



## The quest for comfortable electronic implants

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## Tenants of this talk

- Main objective : improve comfort
- How small can we make them
- How to select materials
- Above all : the biocompatibility issue

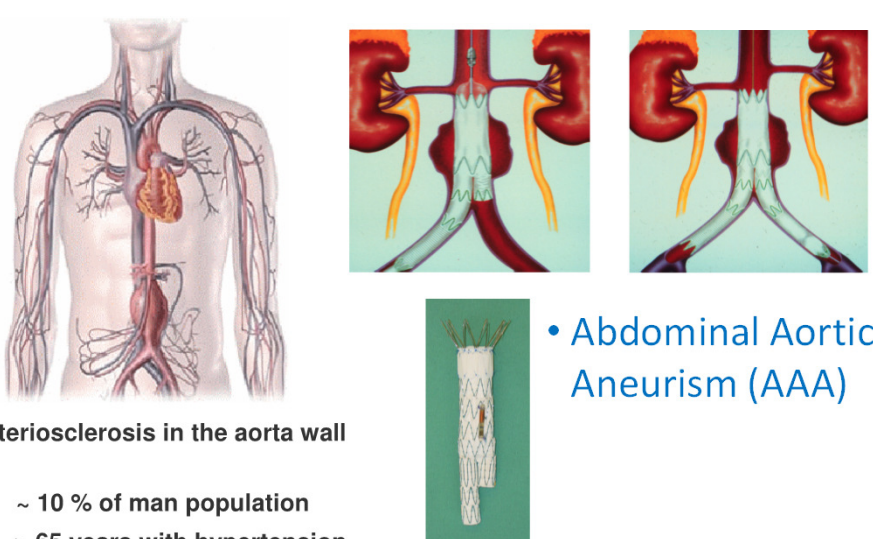
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## A challenging *permanent* implant application



Atherosclerosis in the aorta wall

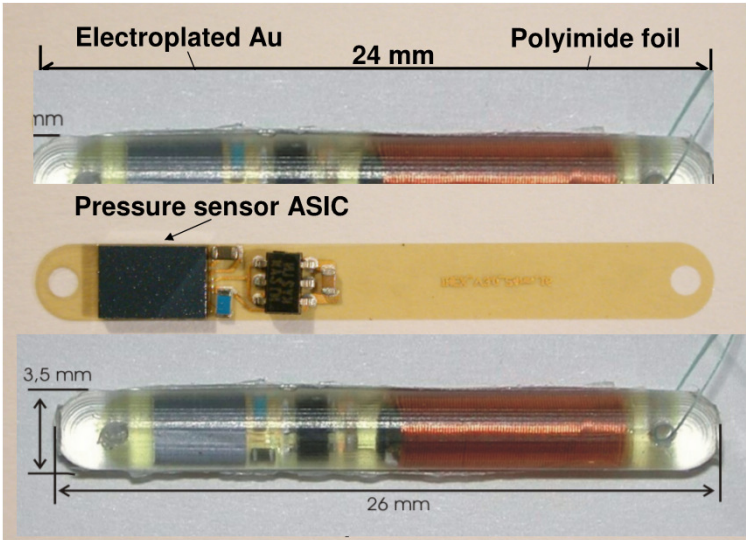
- ~ 10 % of man population > 65 years with hypertension

- Abdominal Aortic Aneurism (AAA)



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## Packaged pressure monitor




