Capteurs CMOS physiques & physiologiques flexibles et basse consommation

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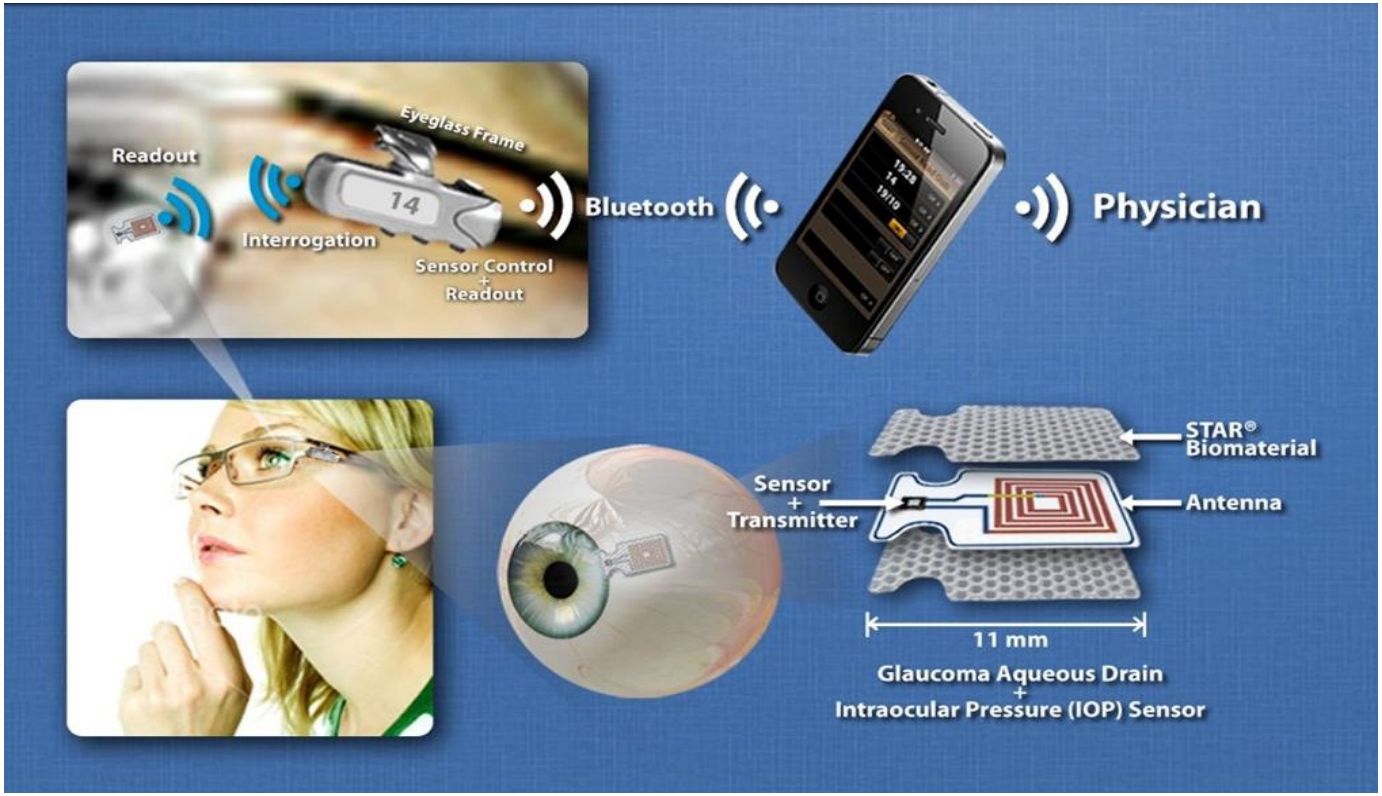
fεtCh 2019

icteam UCLouvain

Outline

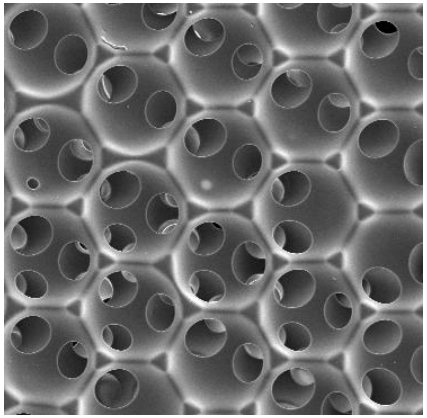
- Ultra-low-power sensing and circuit blocks
  - Starting case in UCL : implantable eye pressure system
  - Challenges, Innovative concepts, Specific technologies
- UCL Developments within CONVERGENCE project
  - Strain sensor for body deformations
  - Ultra-thin sensor for skin temperature
- Conclusions & Perspectives

