MEMS WAFER LEVEL PACKAGING FOR IMPLANTABLE DEVICES

MEMS-Sensors workshop |Jean-Charles Souriau | July 3rd 2018

AGENDA / OUTLINE / OVERVIEW

AGENDA / OUTLINE / OVERVIEW

CONTEXT

“Gradually the electronic devices that were previously external enter in the human body in order to improve therapy or physiological parameter measurements”

Cochlear implants

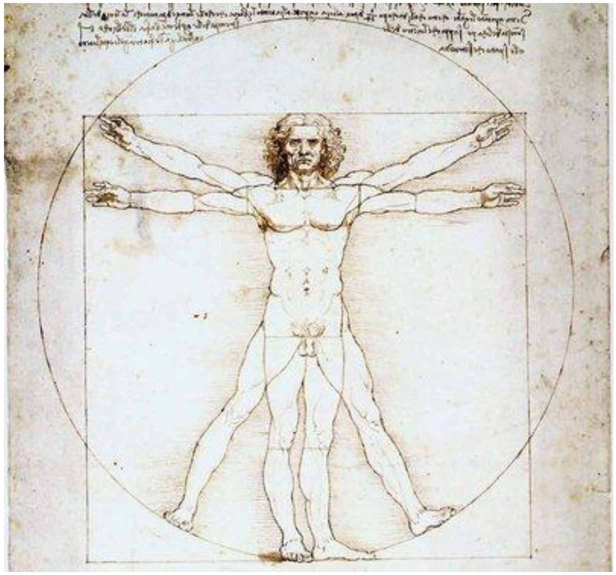
Medline plus

Brain stimulation

Brain activity sensing

Retina implants

© Inserm, Serge Picaud



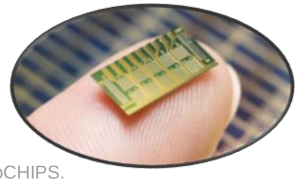
Heart Stimulation

Sorin CRM

Vagus nerve Stimulation

Europe Orient new

Contraceptif implant



MicroCHIPS.

Localized drug delivery

Bladder Stimulation

RFID MICROCHIP IMPLANT (HUMAN)

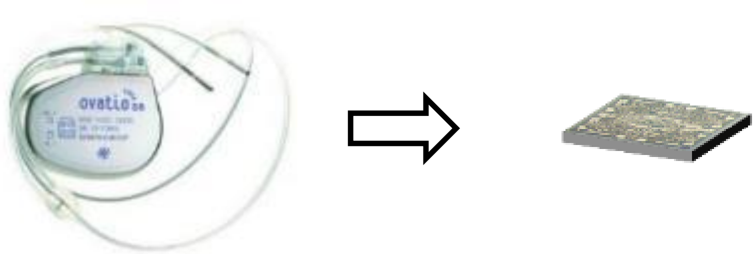
A surgeon implants British scientist Dr Mark Gasson in his left hand with an RFID microchip (March 16, 2009)

Source Wikipedia

CHALLENGES OF MEDICAL IMPLANT

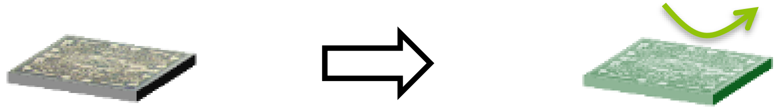
- Miniaturization

  → Break-through packaging solution: shrink the packaging at the die level



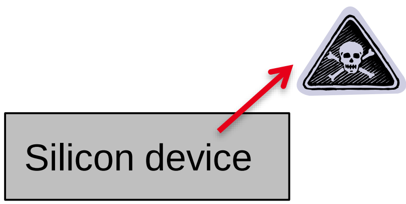
- Biocompatible encapsulation

  → Need for a diffusion barrier



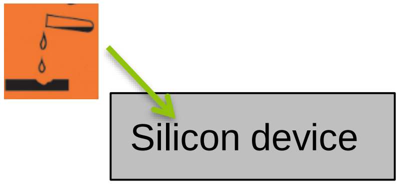
CHALLENGES OF MEDICAL IMPLANT

Preserve the human body from toxic substances of electronic device

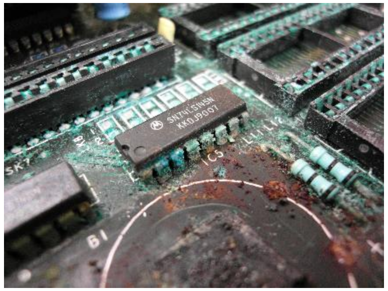


Semiconductor devices are not friendly

Preserve the device from corrosive substances of the human body

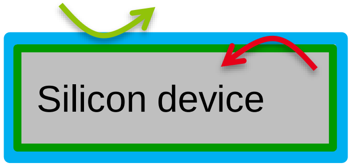


Blood plasma has a high concentration of sodium chloride

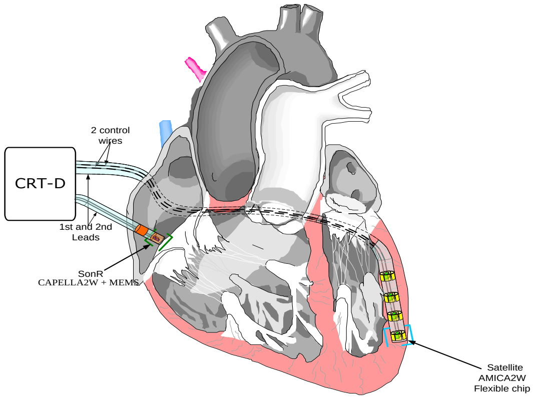


bi-directional diffusion barrier needed

Multi Barrier recommended



TECHNOLOGICAL DEVELOPMENT IN CEA-LETI



- Industrial partner: SORIN GROUP ➡ LivaNova

- Application:

  Cardiac implantable device

- Objective:

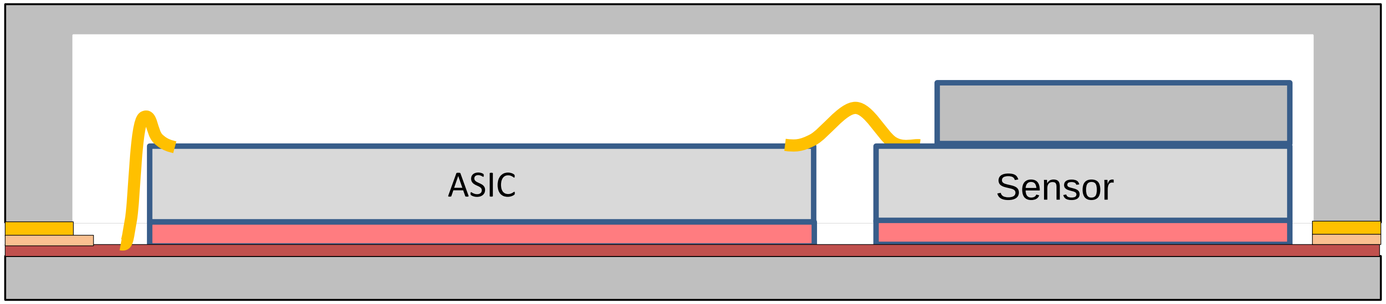
  To integrate a MEMS accelerometer and an ASIC chip in cardiac lead in order to sense the endocardial acceleration signal

- Life target

  > 10 years

HERMETIC PACKAGE

Electronics devices are encapsulated in a hermetic box



Hermetic box choices:

- Metal
- Ceramic
- Silicon

LETI ENVIRONEMENT

Bio medical plateform

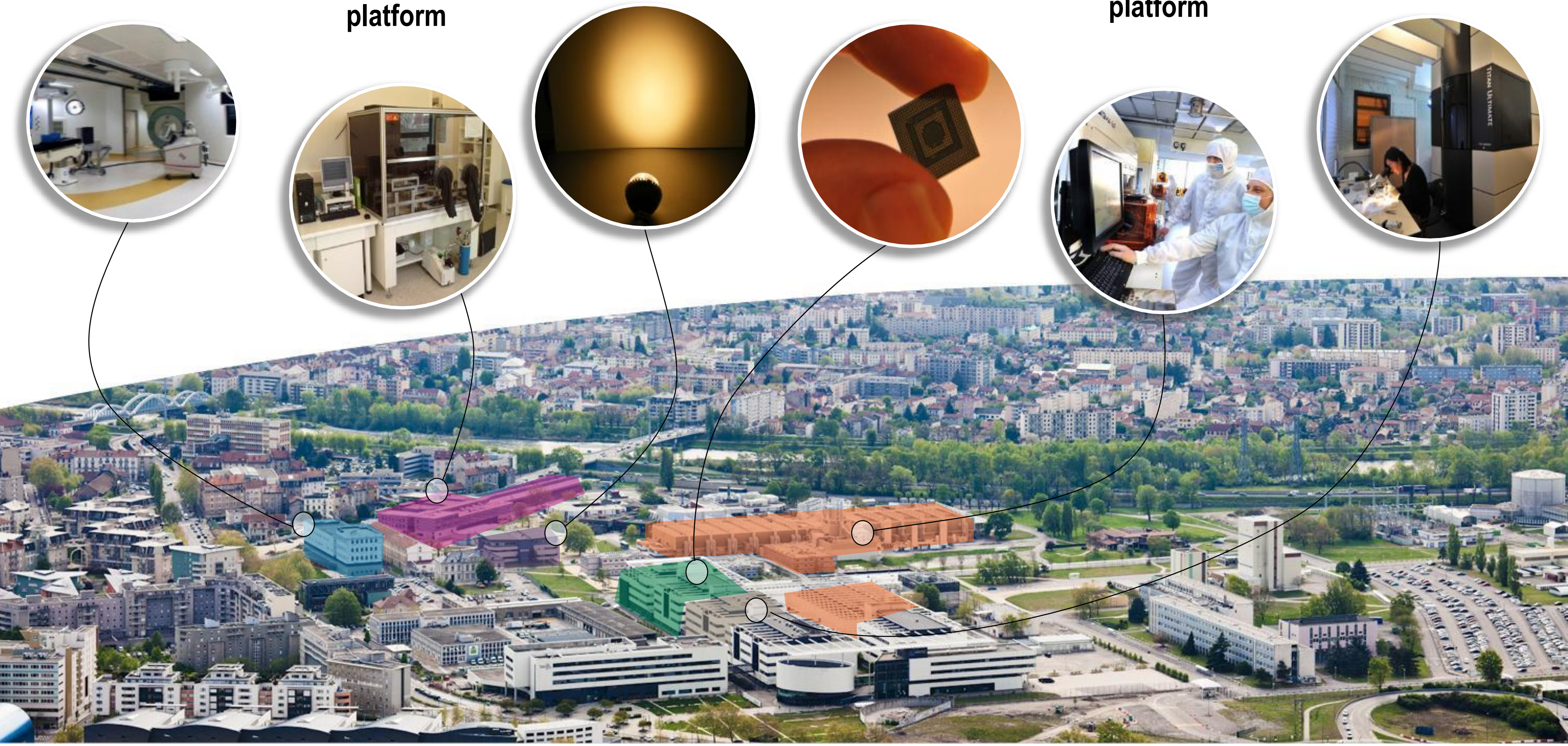
Chemical & material platform

Photonic plateform

Embedded systems

Micro & Nanoelectronic platform

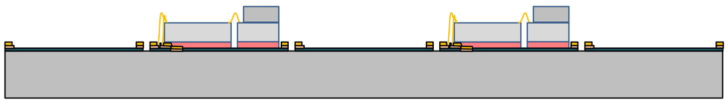
Nanocharacterisation platform

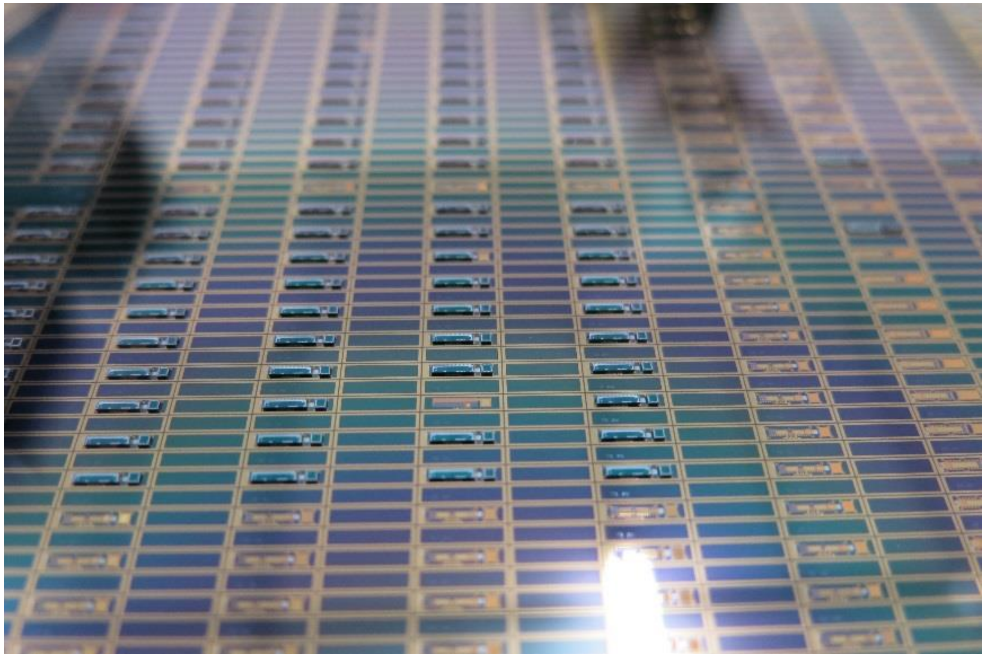


AGENDA / OUTLINE / OVERVIEW

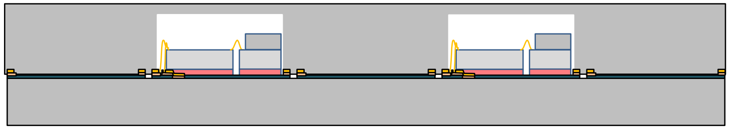
WAFER LEVEL INTEGRATION

Interposer wafer





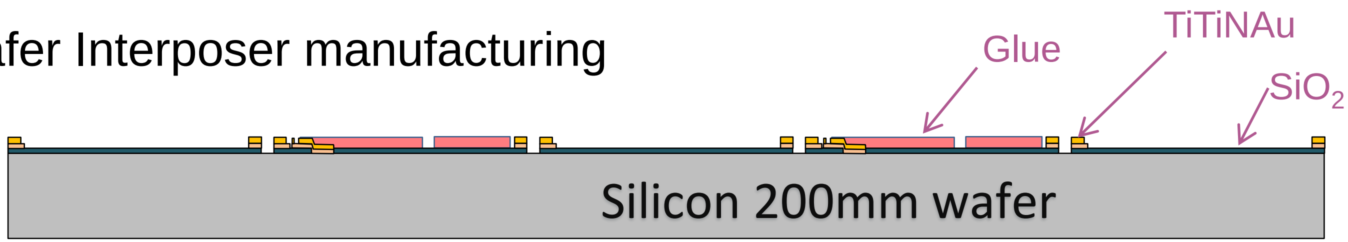
Lid wafer



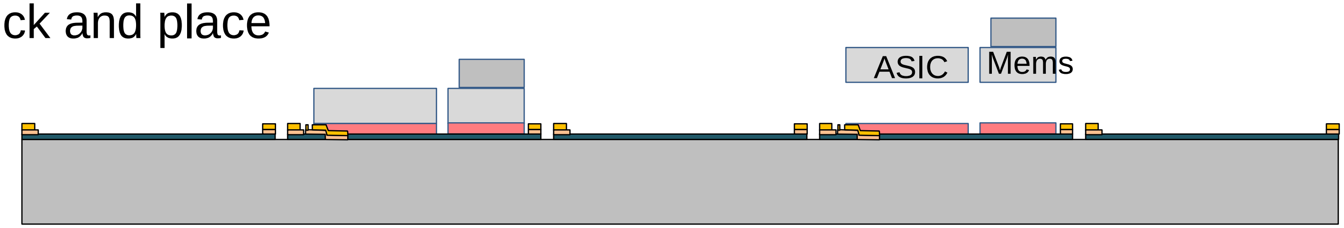
Performed in CEA-LETI clean room