Electroplated Au 24 mm Polyimide foil

nm

Pressure sensor ASIC

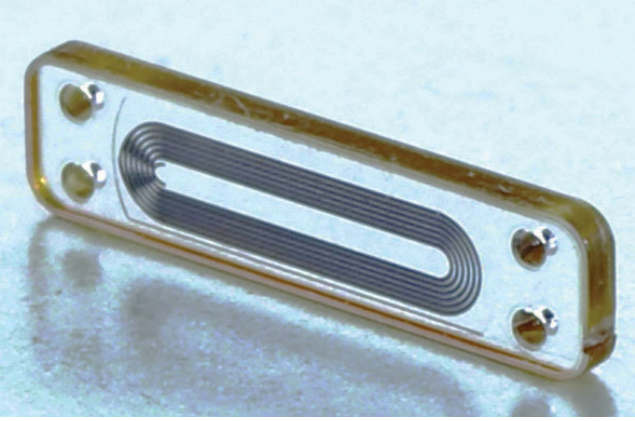
3,5 mm

26 mm

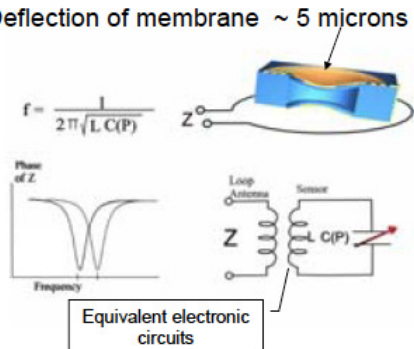


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## Keep it simple ! (CardioMEMS)




Deflection of membrane ~ 5 microns

$$f = \frac{1}{2\pi\sqrt{L C(P)}}$$


Equivalent electronic circuits

- Mark Allen



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## Foreign materials in the bloodstream

- Nature designed blood to encapsulate foreign particles
- Foreign particles will result in :
  - Trombosis and restenosis
  - Clogging of vessels
- What can be done ?
  - Medication & controlled drug release (heparin)
  - Coatings to improve hemocompatibility

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## Packaging : the biggest challenge

- Glass capsules / laser sealing
- PDMS or silicone rubber : mind the fluid ingress
- Parylene-C : the holy grail ?
- Importance of surface treatment
- Avoid the need of open sensors
- How flexible can we make them ?



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## “Bio-glass” still going strong

- Valtronic



Gerald Loeb's BION

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## Parylene-C is a good candidate

- Conformal coating (!)
- Strong hermeticity
- Wettability to be improved !
  - Better biofouling
  - Oxygen plasma treatment (low power) -> carbonyl groups
  - Followed by an SF6 plasma to create fluorinated groups

X.Bi et al., Plasma-treated Switchable wettability on Parylene-C surface, IEEE-NEMS 2012, Kyoto, Japan, March 2012

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## Experimental results

**Strong Hydrophobicity** →

PDMS samples

Parylene-C deposition

Plasma treatment

Static contact angle measurement

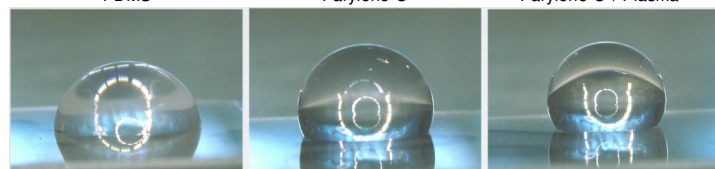
**Enhanced Hemocompatibility:**

- Tunes adsorption of blood proteins
- Prevents platelets adhesion and thrombus formation

Plasma treatment

Gas	Power [W]	Flow [sccm]	Time Min
O <sub>2</sub>	100	100	10
SF <sub>6</sub>	100	100	1


PDMS                      Parylene-C                      Parylene-C + Plasma



Combined effect of :

Surface roughening
Fluorinated groups


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## Our quest : the comfortable implant

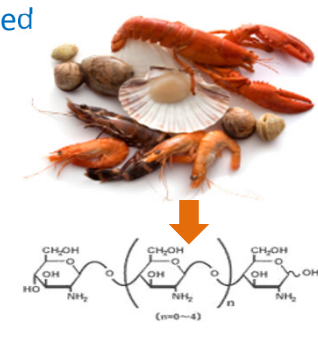
- Develop ECoG arrays largely based on resorbable materials
  - Strong enough during insertion
  - Lower irritation during use
- Target use in lesion cavities
  - Design for high mechanical flexibility
  - Recording and stimulation for therapy

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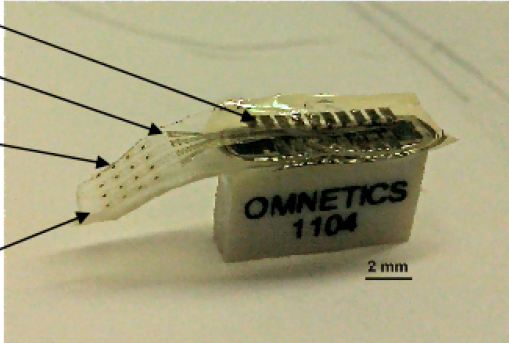
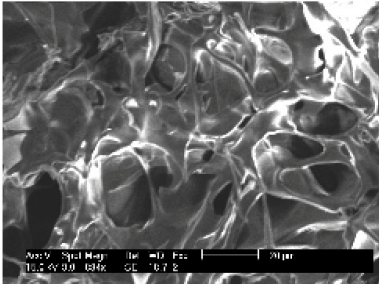
## Material selection

