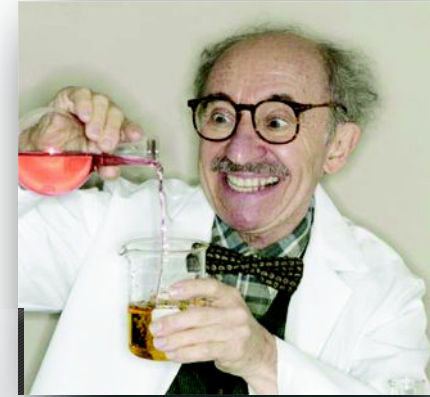
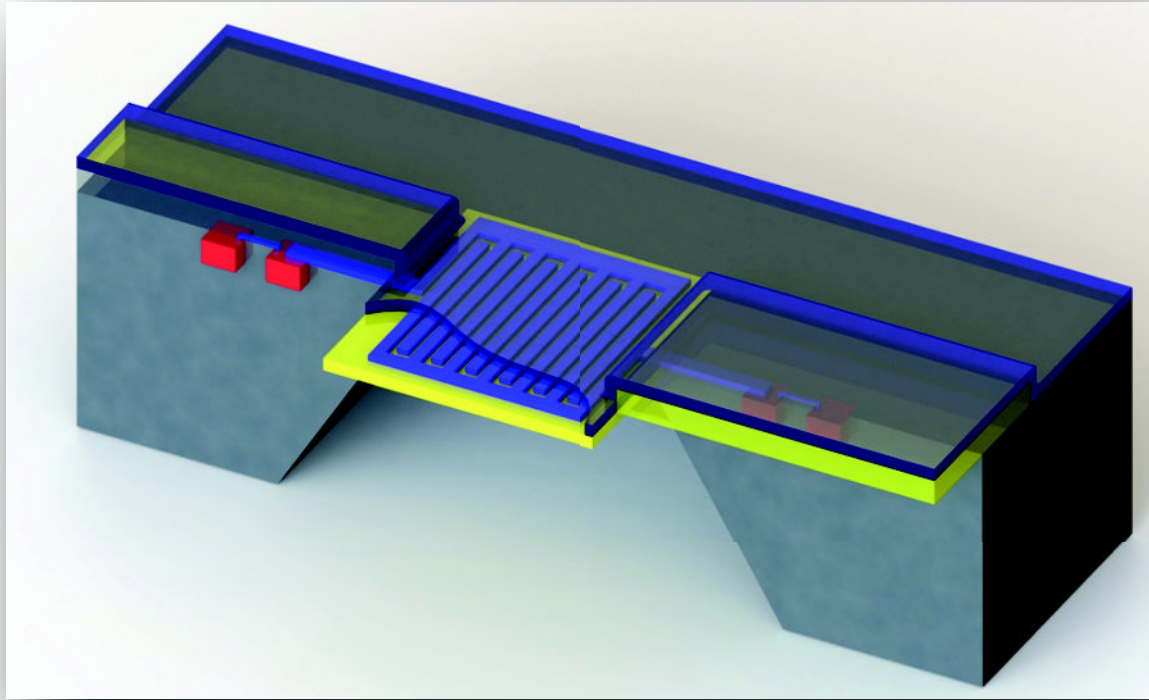
- No post-radiation threshold shift (due to thin gate oxide),
- Parasitic transistor formation induced leakage current increase around the layout edges,
- Post-irradiation interface trap generation induced leakage current increase.



