Advancements in **Porous Silicon** and **Silicon-On-Insulator** Membranes for Biosensing and Irradiation Recovery

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Louvain la Neuve, located in Belgium

Louvain la Neuve

Louvain la Neuve – then (1972)

Louvain la Neuve – now

UCL - ICTEAM Institute

- **Electrical Engineering (ELEN)**
- Computing Science Engineering (INGI)
- Mathematical Engineering (INMA)

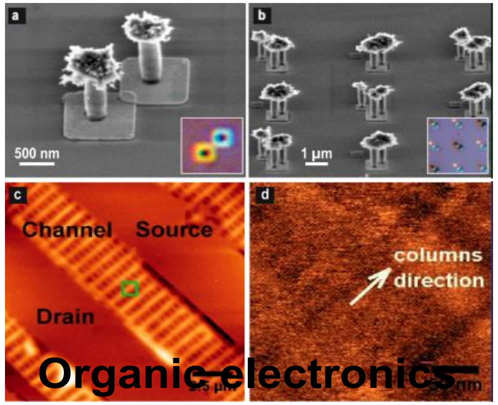
- **WELCOME** and **WINFAB** technology platforms

- About 40 professors
- More than 200 researchers
- 20 computer scientists and technicians

WINFAB platform for micro-nano-fabrication

winfab
WALLONIA
INFRASTRUCTURE
NANO
FABRICATION

- **1000 m^2** of clean rooms on 2 levels
- **Cleanliness:** Critical work areas in **class 1 / ISO 3** (stand-by)
  « less than 100 particules ≥300 nm/m^3 of air »
- **Activities :** more than **40** specialized pieces of **equipment**, **50 to 80 users**, more than **20 R&D projects** in parallel
- **Supports research activities from micro down to nano scale in**
  - Biosensors
  - MEMS-NEMS
  - SOI-CMOS co-integration
  - Organic electronics
  - Nanoelectronics
  - Photovoltaics



icteam

Institute of Information and Communication Technologies, Electronics and Applied Mathematics

UCL

Wallonia Electronics & Communications Measurements

Welcome to multiparametric characterizations

from molecules to signals

in a 350 m² state-of-the art measuring facility for devices, sensors, circuits and systems

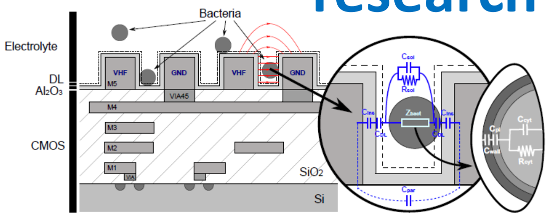
2.13 MEuros equipment over 10 years – over 120 yearly users from 4 corners of the globe

open to research, PhD/Master studies, industry

http://www.uclouvain.be/welcome info-welcome@uclouvain.be

From microsensors to microsystems for health, environment and monitoring applications

Process / device research



(Micro)System applications

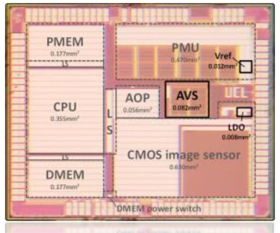
Microfabrication

winfab
WALLONIA
INFRASTRUCTURE
NANO
FABRICATION

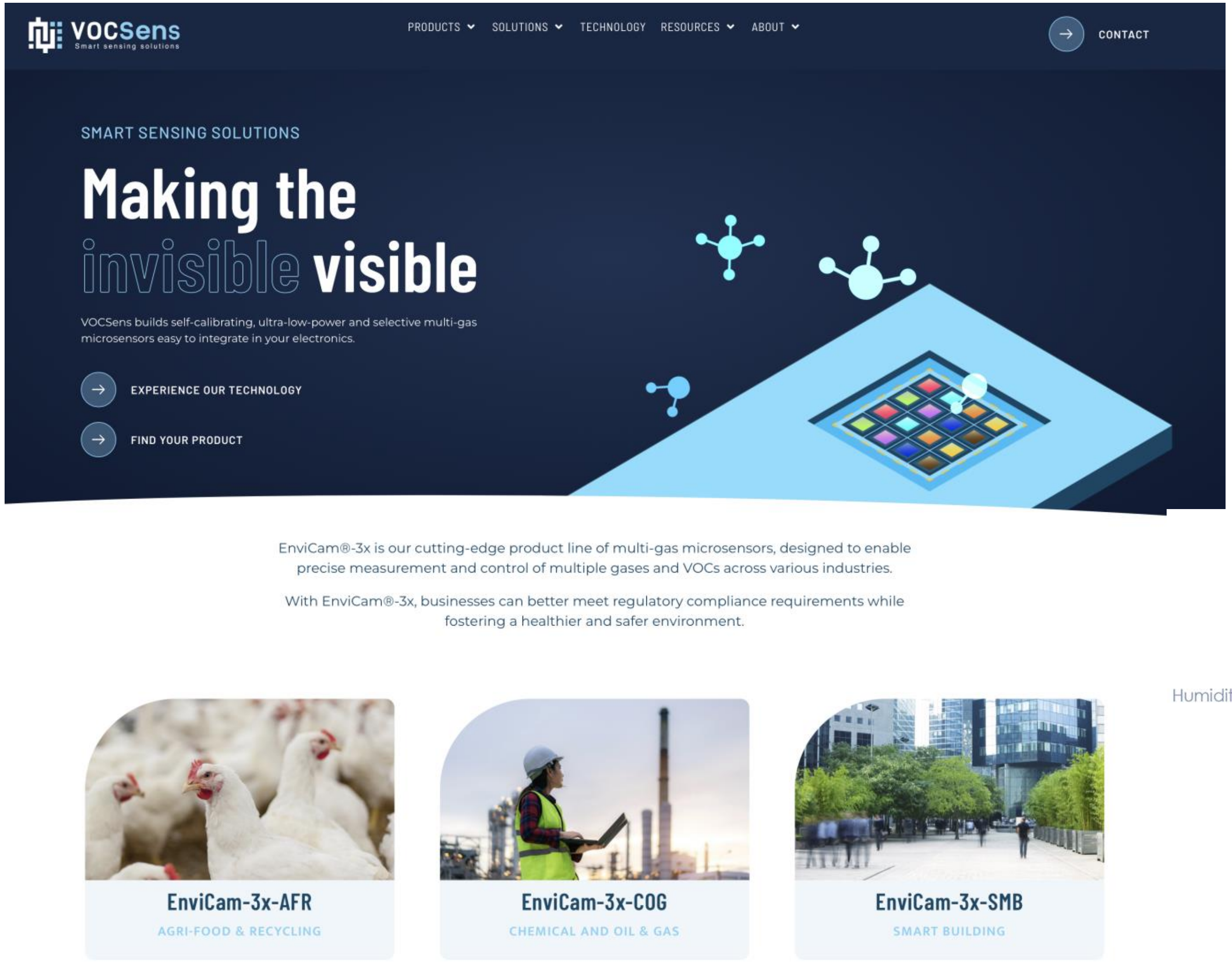
Electrical characterization

welcome
wallonia electronics
and communications
measurements

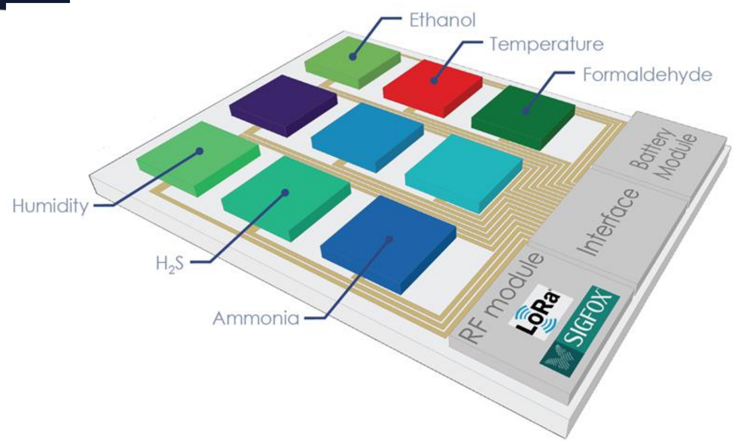
Circuit design



Many collaborations within UCL and abroad !



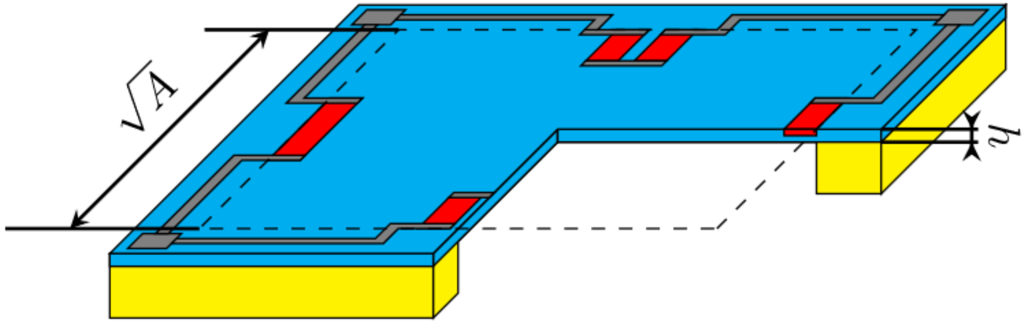
UCLouvain spin off

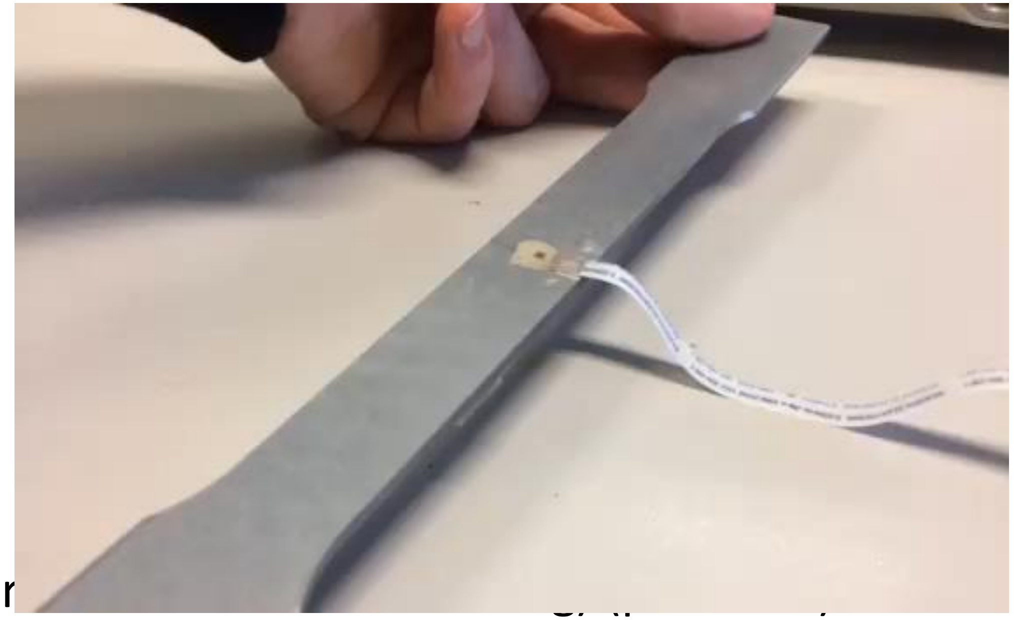


R&D in integrated micro-sensors & energy harvesting

Gas, Flow, Pressure, Humidity, Temperature, Heat
Light, Radiation, Magnetic field, Electrical arcs
Biomolecules (DNA, Proteins, Bacteria…)
Microfluidics, Fluid properties

PV (Si, CIGS, CZTS)
RF (CMOS rectifiers)

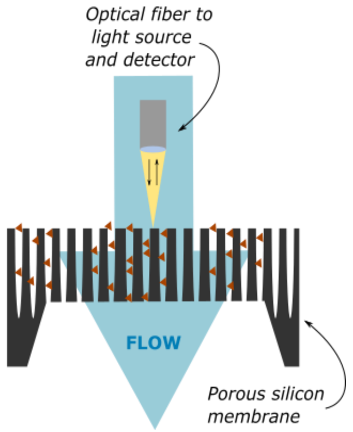


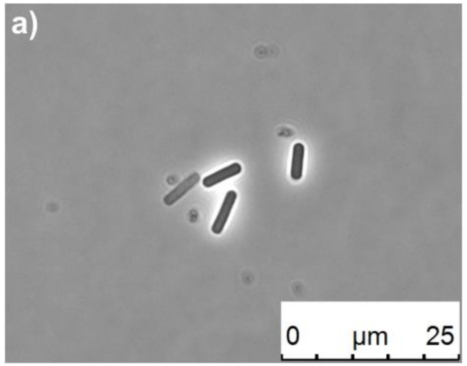


Record performance for

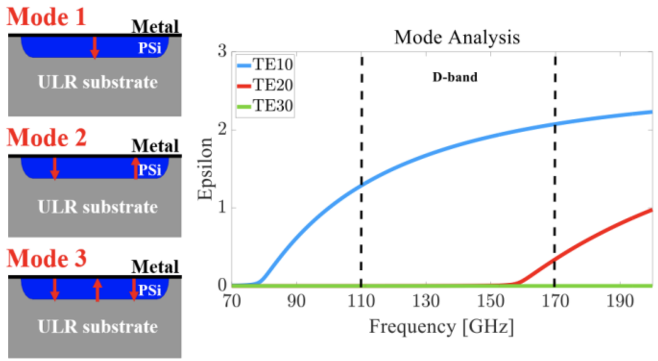
- µW / HT / GF > 1000 Strain gauges on Si (str
- mbar pressure sensor (eye implant)
- 10µm-thick Si proton beam detector (hadrontherapy)
- few-bacteria detection (point-of-care)
- UV sensing (SPAD)…

BACTERIAL DETECTION IN COMPLEX SAMPLES



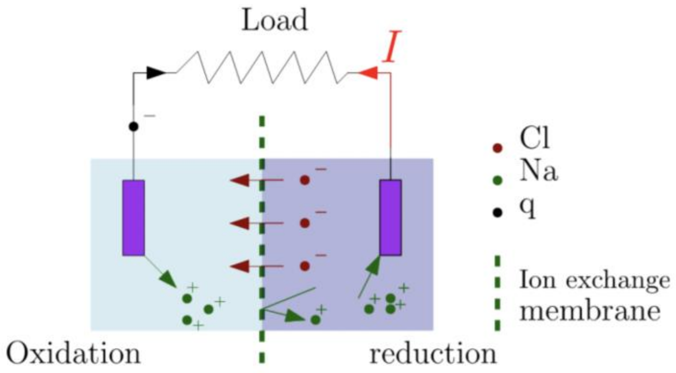


THz WAVEGUIDES



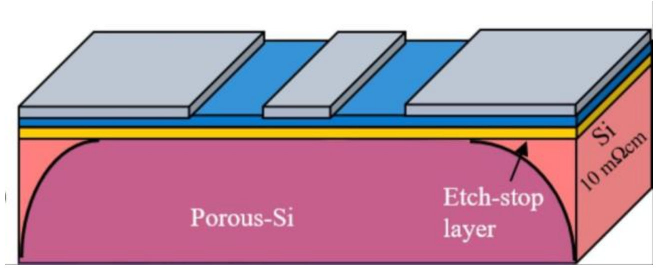
Collaboration with Prof. Dimitri Lederer’s team

BLUE ENERGY & IONTRONICS



RED cell

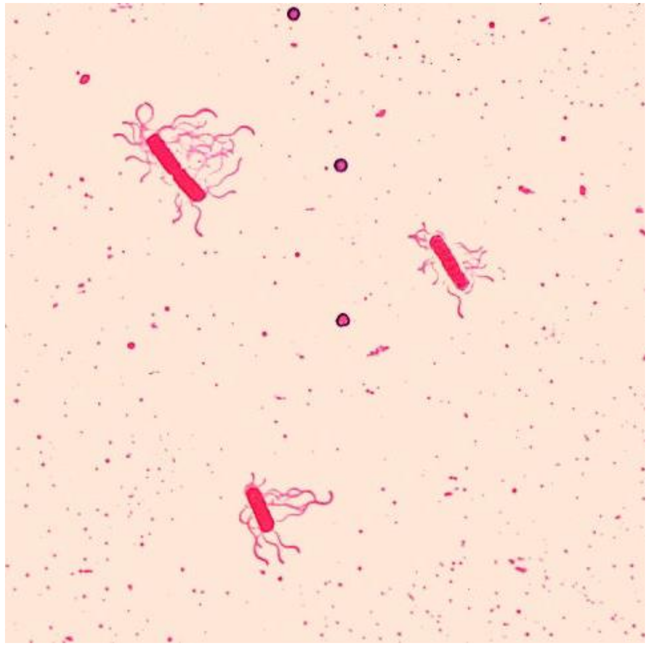
RF SUBSTRATES



Prof. Jean-Pierre Raskin’s
RF SOI group

Porous Silicon Membrane for biosensing

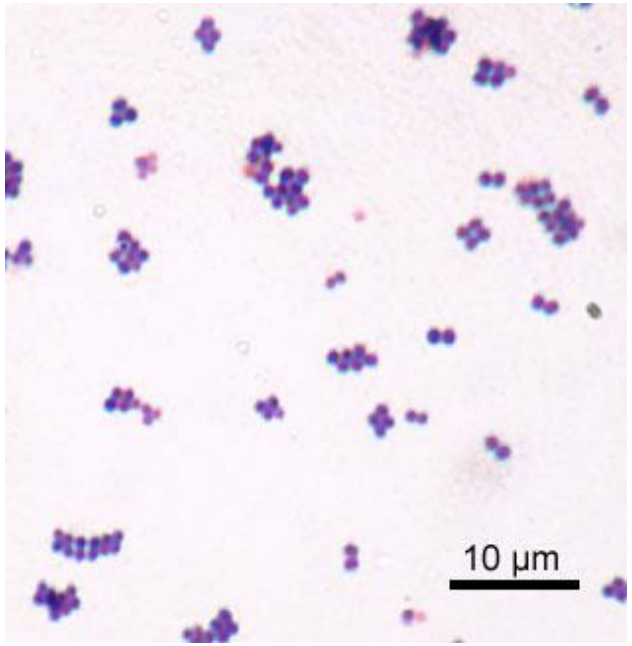
BACTERIA?



B. cereus

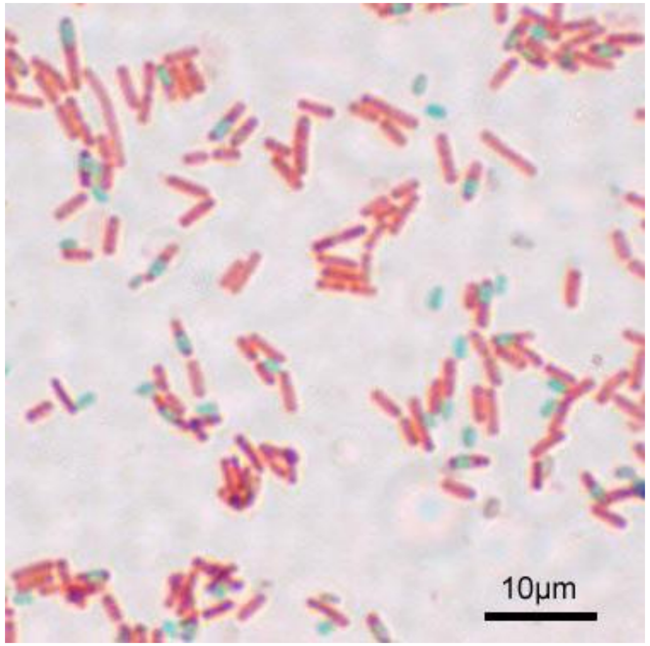
Gastrointestinal, respiratory tract, nosocomial, eye, CNS, urinary tract and cutaneous infections, endocarditis, osteomyelitis. The potential of this bacterium to cause life threatening infections has increased.

[https://www.msjonline.org/index.php/ijrms/article/view/2049]



S. aureus (S. epidermidis)

Minor skin infections: boils, abscesses, impetigo;
More serious infections: meningitis, osteomyelitis, pneumonia, septic phlebitis, endocarditis;
MRSA, displays **antibiotic resistance**



B. subtilis

« Not a frank human pathogen, but has on several occasions been isolated from human infections.
Infections attributed to *B. subtilis* include **bacteremia, endocarditis, pneumonia**, and **septicemia**. »

[https://www.epa.gov/sites/default/files/2015-09/documents/fra009.pdf]

RTL info

Ne consommez pas ce fromage : présence possible de E. Coli STEC

Le fromage « VALENCAY » à base de lait cru de la marque Cloche d'or est rappelé par les autorités sanitaires pour risque de contamination à...

Il y a 1 jour

RTBF

Infections à la bactérie Stec dans des homes : le parquet de Bruxelles ouvre une enquête judiciaire

Fin août, des contaminations par la bactérie Escherichia coli productrice de shigatoxines (STEC) avaient touché des...

Il y a 5 jours

Le Soir

Bactérie Stec dans des homes : le parquet de Bruxelles ouvre une enquête sur les contaminations

Les contaminations à la bactérie ont causé neuf décès et provoqué des symptômes chez plus de 70 personnes.

Il y a 5 jours

La Libre.be

Infections à la bactérie Stec dans des homes: voici la source la plus probable de l'épidémie

La viande bovine hachée crue est la source de contamination par la bactérie Escherichia coli productrice de Shiga-toxines (Stec) la plus...

Il y a 5 jours

VRT

De la viande bovine crue hachée serait la cause la plus probable de l'épidémie de Stec mortelle dans des maisons de repos

L'Agence fédérale pour la sécurité de la chaîne alimentaire (Afsca), l'Agence pour une vie de qualité (AVIQ), le Departement des Soins...

Il y a 5 jours

Virgule.lu

Les victimes de la bactérie Stec se multiplient en Belgique, des cas en province de Luxembourg

La bactérie Stec est une variante dangereuse d'Escherichia coli capable de produire une toxine puissante. Selon la professeure Sandra Van...

Il y a 4 semaines

BruxellesToday

Bactérie Stec: un premier enfant contaminé dans une crèche

La bactérie Stec (Escherichia coli productrice de shiga-toxines) a touché plusieurs maisons de repos en Flandre et aurait mené à la mort de cinq personnes. Ces...

Il y a 1 mois

Artsenkrant

Contaminations STEC en MRS: de la viande bovine hachée crue en cause

Des contaminations par la bactérie E. coli productrice de Shiga-toxines (STEC) ont été détectées dans 11 maisons de repos lors du mois...

Il y a 5 jours

Le Vif

Qu’est-ce que la bactérie Stec, qui menace les maisons de repos? Le point en 3 questions

«C'est une bactérie d'origine animale, mais qui peut se retrouver dans toutes sortes de produits, précise Cécile Meex. Les animaux porteurs...

Il y a 1 mois

RTL info

Bactérie E-Coli Stec: le parquet de Bruxelles ouvre une enquête judiciaire

Société bruxelles Sciences et Santé vidéos Sujet par sujet Ecoli Stec maison de repos décès afsca alimentation nourriture viande hachée...

Il y a 4 jours

Ouest-France

Rappel massif de fromages : ce que l'on sait des 21 personnes contaminées par la Listeria

Mercredi 13 août, Santé publique France a donné plus de détails sur les 21 cas de listériose détectés en France et qui pourrait avoir un...

Il y a 1 mois

Radio France

Rappel massif de fromages pour des soupçons de contamination par la bactérie Listeria : épisode du podcast Enquêtes

Plus de 40 lots de fromages ont été retirés de la vente en France en raison d'un risque de listériose. Santé Publique France a recensé 21...

Il y a 1 mois

Le Dauphiné Libéré

Consommation. Plus de 40 fromages rappelés, un « lien possible » avec 21 cas de listériose dont deux décès

Le site Rappel Conso alerte les consommateurs sur plus de 40 lots de fromages vendus notamment par la plupart des grandes surfaces.

Il y a 1 mois

France 3 Régions

21 cas possibles de listériose, dont deux décès... Plusieurs fromages de la laiterie creusoise Chavegrand rappelés pour suspicion de listéria

Plus de 40 lots de fromages ont été rappelés pour suspicion de contamination par la listeria monocytogenes, le mardi 12 août.

Il y a 1 mois

BFMTV

Morbier, tomme...Des fromages au lait cru rappelés à la suite de suspicions de contamination à la bactérie E. coli

VIDÉO - Des lots de fromages au lait cru ont fait l'objet d'un rappel jeudi et vendredi à la demande du fabricant, la société Perrin-Vermot,...

21 févr. 2025

France 3 Régions

Contaminations à la Listeria : une quinzaine de fromages rappelés par les supermarchés en France

Plusieurs fromages vendus dans la grande distribution ne doivent pas être consommés. Ils font l'objet de rappels nationaux depuis le début...

Il y a 1 mois

Le Dauphiné Libéré

Consommation. Raclette, morbier, tomme : des fromages au lait cru potentiellement contaminés par une bactérie

Des fromages des marques Jean Perrin et Nos régions ont du talent sont potentiellement contaminés par la bactérie Escherichia coli et...

19 févr. 2025

Radio SCOOP

Du fromage à raclette rappelé dans toute la France

Plusieurs fromages au lait cru (raclette, morbier, tomme) sont rappelés en raison d'un risque de contamination à E. coli, une bactérie...

19 févr. 2025

France 3 Régions

La bactérie Listeria retrouvée dans des fromages de Cîteaux, la vente suspendue : "c'est un très gros préjudice"

C'est au cours d'auto-tests pratiqués sur leur production de fromages que les moines de Cîteaux ont stoppé la fabrication.

12 mai 2025

Le Figaro

E. coli : deux fillettes contaminées par la bactérie, l'une d'elles frôle la mort

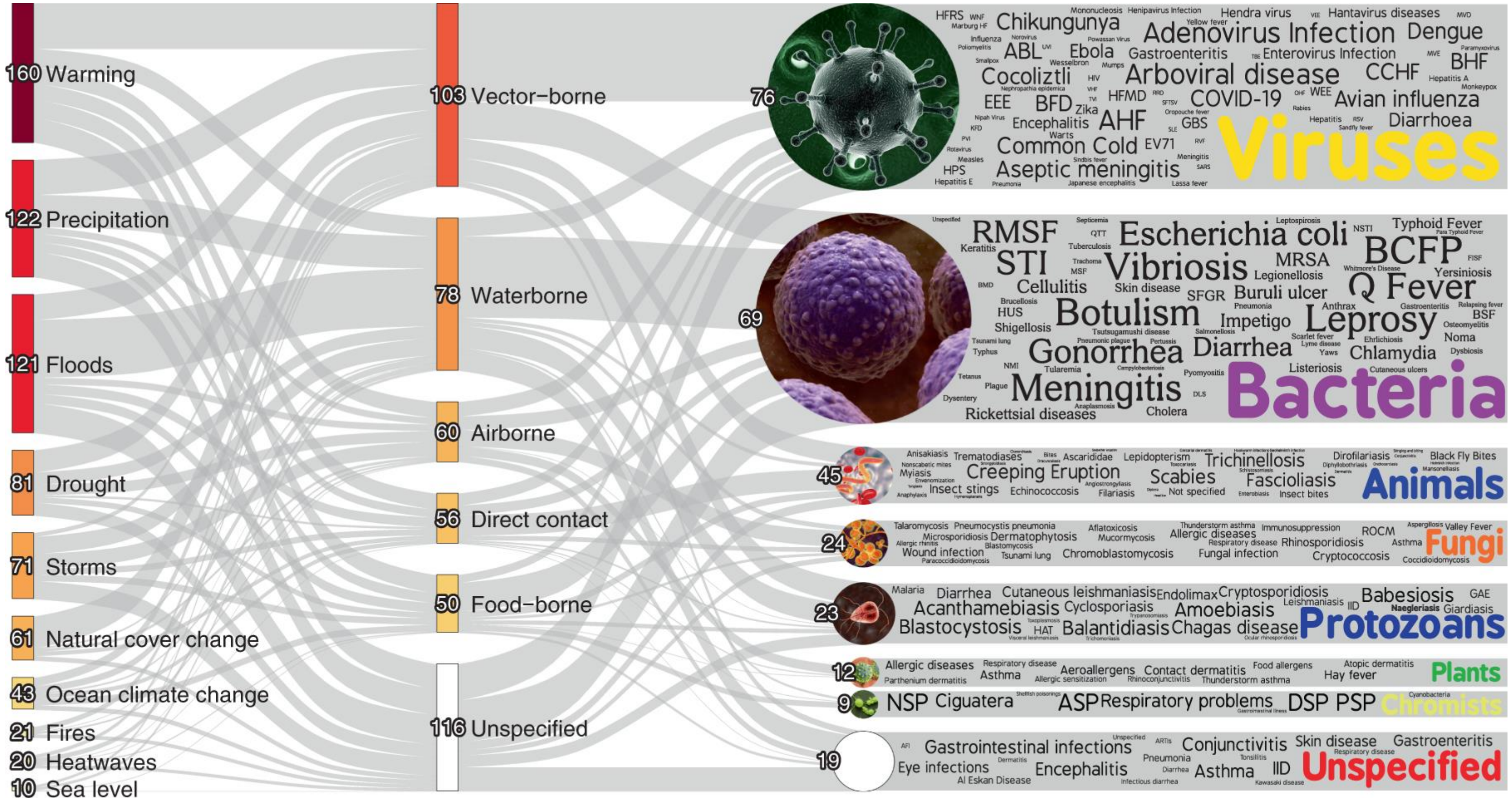
Élise, 7 ans, est hospitalisée à Lyon depuis décembre dernier pour une contamination par la bactérie E. coli, présente dans du fromage.