WAFER LEVEL PROCESS FLOW 1/3

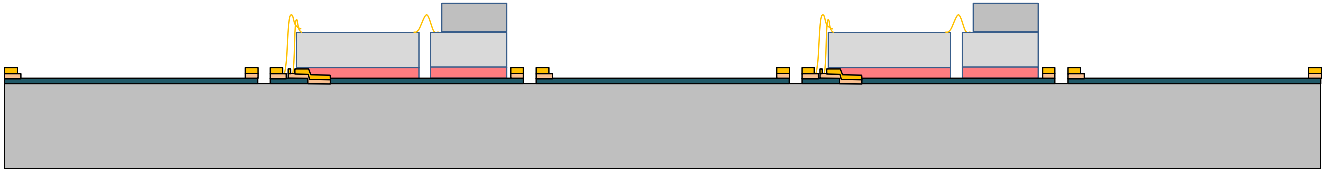
- Wafer Interposer manufacturing



- Pick and place

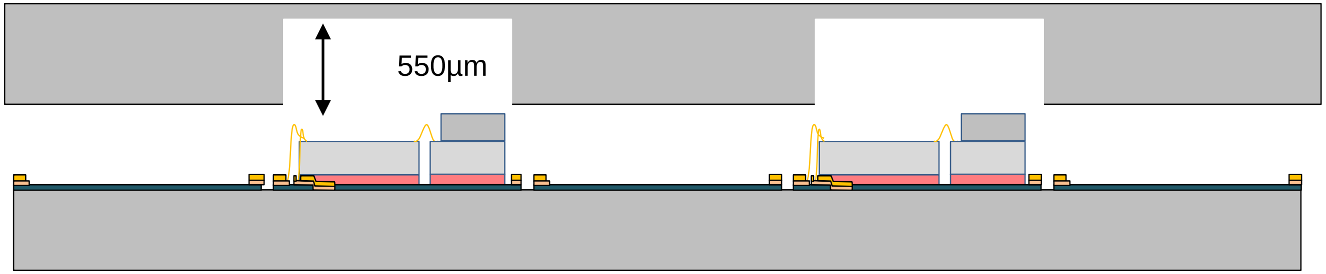


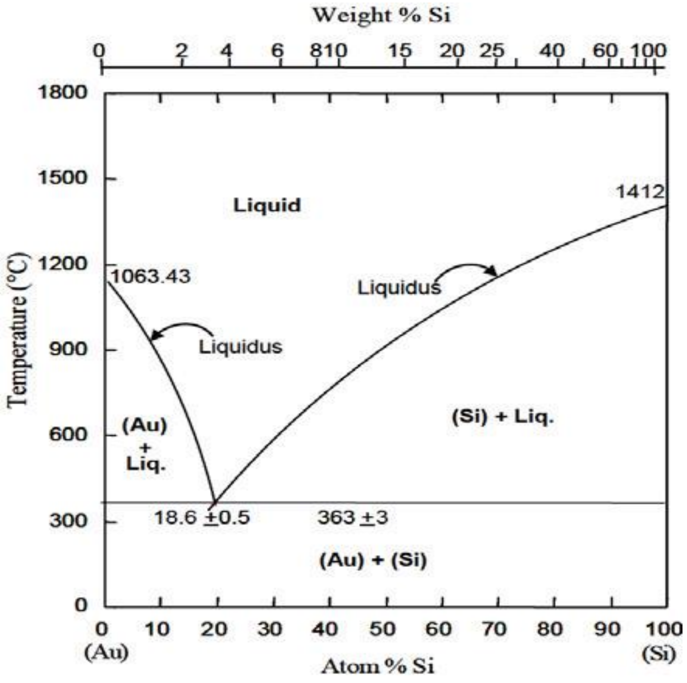
- Wire bonding



- Cavities etching

WAFER LEVEL PROCESS FLOW 2/3





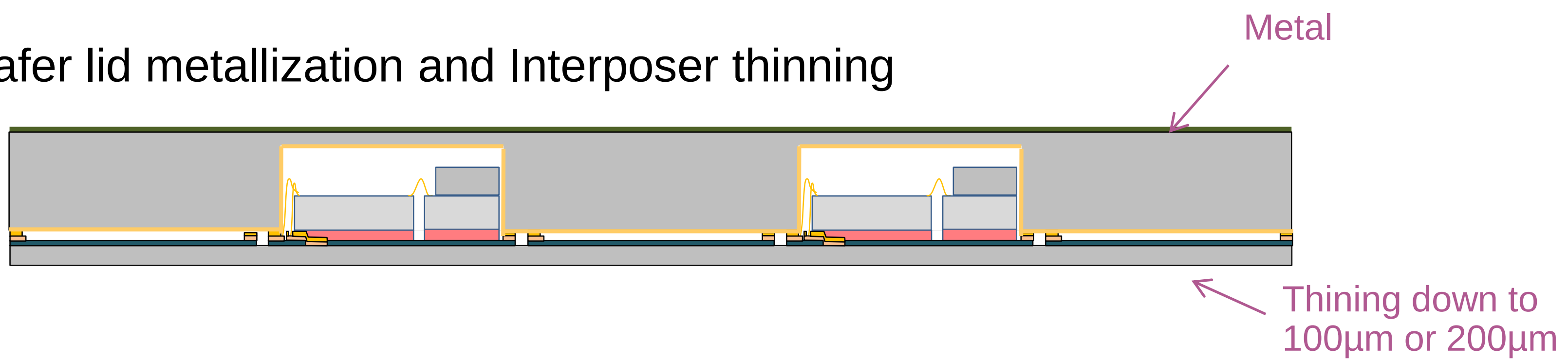
- Lid wafer was bonded to the interposer wafer by eutectic AuSi formation

Bonding conditions:

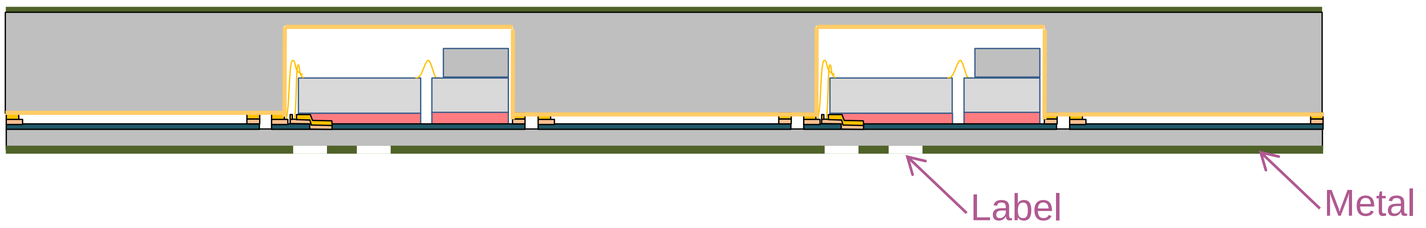
Temperature 400°C,
Pressure = 10000N
Time = 30 minutes.
Pressure in chamber ~ 5 10^{-3} mbar