- Non-resorbable backbone:
  - Pt electrodes and connectors, PI or parylene C insulation
  - Classical materials, but very thin and finely patterned
- Resorbable material: Chitosan
  - It can be dissolved in an acidic environment, facilitating spin-on processing
  - Good adhesion
  - Has haemostatic and antiseptic properties
  - Can be formed into a porous, fast resorbable form
  - Degradation rate can be varied by altering the degree of deacetylation



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## Fabrication



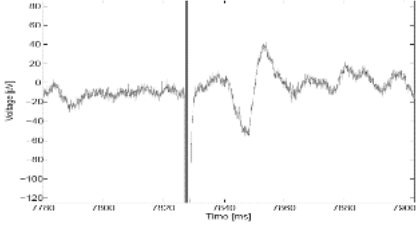

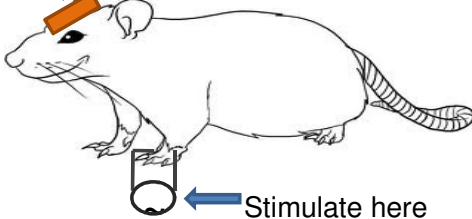
Bondpaths for connector  
Insulated microwires (width > 10  $\mu\text{m}$ )  
Electrodes ( $\varnothing$  92  $\mu\text{m}$ )  
Sheet of porous chitosan

OMNETICS 1104  
2 mm

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## In vivo testing

- Implantation on meninges -> or under meninges in rats
- Measure physiological response