9 févr. 2024

Over half of known human pathogenic diseases can be aggravated by climate change

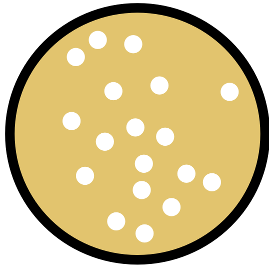
Camilo Mora, Tristan McKenzie, Isabella M. Gaw, Jacqueline M. Dean, Hannah von Hammerstein, Tabatha A. Knudson, Renee O. Setter, Charlotte Z. Smith, Kira M. Webster, Jonathan A. Patz & Erik C. Franklin

Nature Climate Change **12**, 869–875 (2022) | Cite this article



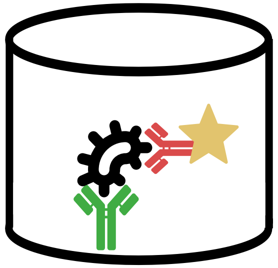
https://camilo-mora.github.io/Diseases/

Traditional methods for bacterial detection



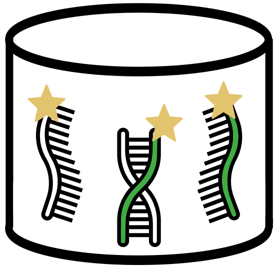
Culture

- ✓ Cost-effective
- ✓ Specific
- ✓ Sensitive (1 CFU*/mL)
- × Time-consuming (>12h)
- × Prone to errors



ELISA

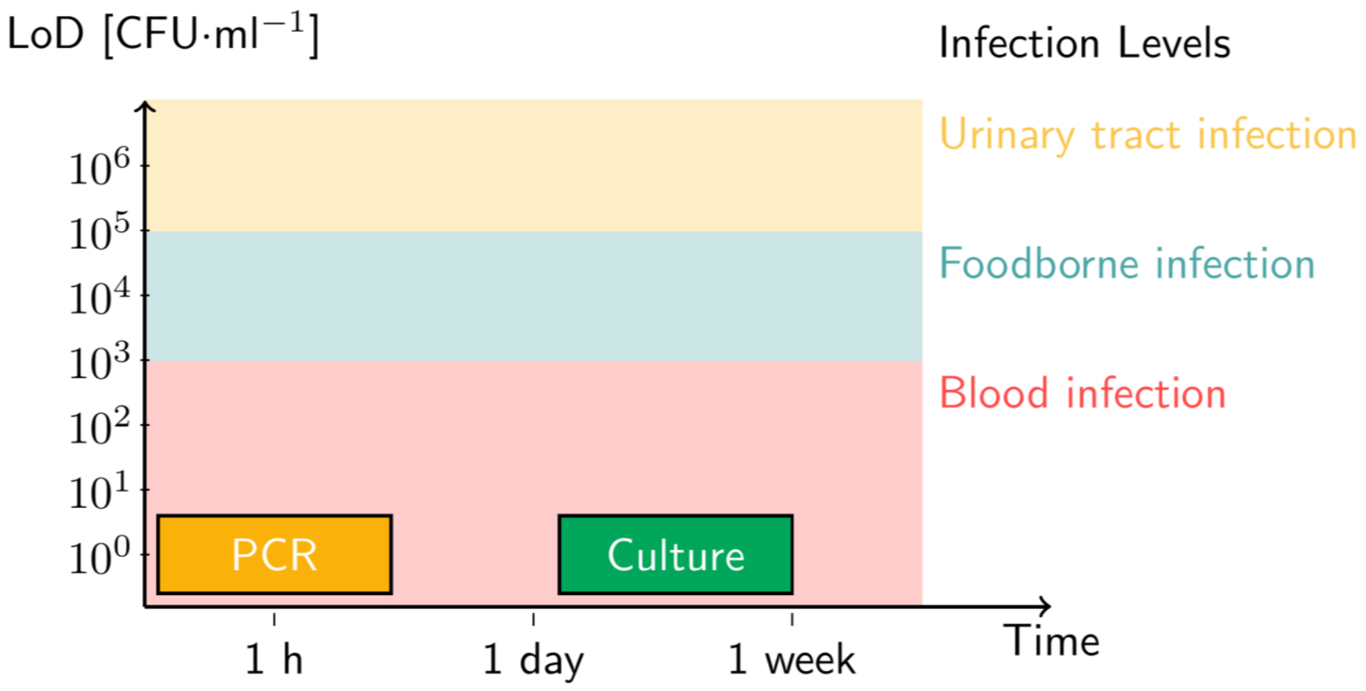
- ✓ Fast (>2h)
- ✓ Specific
- ✓ Sensitive (1-10 CFU*/mL)
- × Expensive



PCR

- ✓ Fast (>1h)
- ✓ Specific
- ✓ Sensitive (1 CFU*/mL)
- × Expensive
- × High-end instrumentation
- × Prior knowledge of suspected pathogen

* CFU = Colony Forming Units



Assay time
Sensitivity
Selectivity
Reliability/Robustness
Complex sample
Versatility
Cost
Portability

PSI MEMBRANES

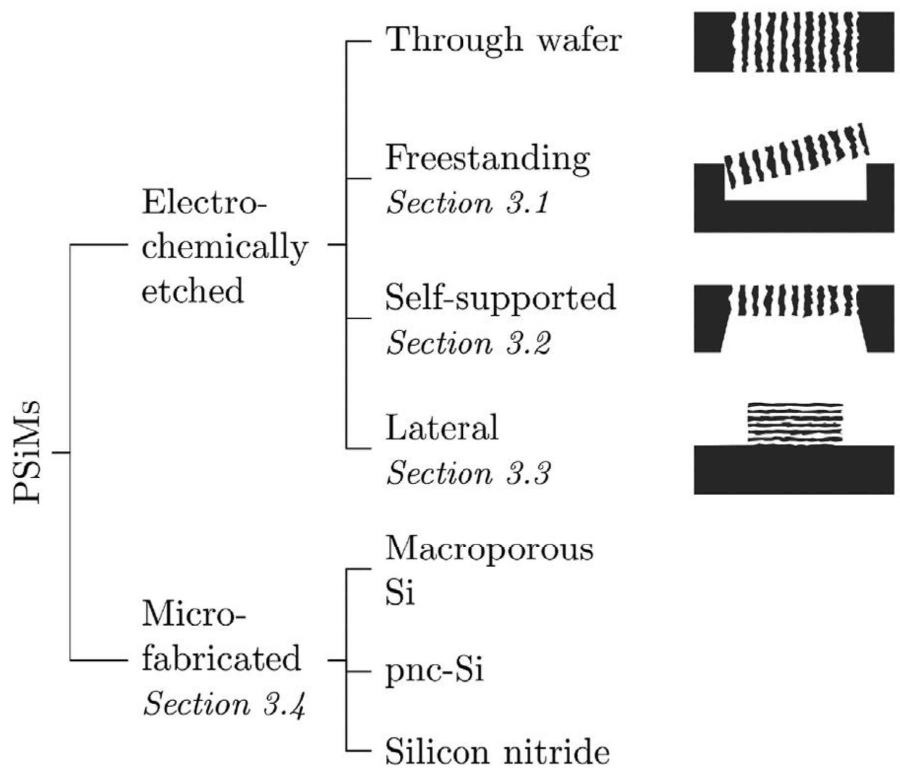
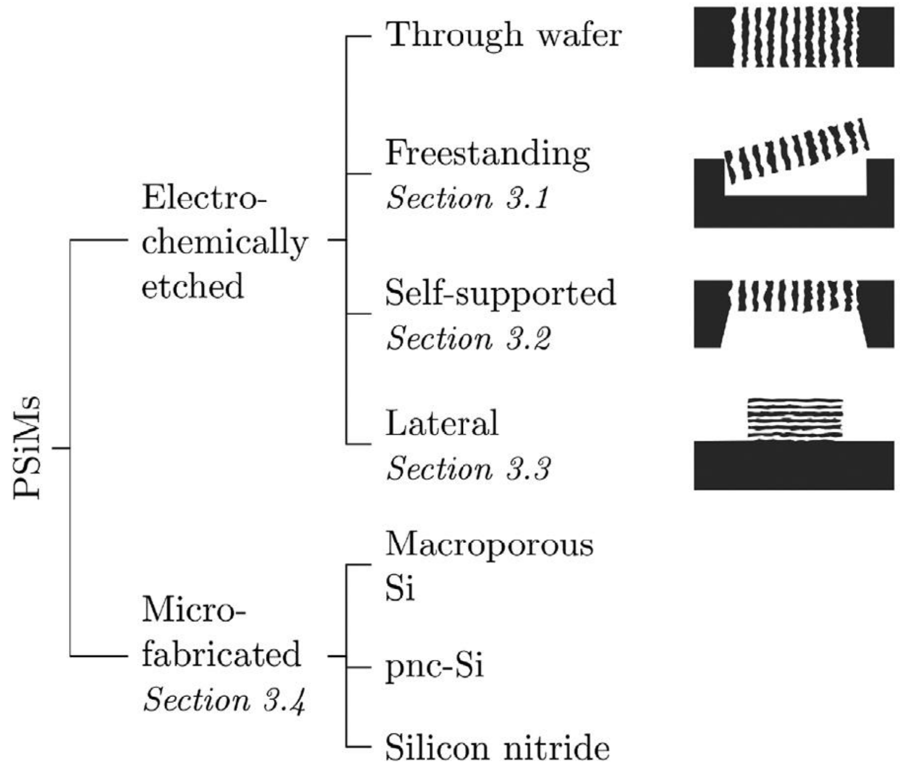


Fig. 2. Summary of porous membranes fabrication techniques.

Table 1
Recent advances in the applications fields of porous silicon membranes (*Note: C, F, FT, L, M, S stand for, respectively, Commercial, Freestanding, Full Thickness, Lateral, Microfabricated and Self-supported.*)

Application field	Membrane characteristics	Membrane thickness	Detailed application	Ref.
Microfluidics	M, mesoporous	15 nm	Size and charge selective filtration	[150]
	S, mesoporous	5 μm	Filtration of small biological molecules from mixtures	[81]
	L, mesoporous	10 – 20 μm	Size and charge selective filtration	[99,151,152,100,153]
	S, macroporous	215 μm	Electro-osmotic pump	[90]
Medical	F, macroporous	4.29 μm	Drug delivery patch and optical monitoring of drug release	[7]
	M, macroporous	50-60 nm	Culture of human umbilical vein vascular endothelial cells	[8]
	M, macroporous	500 nm	Reconstruction of the intestinal barrier of a trout via cell culture	[9]
	M, mesoporous	75 nm	Small-format hemodialysis with high toxin elimination capabilities	[10]
	M, macroporous	30 μm	Transmigration assay for cancer cells	[11]
	F, mesoporous	276 μm	Scaffold for the culture of oral mucosal epithelial cells	[12]
	C, macroporous	1 – 10 μm	Support for the investigation of pore-spanning lipid membranes	[154–160]
	M, mesoporous	30 nm	Cell culture of endothelial cells	[13]
	F, macroporous	12 – 15 μm	Tissue scaffold integrated with cell-laden hydrogel biomaterials	[14]
	M, macroporous	5 μm	Lung-on-chip microfluidic device	[15,161]
	M, macroporous	10 μm	Culture of intestinal epithelial cells	[16]
	S, macroporous	130 – 150 μm	Mechanical cell lysis and DNA isolation	[17,88]
	F, mesoporous	4 – 5 μm	Implantable scaffold for cell culture	[18]
Sensing	S, macroporous	~50 μm	Electrophysical NO_2-gas detector	[85]
	F, mesoporous	1.7 μm	Silver-modified sensor for SERS-based detection of miRNA	[59]
	L, mesoporous	10 μm	Interferometric transducer for solvent detection	[153]
	F, mesoporous	1.6 μm	Optical detection of ethanol vapour	[138]
	S, mesoporous	2.5 μm	Impedance spectroscopy of the formation of a lipid membrane	[94,95]
	F, mesoporous	29 μm	Electrostatic isopropanol vapour sensor	[20]
	F, mesomacroporous	5.5 μm	Optical detection of Bovine Serum Albumin	[21]
	F, mesoporous	17 – 21 μm	Optical detection of dissolved gas concentrations in liquids	[137]
	M, mesoporous	50 nm	Nanopore-based sensing of DNA translocation	[110]
	S, mesoporous	20 μm	Multi-assay solvent vapour optical detection	[162]
	F, mesoporous	870 nm	Multianalyte detection using silver-decorated sensors	[67,68]
	M, mesoporous	15 nm	Optical detection of Bovine Serum Albumin permeation	[22]
	F, mesomacroporous	4.5 μm	Electrochemical detection of MS2 bacteriophage	[71]
	F, mesomacroporous	4.5 μm	Label-free electrochemical detection of bacterial toxin	[163]
	M, mesomacroporous	50 nm	Electrochemical detection of ion-transfer across the PSiM	[113]
	C, macroporous	475 μm	3D liquid core sensor array	[164]
	S, mesoporous	340 nm	DNA translocation detection	[96,97]
	M, macroporous	50 μm	Immunoassay for specific leukocyte subsets	[103]
	S, macroporous	1 – 3 μm	Transmembranes proteins sensing	[87]
	C, mesomacroporous	10-15 nm	DNA translocation detection	[165–167]
	F, mesoporous	19.9 μm	Optical aptasensors with multiple target-binding sites	[23]
	S, mesoporous	4 – 15 μm	Optical detection of enzyme adsorption and streptadivin binding	[19,79,168]
Energy conversion	F, micro/macroporous	10 – 30 μm	Wide-gap absorber for solar cells	[66,64]
	S, mesoporous	~70 μm	Implantable glucose biofuel cell	[89]
	S, mesoporous	5 – 20 μm	Ion-exchange membrane for micro fuel cells	[27]
	S, mesoporous	50 μm	Anion exchange membrane for Glucose/O_2 micro fuel cell	[28]
	S, macroporous	125 μm	Membrane-electrode assembly for H_2/air-fed micro fuel cells	[29]
	S, macroporous	230 μm	Microfluidic electric generator	[91]
	S, mesoporous	13 μm	Monolithic Si electrode for micro fuel cells	[30,98]
	F, macroporous	50 μm	Anode for lithium-ion batteries	[63,60,65]
	F, mesoporous	200 μm	Anode for lithium-ion batteries	[31]
	M, macroporous	5 μm	Electrode grids for micro fuel cells	[32]
	S, micro/macroporous	210 μm	High-conductivity electrodes for micro fuel cells	[33]
	M, macroporous	280 μm	Ion-exchange membrane for photoelectrochemical cell	[34]
	S, macroporous	50 μm	Electrode for methanol micro fuel cell	[35]
	S, macroporous	60 μm	Cathode for self-breathing microfuel cells	[36]
	FT, meso/macroporous	500 μm	Membrane-electrode assembly for hydrogen/oxygen micro fuel cells	[57,37]
	S, mesoporous	100 μm	Proton exchange membrane for methanol micro fuel cells	[83,84]
	S, meso/macroporous	80 – 100 μm	Pervaporation membrane for methanol vapour-fed micro fuel cells	[80]
Electronics	F, mesoporous	46 μm	RF insulating and supporting substrate for microfabricated inductors	[61]
	S, mesoporous	10 μm	MEMS-based superheated loop heat pipes	[24]
	M, macroporous	600 nm	Thermal management device	[25]
	S, mesoporous	300 μm	Thermal isolation layer for high temperature micro-hotplates	[26]
	F, macroporous	2.46 μm	Flexible optoelectronics device	[72]
	F, mesoporous	1.92 μm	Modulator for photodetector	[74,75]
	FT, mesoporous	380 μm	CMOS compatible RF insulating substrate	[58]

R. Vercauteren; G. Scheen; J.-P. Raskin; L. A. Francis; Porous silicon membranes and their applications: Recent advances, *Sens. Actuator A-Phys.* ***2021,*** 318, 112486, https://doi.org/10.1016/j.sna.2020.112486



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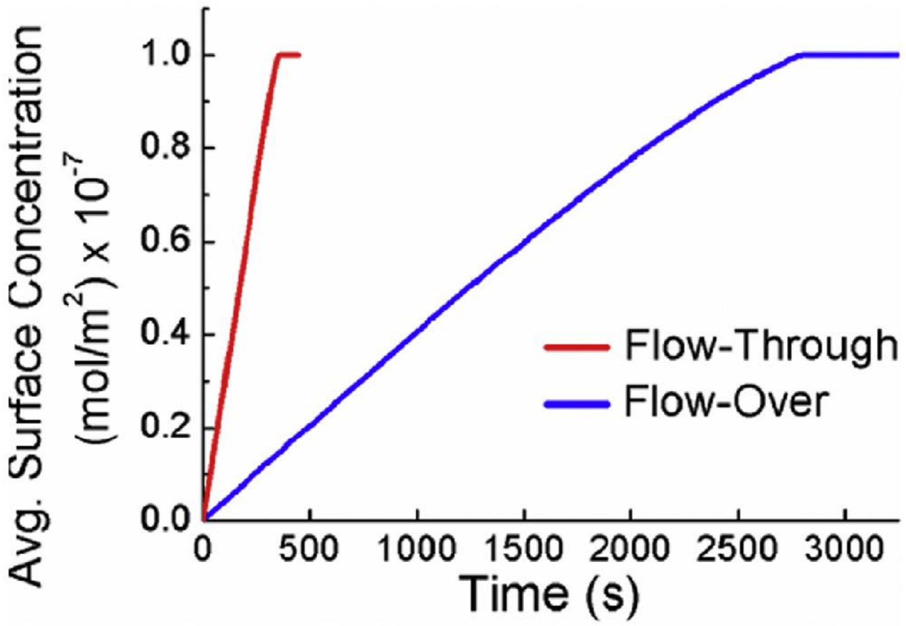
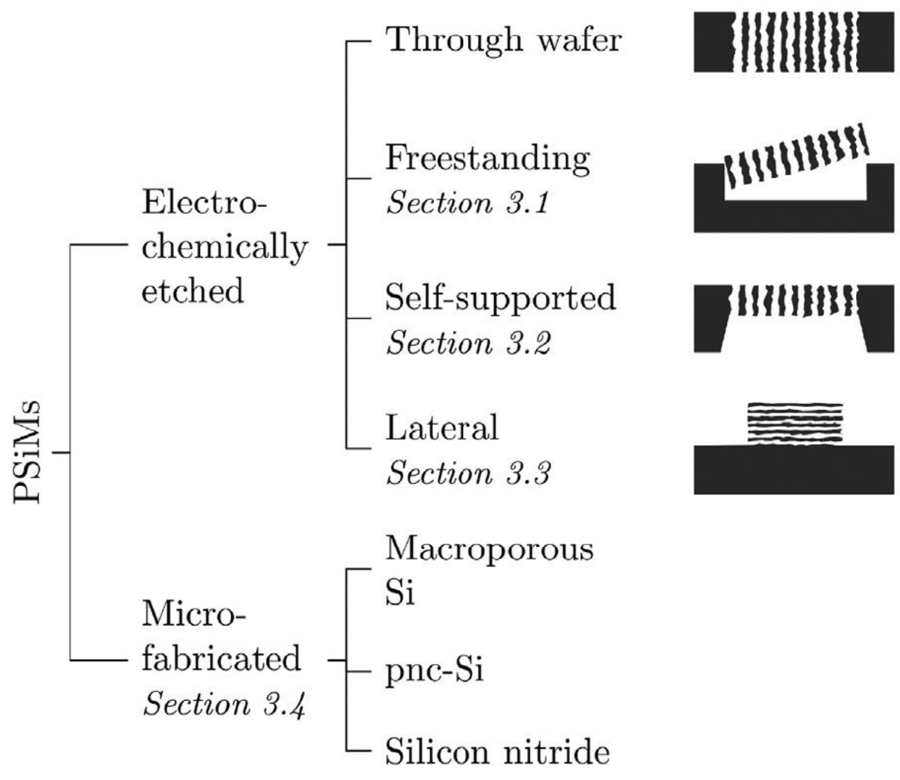


Fig. 11. Simulated average surface concentration of analyte with the same diffusivity, captured by close- and open-ended PSi sensors as a function of time; reprinted from [19], Copyright (2016), with permission from American Chemical Society.

R. Vercauteren; G. Scheen; J.-P. Raskin; L. A. Francis; Porous silicon membranes and their applications: Recent advances, *Sens. Actuator A-Phys*. ***2021,*** 318, 112486, https://doi.org/10.1016/j.sna.2020.112486



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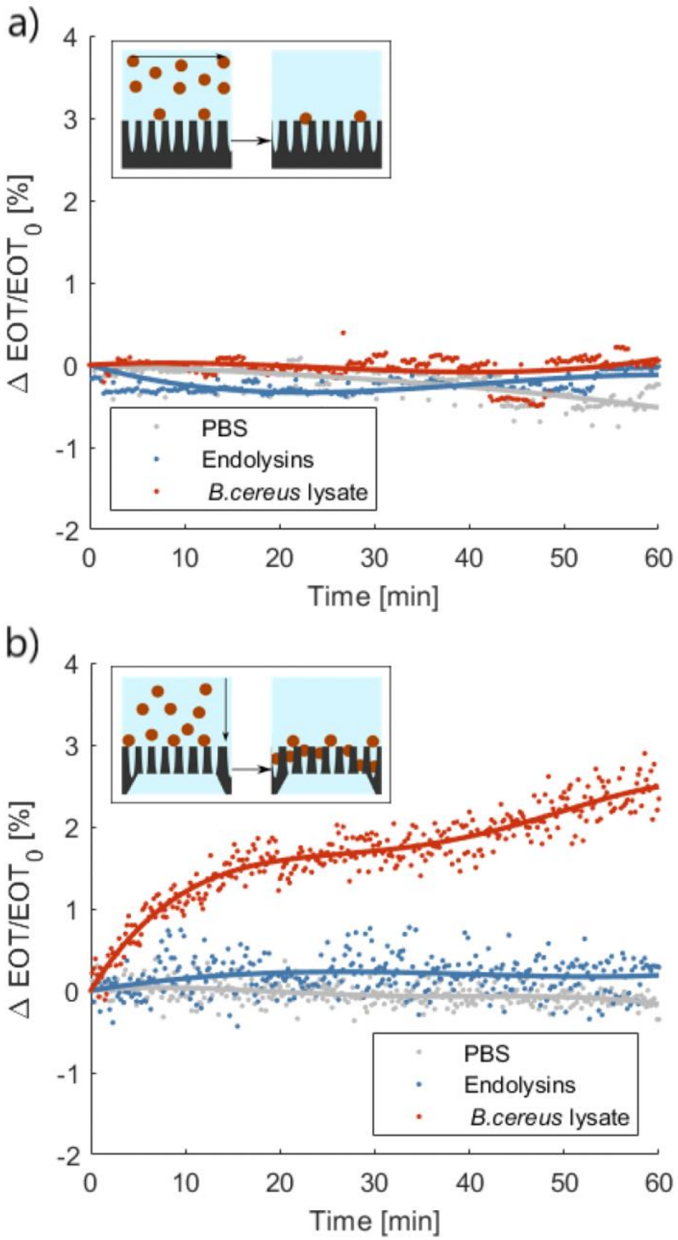

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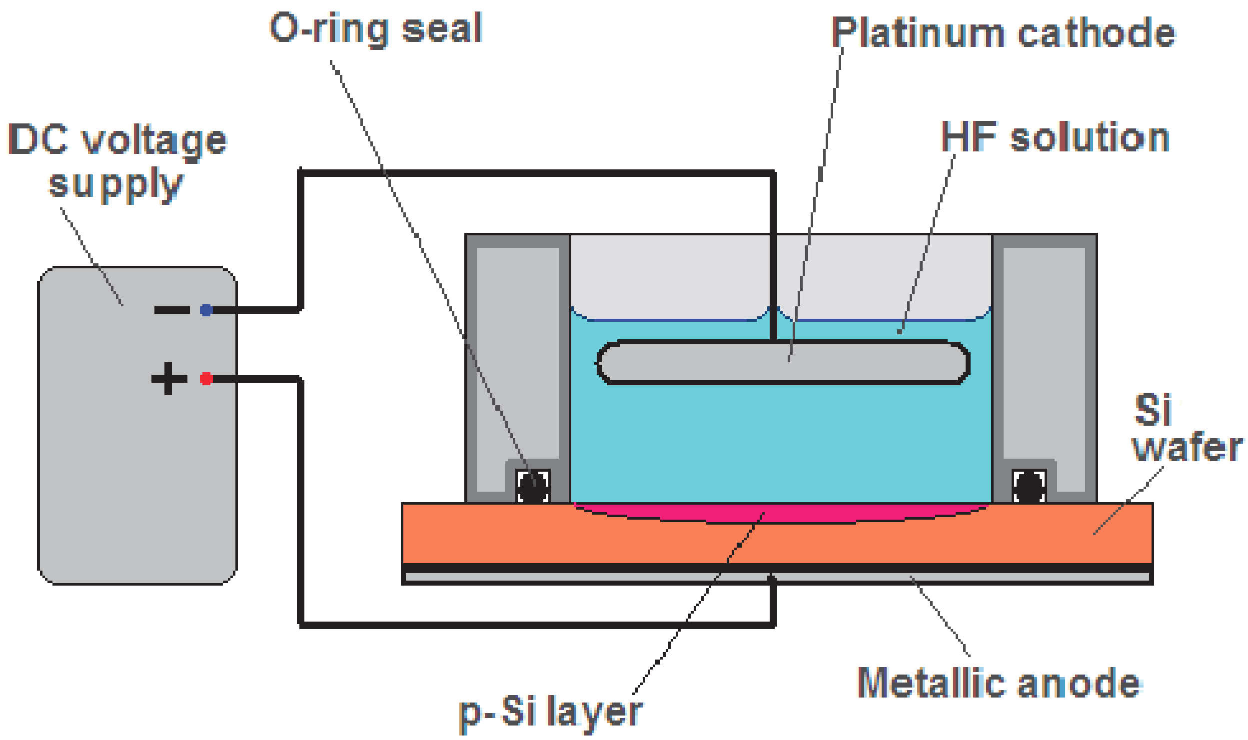
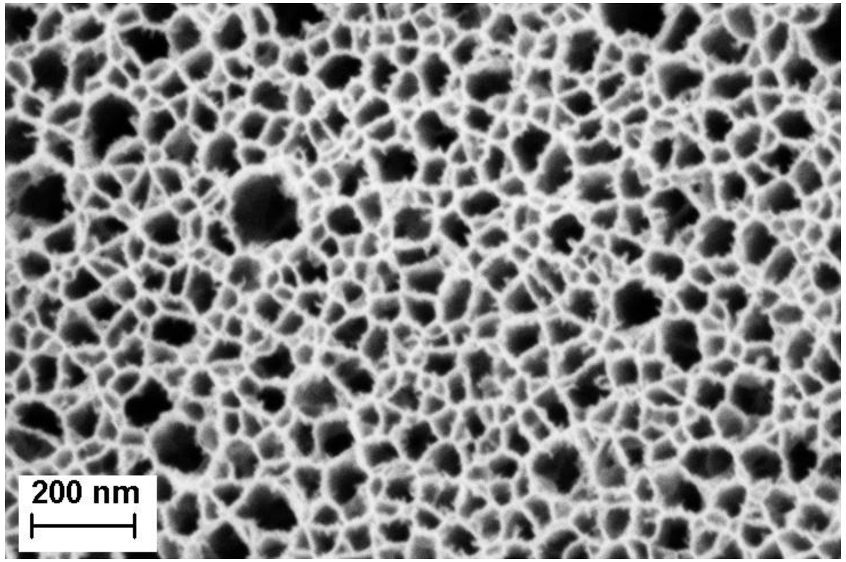
Electrochemical etching





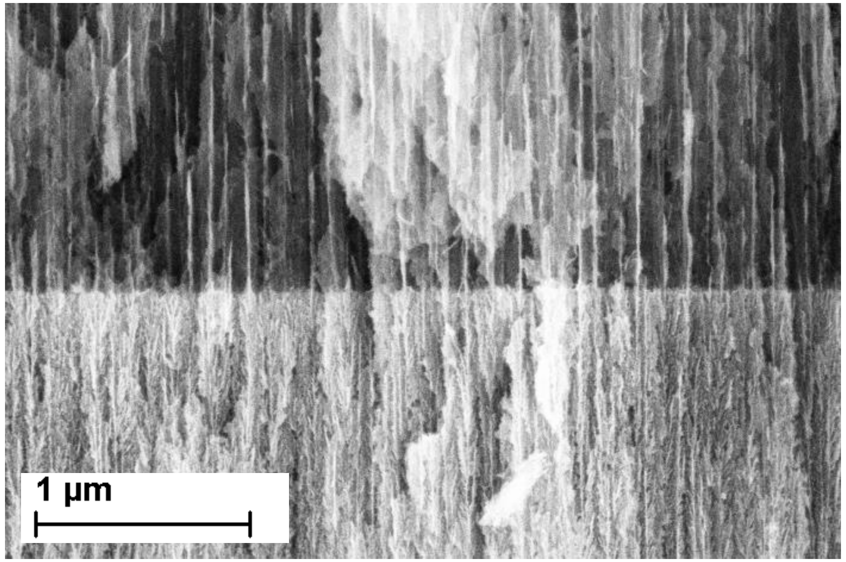
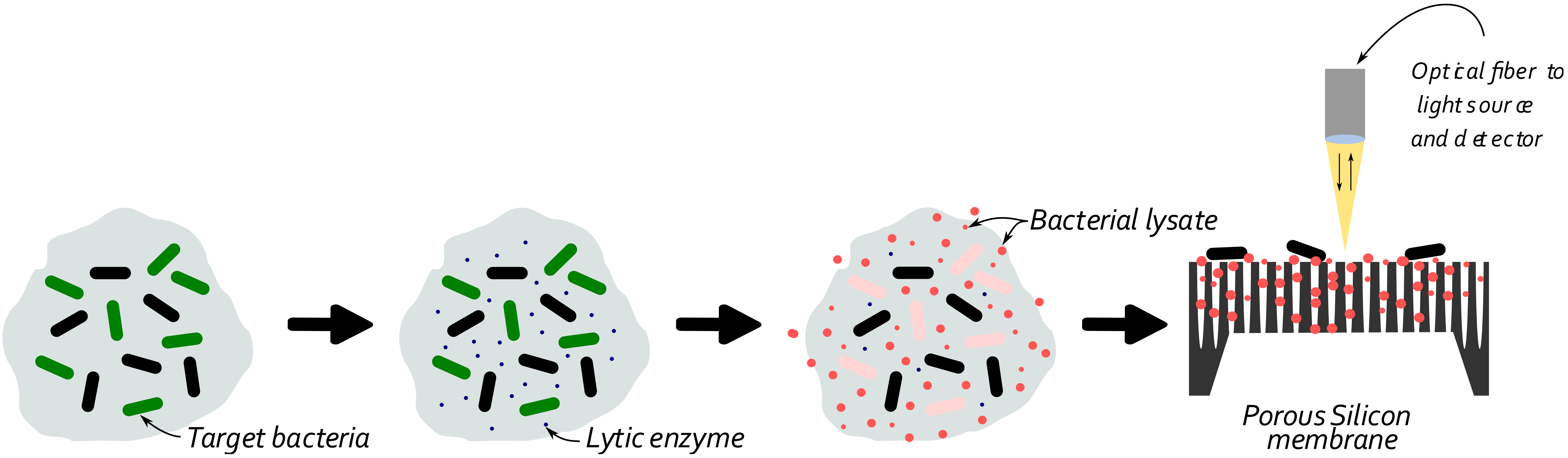
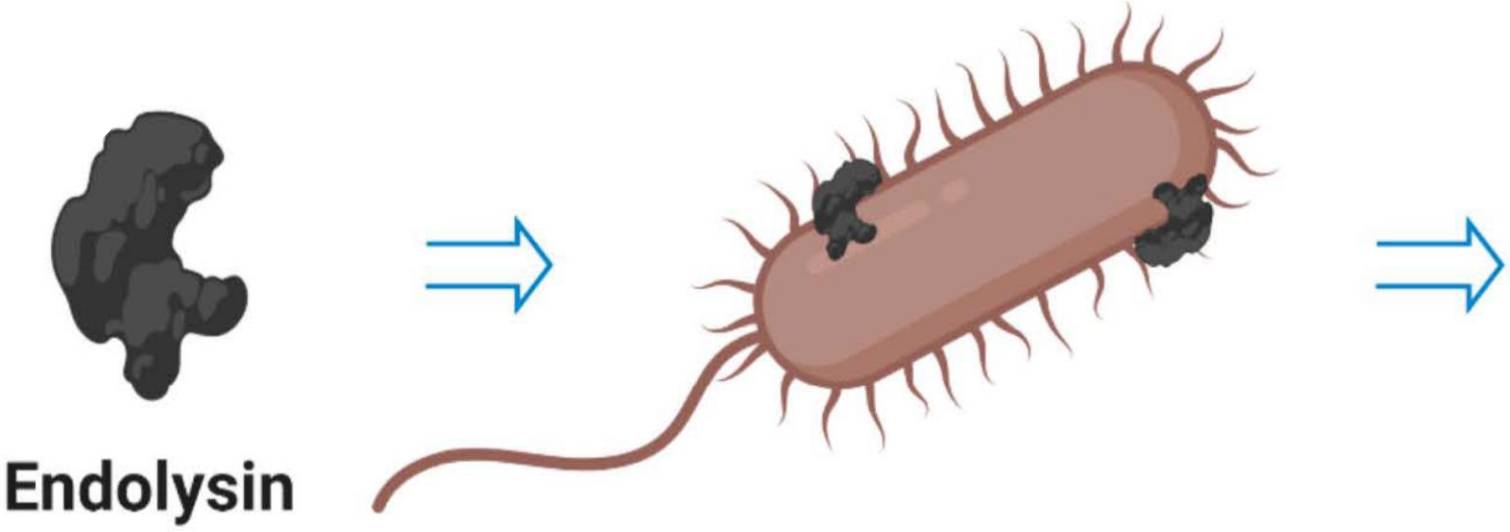
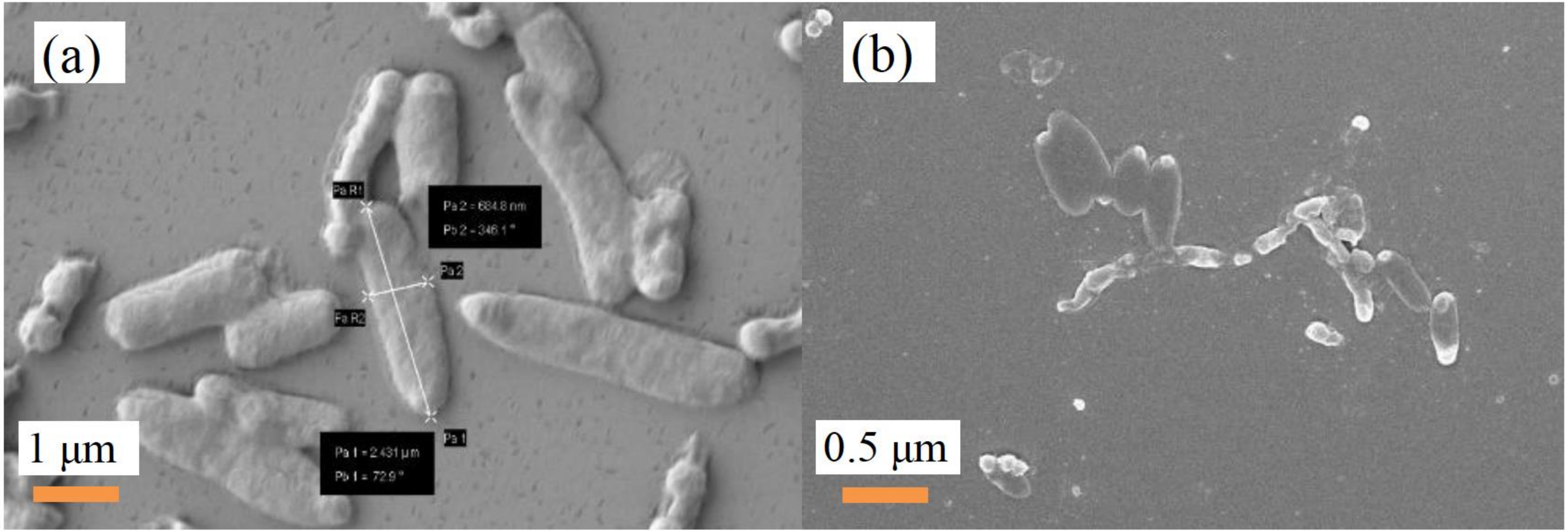


Image from de la Mora, Bety & Lugo, Eduardo. (2013). Porous Silicon Biosensors. 10.5772/52975.