WAFER LEVEL PROCESS FLOW 3/3

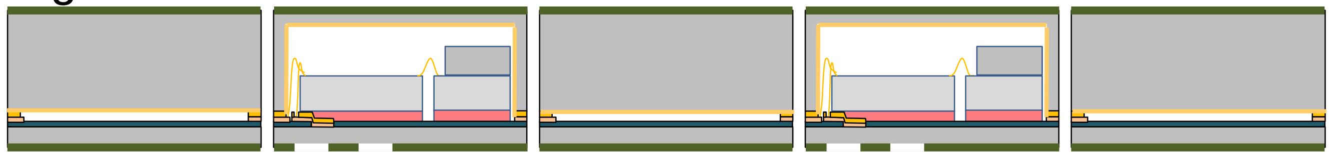
- Wafer lid metallization and Interposer thinning



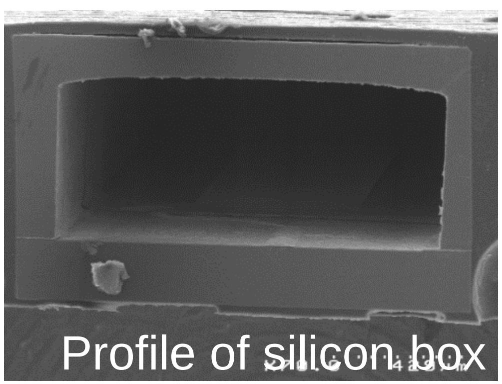
- Metallization and device labeling

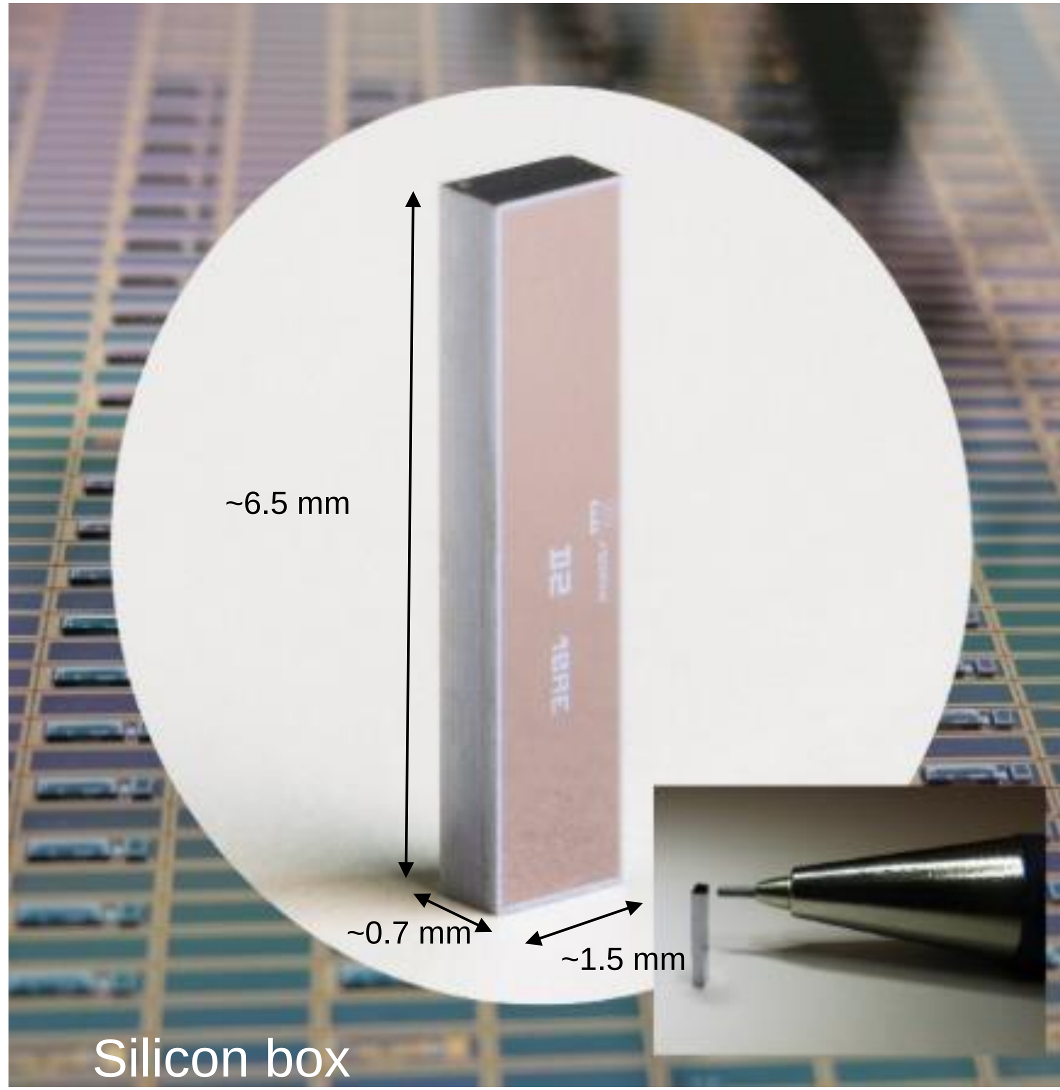


- Dicing



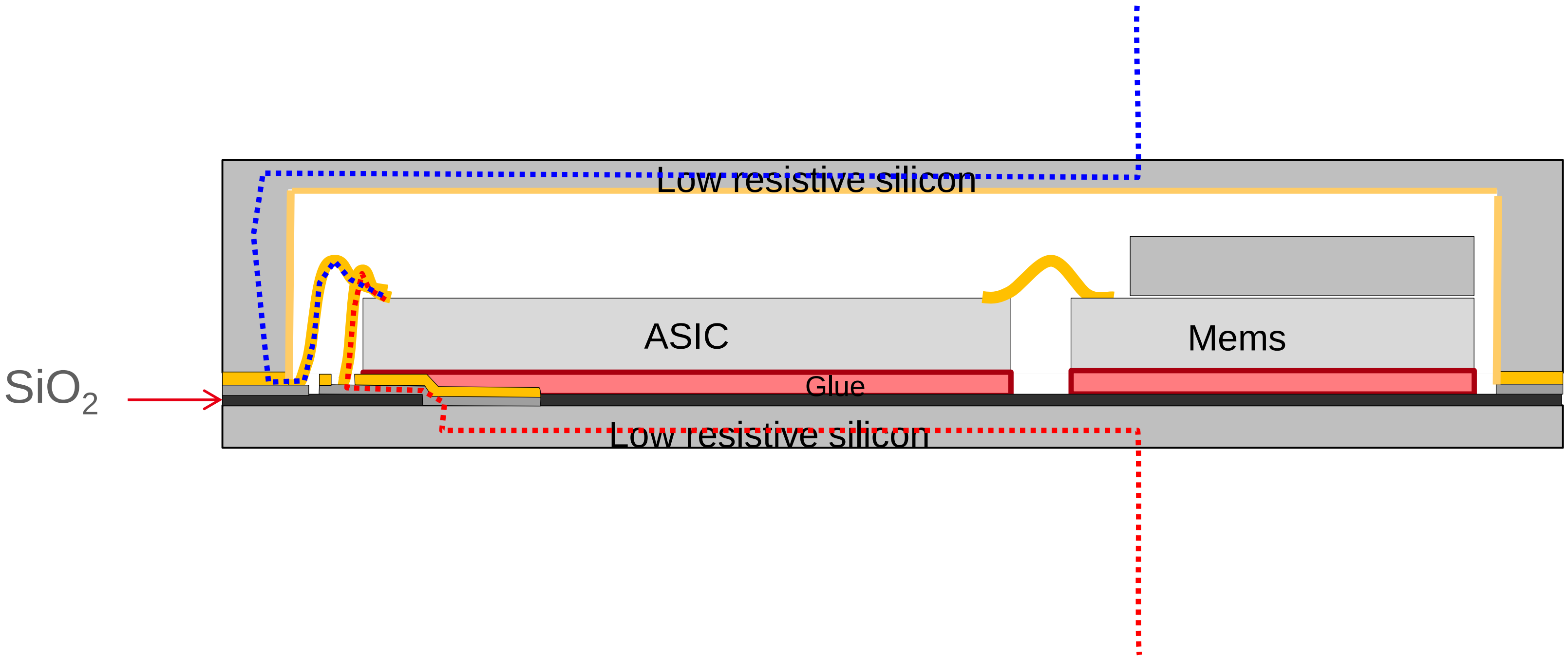
VIEW OF FINAL SILICON PACKAGE





INNOVATIVE APPROACH

The electrical interconnection to the two conductor wires is obtained through the interposer and the lid using the conductivity of doped silicon (0.1 to 5 mOhm.cm)