TU Delft

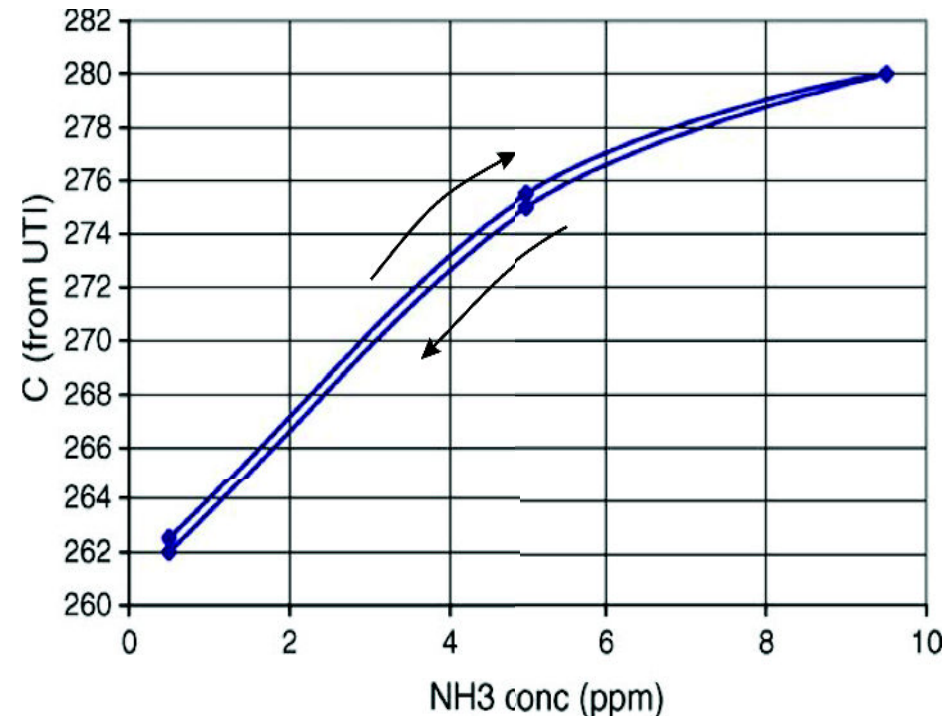


Harsh chemical