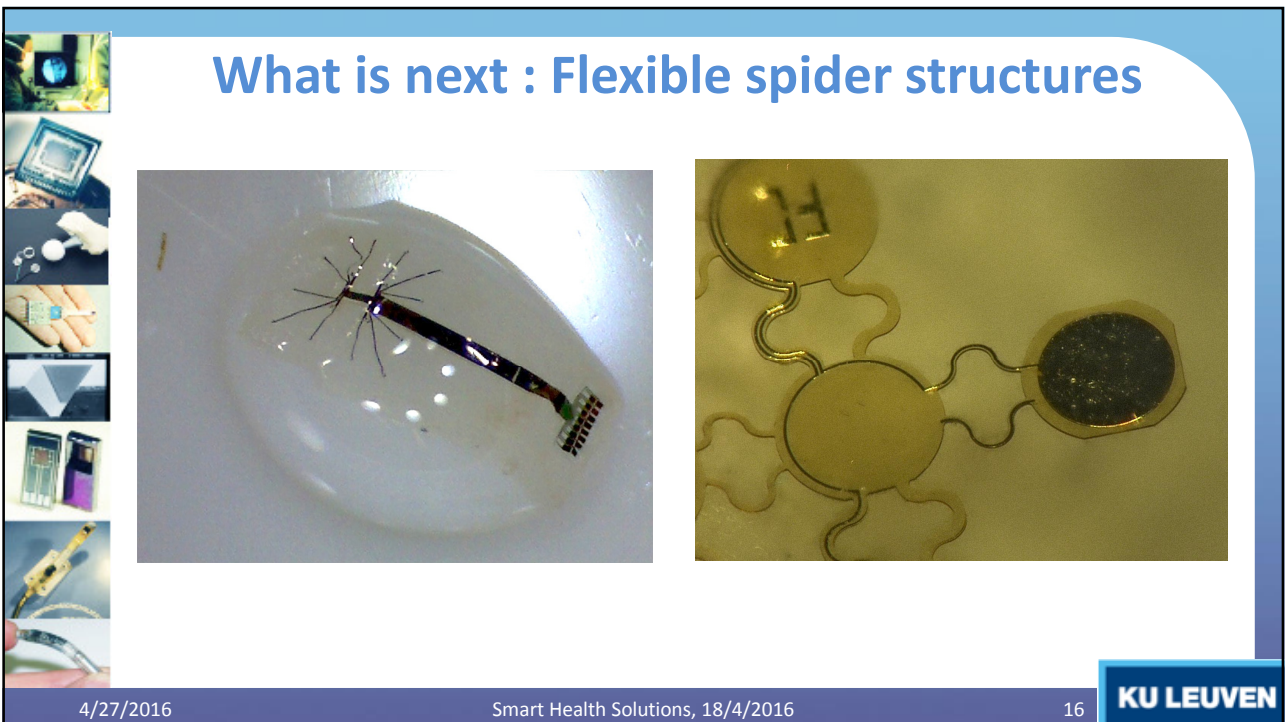
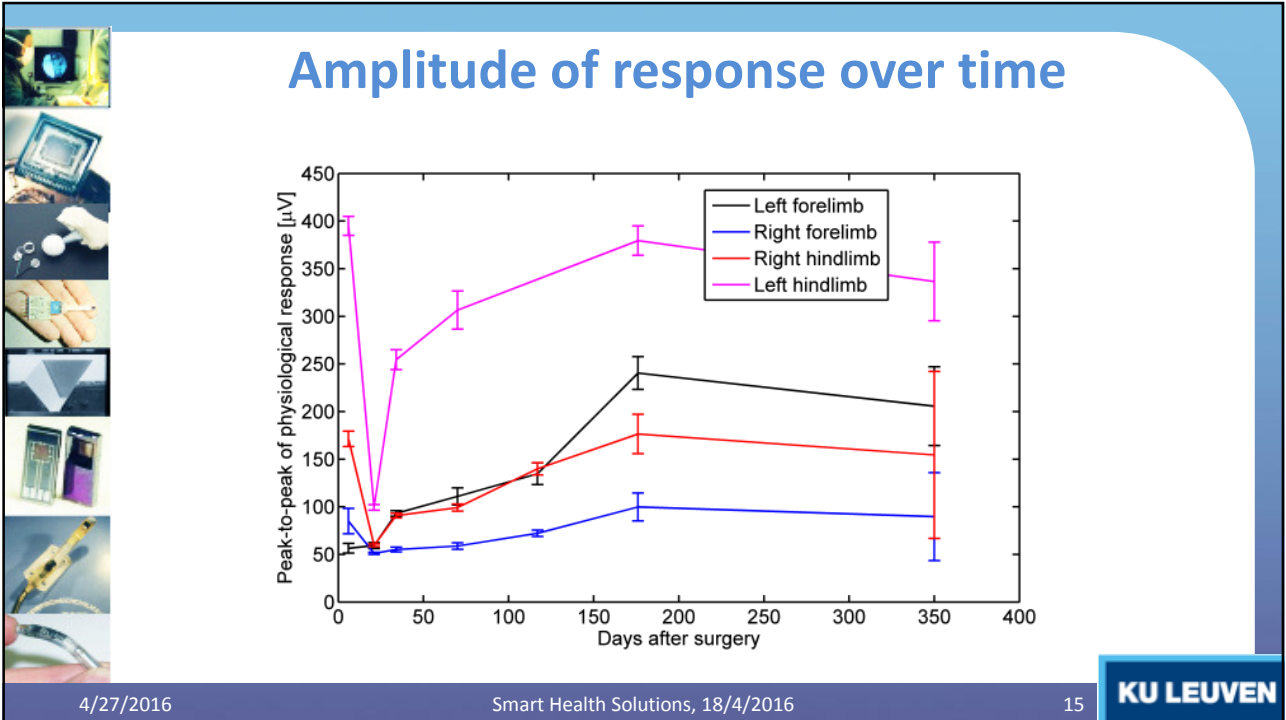


Measure here

Stimulate here

Typical measurement of stimulus and physiological response

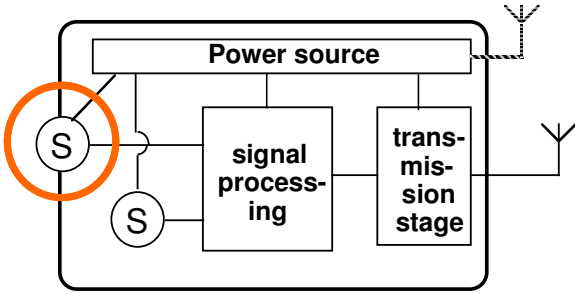
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## Sensing in permanent implantable devices