AGENDA / OUTLINE / OVERVIEW

CHARACTERIZATION

- Hermeticity

  Residual Gas Analysis

- Biostablilty

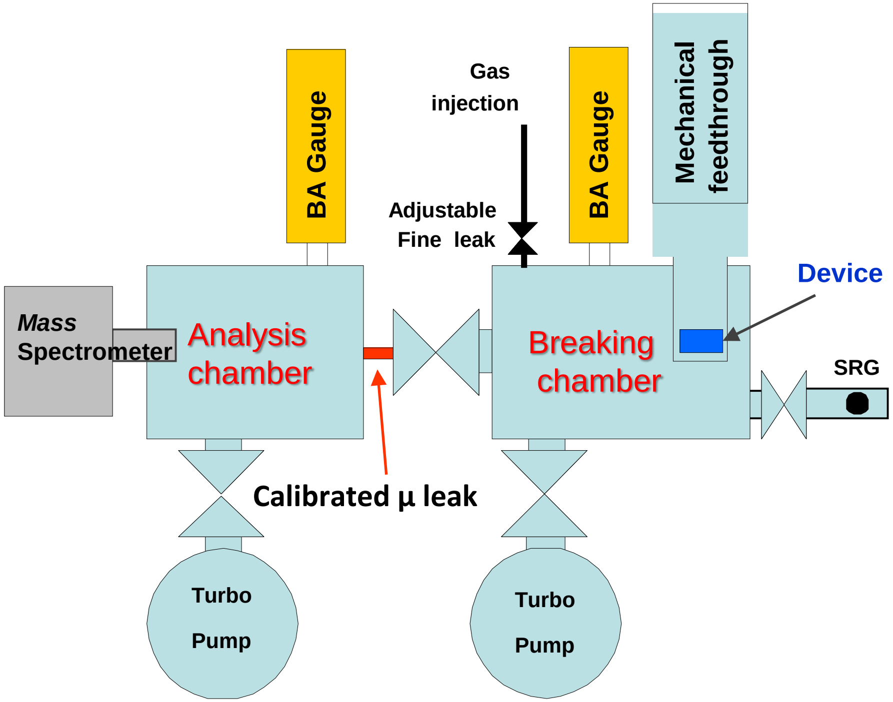
  Aging test in Phosphate-Buffered Saline solution

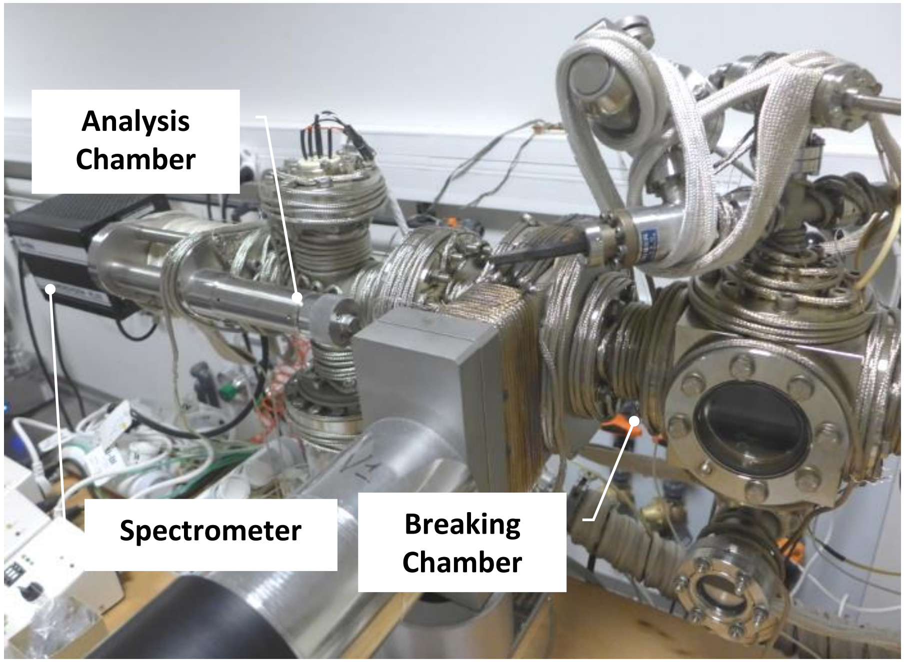
- Biocompatibilty

  Invitro test

RESIDUAL GAZ ANALYSIS

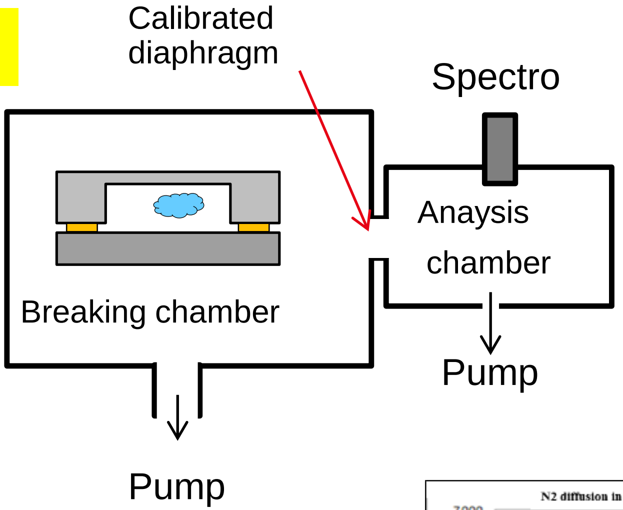
Specific tools has been developped in CEA-LETI to analyse small amount of gases inside low volume at low pressure (1mm^3, 10^{-3} mb -> 4 10^{-14} moles)