Target bacteria
Lytic enzyme
Bacterial lysate
Optical fiber to light source and detector
Porous Silicon membrane

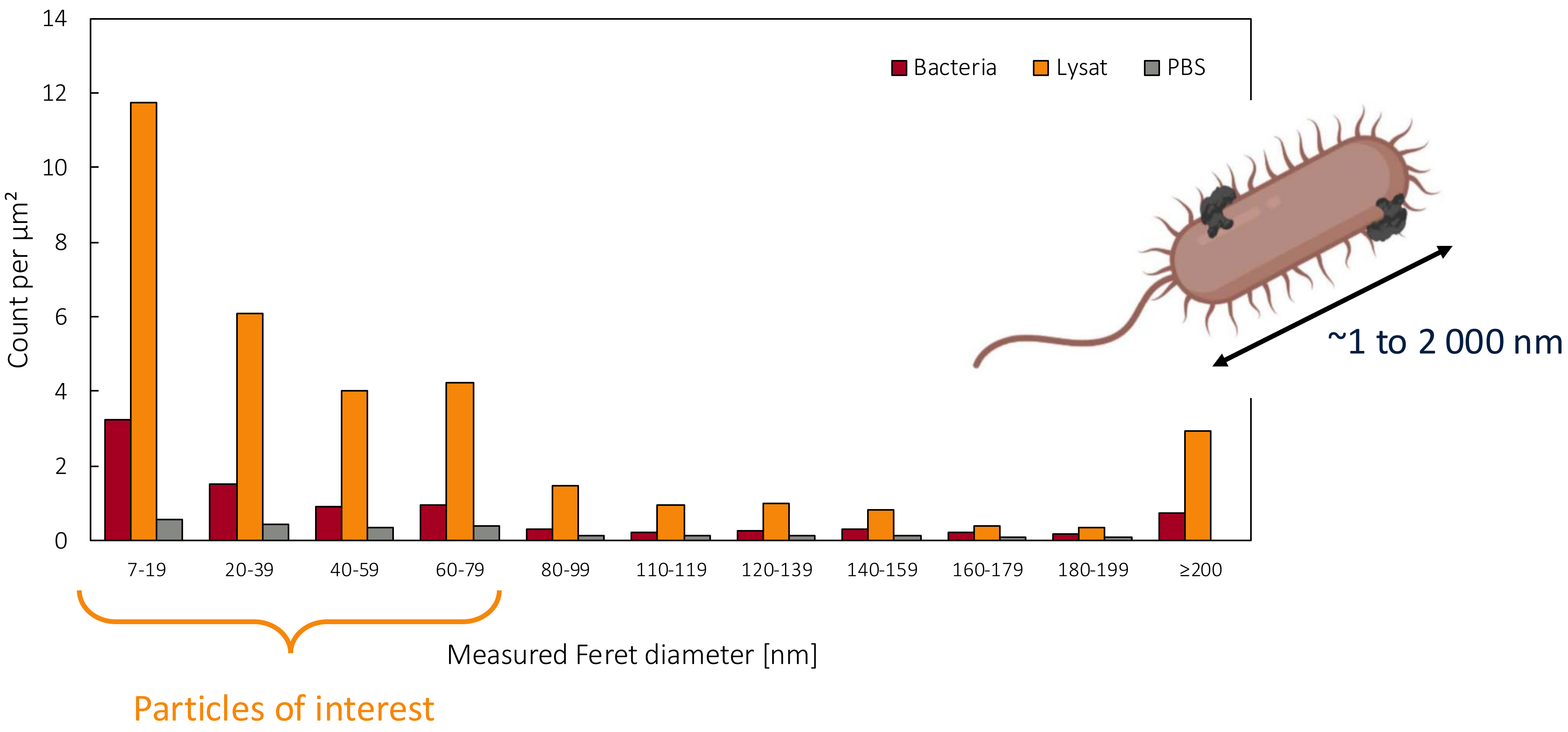


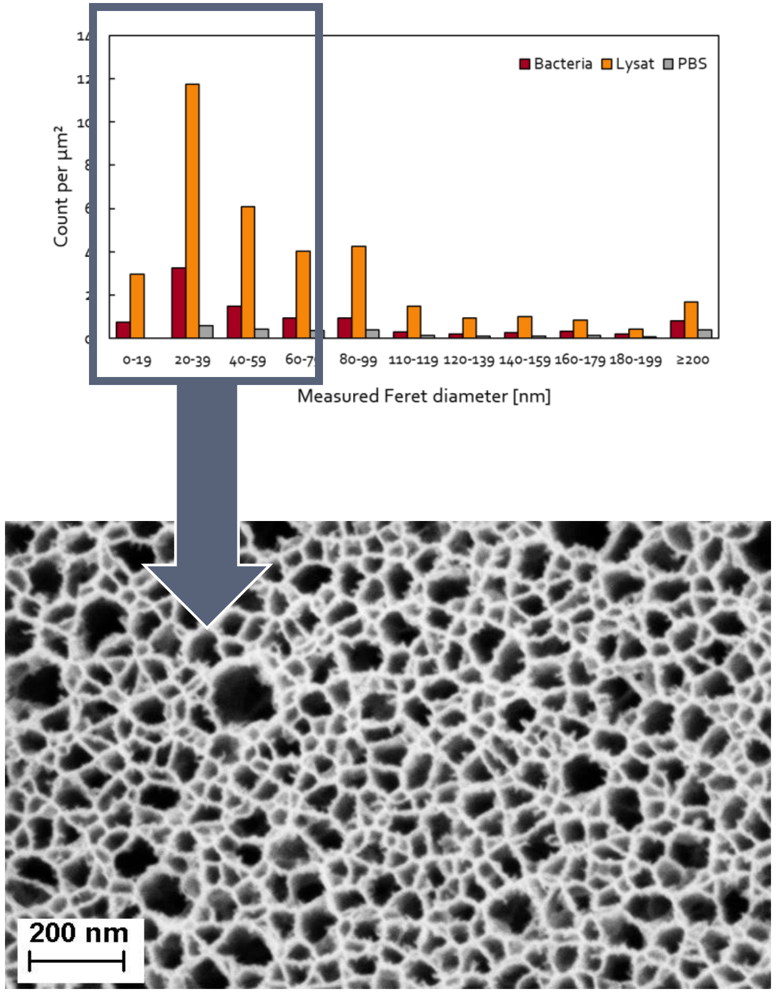
Lytic enzymes can be produced by bacteria or bacteriophage



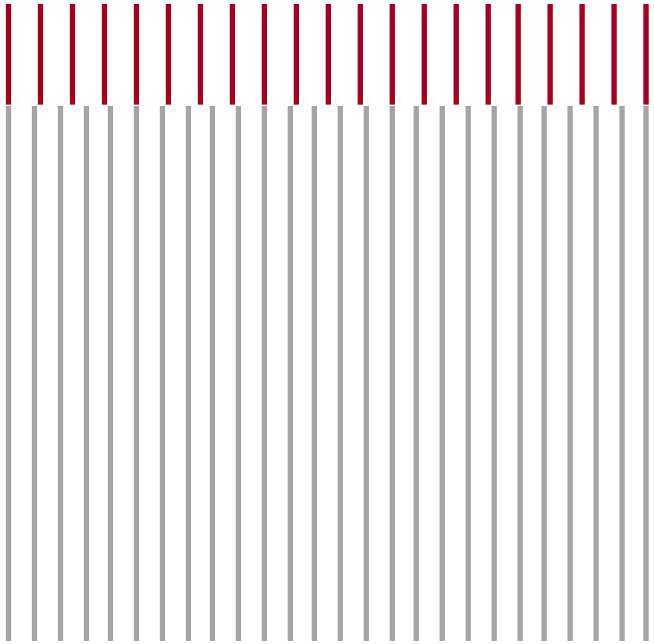
SEM observations of (a) *E. coli* bacteria and (b) *E. coli* lysate (through phage lysis).

Model: *Bacillus cereus* (ATCC10987)





Porous silicon **interferometer**



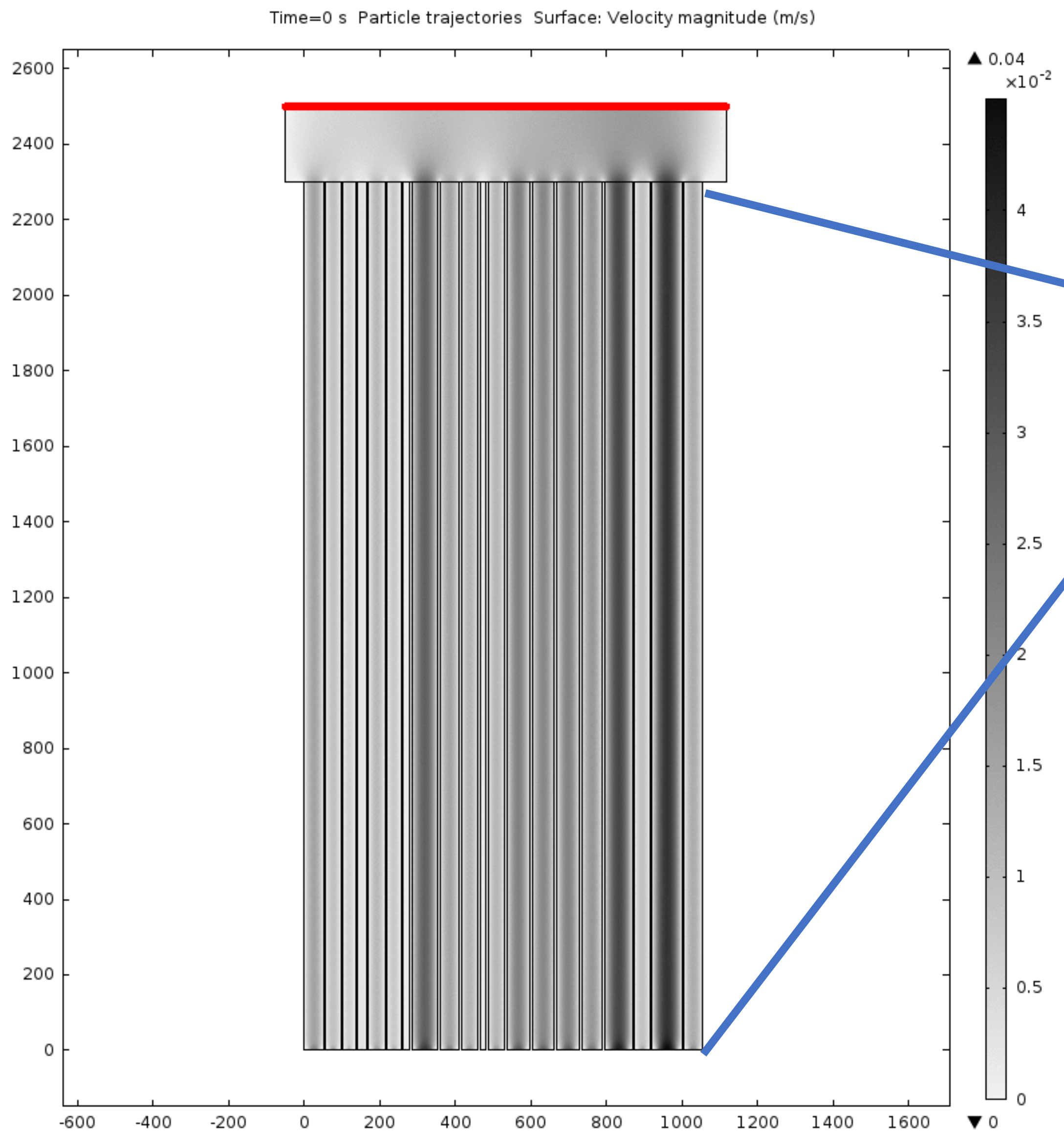
Sensing layer

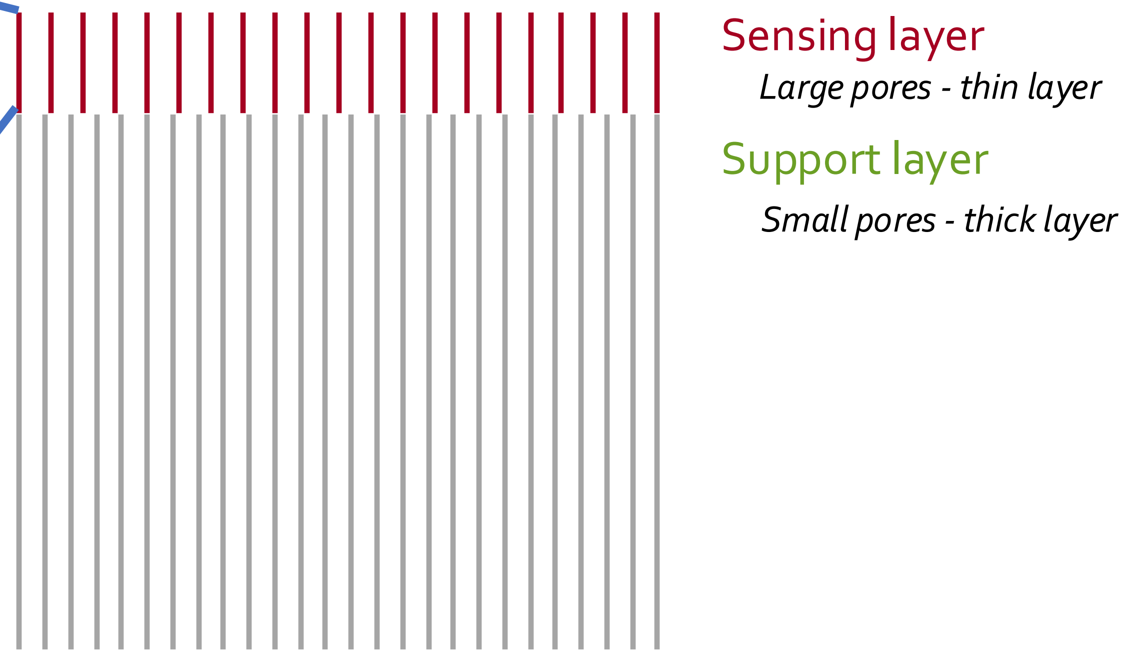
Large pores - thin layer

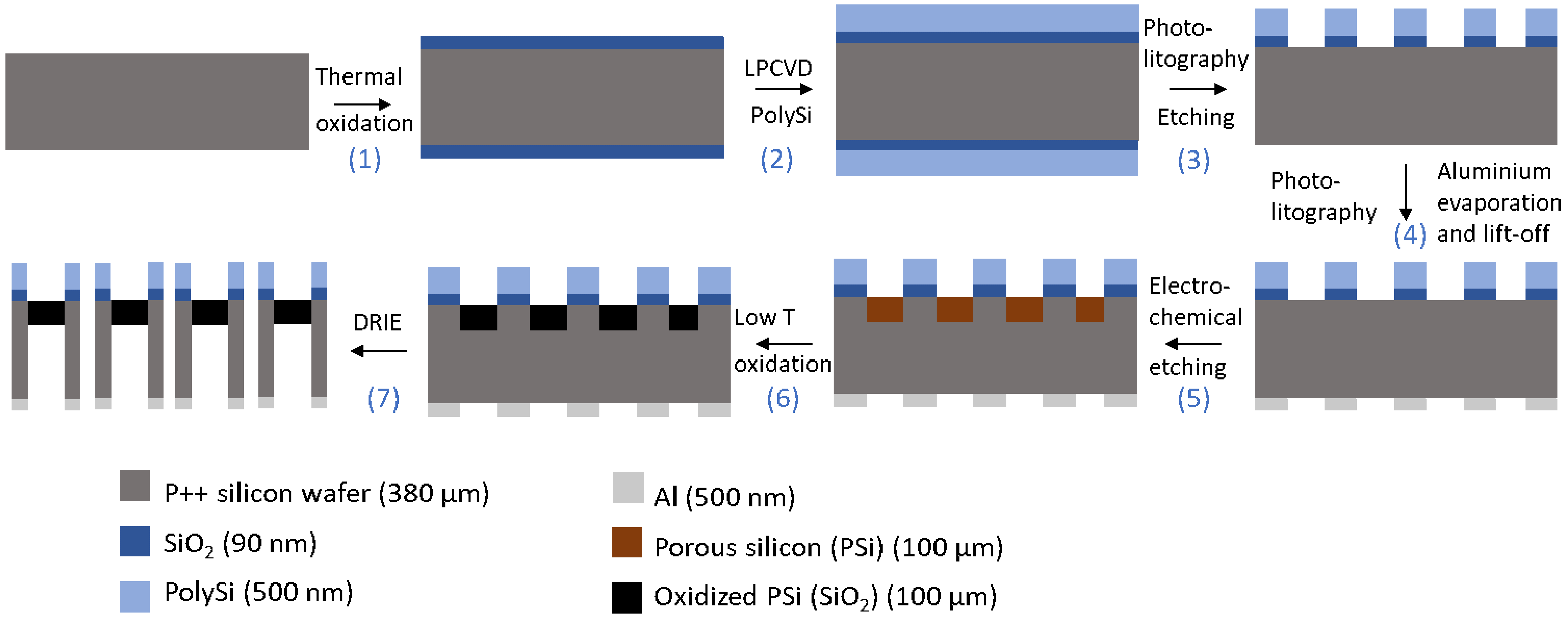
Support layer

Small pores - thick layer

F.E.M. simulation (Comsol Multiphysics)

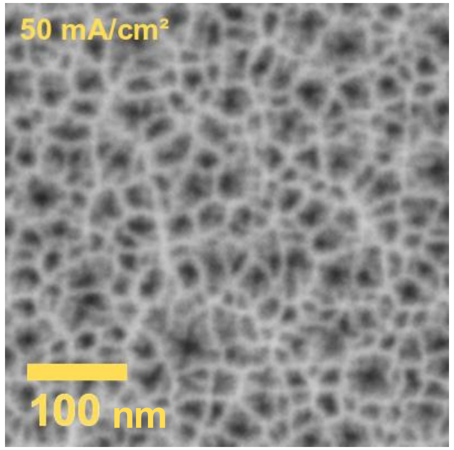




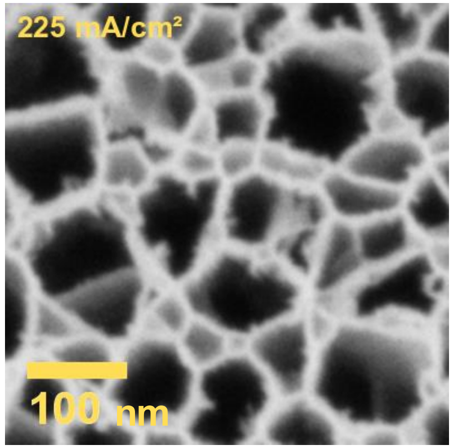

Thermal
oxidation
(1)
LPCVD
PolySi
(2)
Photo-
litography
Etching
(3)
Photo-
litography
(4)
Aluminium
evaporation
and lift-off
Electro-
chemical
etching
(5)
Low T
oxidation
(6)
DRIE
(7)
P++ silicon wafer (380 µm)
SiO_2 (90 nm)
PolySi (500 nm)
Al (500 nm)
Porous silicon (PSi) (100 µm)
Oxidized PSi (SiO_2) (100 µm)

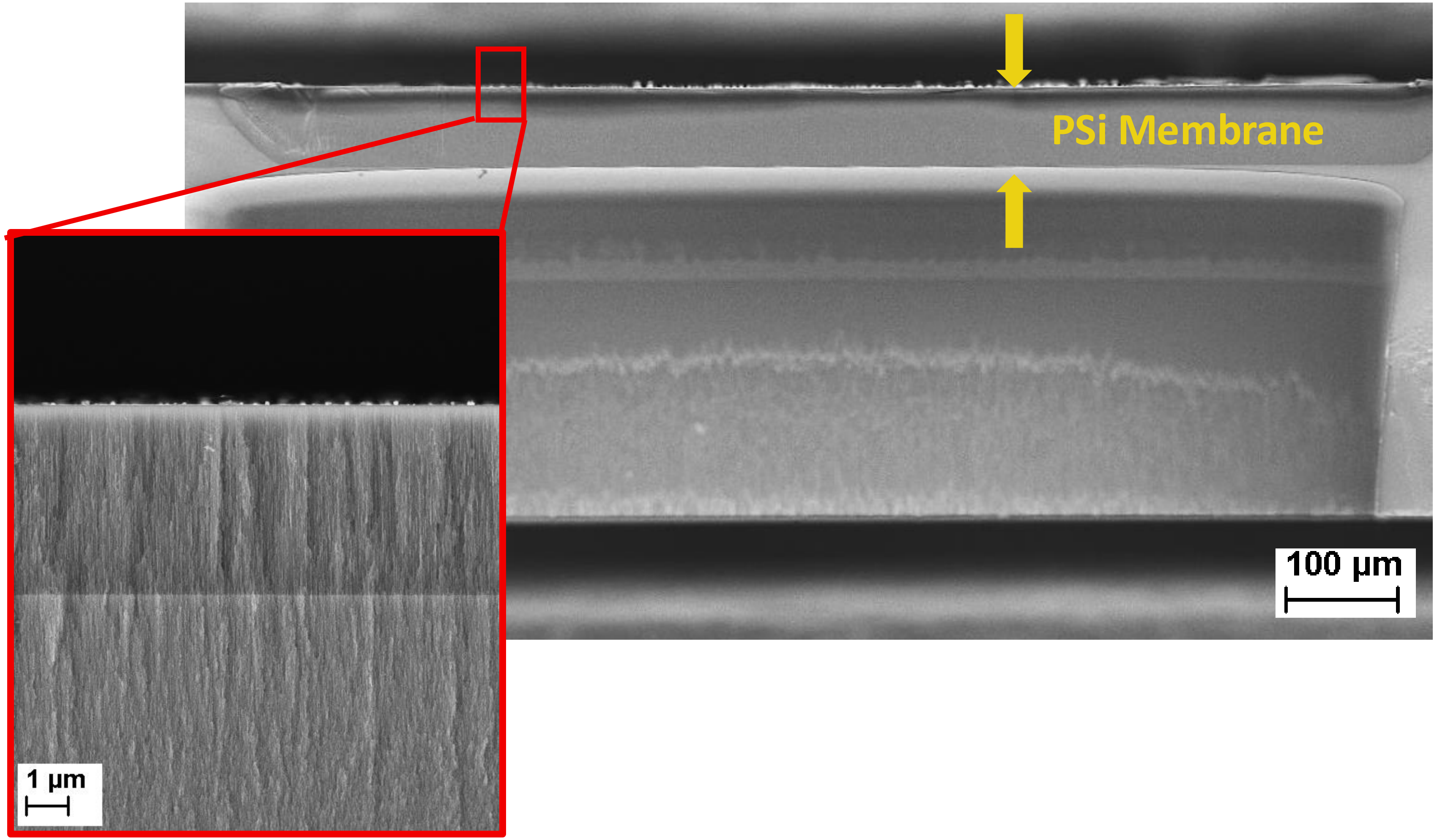
Filtration membrane/sieve

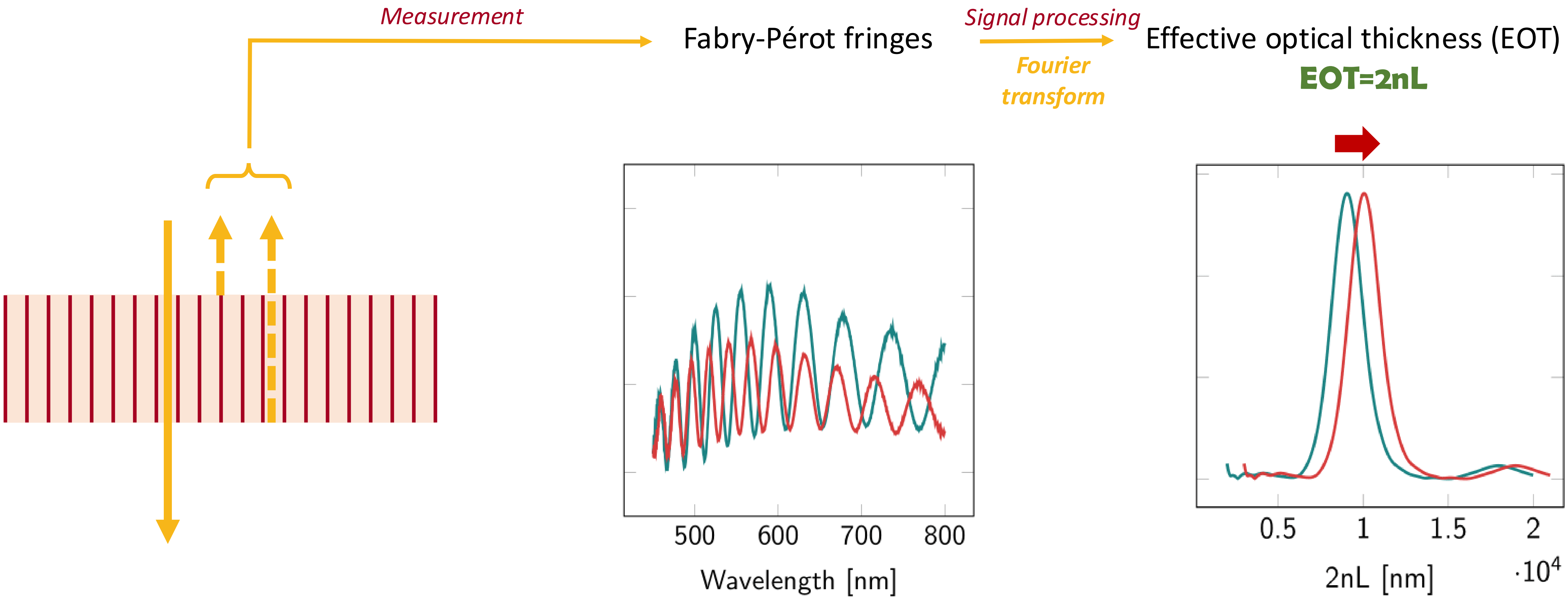
Small pores
~15 nm



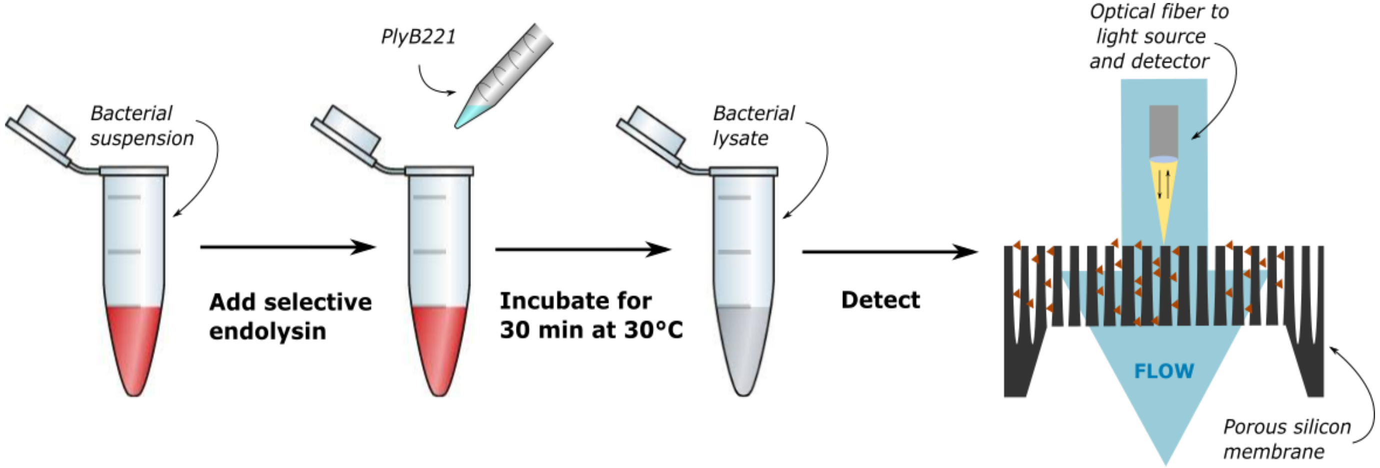
Large pores
50 nm and
above



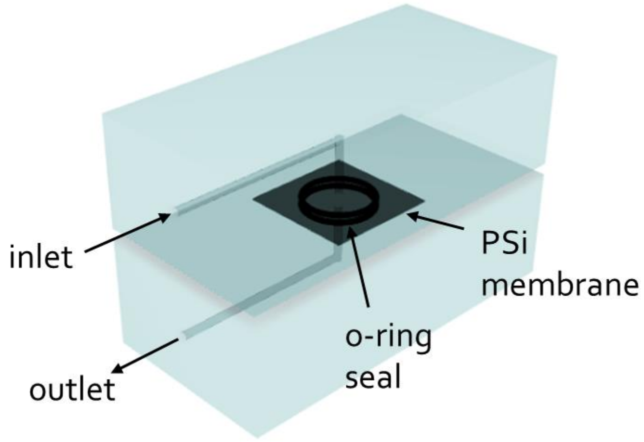


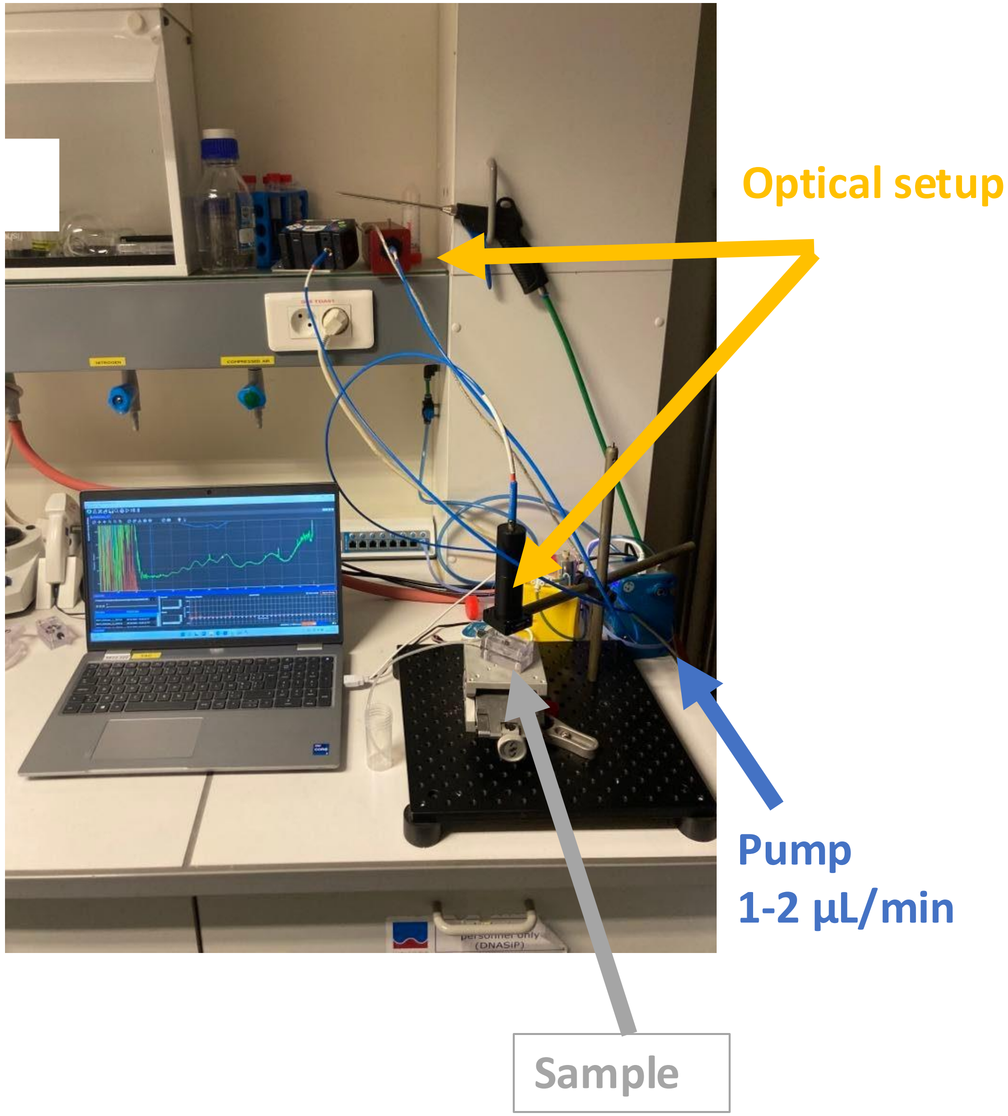

Measurement
Fabry-Pérot fringes
Signal processing
Fourier transform
Effective optical thickness (EOT)
EOT=2nL
500
600
700
800
Wavelength [nm]
0.5
1
1.5
2
2nL [nm]
·10^4