1. Ultra-low-power sensing and circuit

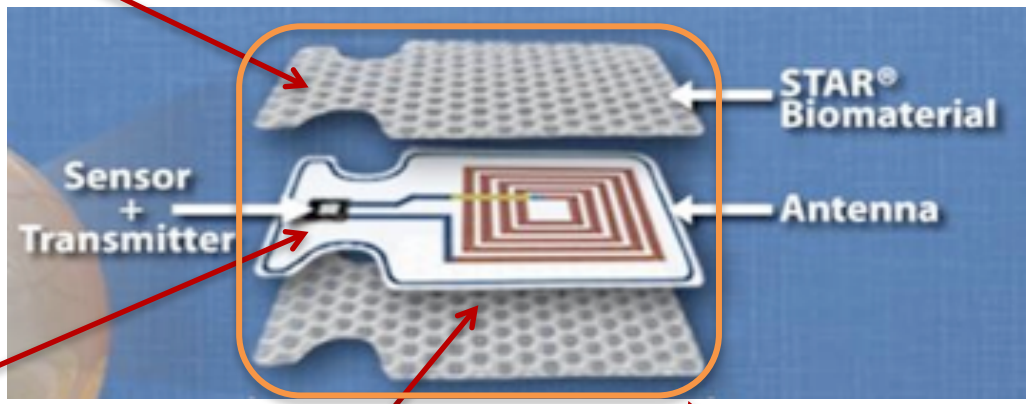


- Glaucoma management IOP microsystem that combines therapeutic and diagnostic benefits in one ophtalmologic implant for long-term monitoring
- Regional project with iStar, Rosselini and U. Liège

1.1 Challenges



STAR® Biomaterial :
'sweet-spot' precision-pore geometry
for anti-fibrotic, pro-healing, biomimetic performance !



MEMS Pressure Sensor :
Highly-sensitive in 0 - 70 mmHg range
with 0.5 - 1 mmHg precision !

Wireless power / data transfer :
mm^3-inductive coupling => all circuit blocks ≈ 100 µW
for sensor read-out and communication distance of a few cm !

Prototype assembly and validation :
Biocompatible materials and packaging techniques !

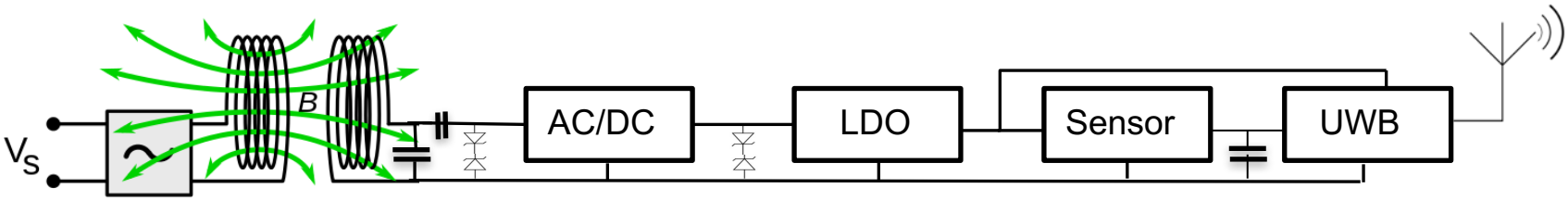
1.2 UCL concepts, technologies & blocks

Towards miniaturization :
Capsule < 8mm length x 1.2mm diameter



- **Inductive coupling @ 1 or 13.56 MHz using ferrite coil** (< 4mm long)
  - Vs. higher frequencies (900MHz – 5GHz for mm-size antennas) :
    - less absorption by body tissues
    - record coupling efficiency when multi-turn + ferrite core @ cm-distance
    - record ULP AC/DC rectifier power efficiency

- **SOI technology** for single-chip solution, i.e. enabling monolithic integration of all system blocks in 4 x 1 x 0.5 mm^3 with highest performance
  - AC/DC rectifier and voltage regulation with CMOS ULP
  - MOSFET-based piezoresistive pressure sensor + oscillator interface
  - Ultra Wide Band pulse data transmission with on-chip antenna



2. Strain sensor: In-body applications

BioImplantable MEMS Array Bone Stress Sensor *[J. Fernando Alfaro, PhD Thesis, 2007]*