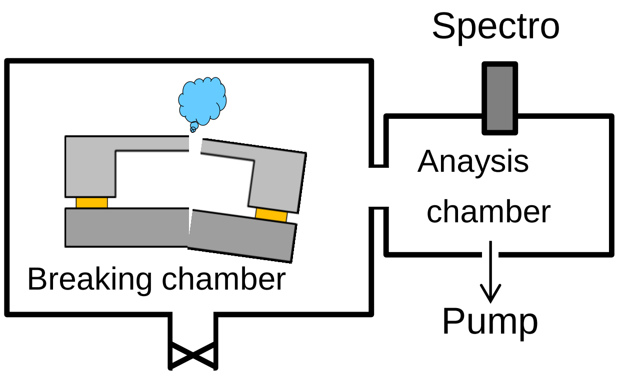


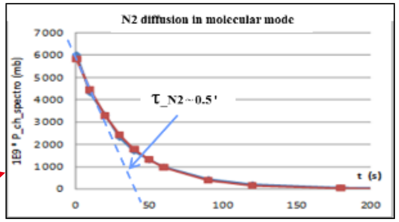
RGA PROCEDURE

1



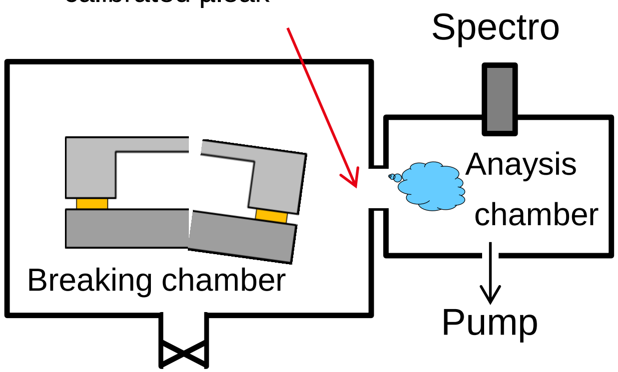
2



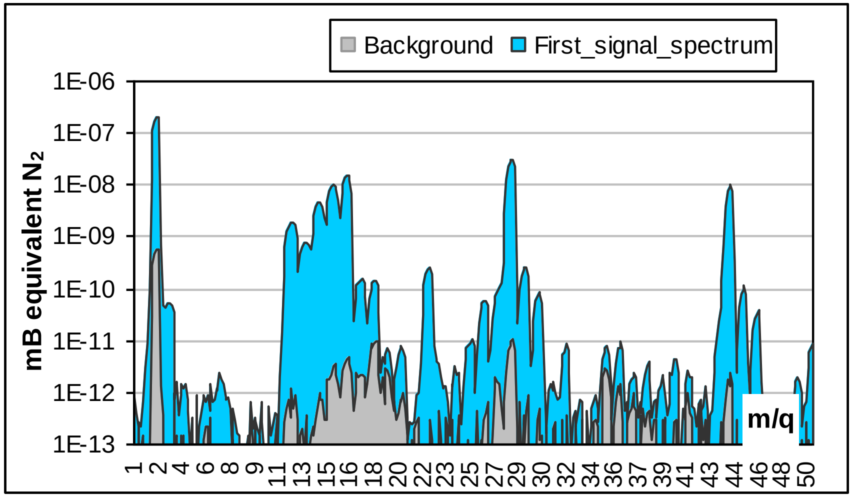


Gases diffuse through a calibrated µleak

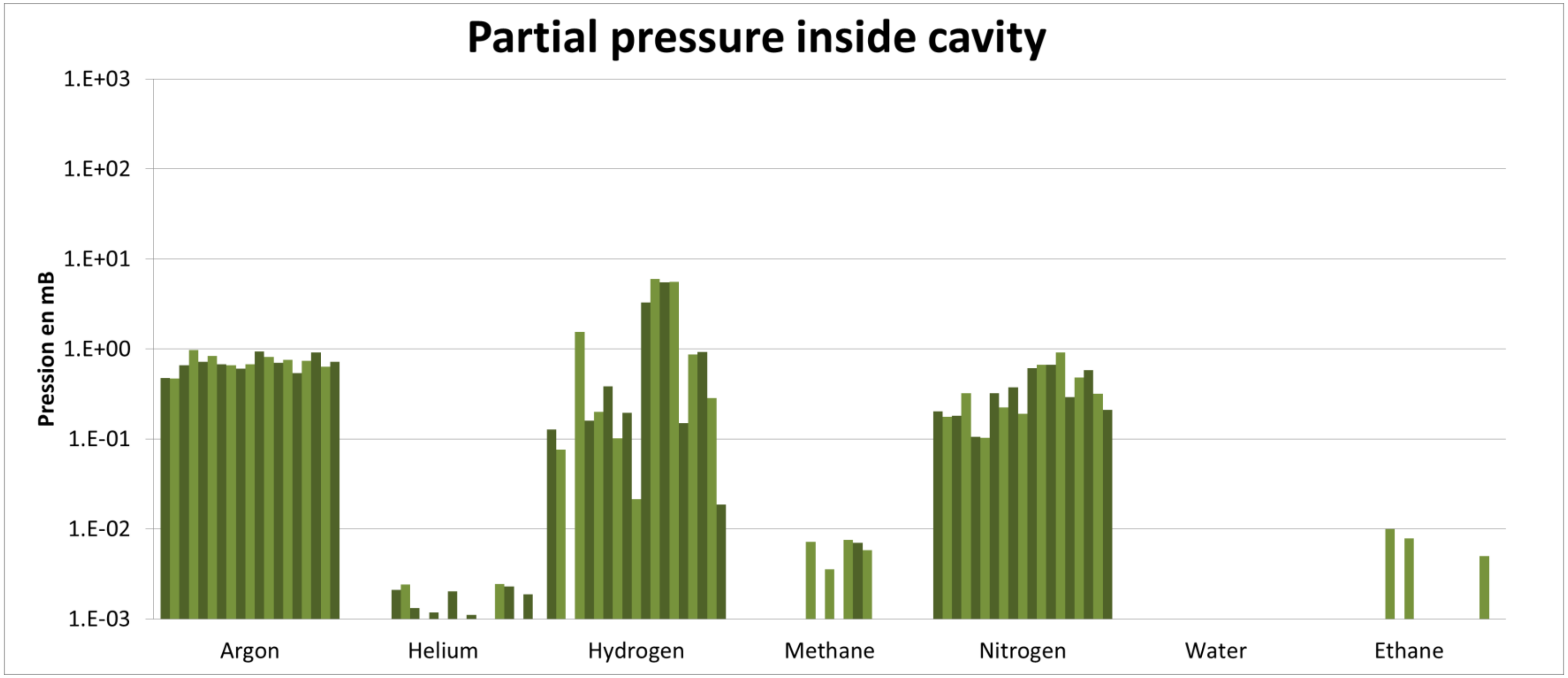
3



Typical spectrogram performed during an RGA experiment



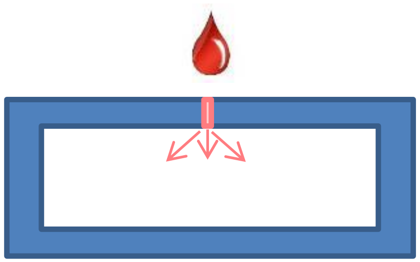
RGA RESULTS ON DEVICES AFTER MANUFACTURING



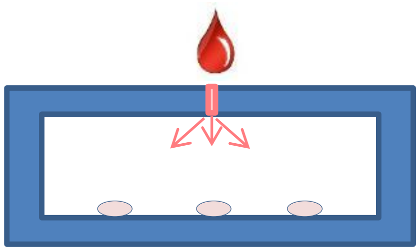
- Total pressure < 10 mbar
- Homogeneous results for Ar but large dispersion for H2
- Origins of Gas detected: entrapped in materials during process deposition, surface preparation or bonding procedure

CAUSE OF FAILURE

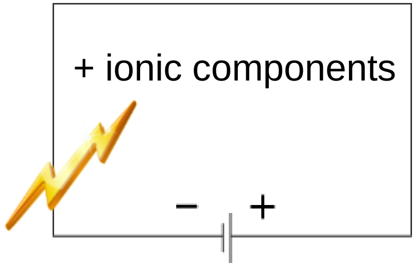
Leak



Drop formation in cavity



Corrosion → Risk of short circuit



Recommandation during the life time

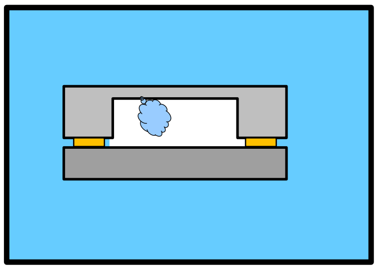
“To be below the dew point in the cavity”

$P_{H20} < 0.062$ atm à T=37°C

$P_{H20} < 0.052$ atm à T=37°C → **$L_{H2O} < 1.2\ 10^{-12}$ atm.cc/s**

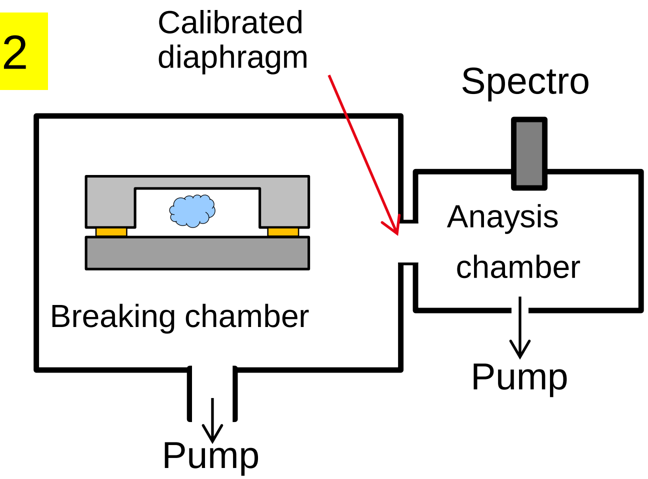
LEAK RATE EVALUATED USING RGA

1

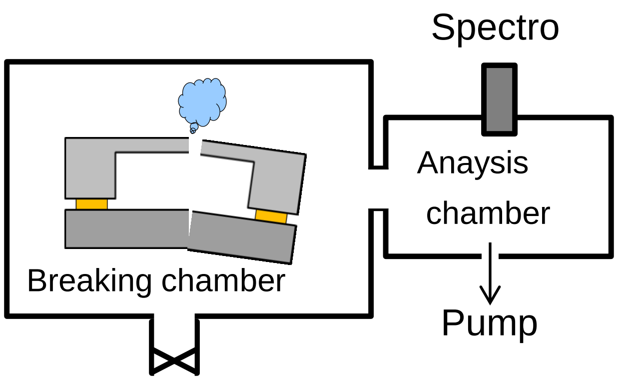


Pressurization with C2H6 (P,time).