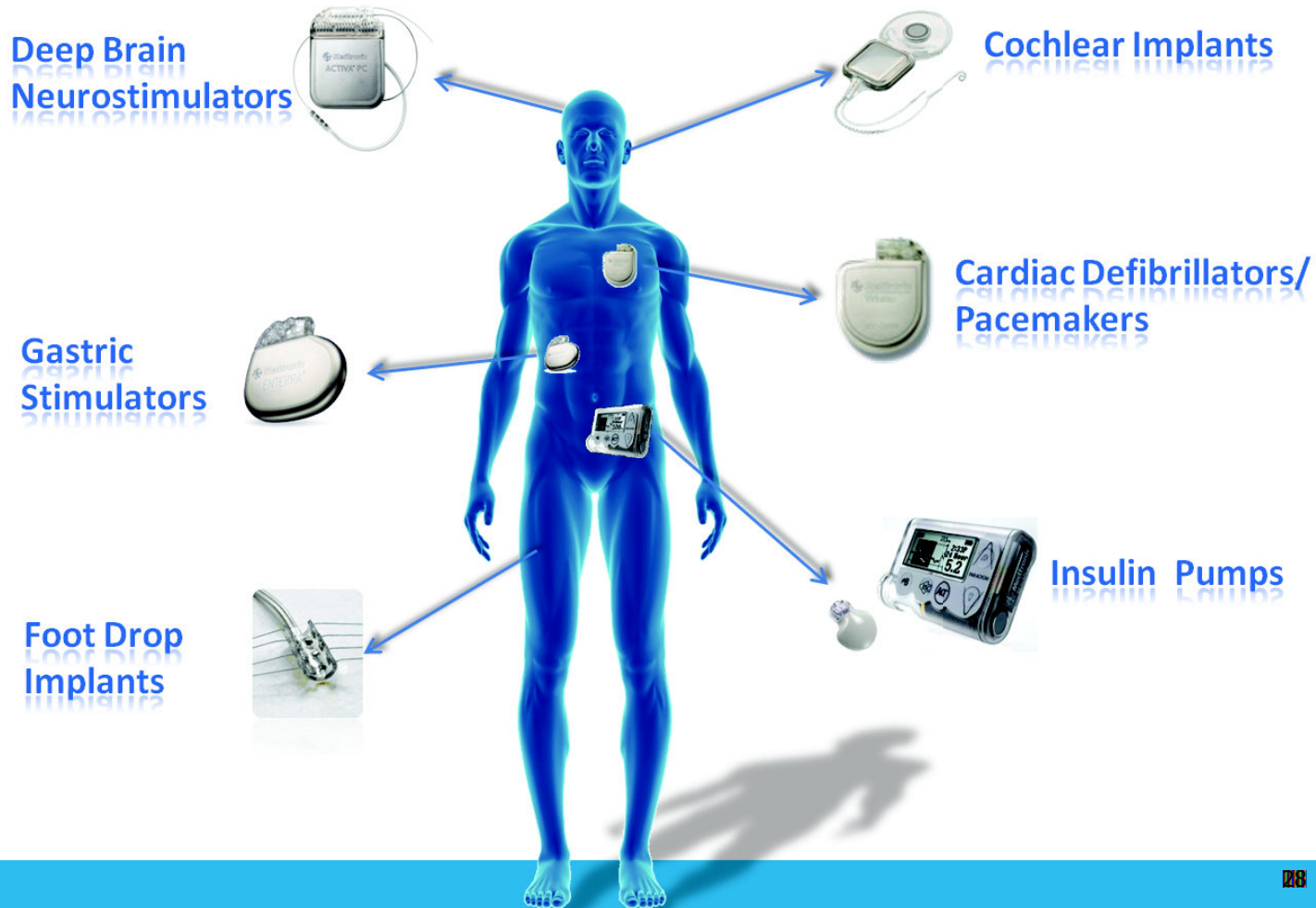


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