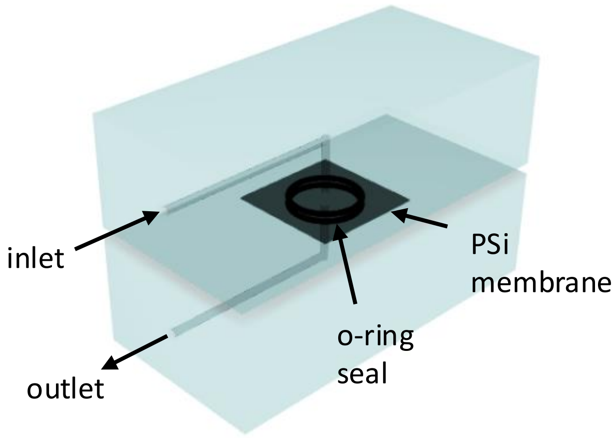
The detection of *Bacillus cereus* lysed by PlyB221 endolysins



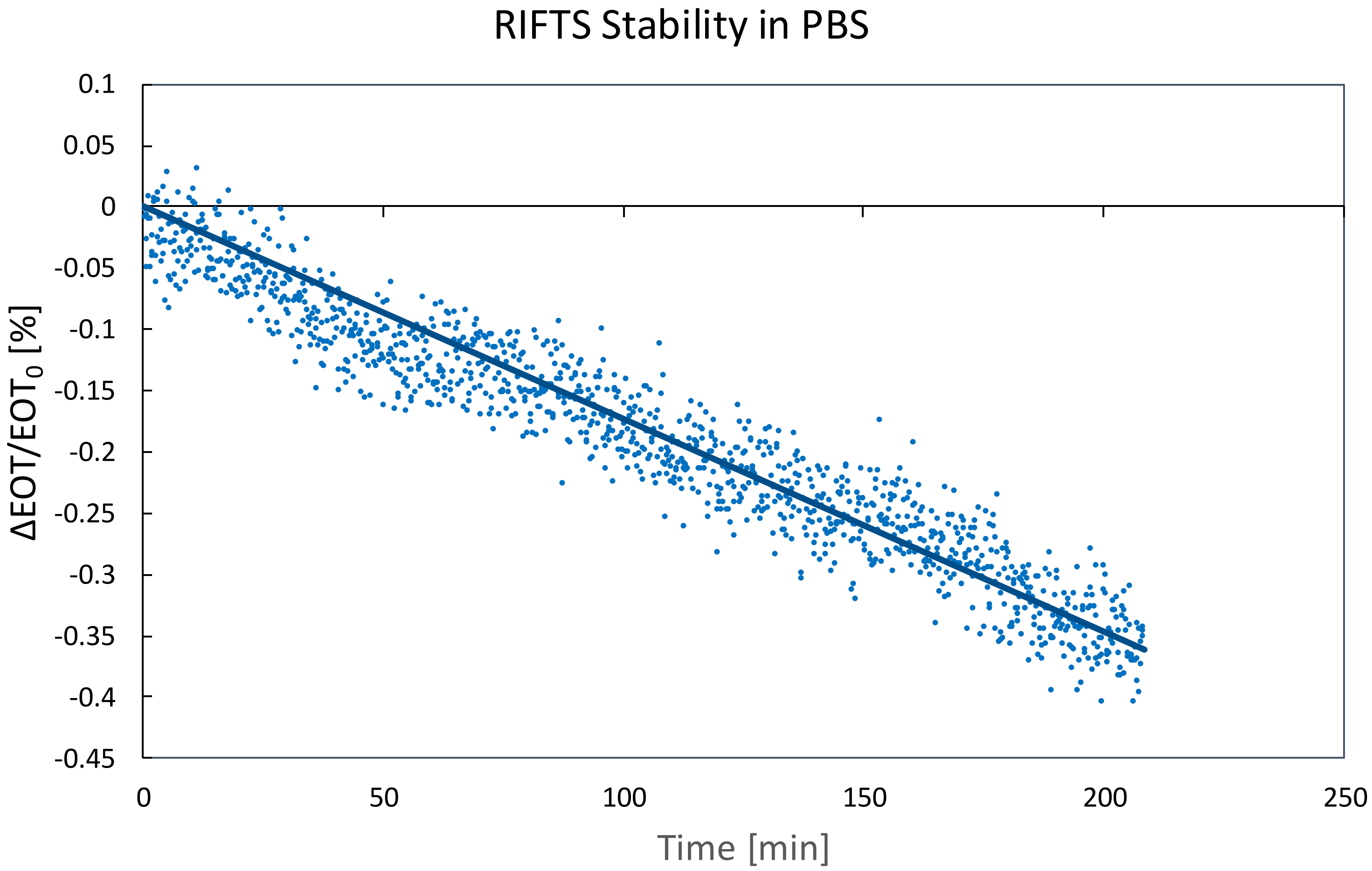
1h30 max







C. Whyte Ferreira, UCLouvain, 2021

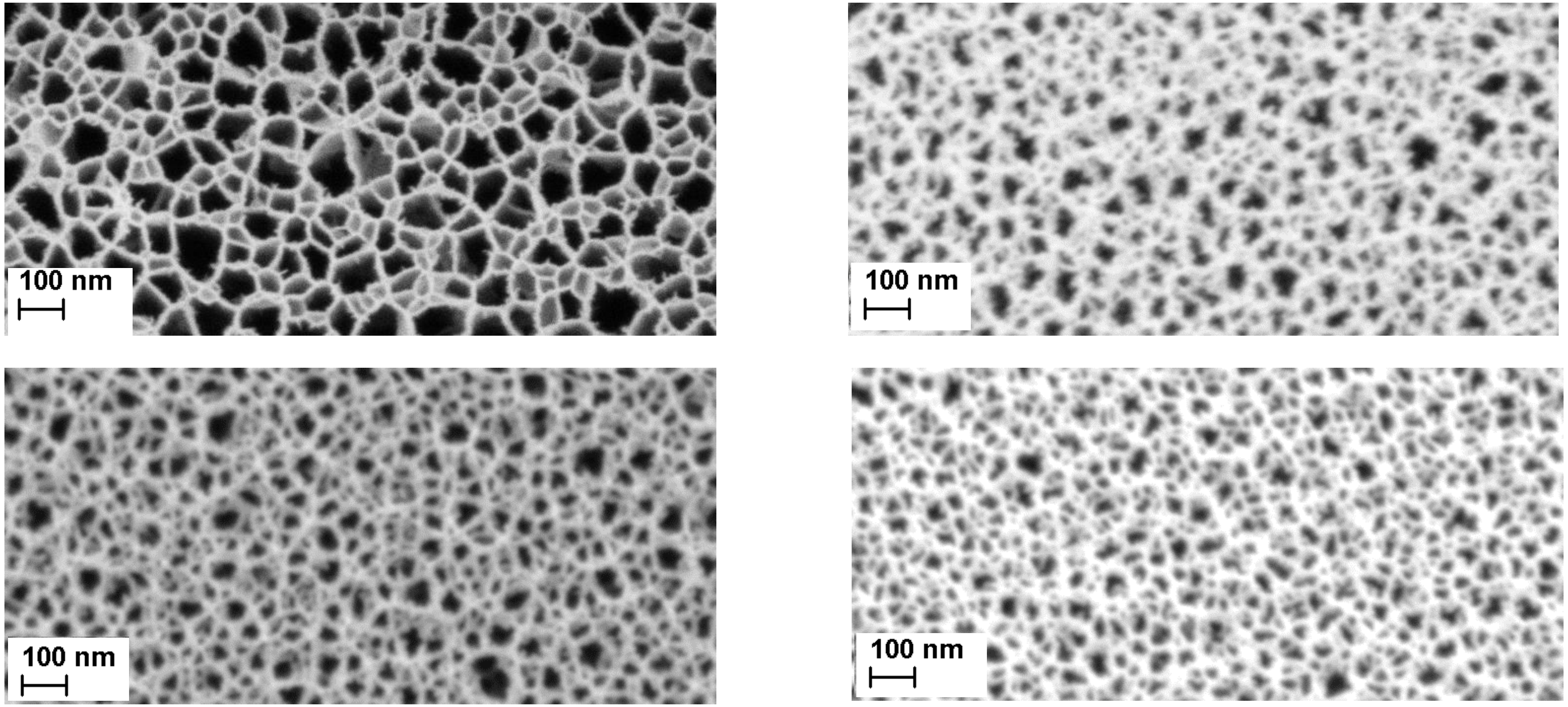


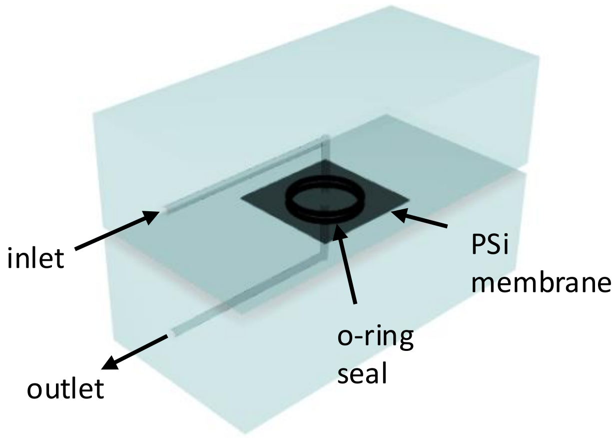
SiO_2

HfO_2

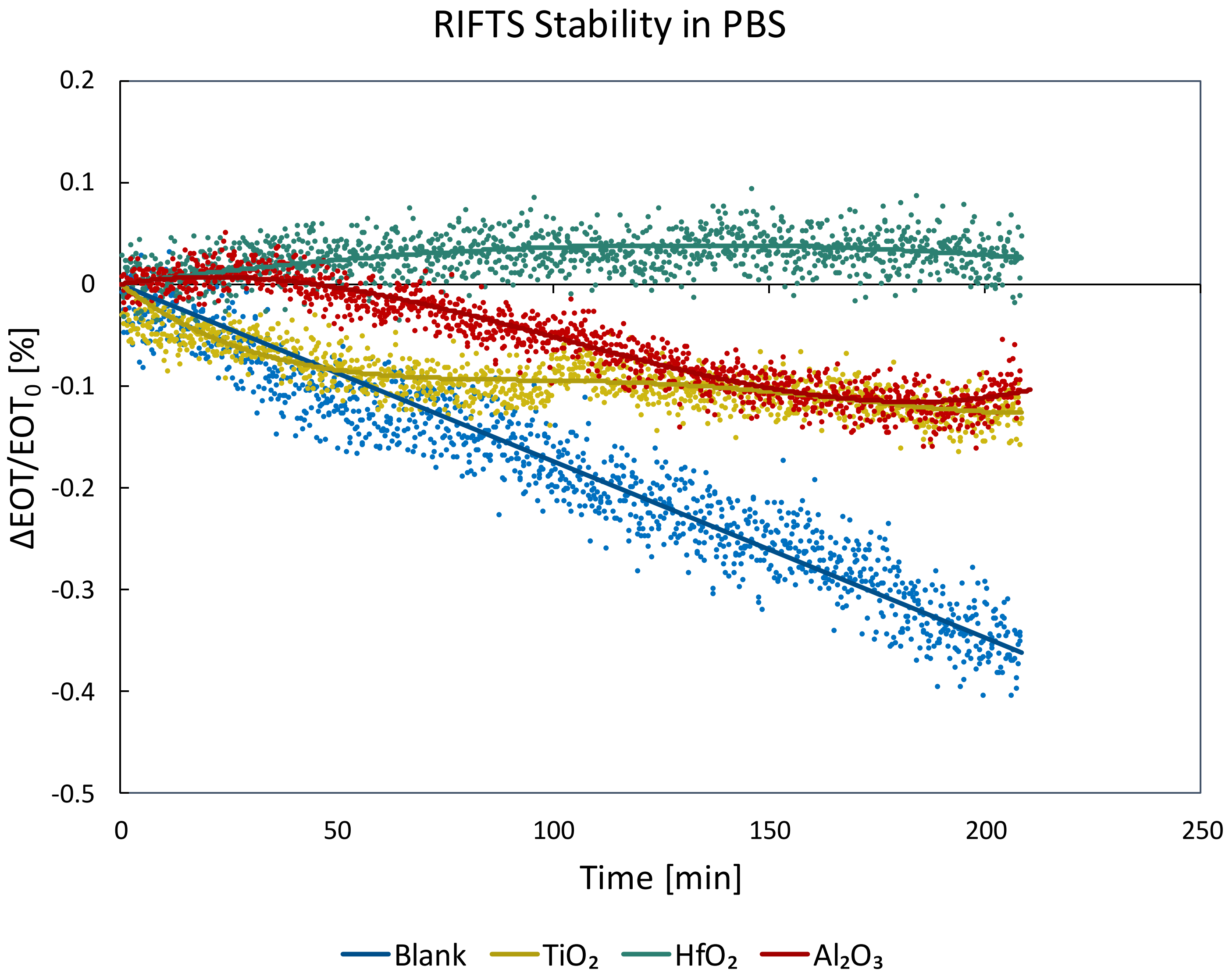
Al_2O_3

TiO_2

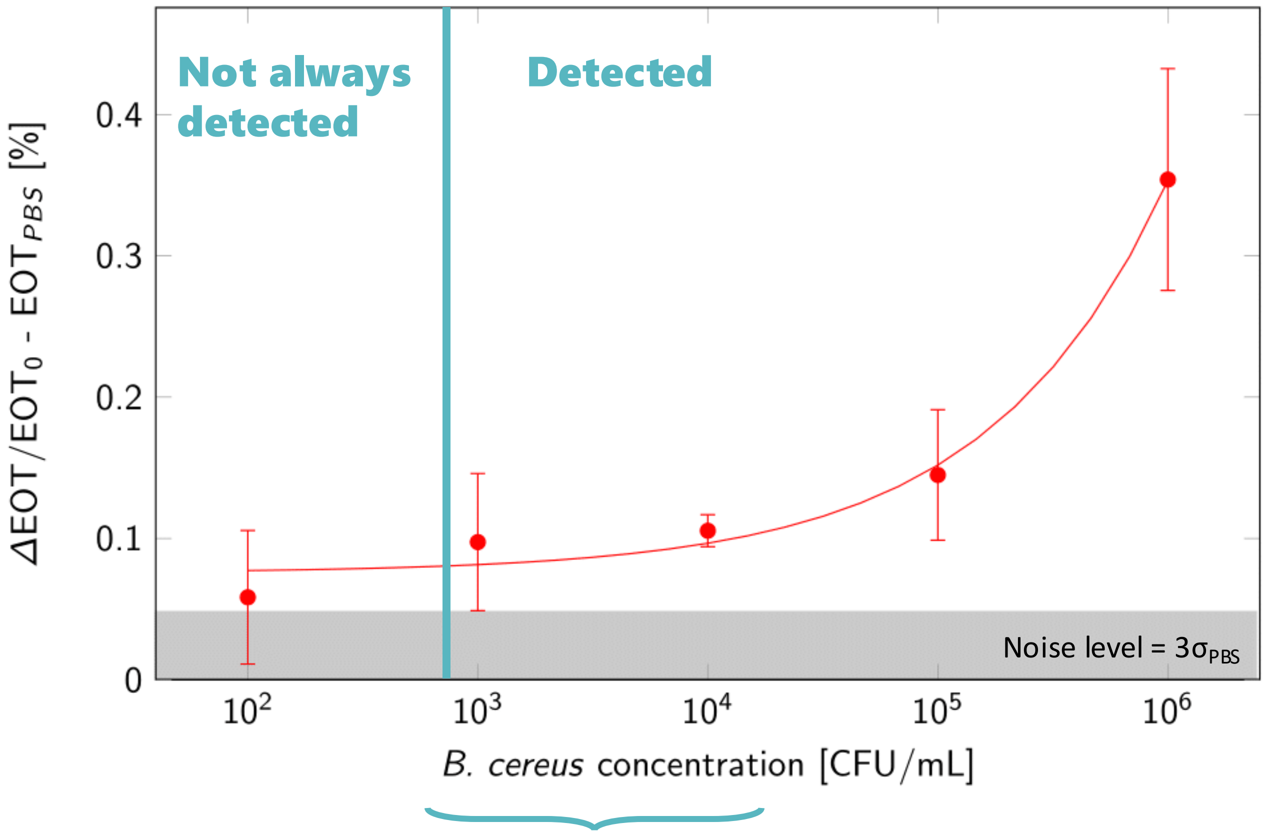




C. Whyte Ferreira, UCLouvain, 2021



Sensitivity

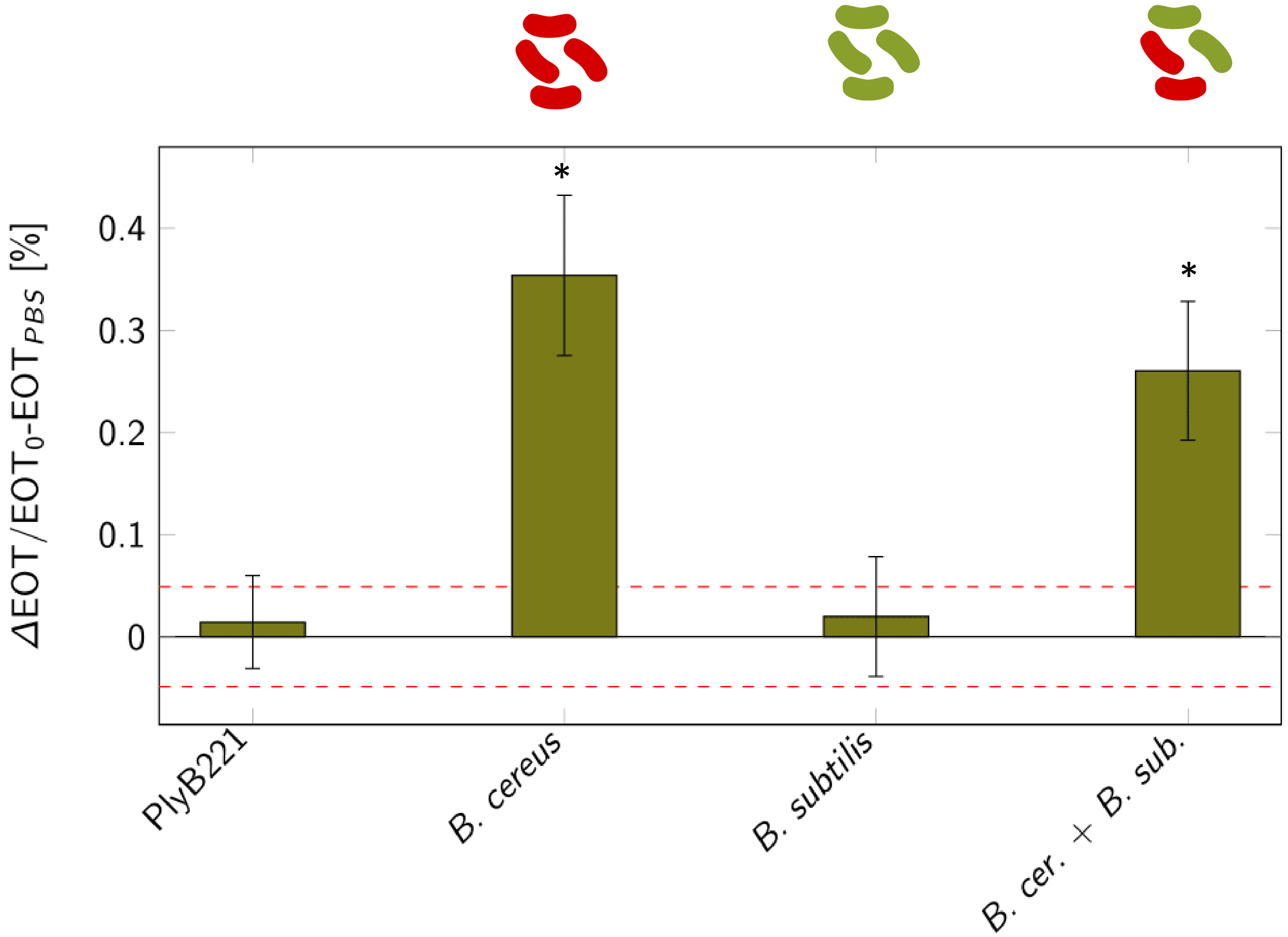


Infection levels for foodborne infection

10^2 CFU/mL ⇨ Detected but not *reliably* *(p-value>0.05)*

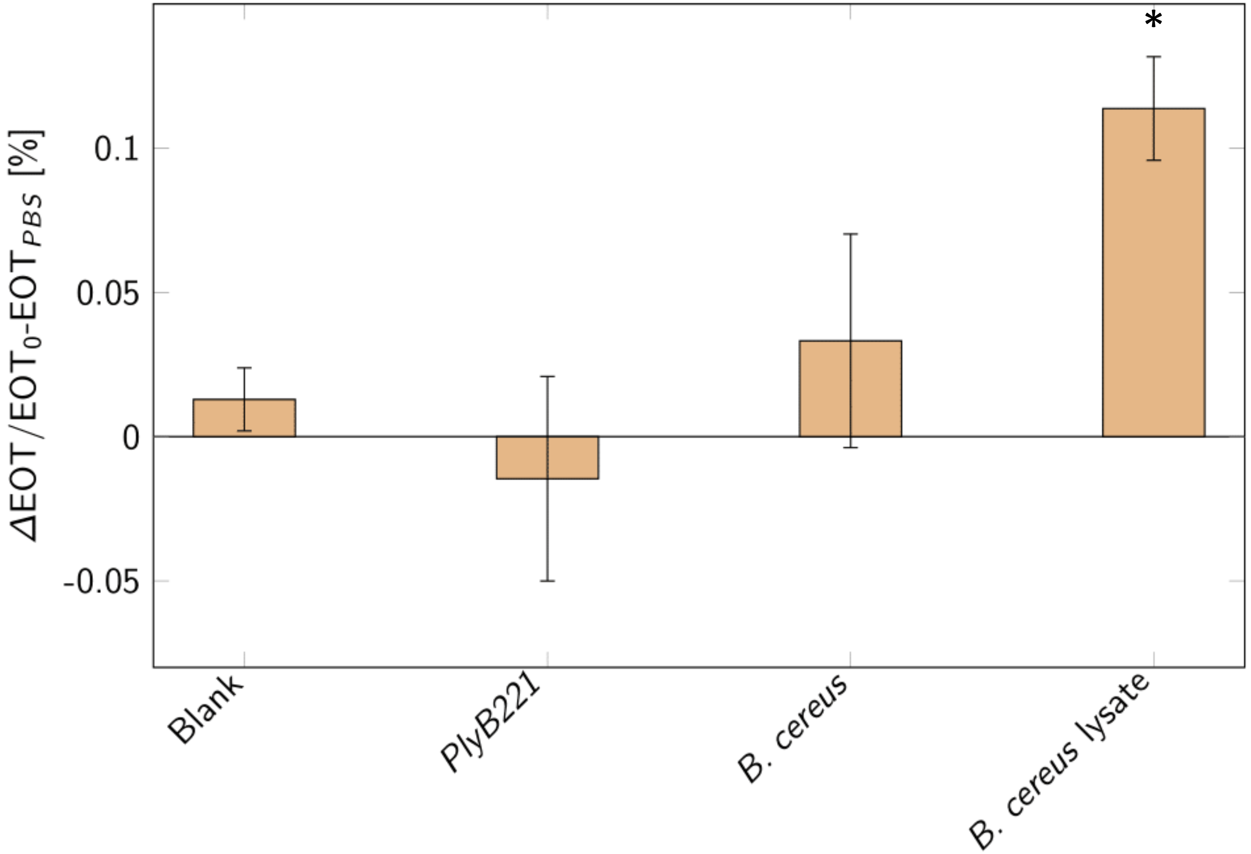
10^3 CFU/mL ⇨ **Limit of Detection (LoD)** *(p-value<0.05)* !