3 x 3 mm^2 Si chip
Measured strain (ΔL/L) ~ 1-100 ppm
For E_{bone} = 100 MPa

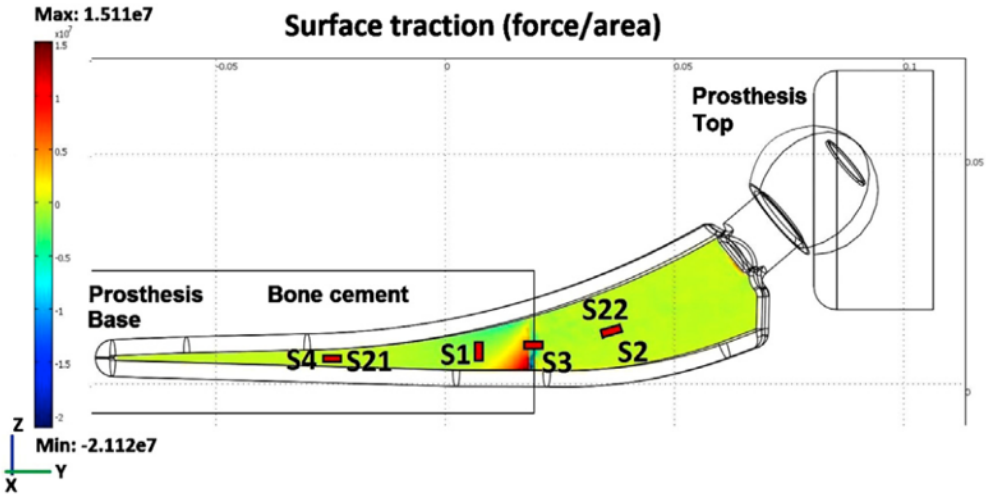
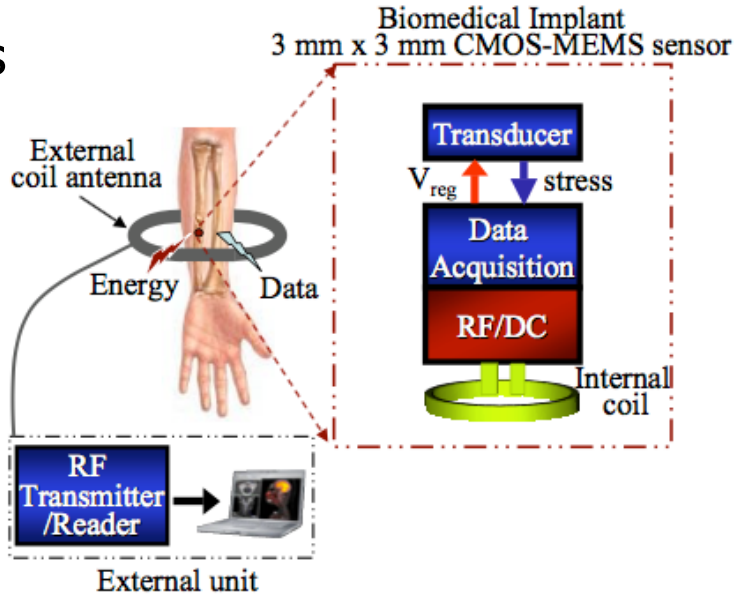


Fig. 1. Simulated stress distribution for the hip-joint prosthesis with solicitation along *y*. The horizontal rectangle indicates the placement of the cement.



Piezoresistive sensors for force mapping of hip-prostheses *[Correia et al, S&A-A, 2013]*

Si thin film piezoresistors with Gauge Factor ~ 28 (i.e. GF = ΔR/R / strain)

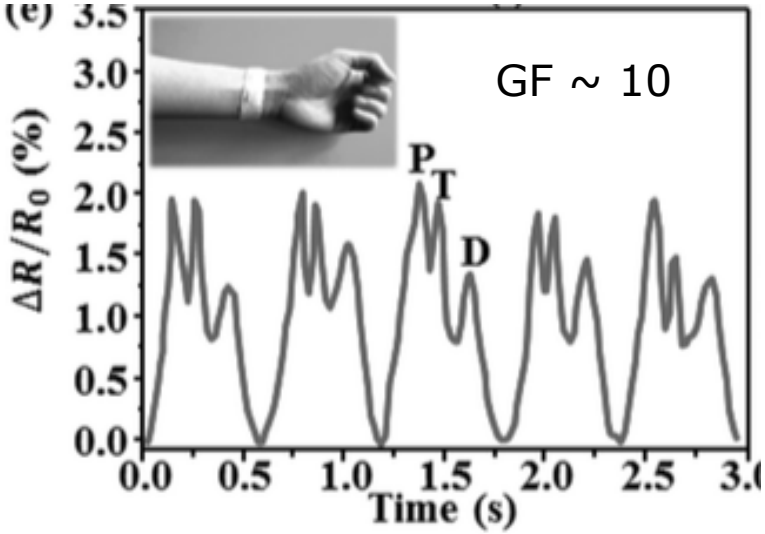
2. Strain sensor: On-Body applications

Many stretchable sensor on hands, limbs, knee…
for strain from 0.5% to >100% exceeding practical Si limits

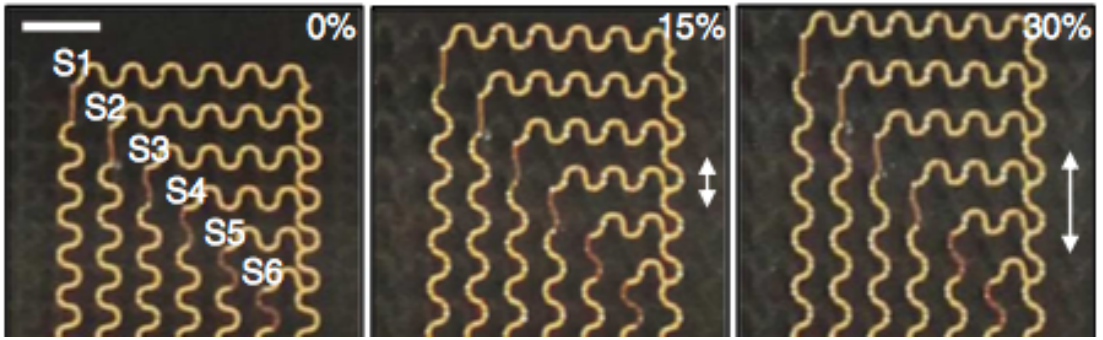
Silicon gauge Ok for subtle movements,
up to about 0.2% deformation…