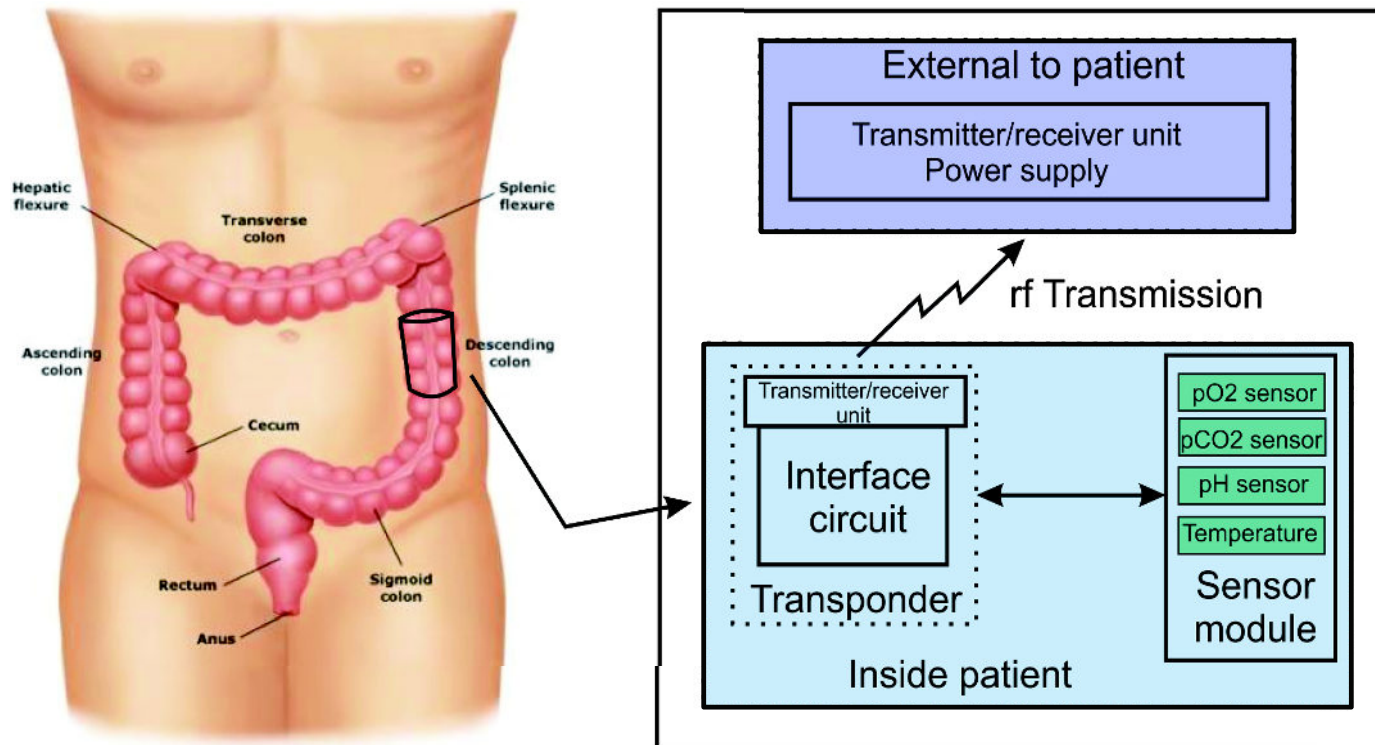
Ammonia sensor