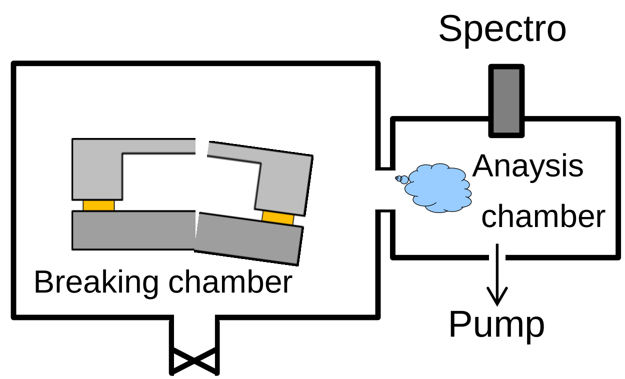
2



3

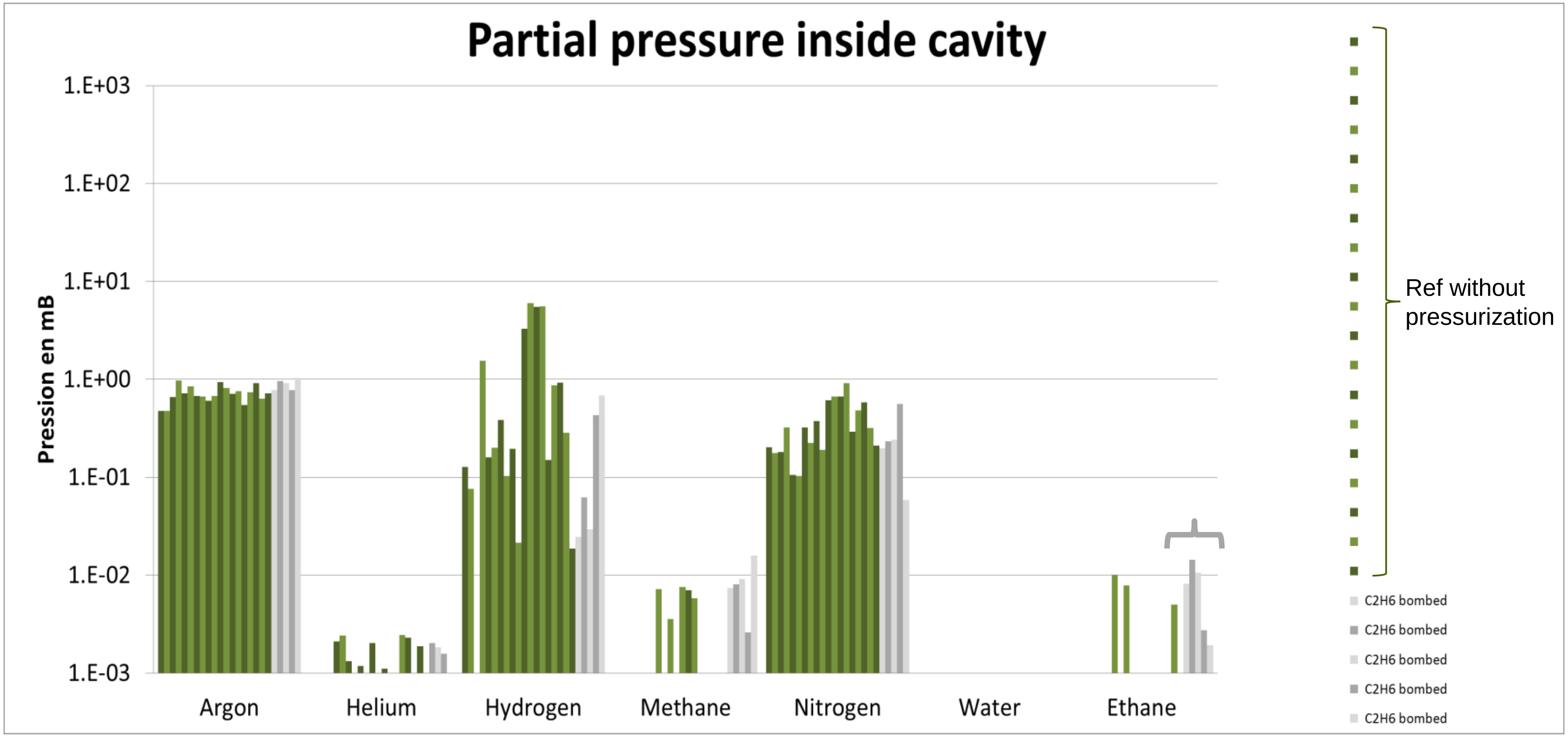


4



$$\Delta Pt = \Delta P_0 e^{\frac{-Lt}{VP0}} \Rightarrow L_{C2H6} \Rightarrow L_{H20} = L_{C2H6} \times \sqrt{\frac{M_{C2H6}}{M_{H2O}}}$$

EXEMPLE OF RGA RESULTS ON DEVICES AFTER PRESSURIZATION WITH ETHANE



- The Ethane is always present after pressurization but values are closed to the limit of detection

  $L_{H2O} < 1\ 10^{-15}$ atm.cc/s

CONCLUSION ON HERMETICITY

- The water standard leak rate was estimated to

  $<1\ 10^{-15}$ atm.cc/s for bonding ring of TiTiN/Au

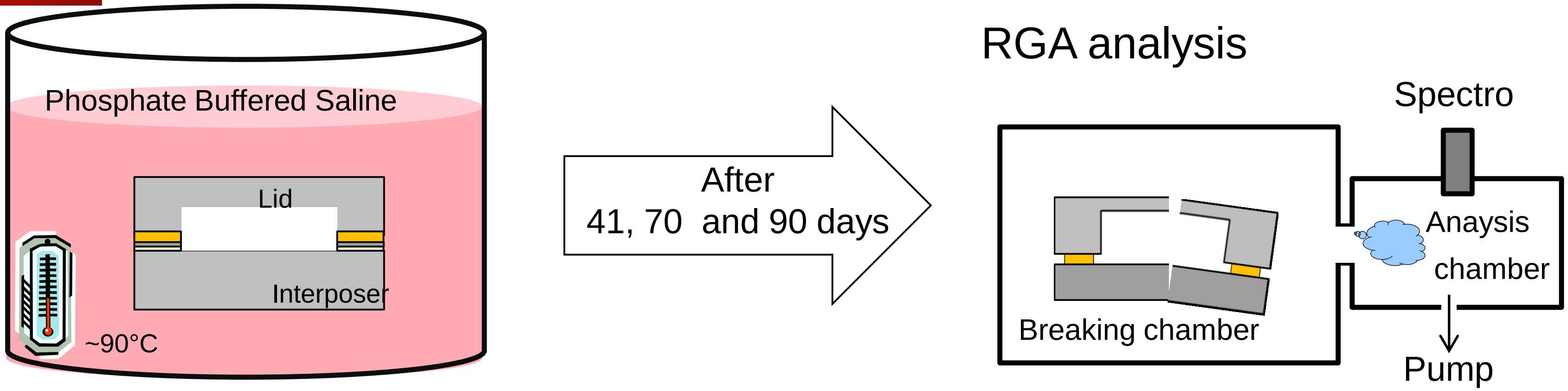
- These leaks guarantee a life time much more than 20 years (L_{H2O} $<1.2\ 10^{-12}$)