Or embedded in polyimide sheets with stretchable electrodes

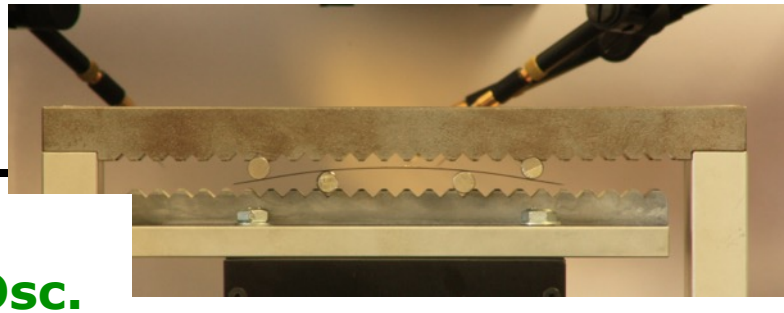
Carbonized Cotton Fabric for High-Performance Wearable Strain Sensors
[Zhang et al, Adv. Funct. Mater. 2017]



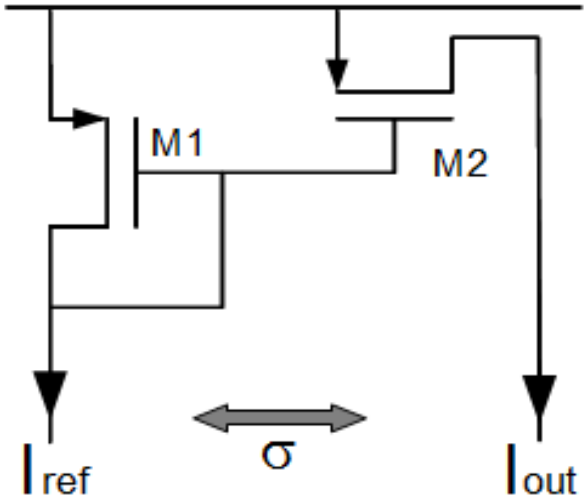
Stretchable Si nanoribbon electronics for skin prosthesis [Kim et al, Nature Com. 2014]
…with GF ~ 200



2.1 CMOS strain sensor



UCL : PMOS Mirror as Current Source of on-chip Current Controlled CMOS Ring Osc.

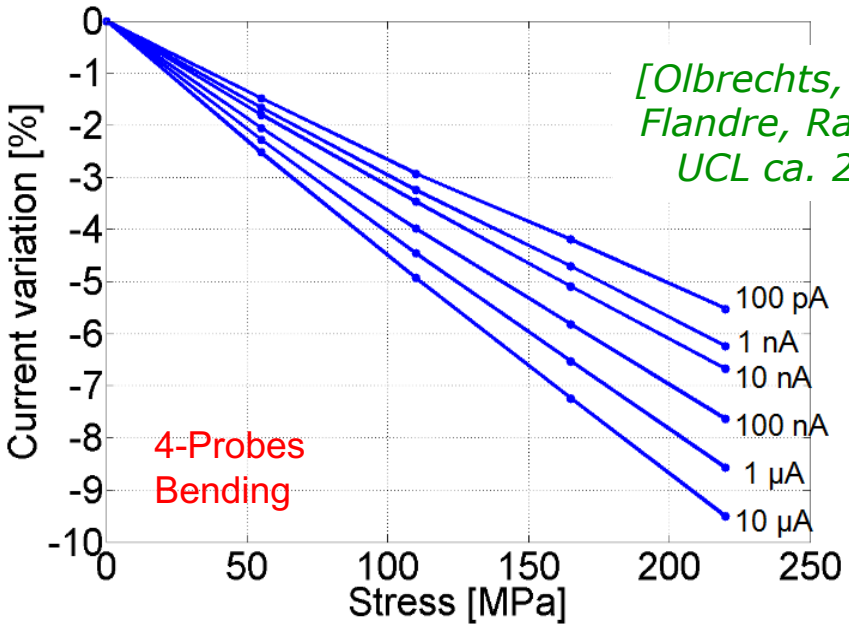


$$I_{out} \cong \left[1+\left(\pi_{PMOS\perp}-\pi_{PMOS//}\right)\cdot\left(\sigma_{xx}-\sigma_{yy}\right)\right]\cdot I_{ref}$$