WIRELESS IMPLANTABLE MEDICAL DEVICES

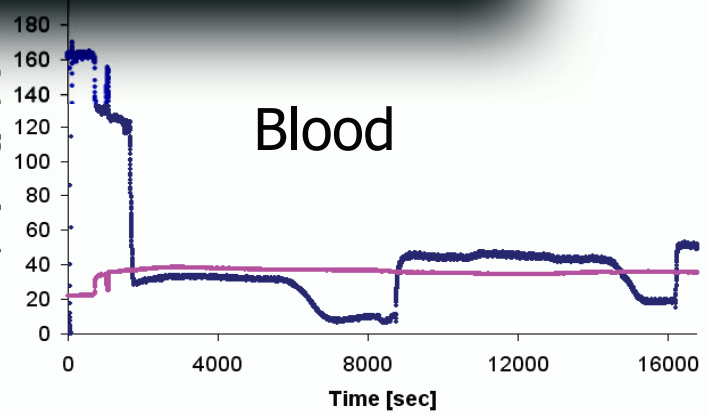
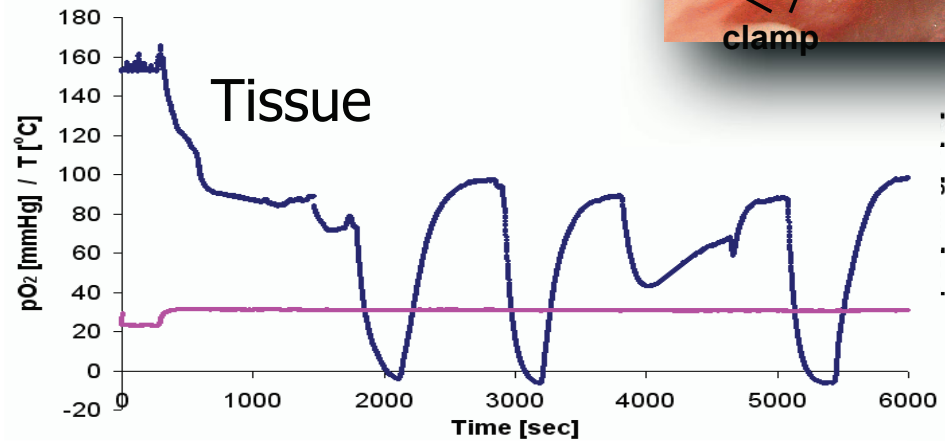
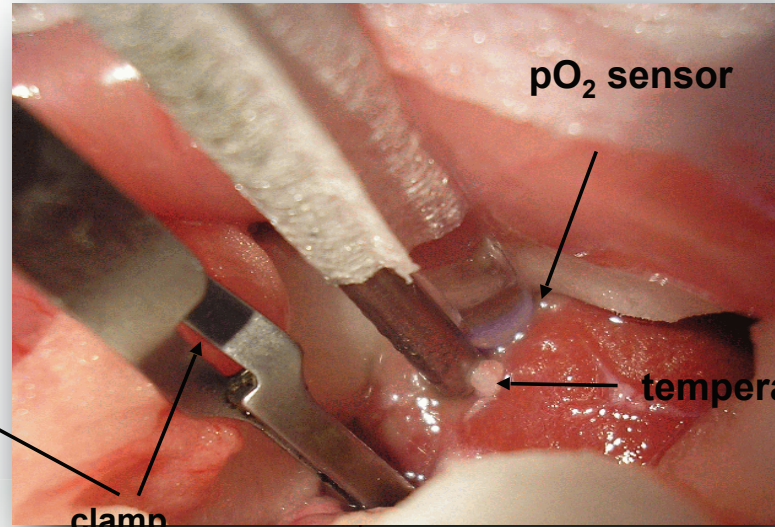
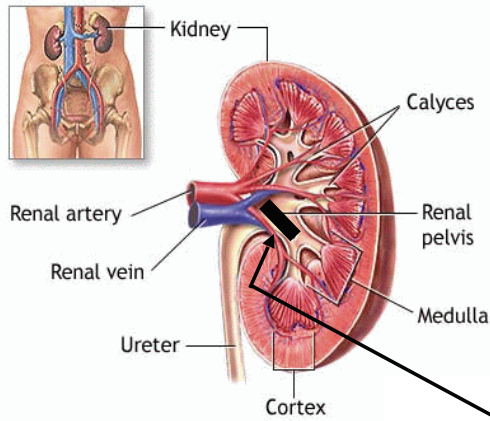