- Monitoring function :
  - built-in sensor
  - 'open' sensor
- Power source
  - battery
  - wireless induction
- Wireless communication
- Intelligent processing
- Biocompatible cage



The diagram illustrates the internal components of an implantable device. It features a 'Power source' at the top, connected to a 'signal processing' block and a 'transmission stage' block. Two sensors, represented by circles with the letter 'S', are connected to the signal processing block. The entire system is enclosed in a biocompatible cage, with external antennas for wireless communication.

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## Probably the best known example

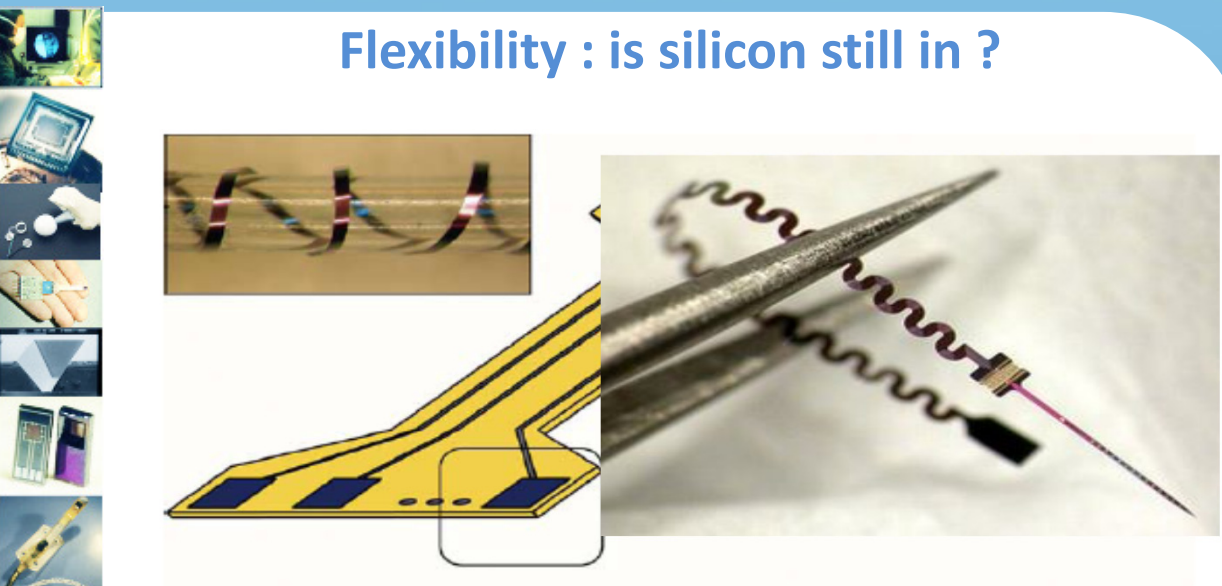


**We need more flexibility**

The image shows a hand holding a Medtronic EnRhythm implantable device, which is a small, circular, metallic device. The device is being held next to a person's chest, where it is implanted. A red banner with the text 'We need more flexibility' is overlaid on the image.

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## Flexibility : is silicon still in ?



The University of Michigan, Ann Arbor


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## More on flexibility: KULeuven electrode



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## More on flexibility of silicon...

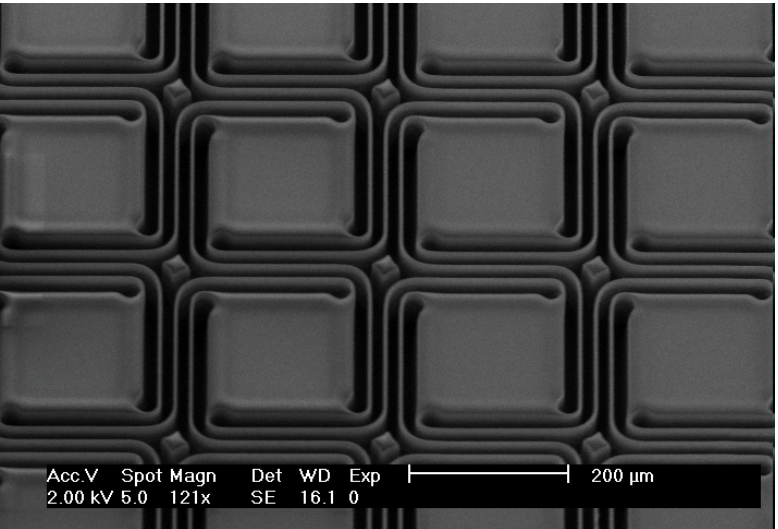


Dinyari, et al., *IEDM* 2009

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## Our continuation on this idea