Selectivity

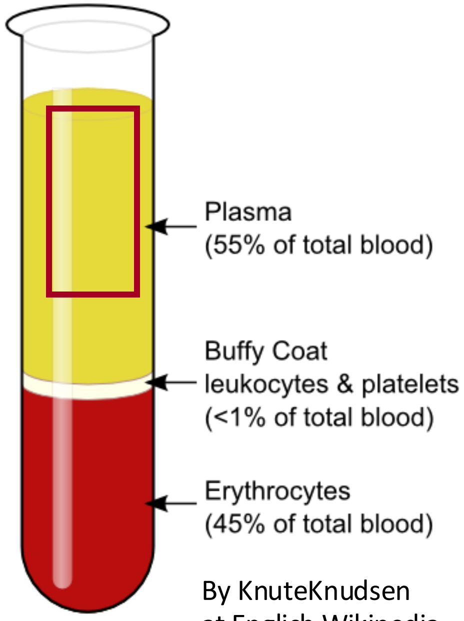


Complex sample: human plasma

Blood without white blood cells, red blood cells and platelets

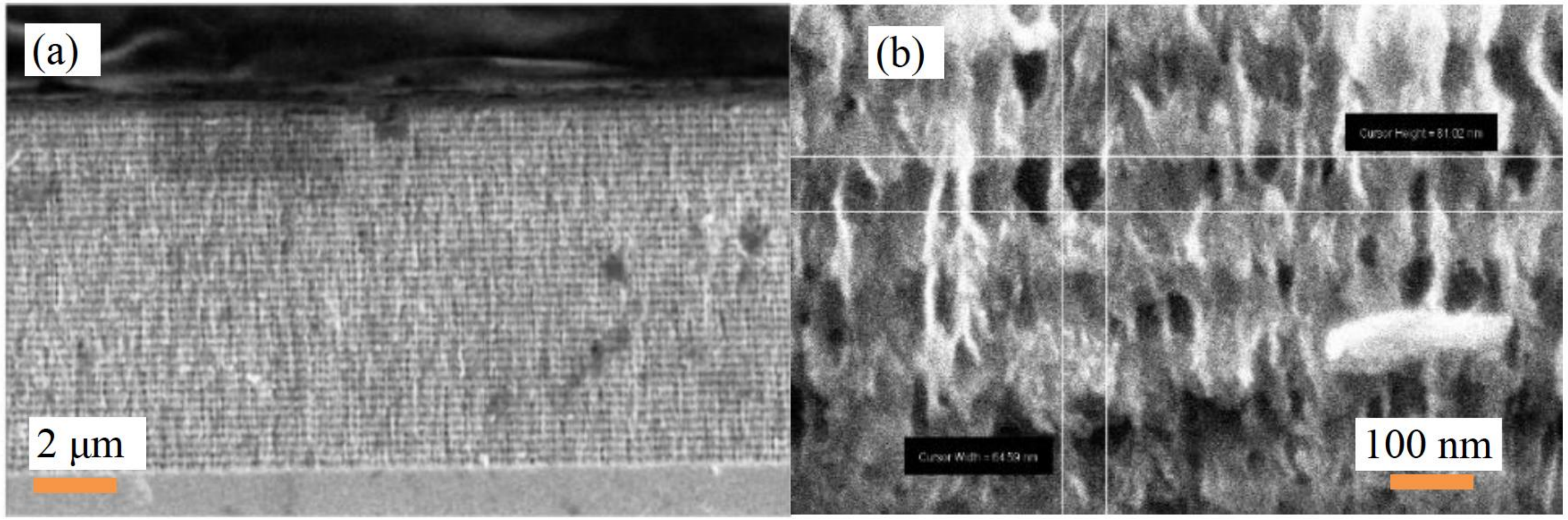


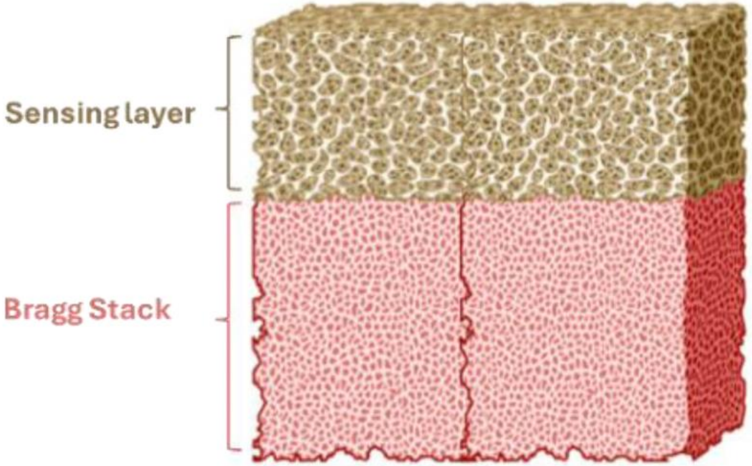
The detection of *Bacillus cereus* (ATCC10987, ~10^6 CFU/mL), lysed by PlyB221 endolysins, shift after 1h

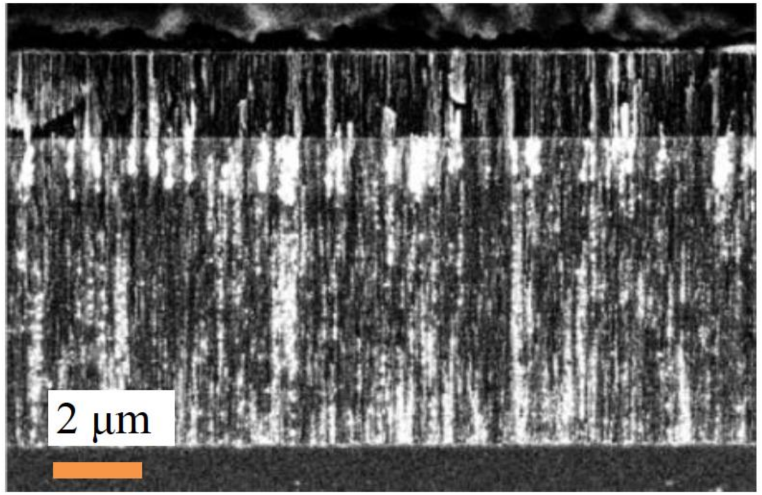


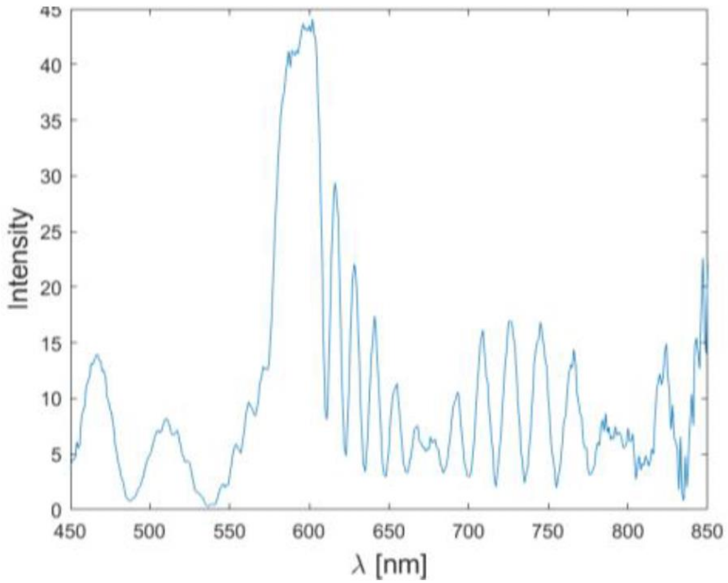
By KnuteKnudsen at English Wikipedia, CC BY 3.0

BRAGG MIRROR



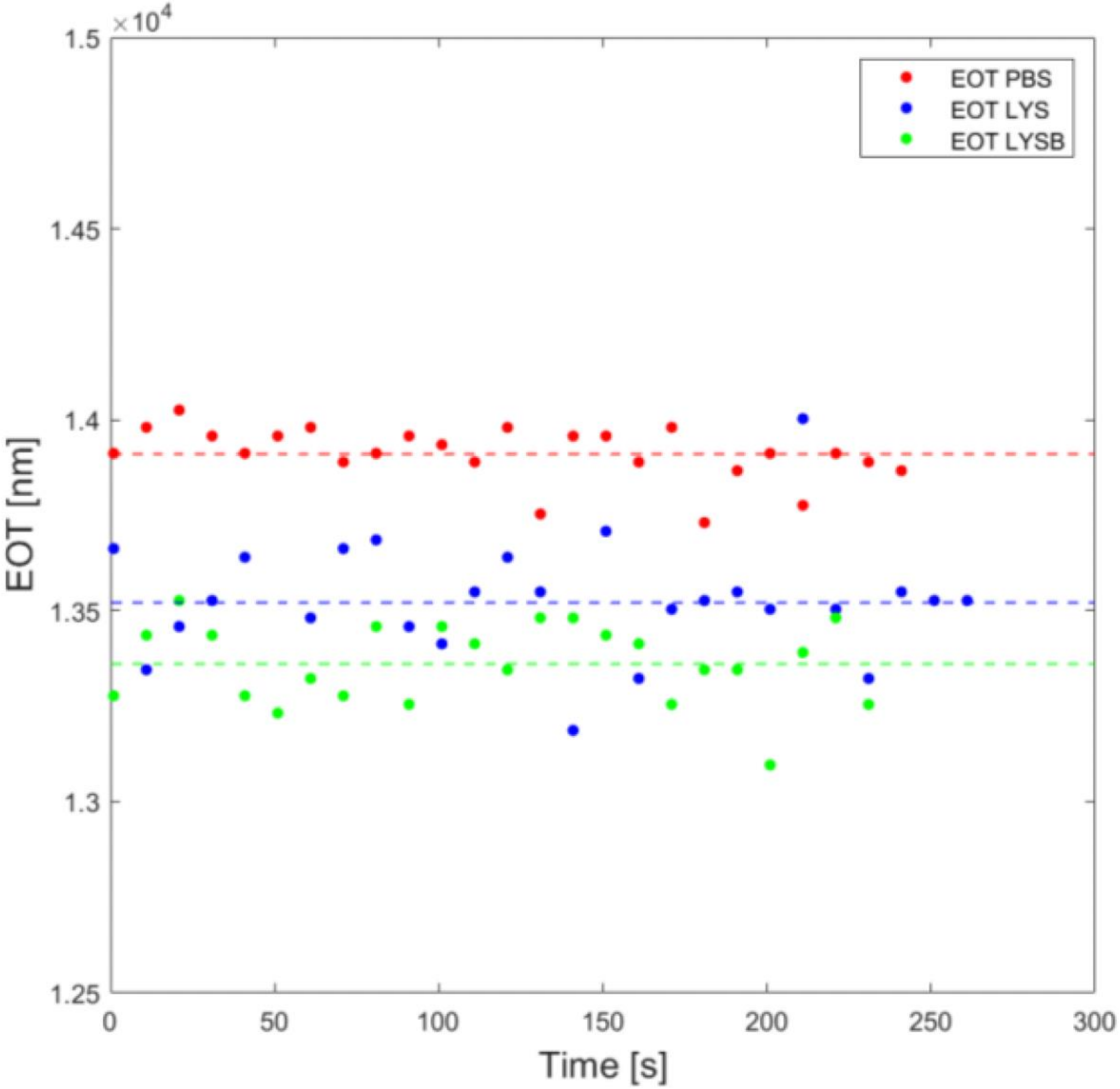






Work of E. Colomer Clavel and C. Gevers

BRAGG MIRROR



4% EOT shift

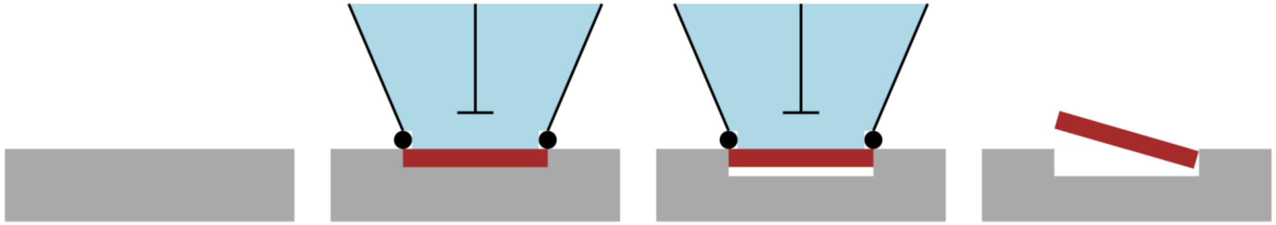
Theoretical LoD

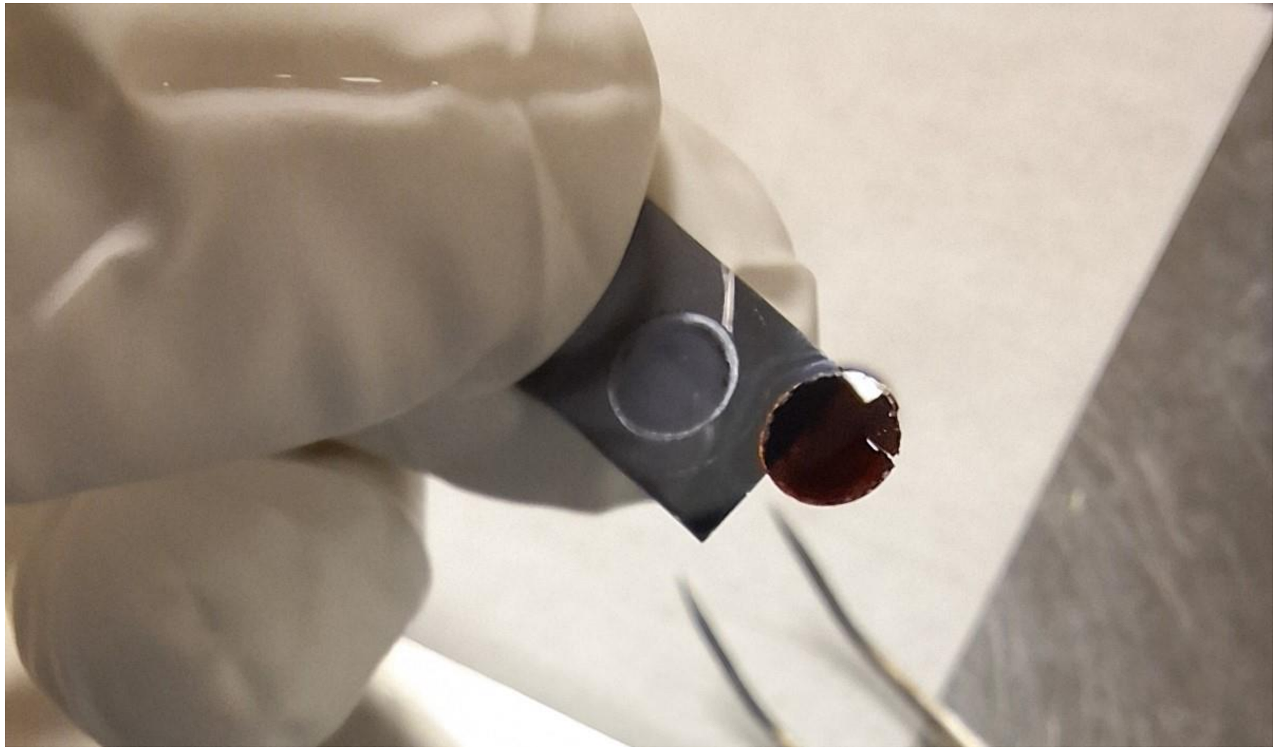
PSi $2.15 \cdot 10^{-1}$ RIU

PSi+Bragg mirror $1.35 \cdot 10^{-3}$ RIU

Work of E. Colomer Clavel and C. Gevers

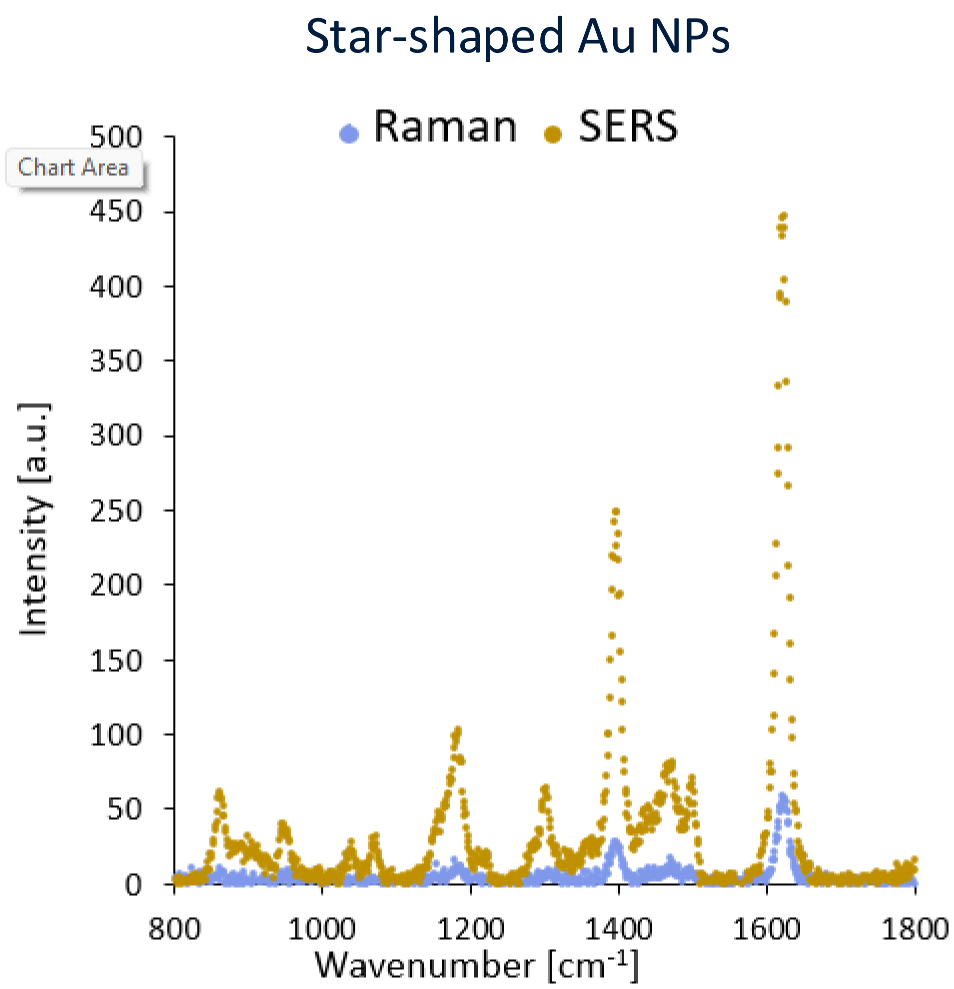
Much simpler method to achieve the fabrication of membranes, if we cope with the mechanical fragility …



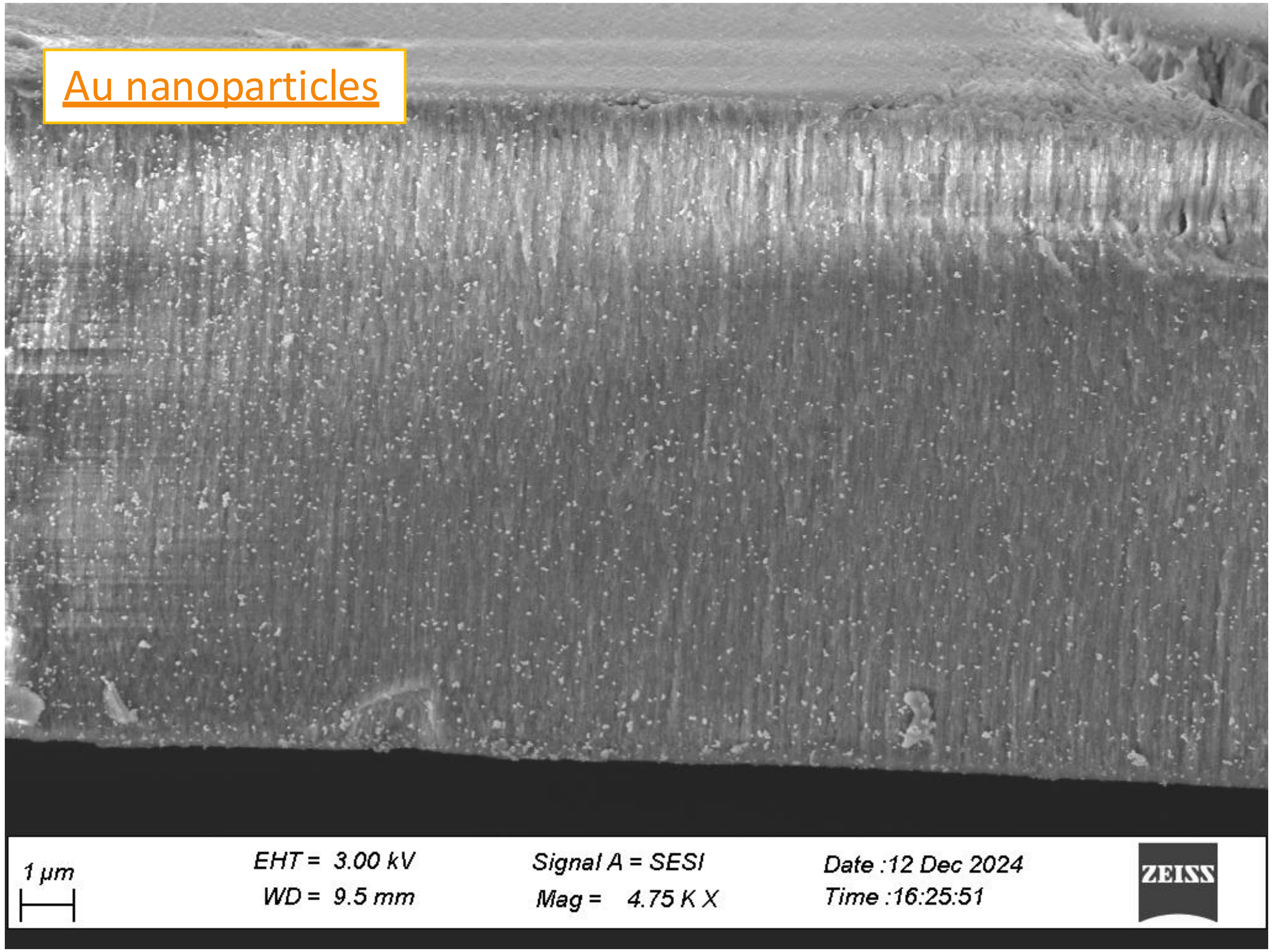


Work of R. Hanus
& C. Gevers

AU NP FOR SERS

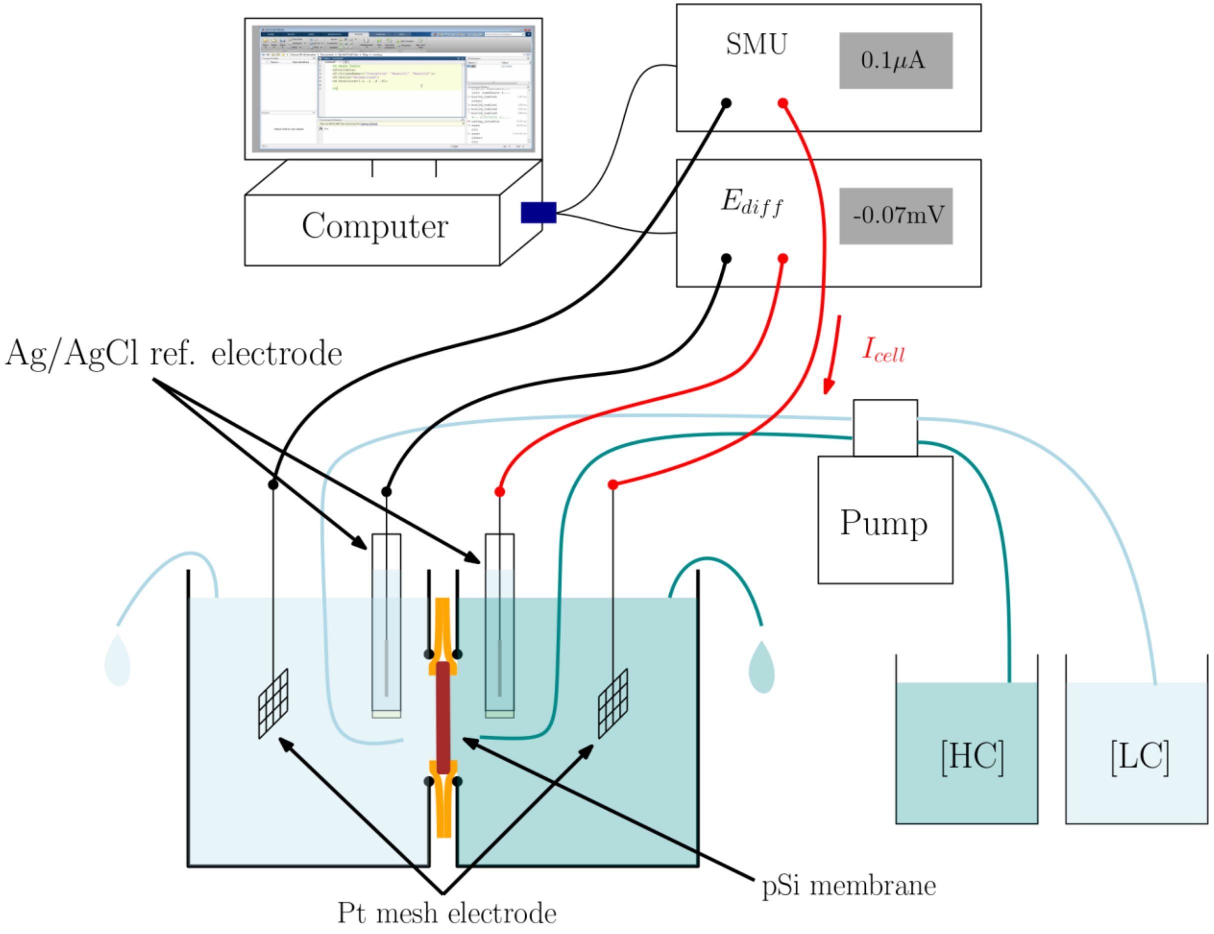


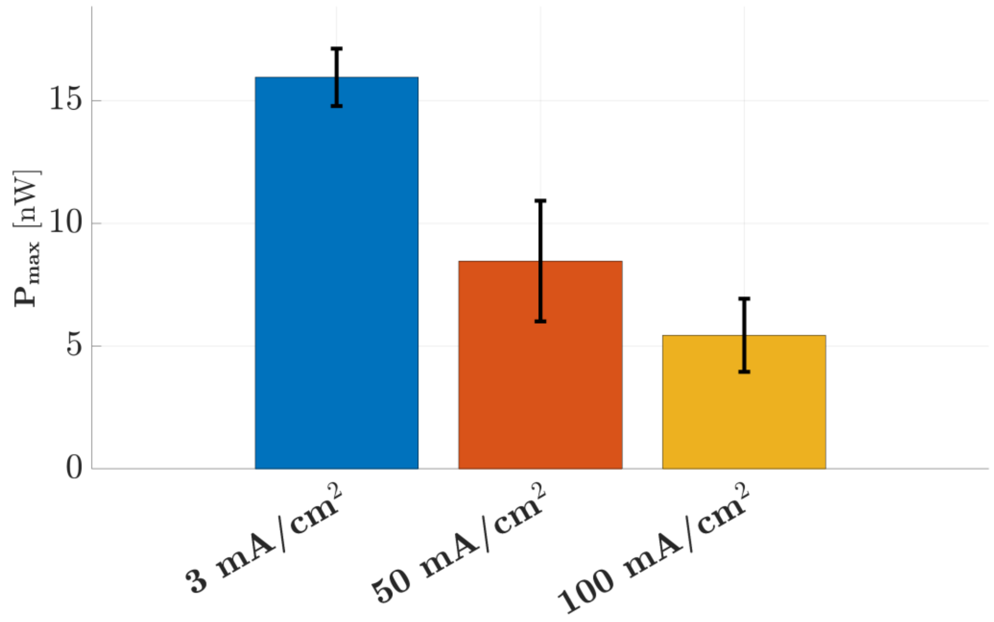
Methylen blue mediation $5 \cdot 10^{-7}$ M



Work of Clémentine Gevers & Louise Lejeune, submitted to ACS Applied Nano Materials

Blue Energy harvesting

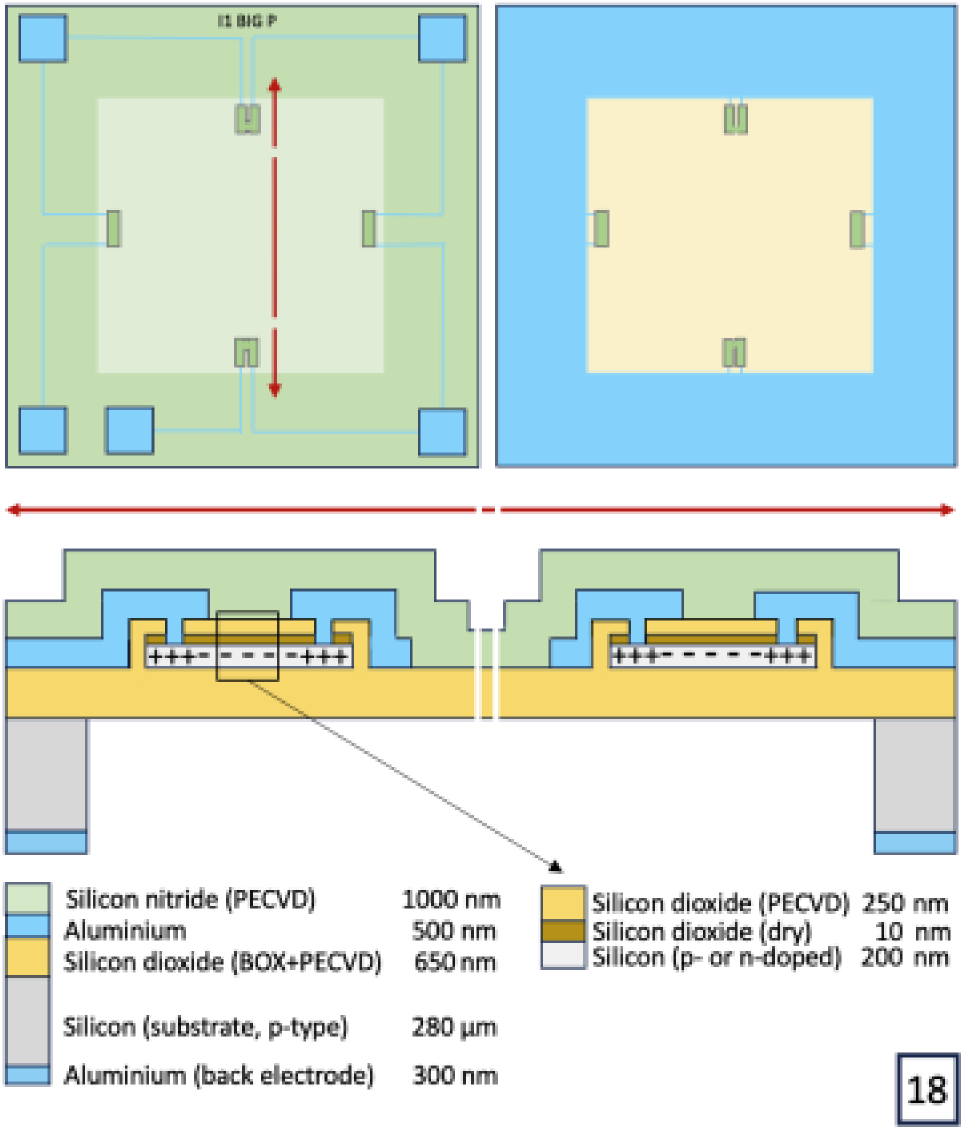




Porosification current density

Work of Romain Hanus, under submission to Wiley - Advanced Engineering Materials

SOI irradiated membranes



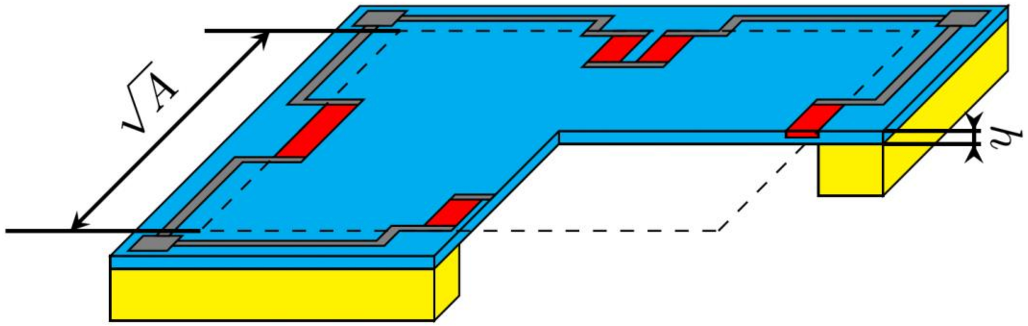


Fig. 1. Cross-section view of a typical piezoresistive pressure sensor: silicon handle wafer is in yellow, silicon or silicon dioxide membrane of thickness *h* and area *A* is in blue, piezoresistors are in red and aluminum conductive lines are in gray, dashed lines delimit the membrane.