with $\sigma = E_{Si}.\varepsilon$

- 5 % / 100 MPa

+ 5 % / 100 MPa



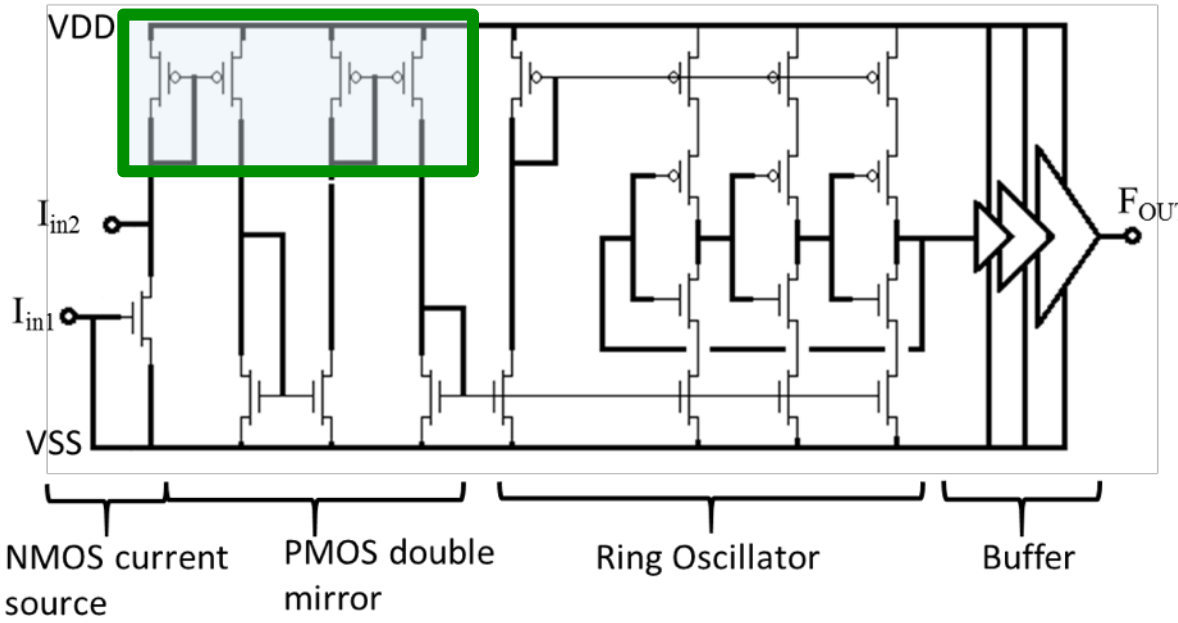
[Olbrechts, Rue, Flandre, Raskin, UCL ca. 2010]

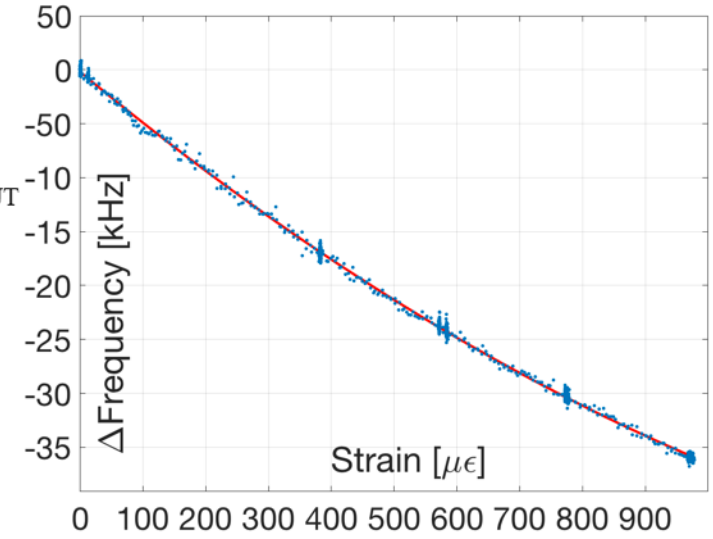
Much lower power consumption
(here < 10µA @ 1.6 V)
than piezoresistive gauges
(typ. mA @ several V)

Much easier read-out circuit
(no amplifier or ADC as for
std piezo or capacitive sensors)

2.2 CMOS strain sensor circuit

Membrane for pressure sensors or Full chip thinning for strain





Vdd = 1.2 - 1.6 V

[Al Kadi Jazairli et al., IRSP 2016]

≈ 10-100 µW
power consumption
(90% in output buffer)

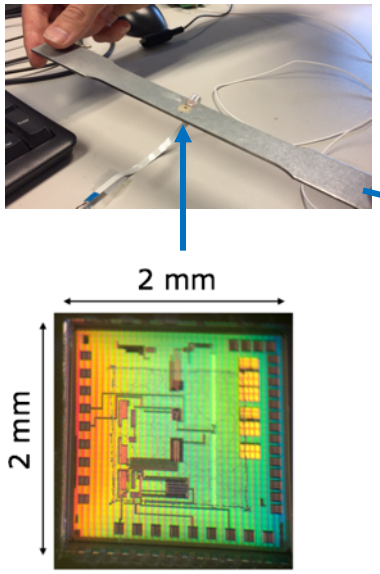
Freq. Output :