In-vivo

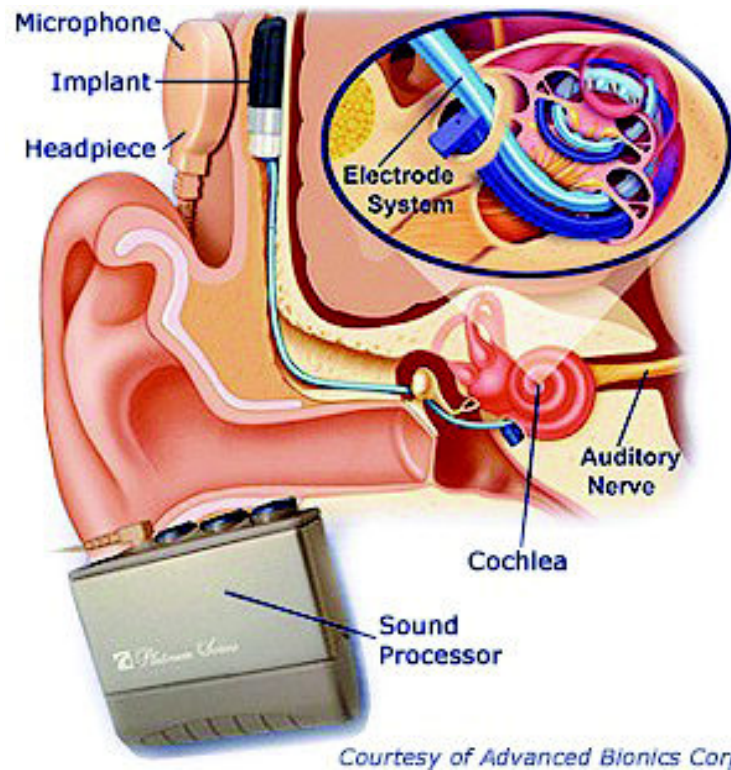


TU Delft and EMC

Oxygen measurements



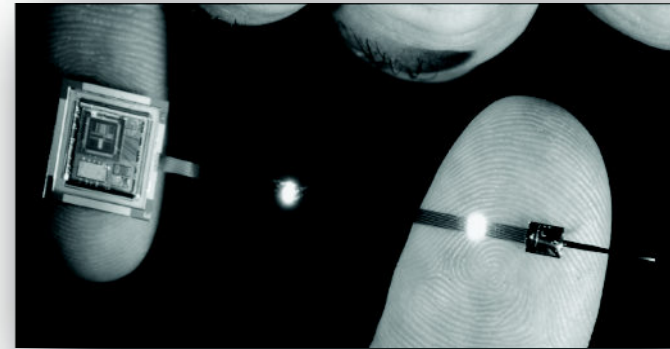
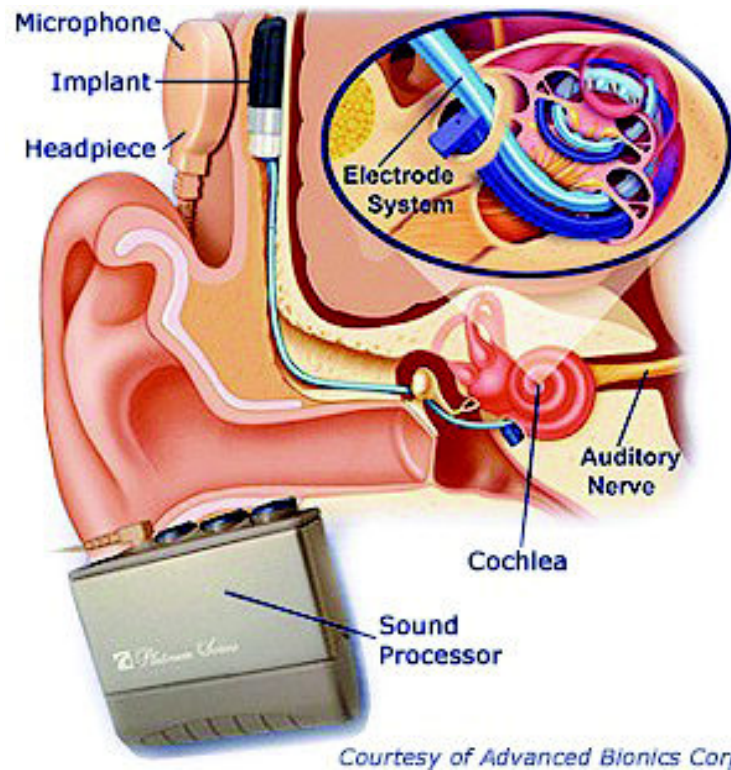
Cochlear implants (CIs)



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)