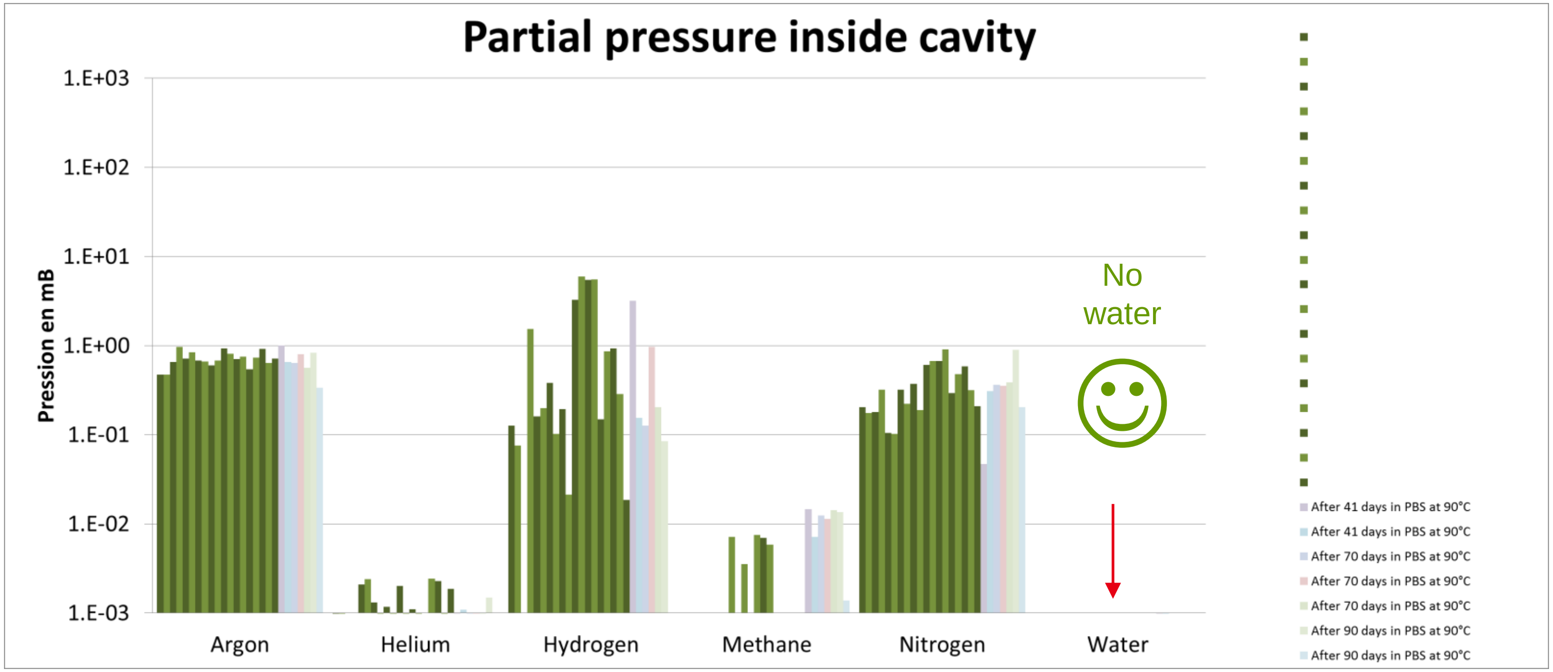
What about biostability ?

Packaging was tested in Phosphate-buffered saline

Phosphate-buffered saline (abbreviated PBS) is a water-based salt solution which the osmolarity and ion concentrations of the solutions match those of the human body (isotonic).

BONDING RESISTANCE IN SALINE SOLUTION





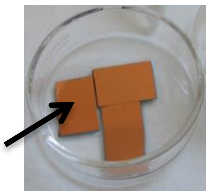
What about biocomp ?

Biological Evaluation of MDs : ISO 10993

Device Category			Biological Effect									
			In-vitro	In-vivo								
Body Contact		Contact duration A – Limited (≤ 24 h) B – Prolonged (24 h to 30 days) C – Permanent (> 30 days)	Cytotoxicity	Sensitization	Irritation or Intracutaneous Reactivity	Systemic Toxicity (Acute)	Sub-chronic Toxicity (Sub-acute Toxicity)	Genotoxicity	Implantation	Hemocompatibility	Chronic toxicity	Carcinogenicity
Implant devices	Tissue/bone	A	X	X	X	O						
		B	X	X	O	O	O	X	X			
		C	X	X	O	O	O	X	X		X	X
	Blood	A	X	X	X	X			X	X		
		B	X	X	X	X	O	X	X	X		
		C	X	X	X	X	X	X	X	X	X	X

PROTOCOL FOR TEST ON EXTRACTS

Extracts preparation (materials)



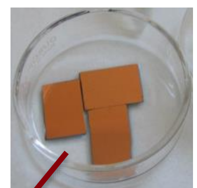
Incubation of extracts
With L929 cells

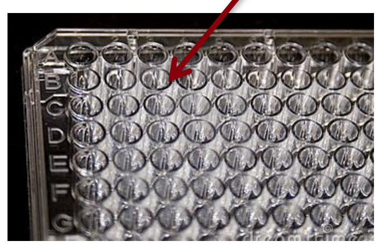
Cell viability assessment

T0

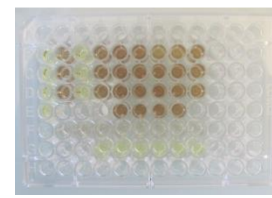
L929 cells seeding

T0 + 24 H





T0 + 48 H



$$\text{Percent viability} = \frac{100 \times OD_{c492e}}{OD_{c492rc}}$$

RESULTS OF CELL VIABILITY

Material	Percent viability of control	System suitability
Positive control (Polyurethane film with ZDEC)	8,6	Met criteria
Negative control (High density Polyethylene)	100	Met criteria

Material	Percent viability of tested materials	Cytotoxic potential
Doped Si wafer	100	No cytotoxic potential ☺
Doped Si wafer / Ti/TiN	100	No cytotoxic potential ☺

AGENDA / OUTLINE / OVERVIEW

BIO PACKAGING LAYER

Interest

Material	Fabrication	Biocomp. (L929)	Biostable (PBS 37°C)
TiO_2	ALCVD 250°C	Yes	Yes
Al_2O_3	ALCVD 250°C	Yes	Yes
HfO_2	ALCVD 250°C	Yes	Yes
SiC	PECVD 350°C	Yes	Yes
SiOC	PECVD 400°C	Yes	Yes
DLC (a-CH)	PECVD 400°C	Yes	Yes
BN	PECVD 400°C	Yes	Yes
SiO_2	PECVD 400°C	Yes	Medium
SiN	PECVD 400°C	Yes	No
crys-ZnO	ALCVD 250°C	No	No

AGENDA / OUTLINE / OVERVIEW

CONCLUSIONS

- A new packaging solution of an ASIC and MEMS for cardiac medical applications was presented.
  - Low profile silicon box manufacturing was demonstrated
- The gas content and hermeticity of the package were analyzed using Residual Gas Analysis
  - The water standard leak rate was estimated to <1 10-15 atm.cc/s which guarantees a life time much more than 20 years.
- Our packaging has presented a good resistant to PBS (>3months at 90°C)
- Cytotoxicity and cell morphology test protocols according to the norm ISO-10993 were developed.
- Good candidates as additional biopackaging layer were identified

Thanks
for your attention

Leti, technology research institute
Commissariat à l'énergie atomique et aux énergies alternatives
Minatec Campus | 17 rue des Martyrs | 38054 Grenoble Cedex | France
www.leti-cea.com