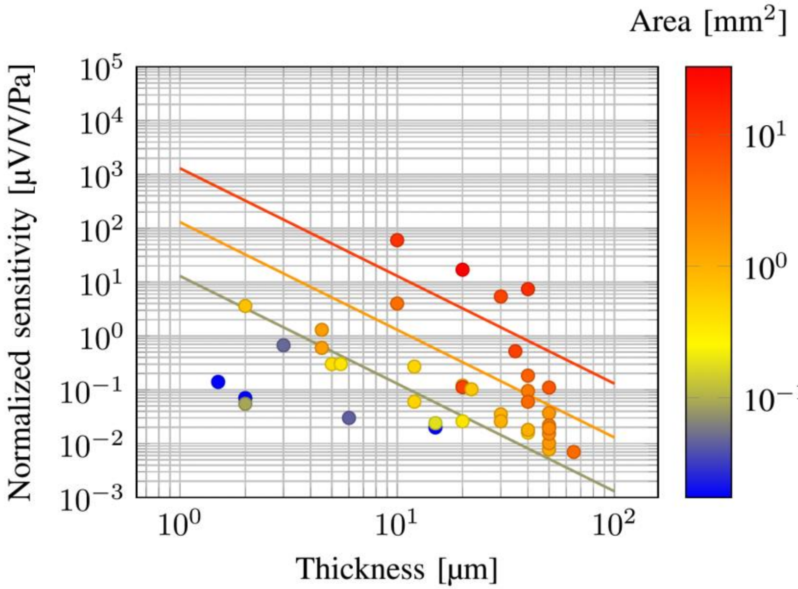
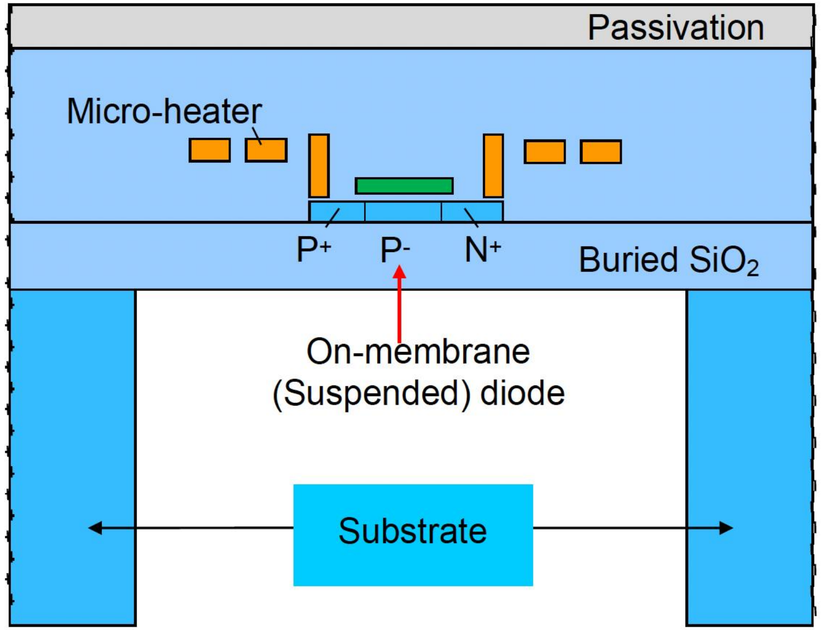
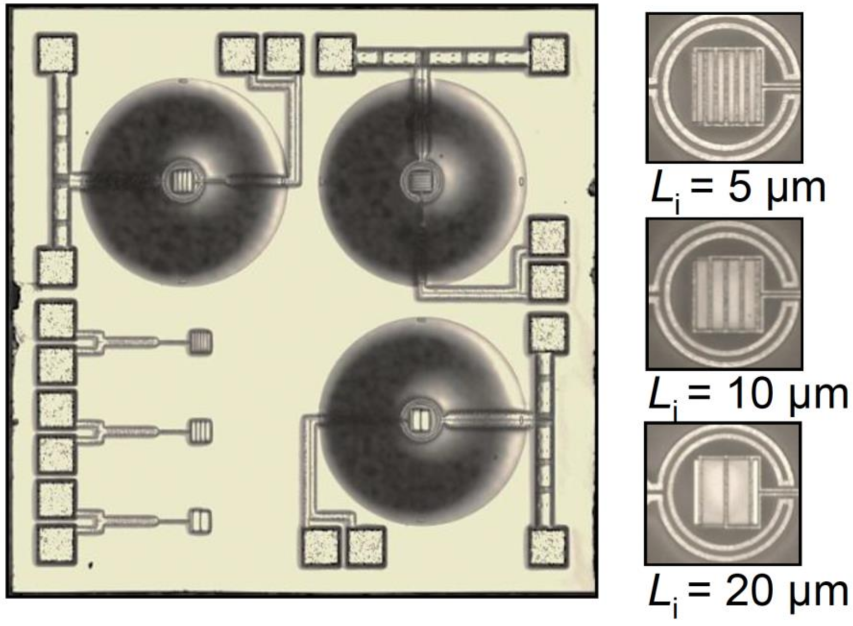


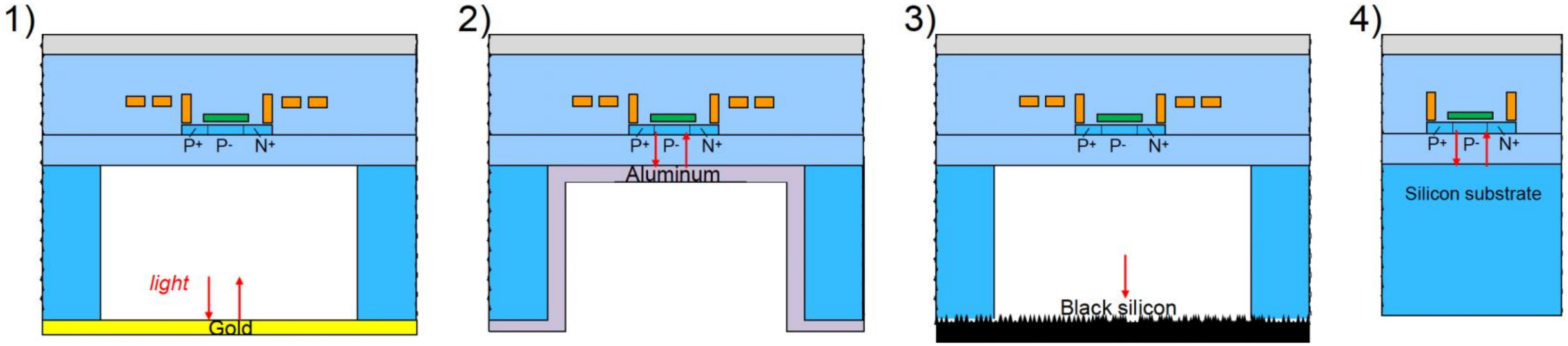
Fig. 4. Normalized sensitivity versus membrane thickness (x-axis) and membrane area (color circles). Lines are theoretical trends obtained with the simple model, eq. (9), for areas of 0.1, 1 and 10 mm^2, from bottom to top.

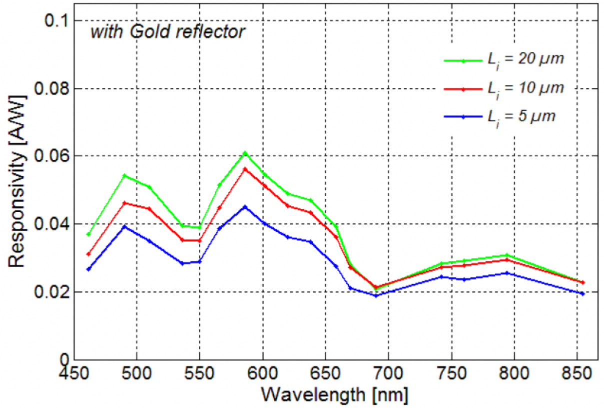
Courtesy of O. Bonfanti (UCLouvain)

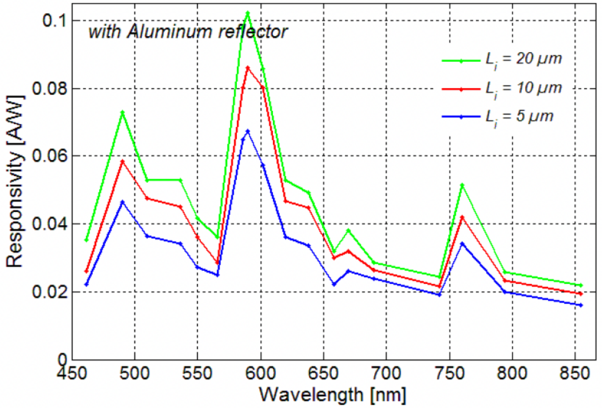
T. Delhaye *et al.*, IEEE Sensors J. 21(1), 2021

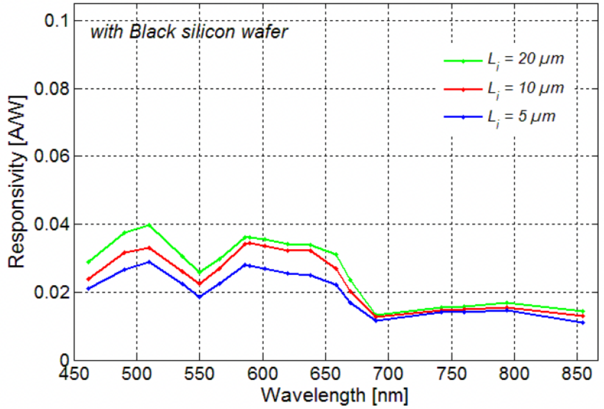


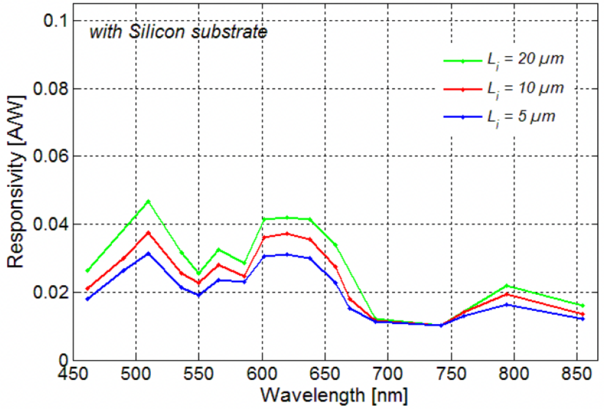




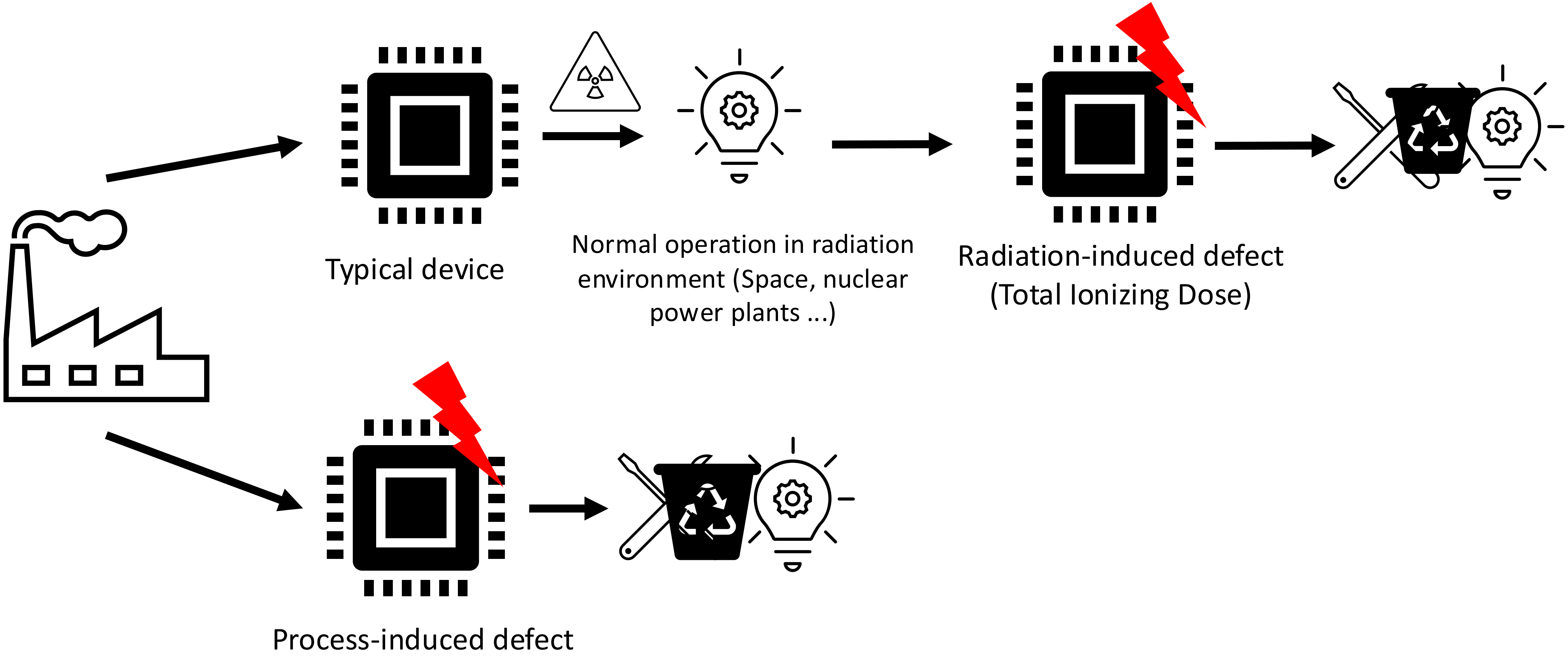




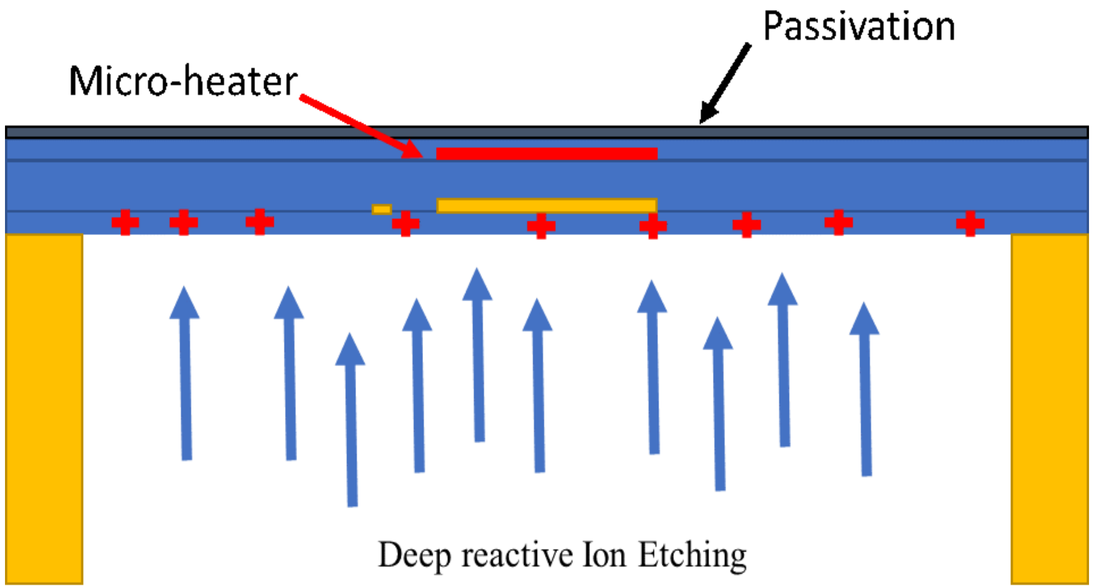


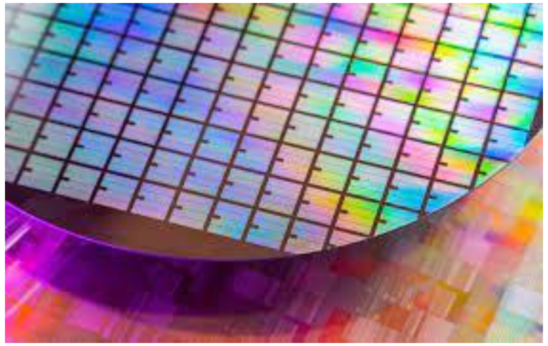


Courtesy of Guoli Li *et al.*, in collaboration with Cambridge U.


Typical device
Normal operation in radiation environment (Space, nuclear power plants ...)
Radiation-induced defect (Total Ionizing Dose)
Process-induced defect

Process-induced defects





- Hot Carrier Injection
- Deep reactive Ion Etching
- Doping variations

➢ **Positive oxide trapped charges.**
➢ **SiO2-Si Interface states.**
➢ **Stress-induced defects**

- Shift of parameters (V_{th}, gm, SS)
- Leakage current.
- Reduce lifetime.

Radiation-induced defects

Total Ionizing Dose (TID)

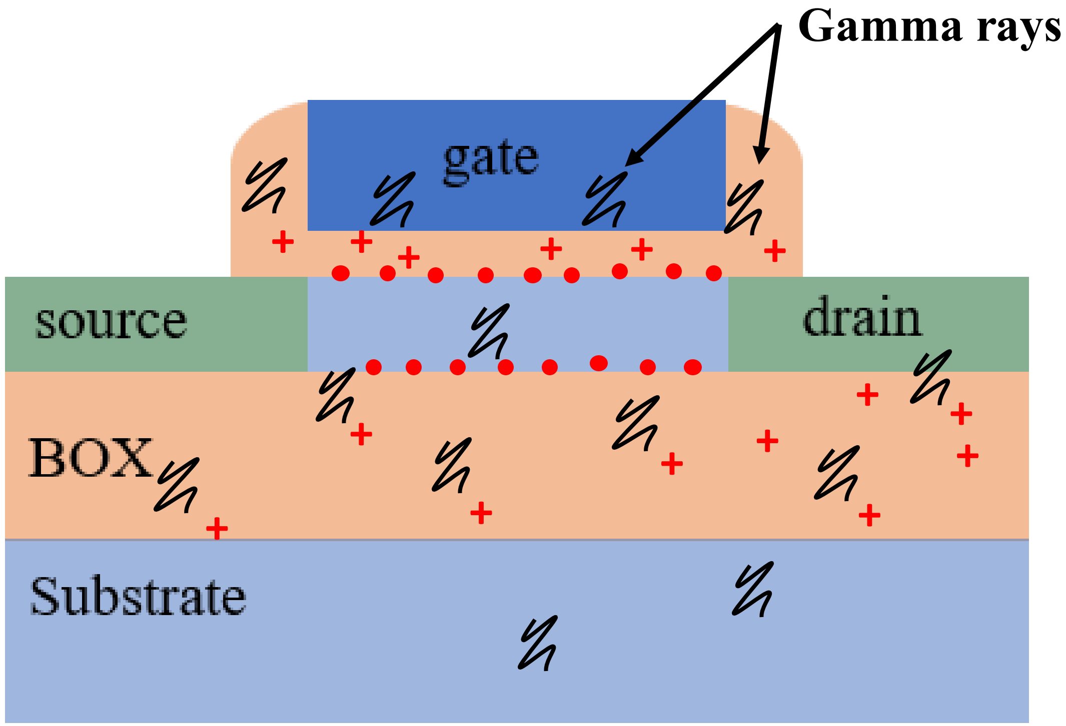
Positive oxide trapped charges.
Interface states.

- Shift of parameters (V_{th}, gm, SS)
- Cumulative degradation
- Reduce lifetime

Permanent failure!!

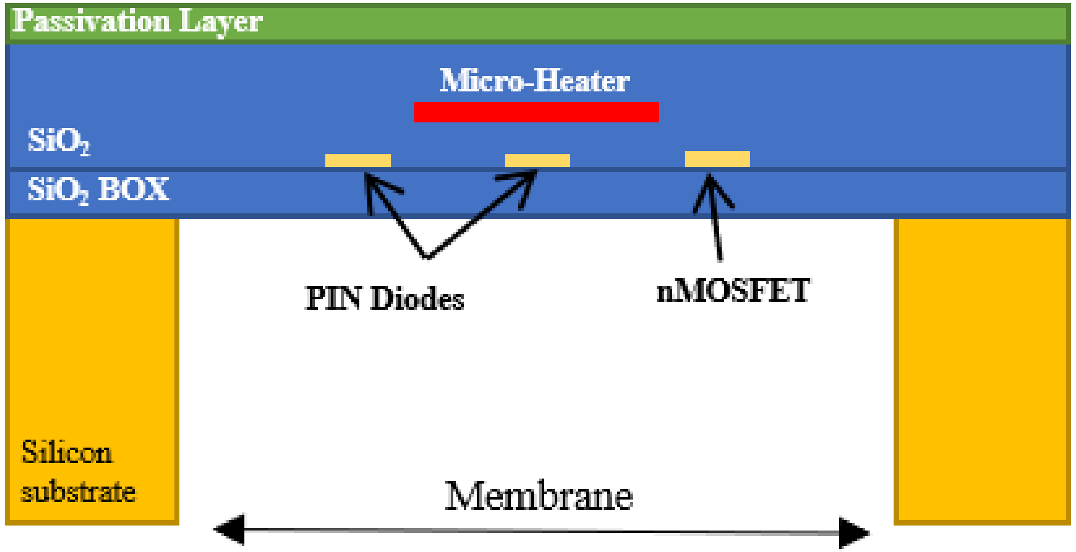
- Shielding
- Radiation hardening by design

In-situ thermal annealing !!!?

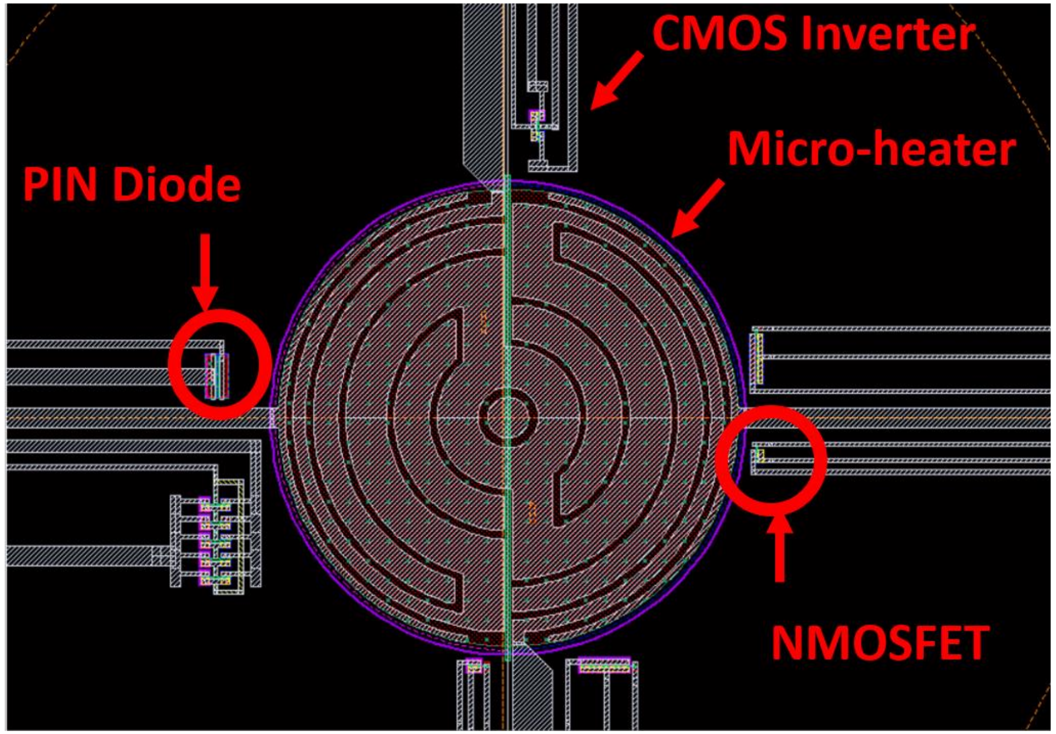


Cross section view of SOI MOSFET structure.

1.0 µm Partially-Depleted SOI technology (XI.10 from XFAB, Germany).

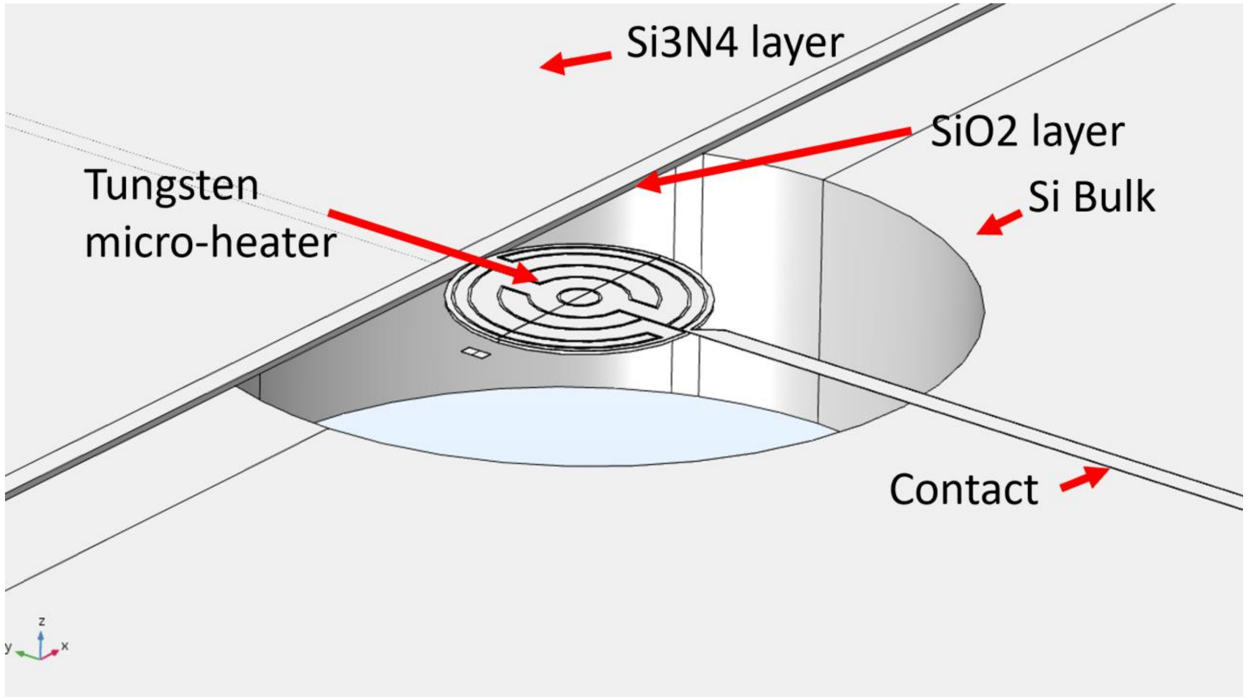


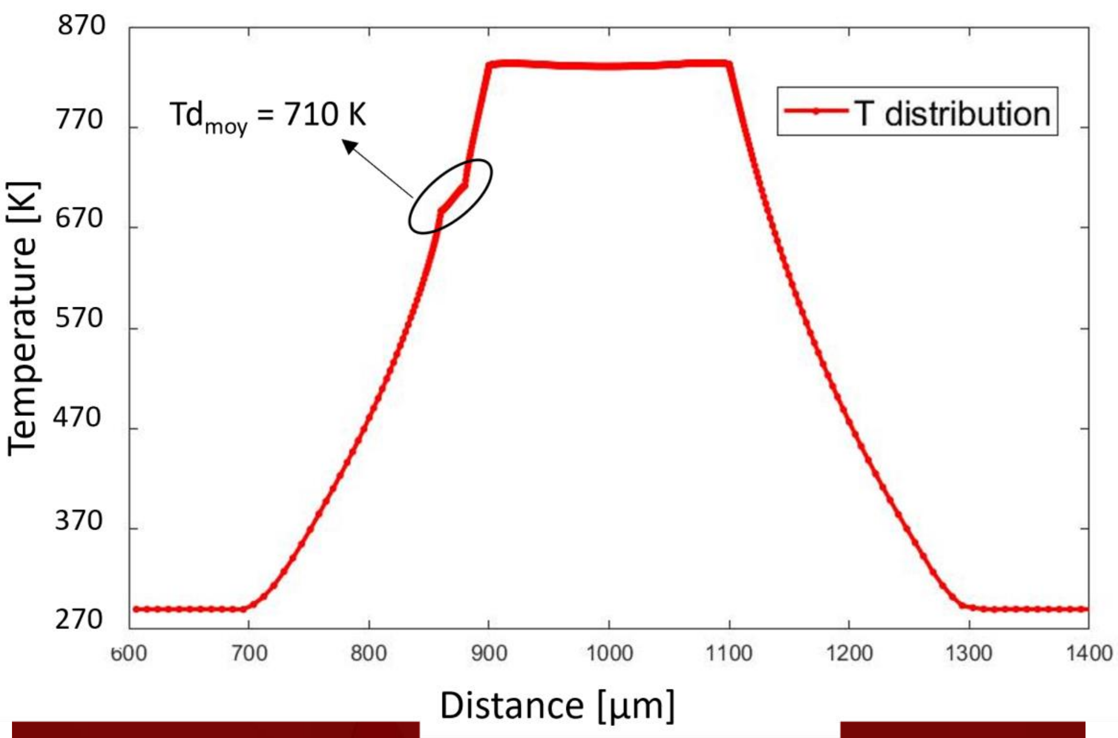
Schematic cross section of the device under test. (S Amor, et al, Semicond.Sci. and Techn., vol. 32, 2016.)



Layout image showing the location of the components around the micro-heater.

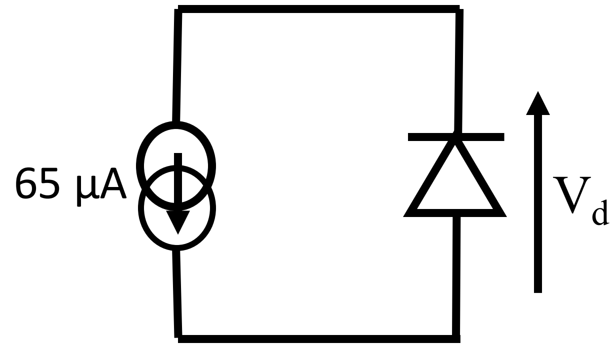
Comsol simulation of the on-membrane micro-heater.