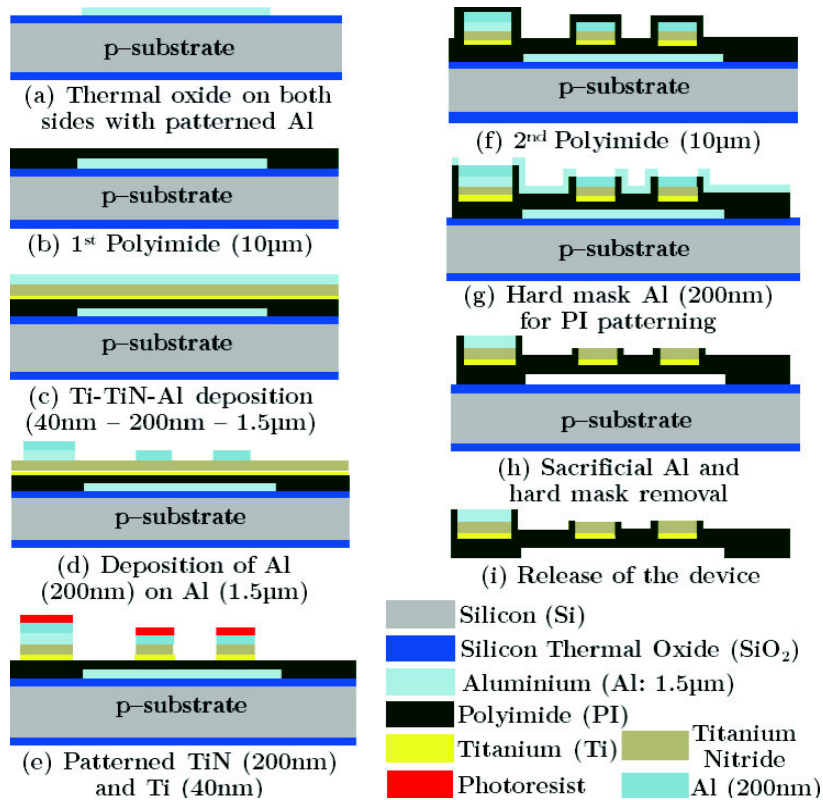


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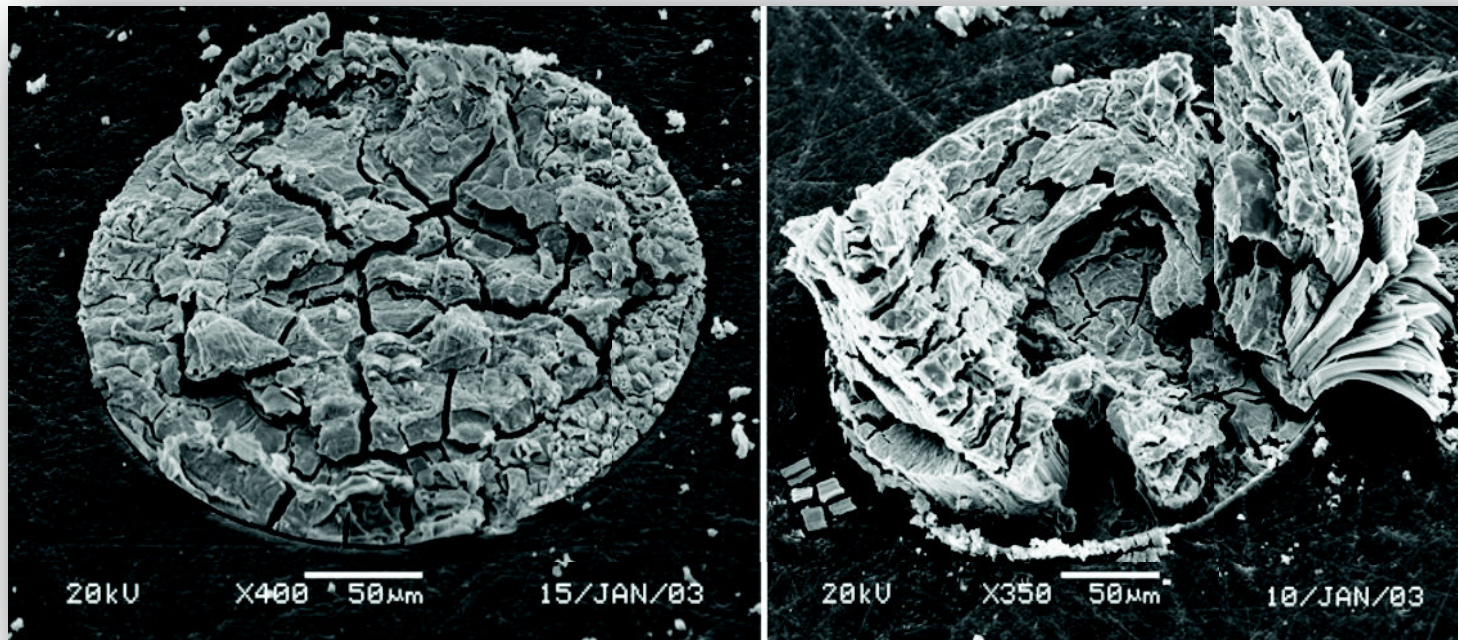
- Challenges:
 - Small
 - 230 channels
 - > 20V into a 1V IC
 - 126dB DR
 - Low power

Electrode for the Cochlear Implant. TUD & LUMC

New generation cochlear implant



Sputtered platinum after extended exposure to a salt solution



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Key research fields and scientific challenges

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

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

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.