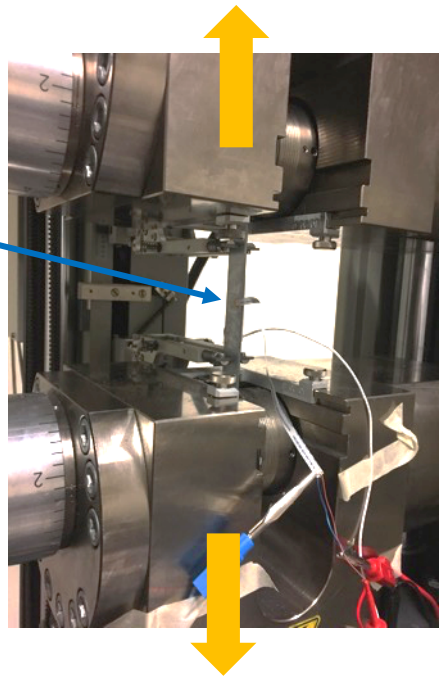
2.5 – 300 kHz

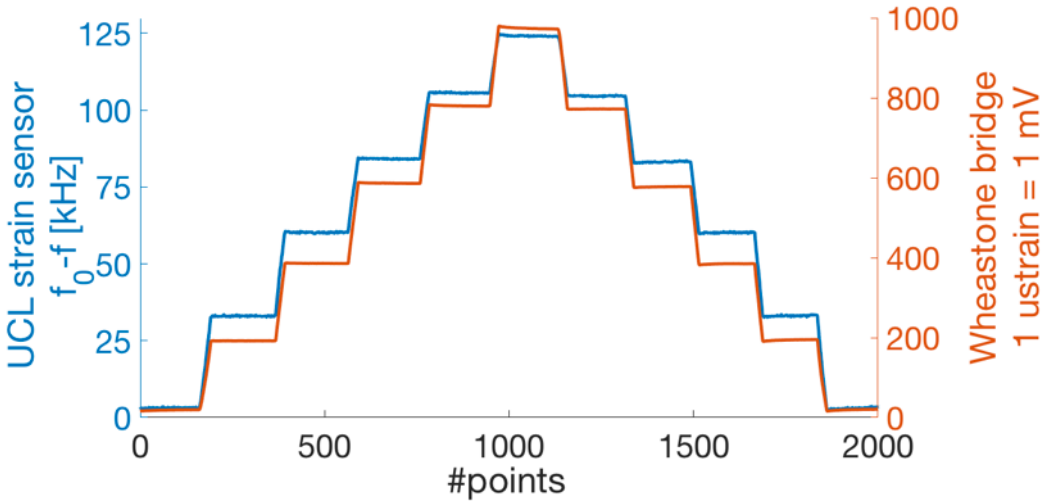
- ✓ high gauge factor: 400
- ✓ sensitivity: 300 ppm/µε
- ✓ precision: 5 µε

2.3 CMOS strain sensor circuit demos

- Dogbone test sample on Zwick traction machine
- Reference: std metallic strain gauge on kapton (GF = 2)
- Chip – glued with Epo-tek P1011S

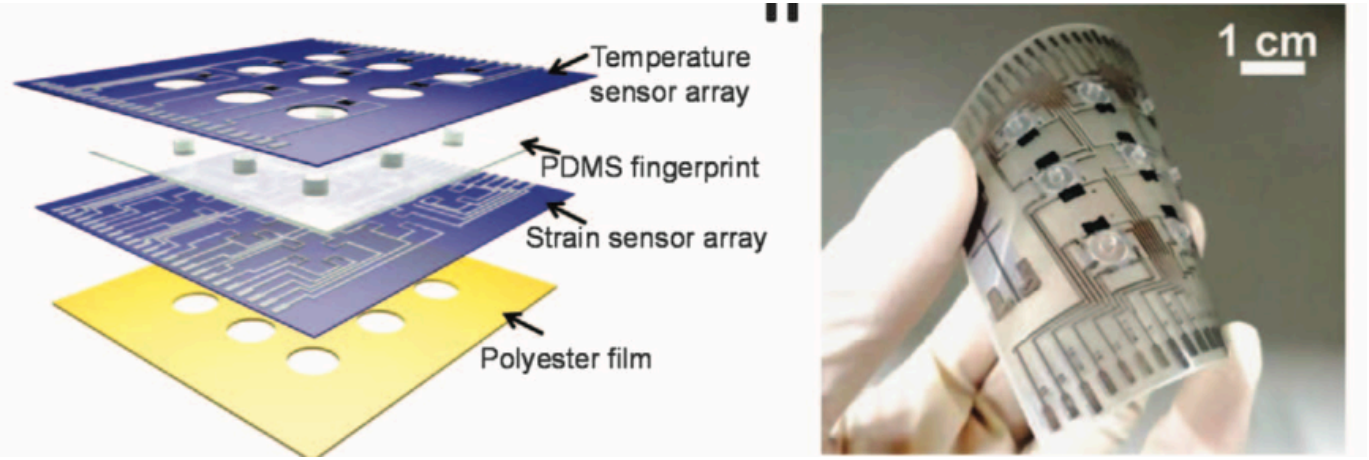






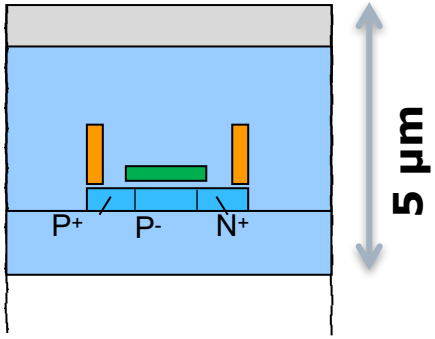
3. Ultra-thin temperature sensor

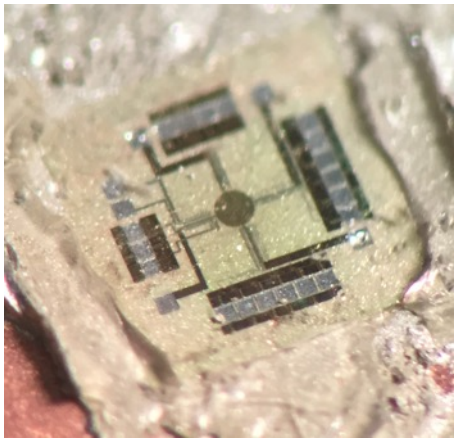
Artificial e-skin sensor arrays *[Harada et at, ACS Nano 2014]*