- DRIE process
- + CMOS (!)




Acc.V Spot Magn Det WD Exp |-----| 200 µm  
2.00 kV 5.0 121x SE 16.1 0

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## New ways to make stretchable connections

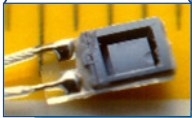

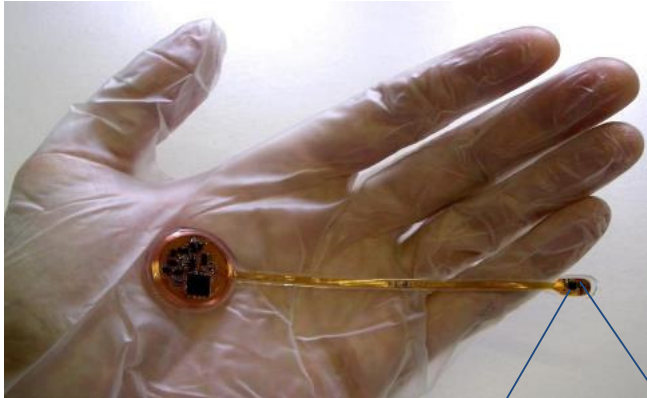
- Gold sputtered with Ti pre-sputtering and plasma pre-treatment



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## Permanent pressure monitoring

- capacitive sensing
- introducing flex
- separate circuit
- inductive powering
- linking with stimulator
- towards the ultimate urologic pacemaker

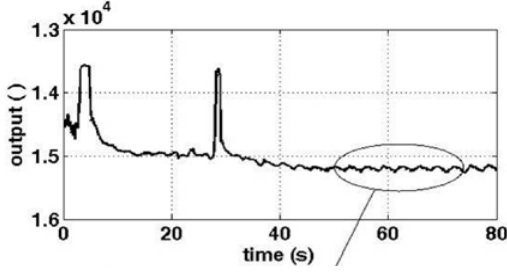


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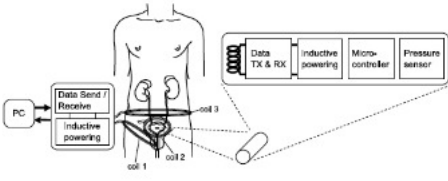
## Interesting phenomena observed



A photograph showing a surgical procedure where a small, yellow, circular device is being implanted into a patient's body. The device is held by forceps and is being placed into a surgical site.



A line graph showing the output of a device over time. The y-axis is labeled 'output ( )' and ranges from  $1.3 \times 10^4$  to  $1.6 \times 10^4$ . The x-axis is labeled 'time (s)' and ranges from 0 to 80. The graph shows a signal that starts at approximately  $1.45 \times 10^4$ , has a sharp peak at about 5 seconds, and then stabilizes around  $1.55 \times 10^4$ . A callout box highlights the signal between 50 and 70 seconds, showing small oscillations around the mean value.




A schematic diagram of the device's internal components. It shows a central unit with four main sections: 'Data TX & RX', 'Inductive powering', 'Micro-controller', and 'Pressure sensor'. The device is connected to a PC via 'Data Send / Receive' and 'Inductive powering' lines. The diagram also shows the device's placement in a human torso, with labels for 'coil 1', 'coil 2', and 'coil 3'.