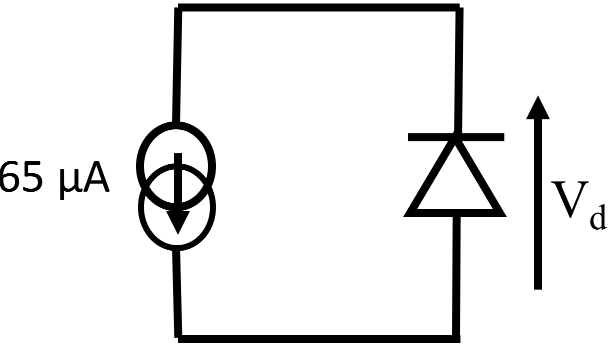


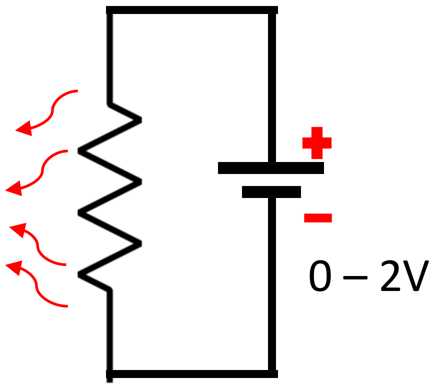
$$V_d = V_0 - d\,(T - T_0)$$

d_{Inner}=1.4 mV/K

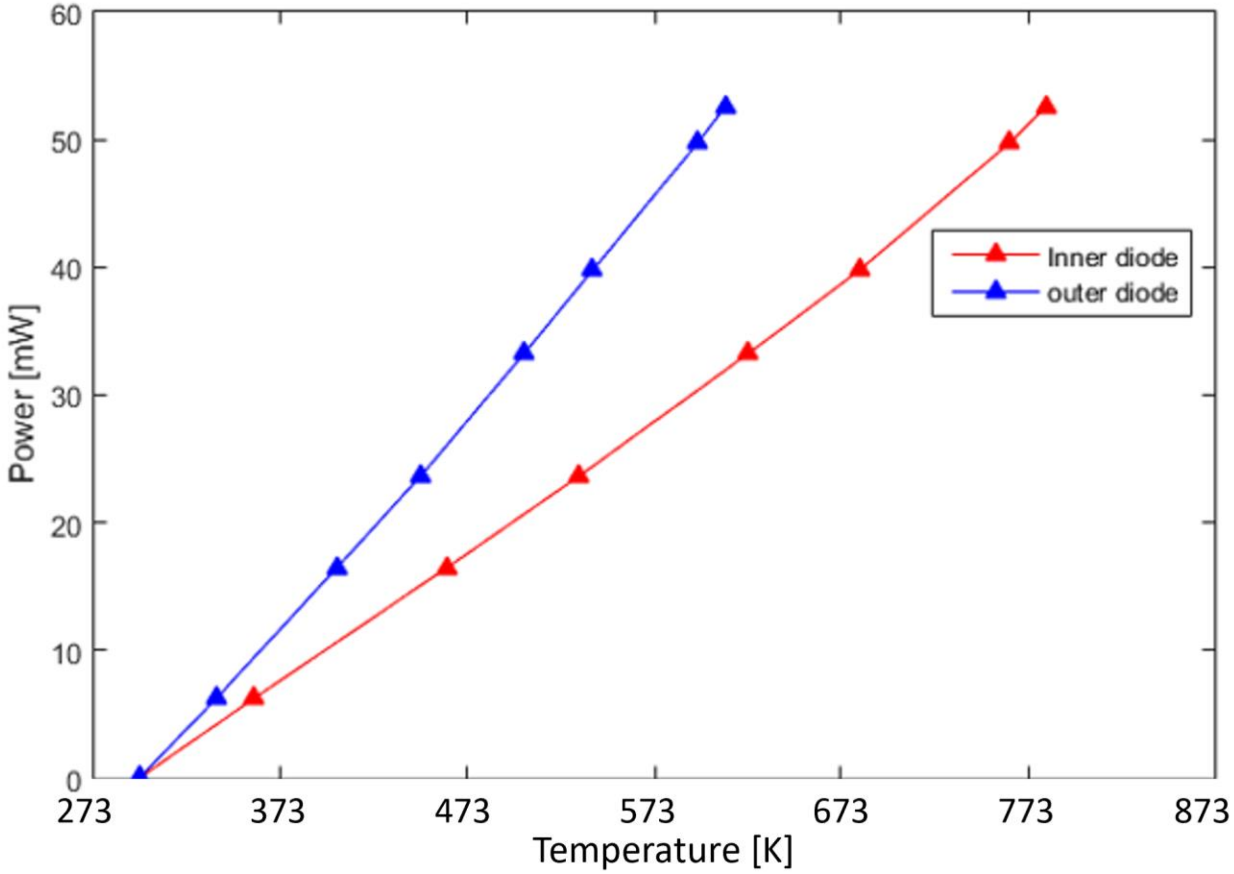


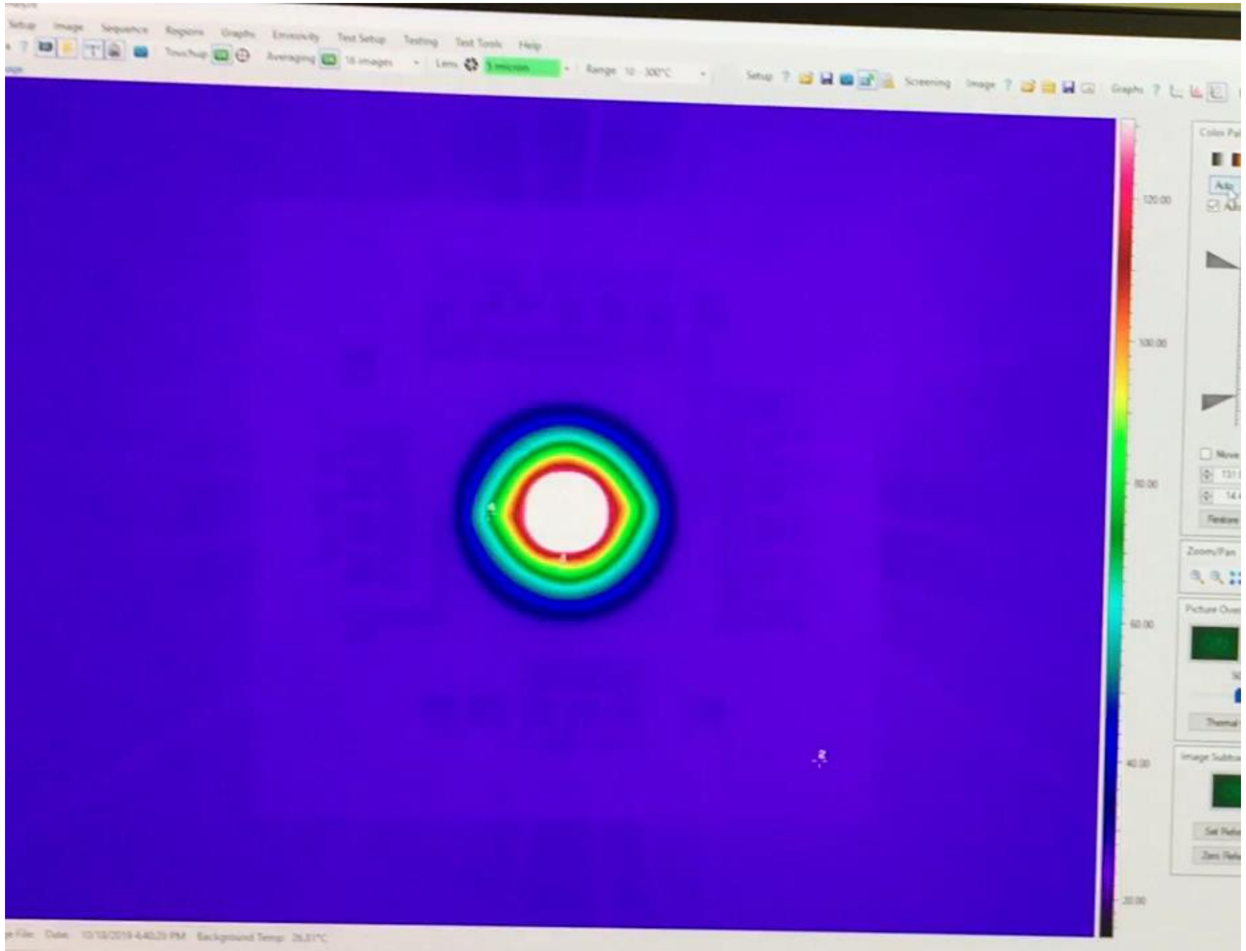
d_{Outer} =1.2 mV/K

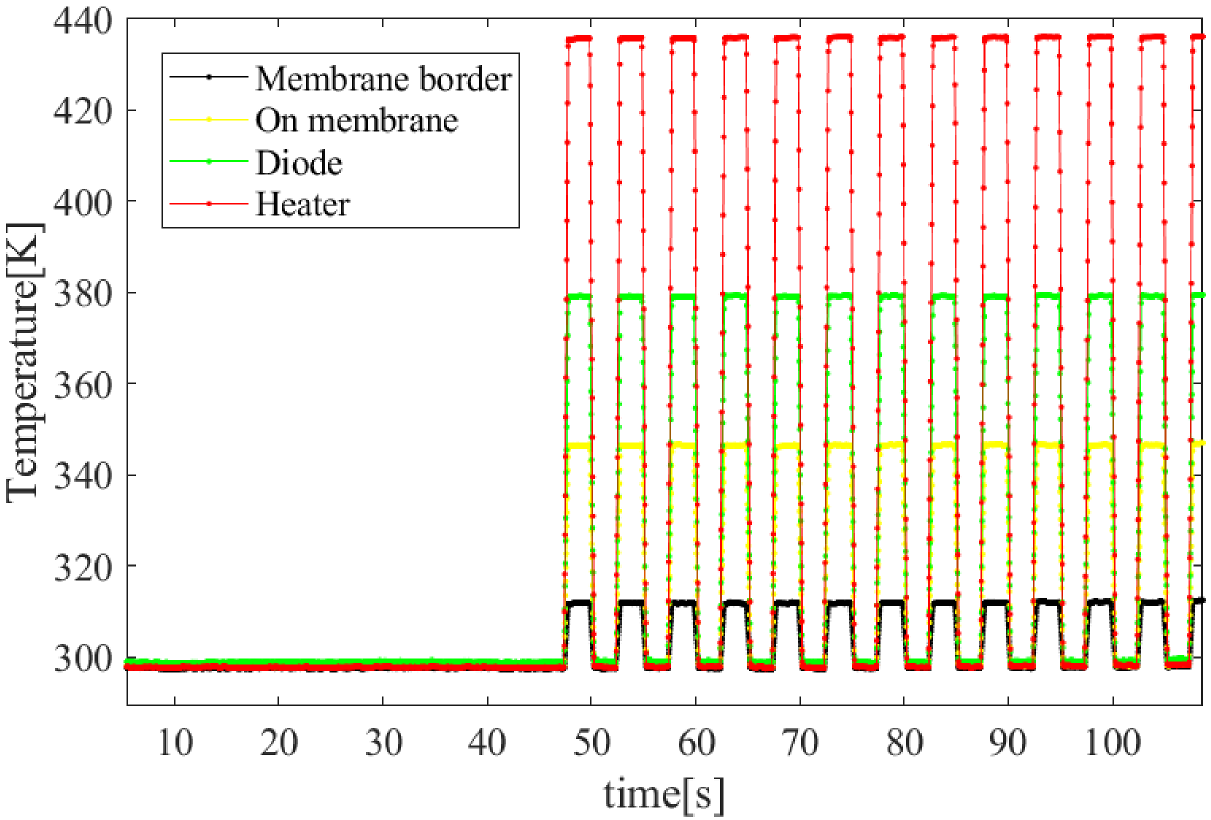




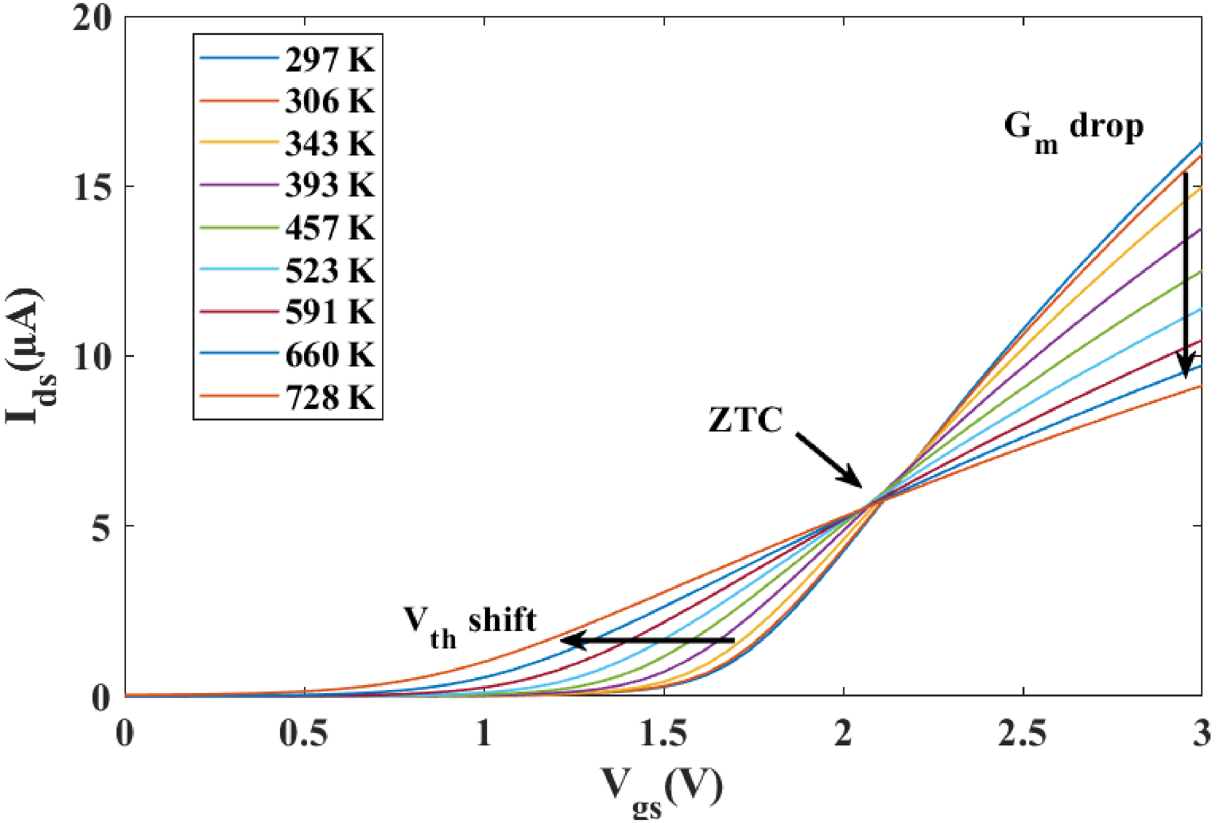
297 K – 733 K

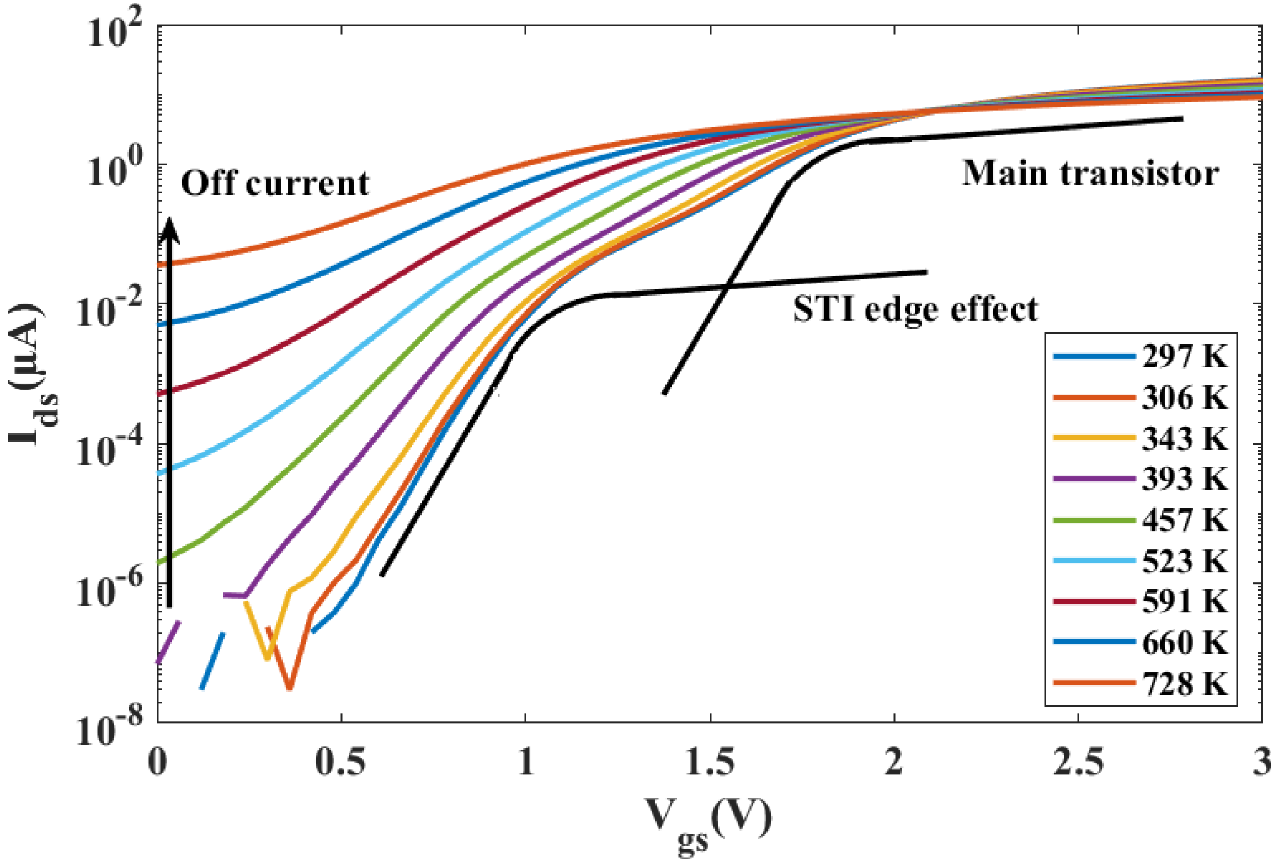




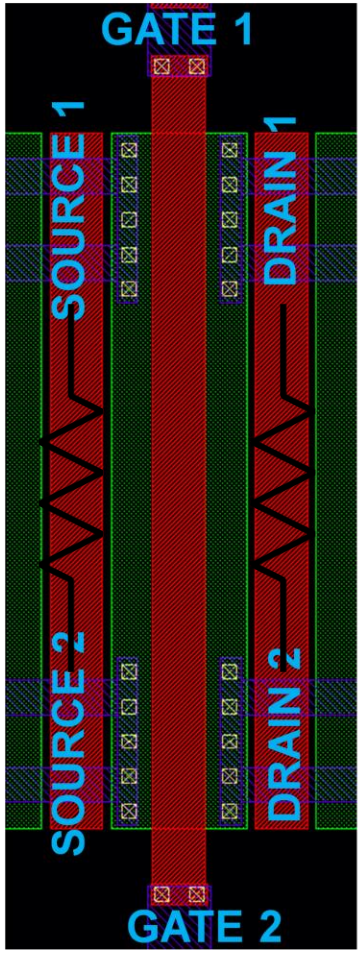


Membrane border
On membrane
Diode
Heater
Temperature[K]
time[s]
440
420
400
380
360
340
320
300
10
20
30
40
50
60
70
80
90
100

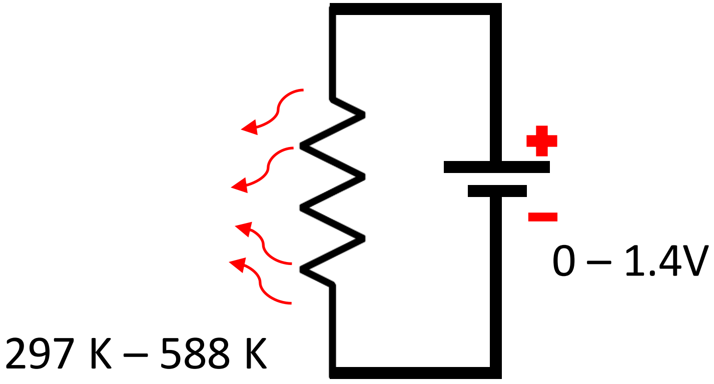




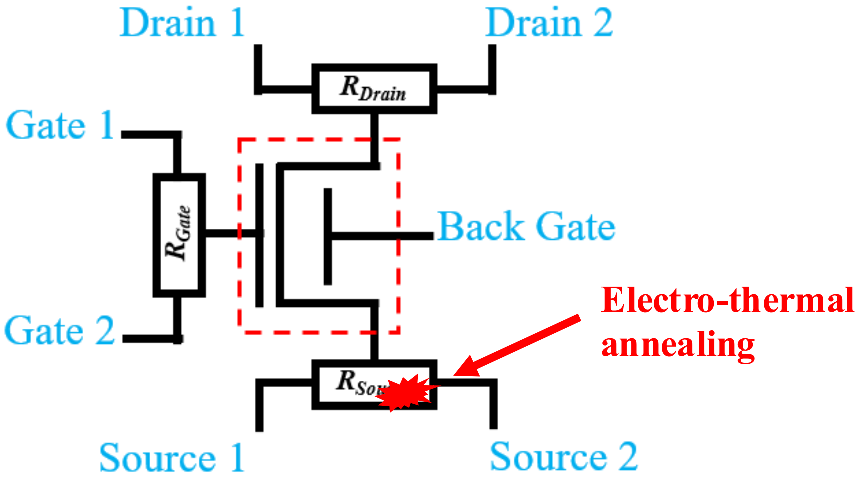
STI = shallow trench isolation



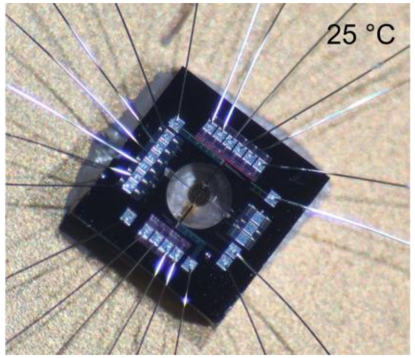
Layout of N-type MOS transistor with thick high-k metal gate oxide, from 28 nm Fully Depleted Silicon-On-Insulator (FDSOI) process.

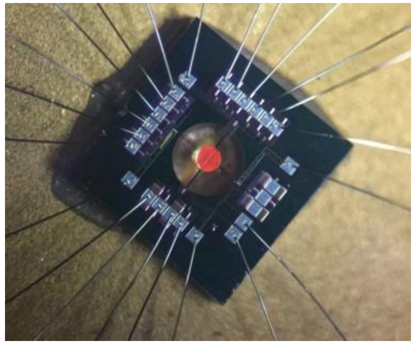


Joule heating



Schematic representation of of N-type MOS with 3 embedded micro-heaters based on 28 nm FDSOI technology.





Simulation results

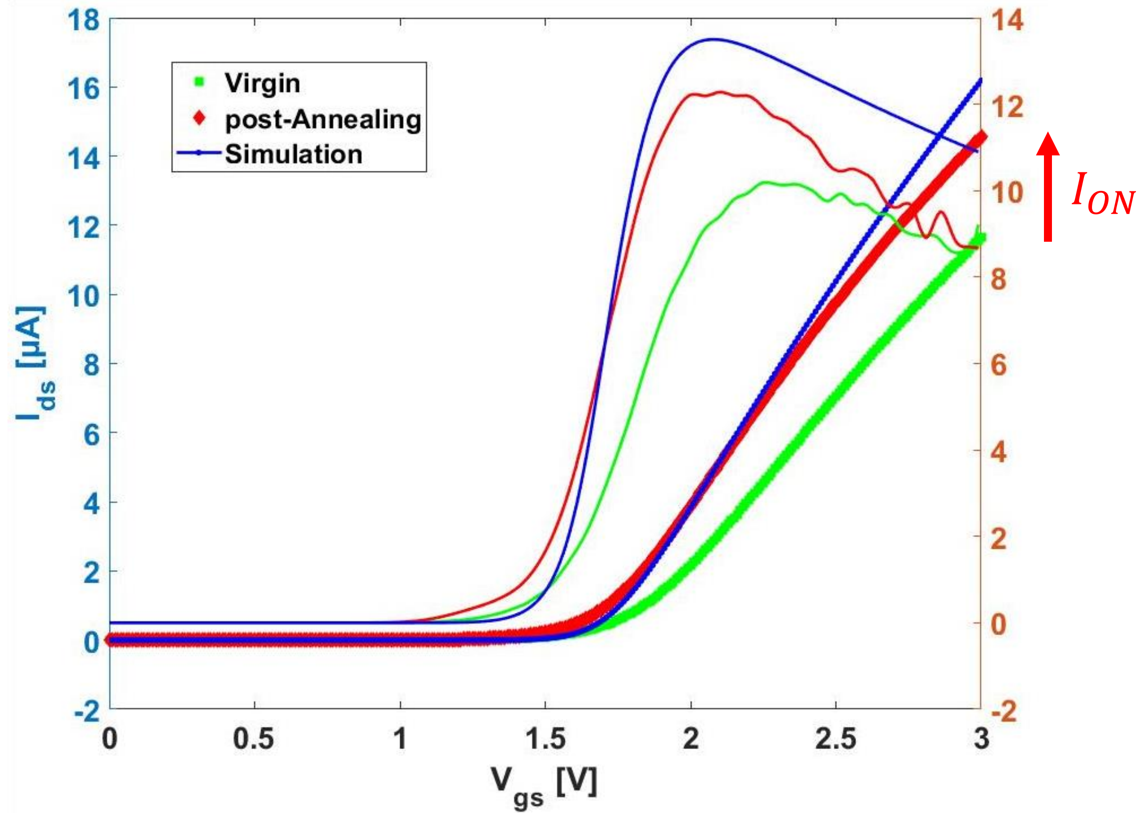
- Cadence simulation based on the pdk of the technology.

DRIE etching

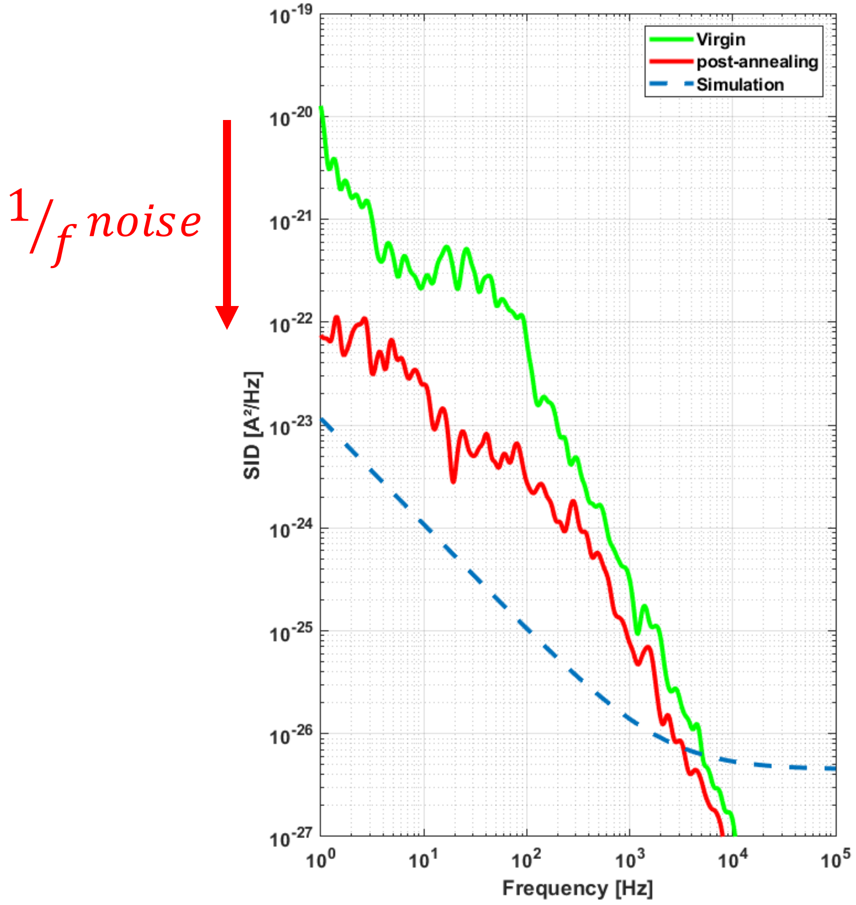
- I-V measurements.
- LFN measurements.

Thermal annealing at 538 K

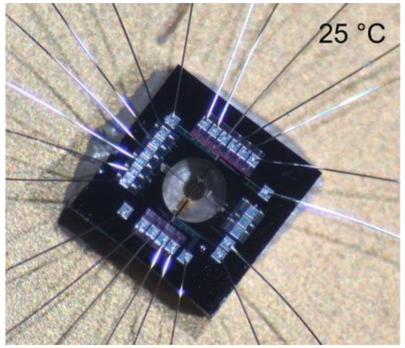
- In-situ thermal annealing for 2 minutes .
- IV and LFN measurements after annealing.



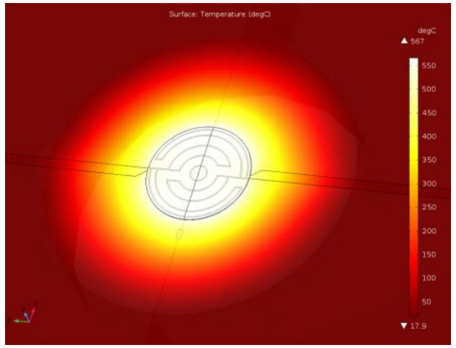
I-V (thick lines) and transconductance g_m (thin lines) measurements of on-membrane n-MOSFET, before and after thermal annealing, compared to Cadence simulation of the ideal MOSFET model in linear regime with V_{ds}=50 mV.



Measured noise power spectral density of the on-membrane n-MOSFET in weak inversion regime, before and after thermal annealing, and compared to 1/f noise Cadence simulation.



348 krad (Si)



Fresh measurements

- I-V and Low Frequency Noise (LFN) measurements in normal conditions.

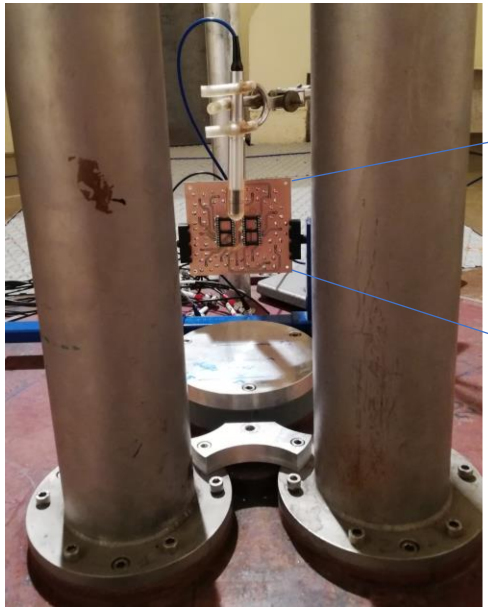
Gamma irradiation

- I-V measurements after each irradiation dose of **1.2 krad (Si).**
- I-V and LFN measurements after irradiation.

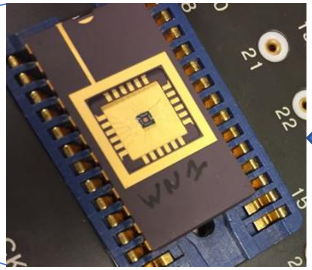
Thermal annealing up to 638 K

- I-V measurements after each step of **30s thermal annealing**.
- LFN measurements after annealing.

Cyclotron, Louvain-La-Neuve, Belgium.



Two Cobalt 60 sources with a dose rate of 1.2 krad/h (Si).



Device Under Test wire-bonded in a DIL 24 ceramic package

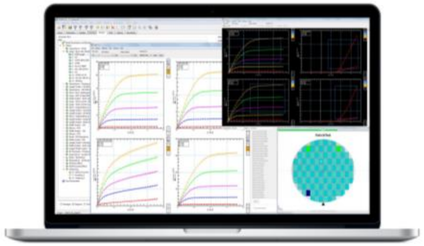
Total Dose 348 krad (Si) !!