UCL concept :

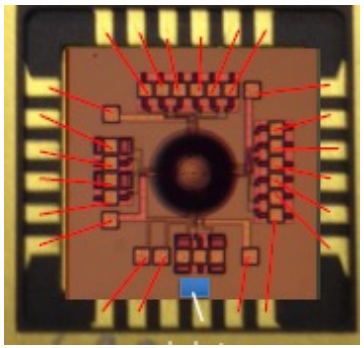
- **SOI lateral thermodiode**
  (Accurate, Low power)
- **Thinned down to a few µm by XeF_2**
  (Fast, CMOS compatible, Highest Si:SiO_2 selectivity, Moderate cost)





3.1 SOI thermodiode characterization

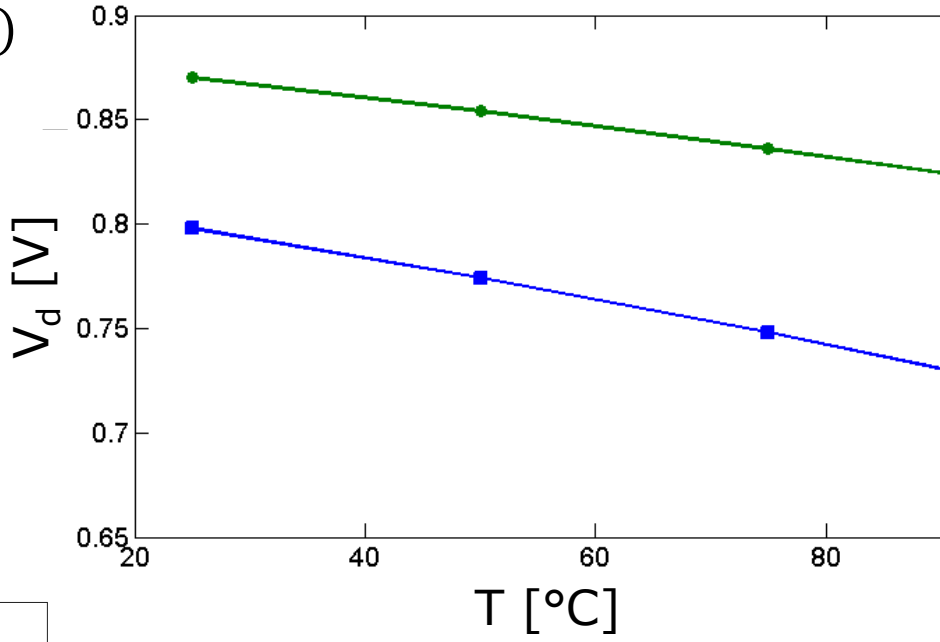
- Constant current mode, embedded microheater