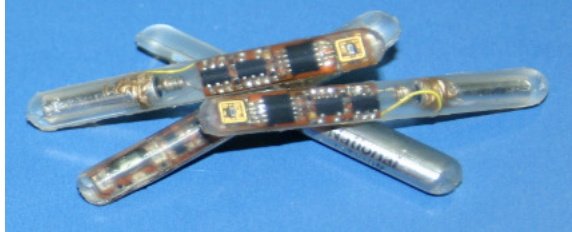
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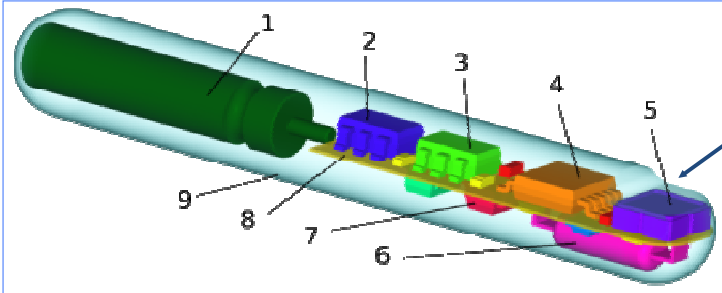
## Bladder pressure diagnosis



A close-up photograph of the flexible, curved device, showing its thin, metallic-looking structure.



Three devices of different sizes and colors (blue, green, orange) are shown against a blue background. They are all flexible and curved.

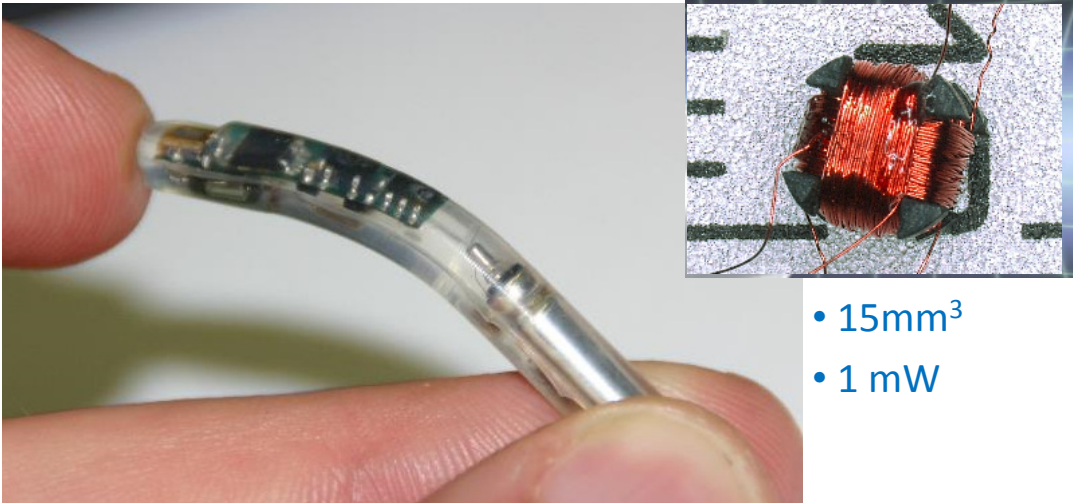


A 3D cutaway diagram of the device, showing its internal components. The components are labeled 1 through 9. A callout box points to component 5, which is labeled 'Capacitive pressure sensor'.

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### Extreme miniaturization of the 3D inductive link