Radiation room

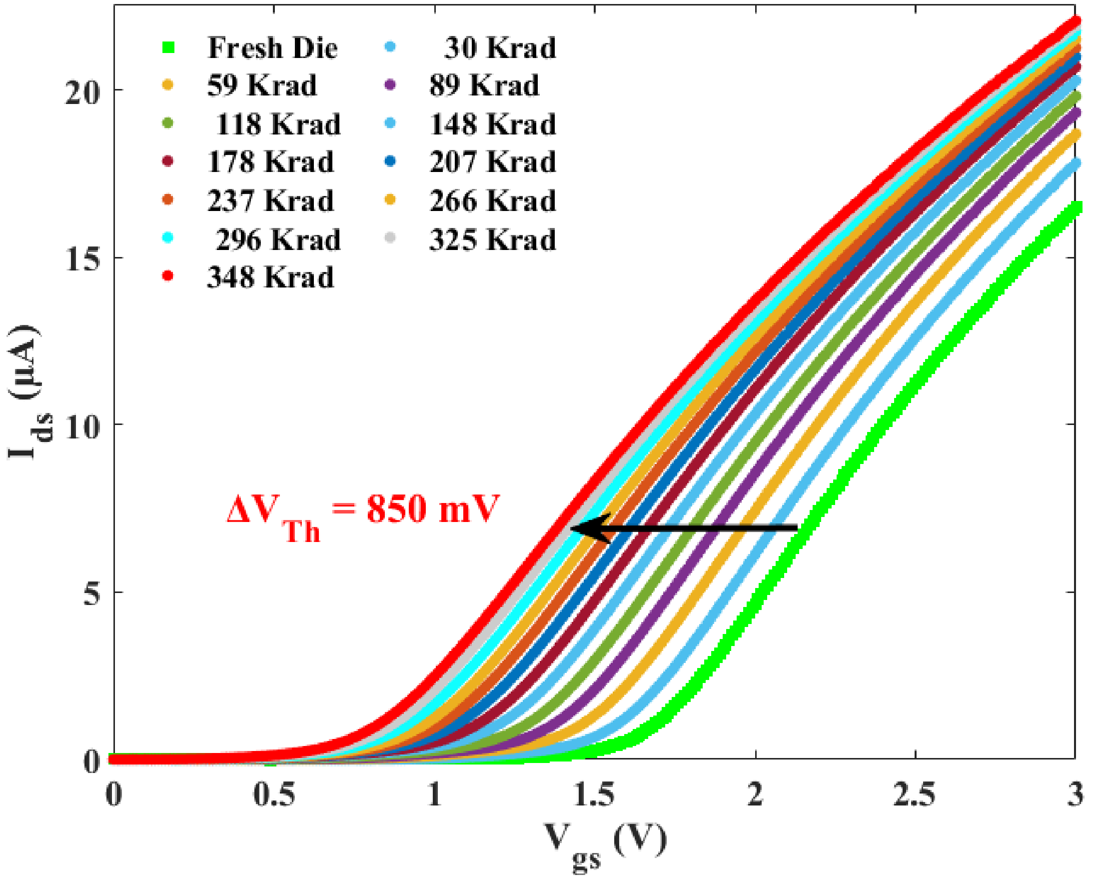
Coaxial cables

HP 4156 Semiconductor Device Parameter Analyzer

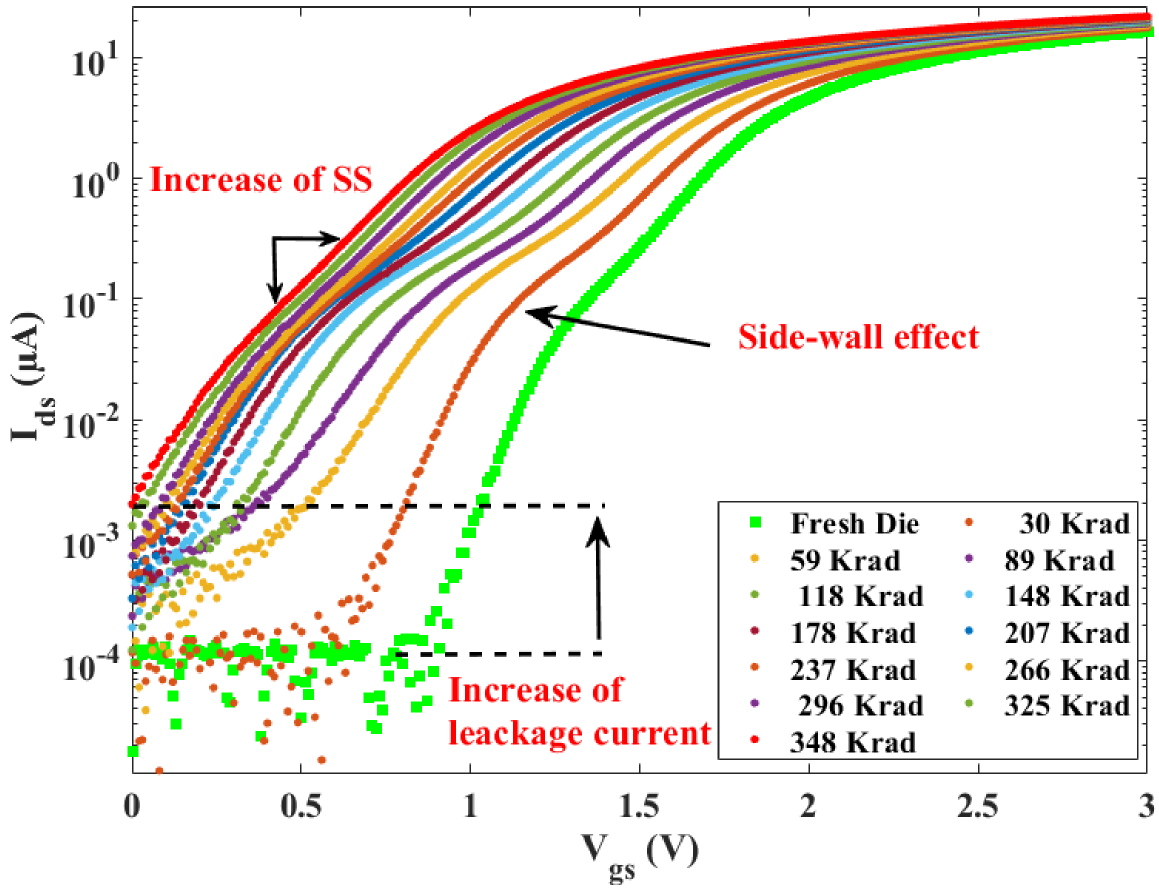
IC-CAP script Recall of a characterisation routine each 3 hours of exposure.



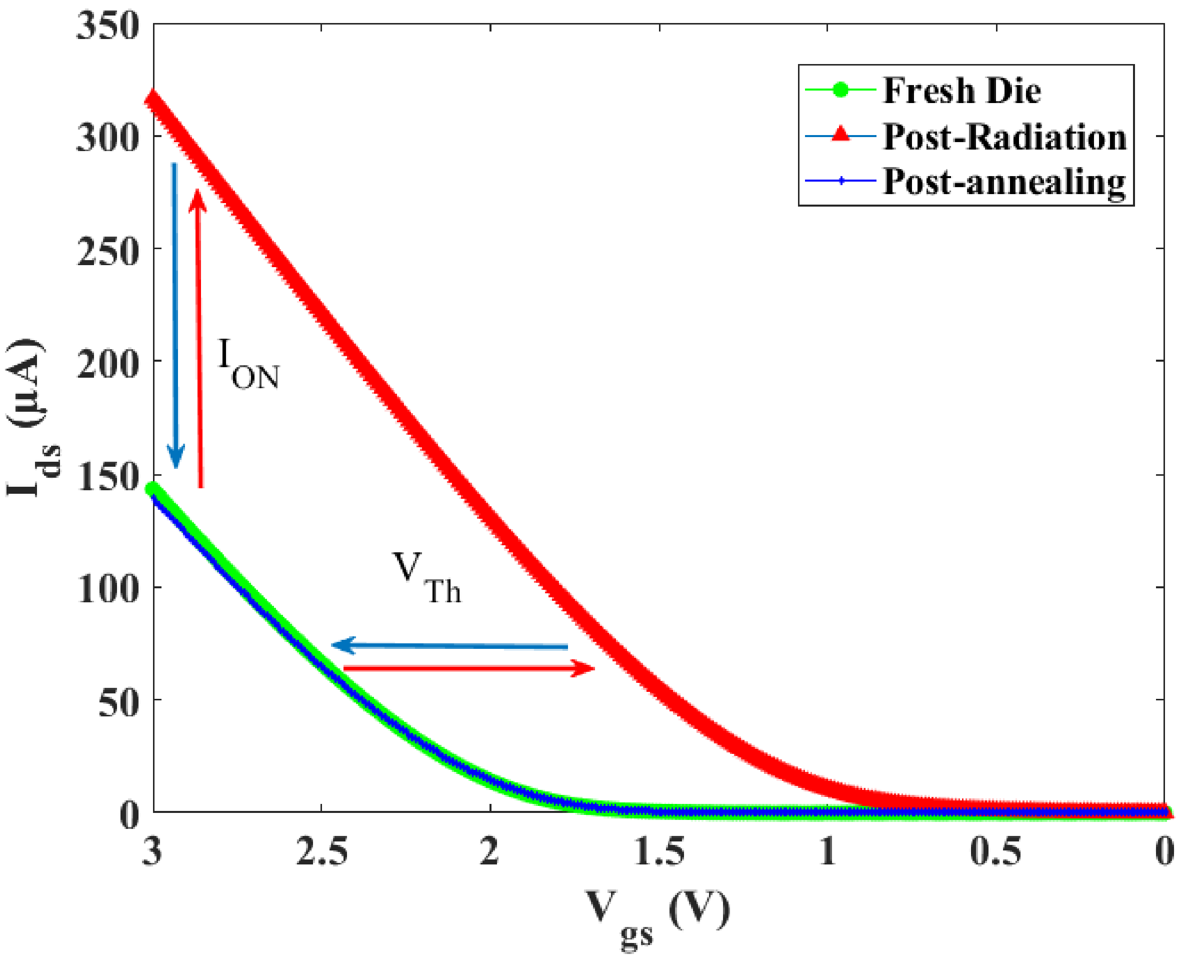
Armored room



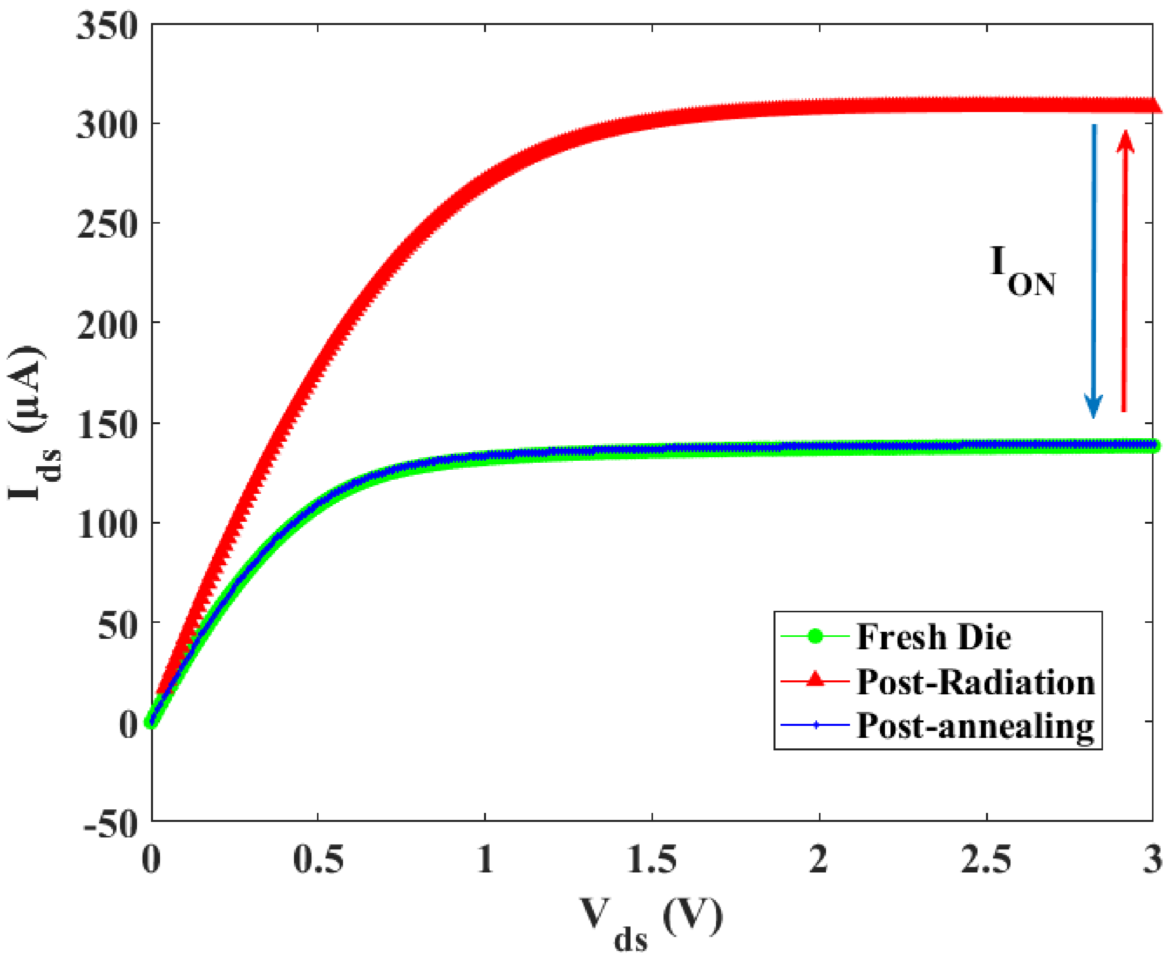
I_{ds} vs V_{gs} characteristics of the 6µm wide transistor. Measured in linear regime under after each 60 krad (Si) of gamma radiation .



Logscale representation of the transistor's I-V characteristics. Measured under gamma radiation after each 60 krad (Si).

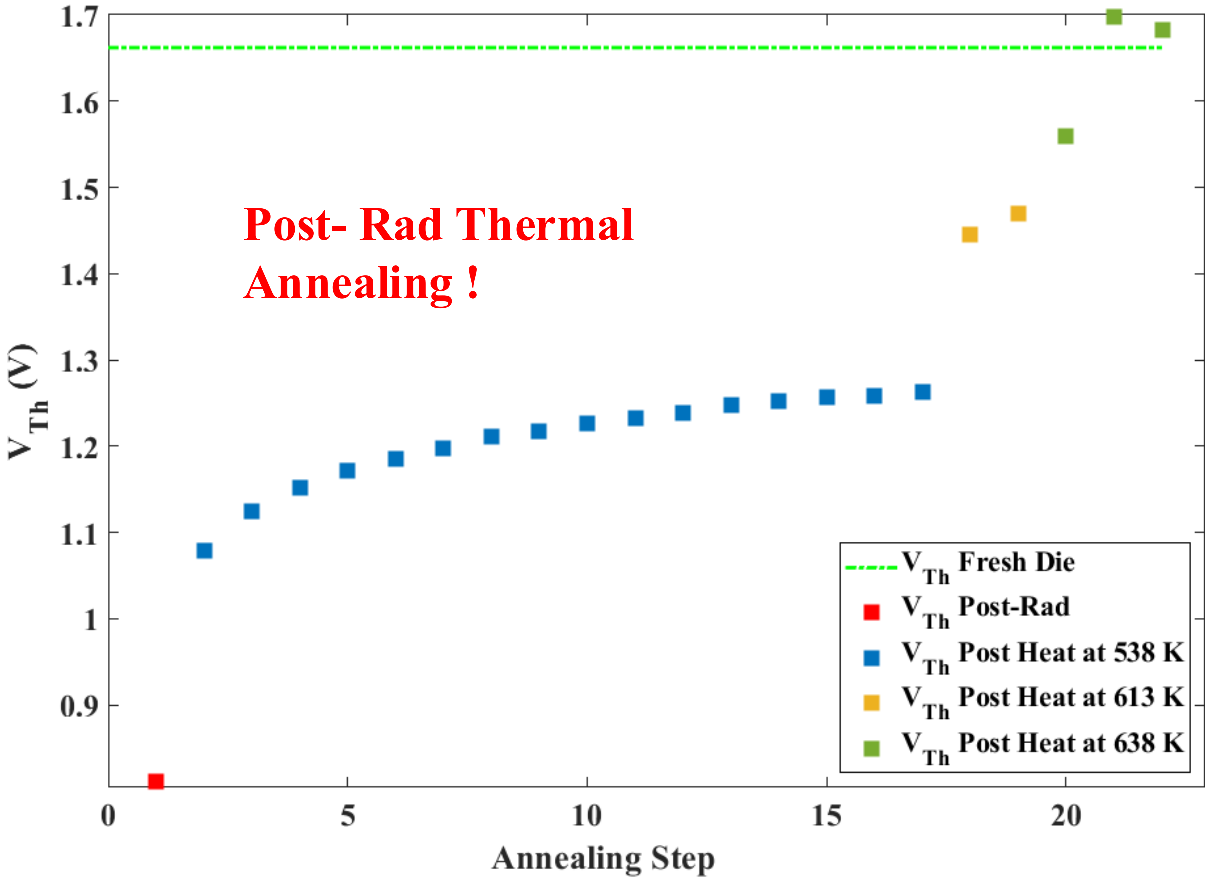


350
300
250
200
150
100
50
0
3
2.5
2
1.5
1
0.5
0
V_{gs} (V)
I_{ds} (μA)
Fresh Die
Post-Radiation
Post-annealing
I_{ON}
V_{Th}



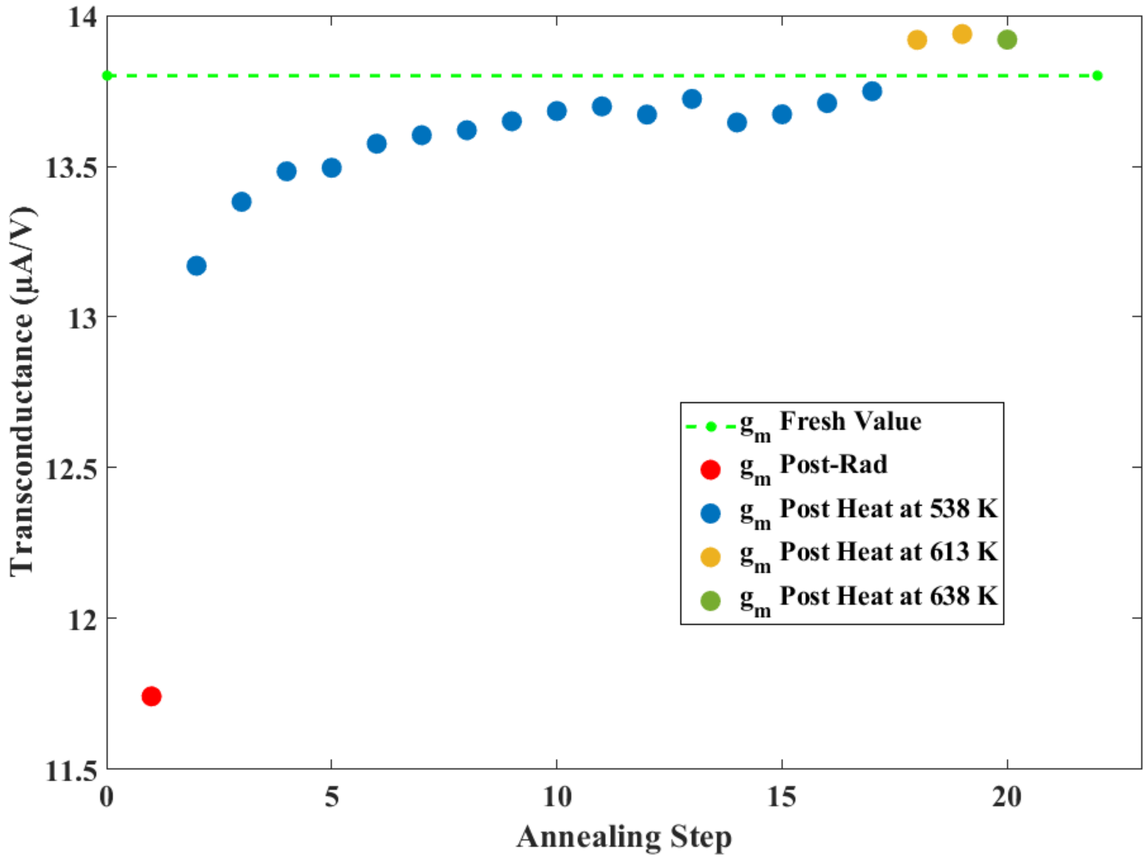
350
300
250
200
150
100
50
0
-50
0
0.5
1
1.5
2
2.5
3
V_{ds} (V)
I_{ds} (μA)
I_{ON}
Fresh Die
Post-Radiation
Post-annealing

Total recovery of V_{Th}

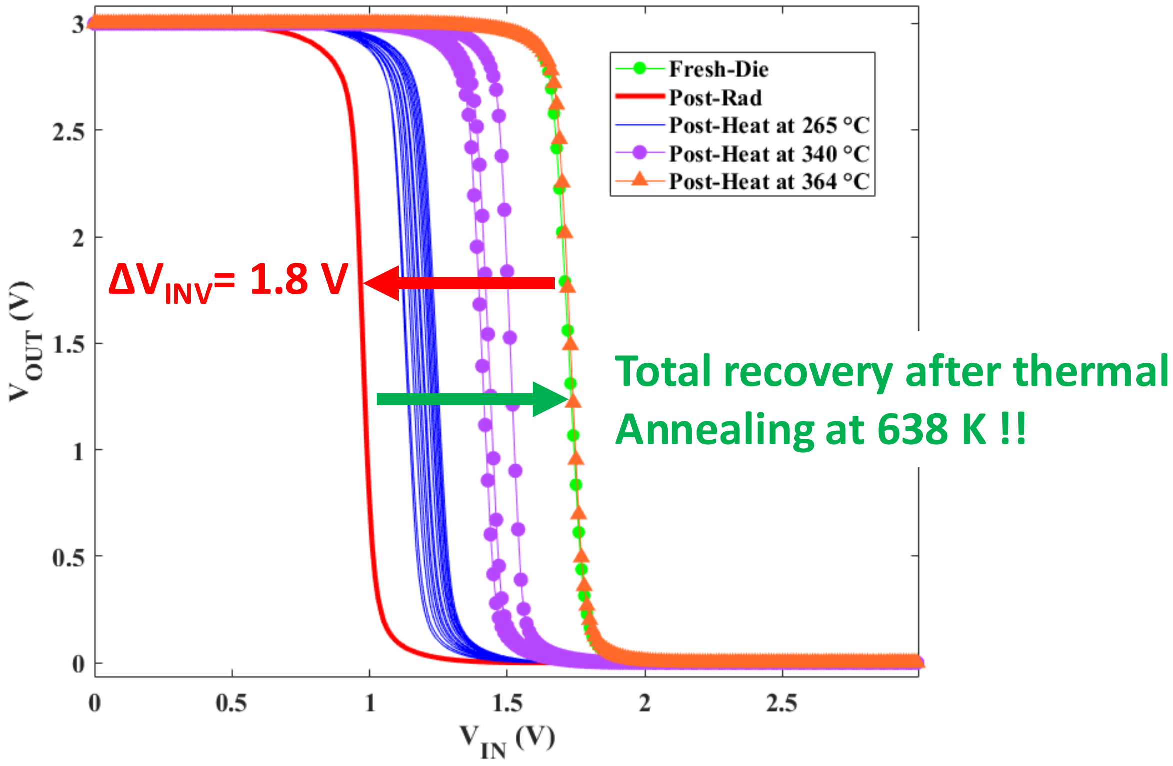


Threshold voltage of the transistor in fresh condition, after irradiation and after each annealing step.

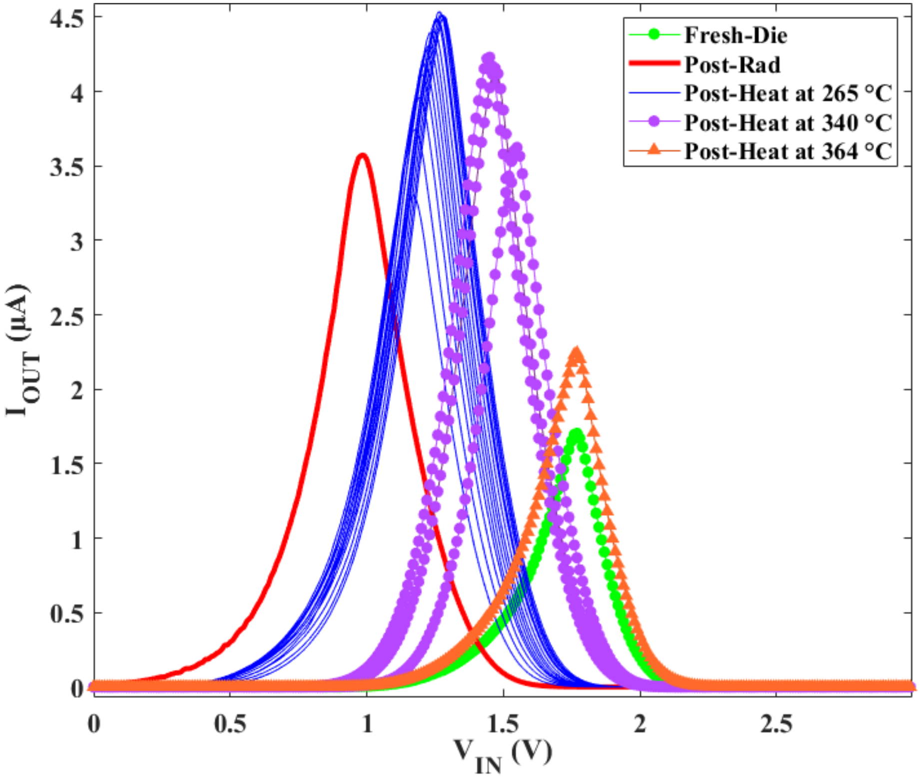
Total recovery of g_m



Maximum transconductance in linear regime, extracted in fresh condition, after irradiation and after each annealing step.

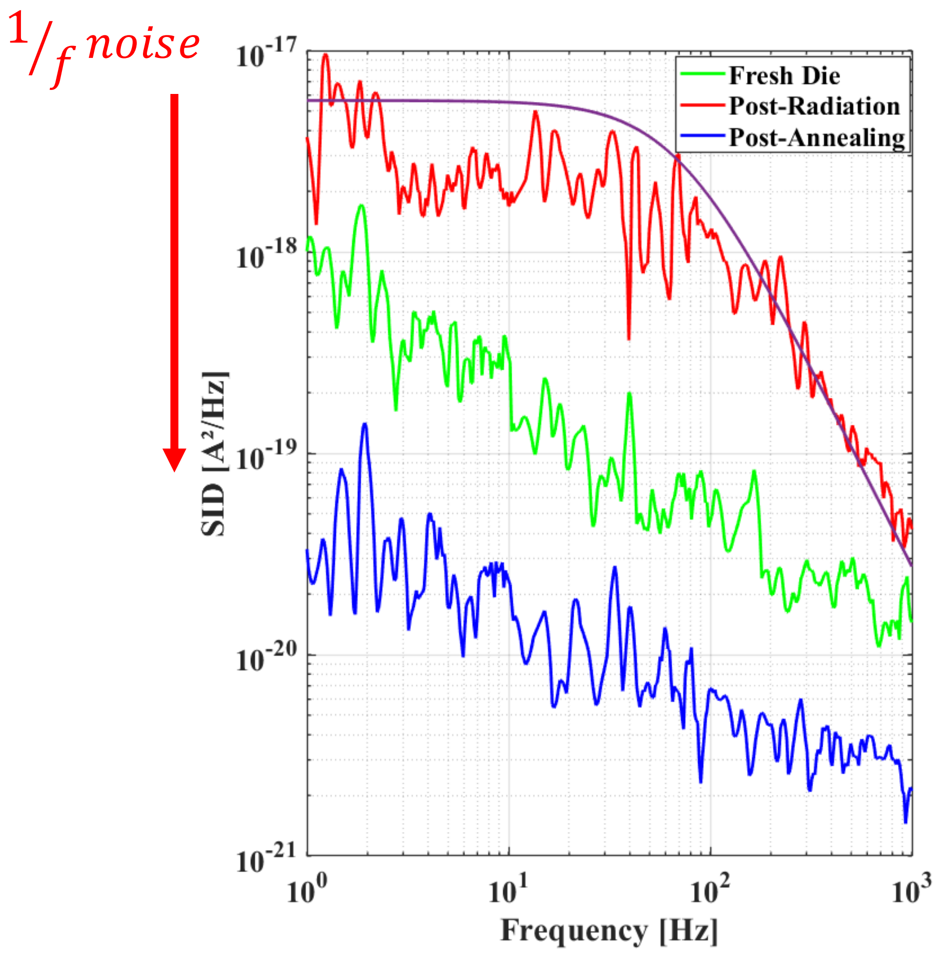


Voltage transfer characteristics of the CMOS inverter after each annealing step

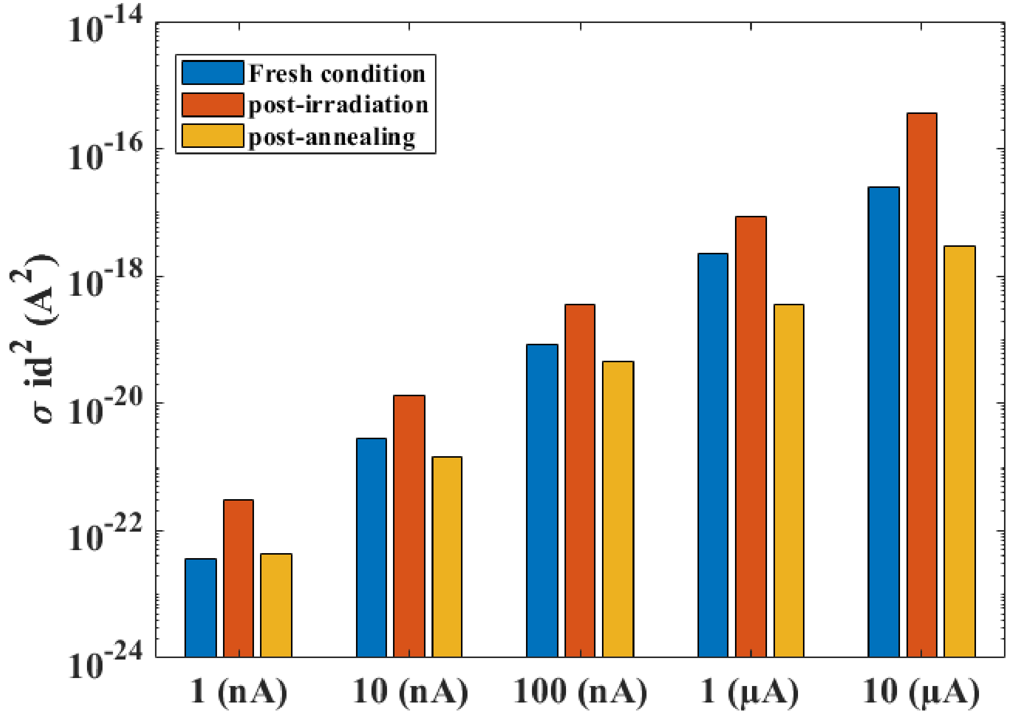


Output current of the CMOS Inverter measured after each annealing step

$^1/_f$ noise



Noise power spectral density of the MOSFETs. Measured Pre-Post radiation and after annealing at V_{ds} = 3 V.



Total power noise at different drain currents (from weak to strong inversion integrated from 1 Hz to 606 Hz).

Summary

- Supported membranes in MEMS applications
  - Porous silicon acts as particles sieve for lysed bacteria
  - Silicon-on-Insulator (SOI) with embedded electronics can be heated up to high temperatures, providing *in situ* low-power annealing of various types of defects

Conferences announcement

Société Française des
Semi-Conducteurs et Oxydes Poreux

scope2025 : Journées SCOPe 2025

23-24 Oct 2025 Louvain-la-Neuve (Belgium)

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Thank you for your attention!

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