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

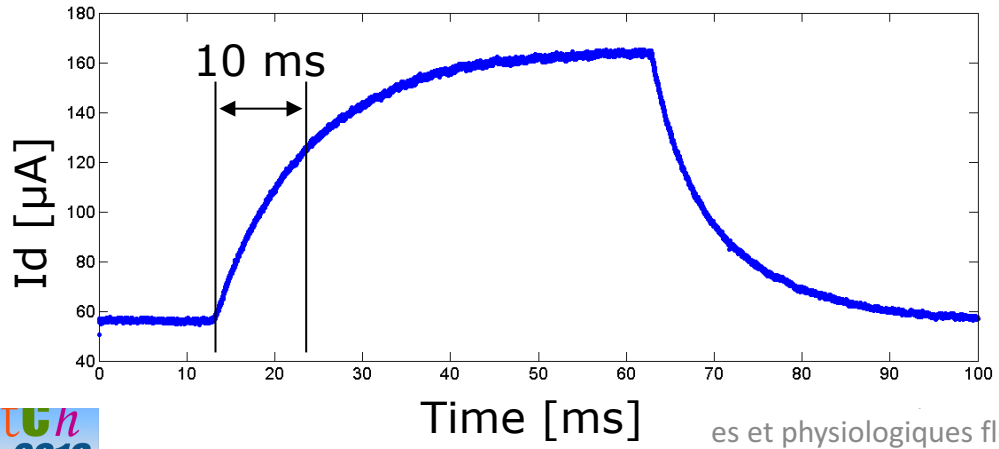
$$d = \frac{V_0 - V_d}{T - T_0}$$

$$\approx 1\ mV/K$$



- Constant voltage,

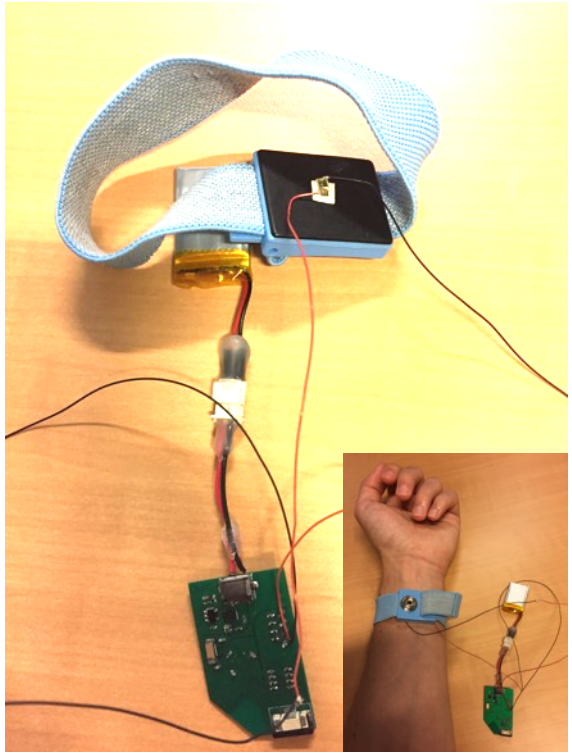
Pulsed mode

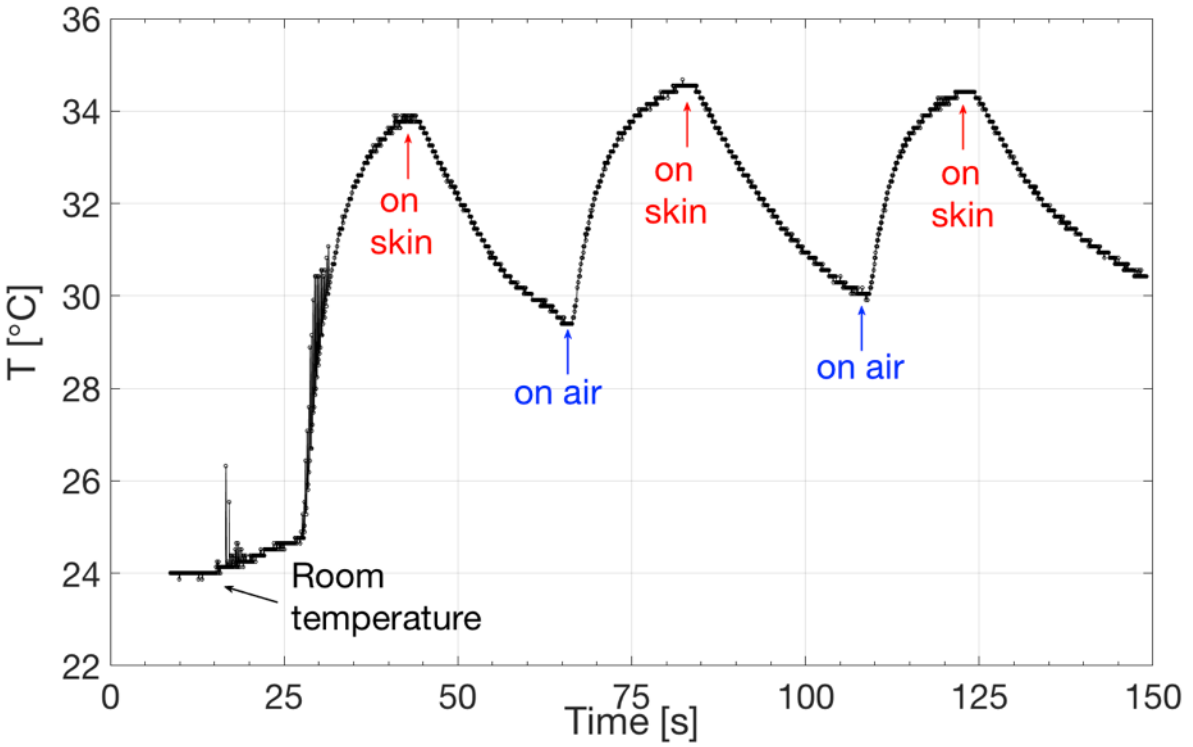


Low thermal mass,
Intrinsically fast

3.2 SOI thermodiode demonstration

With CEA-LETI platform





Data each 50 ms
Diode of 20 x 20 µm^2
on 2 x 2 x 0.4 mm^3 chip

Conclusions

Liu Y et al, "Flexible, Stretchable Sensors for Wearable Health Monitoring: Sensing Mechanisms, Materials, Fabrication Strategies and Features", Sensors 2018, 18, 645

Table 1. Detectable indicators in health monitoring.

Indicator	Position	Measured Parameter	Possible Application
Motion	Hand	Strain, Pressure	Rehabilitation, gesture identification
	Limb	Strain	Rehabilitation, sport training
	Foot	Pressure	Gait detection, sport training
	Throat	Strain	Phonation and deglutition detection
	Face	Strain	Expression identification
Skintemperature	The whole	Temperature	Wound healing, physiological status, Clinical diagnosis
Heart rate/ECG/pulse	Chest, wrist, neck, finger tip	Strain	Detection of Heart failure and cardiovascular disease
Respiration	Chest Nostrils	Strain Pressure, Humidity	Detection of cardiac arrest, apnea, emotional control
Metabolism	Sweating area, oral cavity, eyes	Constituent of biofluids	Evaluating the body status by the appearance & concentration of lactic acid, alcohol, electrolytes, pH