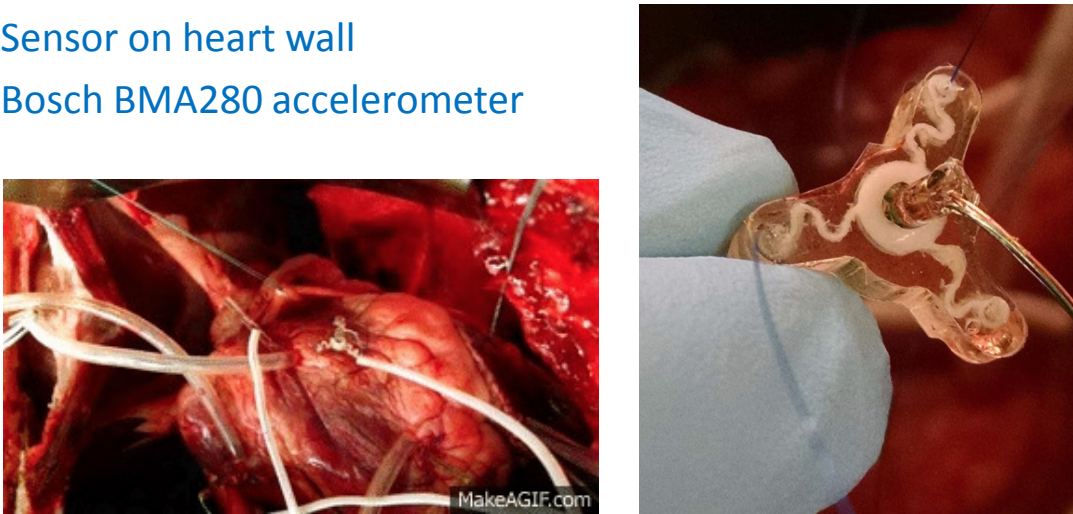


- 15mm<sup>3</sup>
- 1 mW

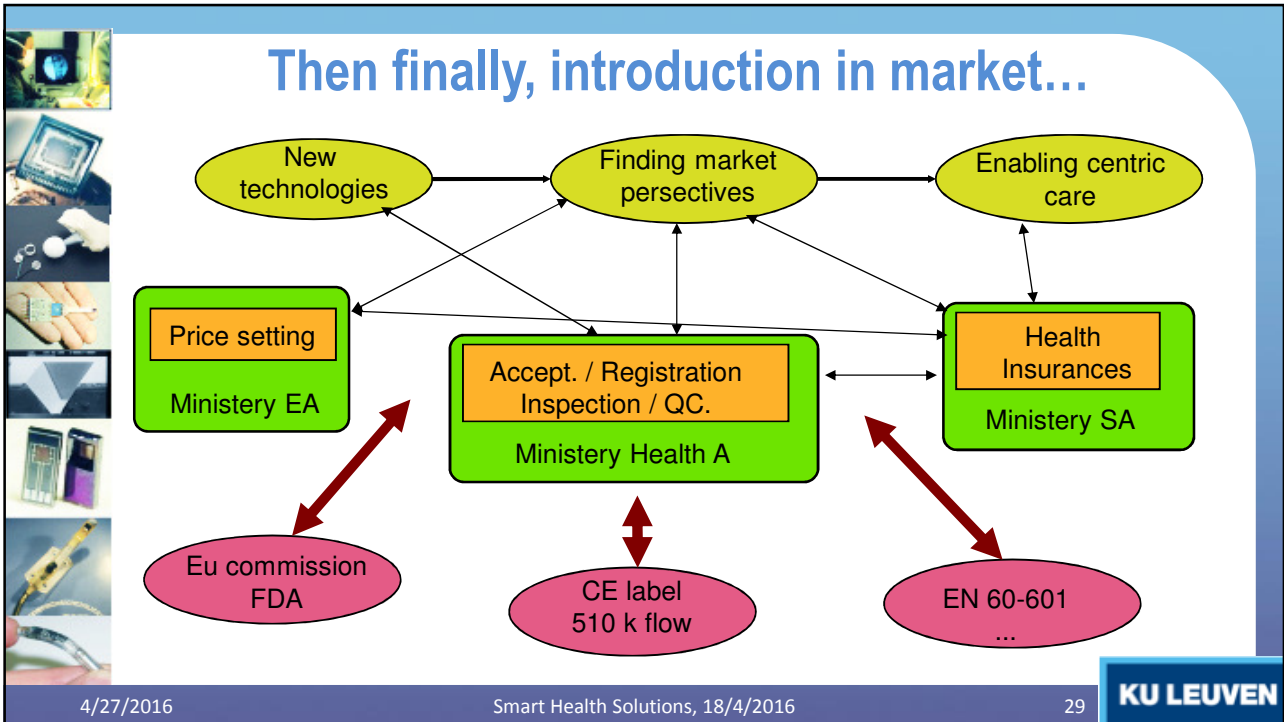
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### Contractility of the heart

- Sensor on heart wall
- Bosch BMA280 accelerometer



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- ### Lessons learned
- Flexibility is key
  - Be modest : avoid complexity
  - Avoid 'open' sensors
  - There is a tremendous opportunity for MEMS
  - Learn from nature
  - Be modest in predictions : it takes a long road to implementation in society !
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**My dream**

Anne Marie Cernoch's artist impression : "Electro-Gelly"



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**Thank you !**



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