Sensors and packages based on LTCC and thick-film technology for severe conditions

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Outline

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

1. Introduction - thick-film technology & LTCC
2. Liquid level sensor - "flip-chip" thick-film technology
3. Jet engine AMB sensor - thick-film @ high temperature
4. Chemical gas microreactor - high-temp. MEMS package
5. Chemical liquid microreactor - LTCC fluidic modules
6. Conclusions & outlook

1. Introduction - thick films

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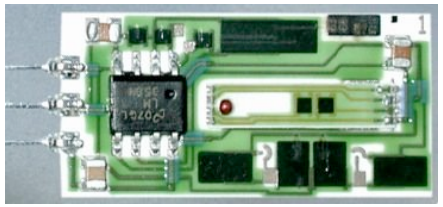
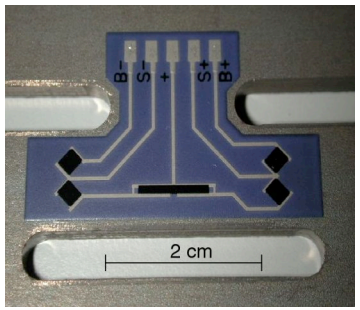
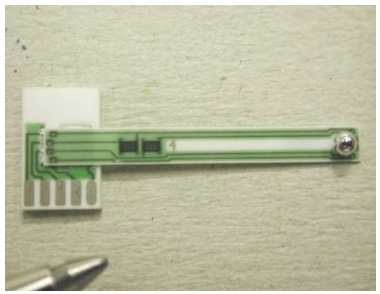
- **Thick-film circuit : series of layers**
  - Screen-printing of layers with a mask
  - Direct dispensing (prototypes)

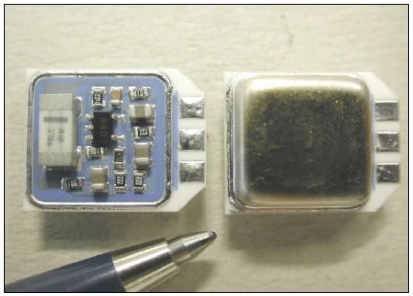


- **Each layer comes as a paste:**
  - Functional material (as powder)
  - Organic vehicle: binder + solvent





- **Materials (usually mineral)**
  - Conductors
  - Resistors : **mechanical & thermal sensors**
  - Dielectrics
  - …**and more!**



1. Thick-film process

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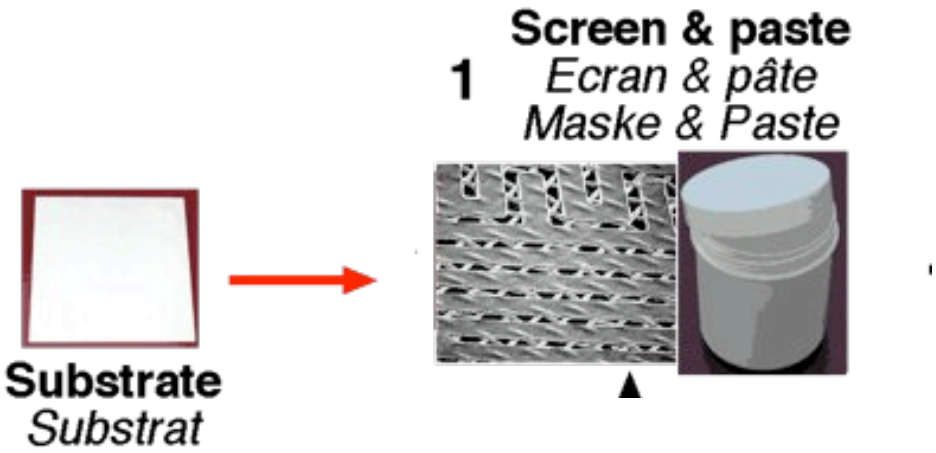

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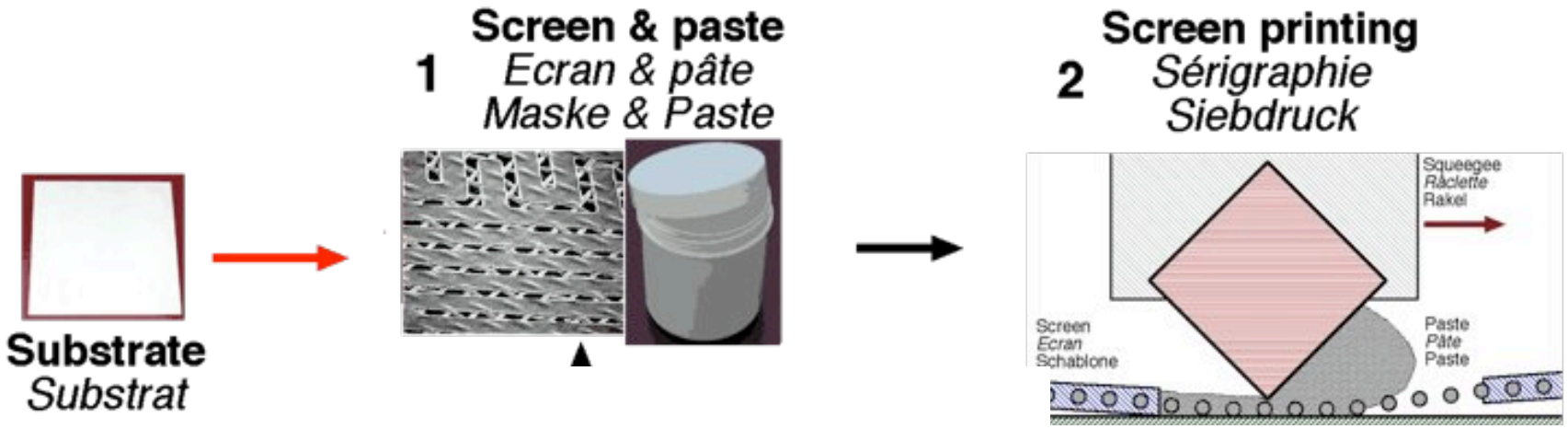

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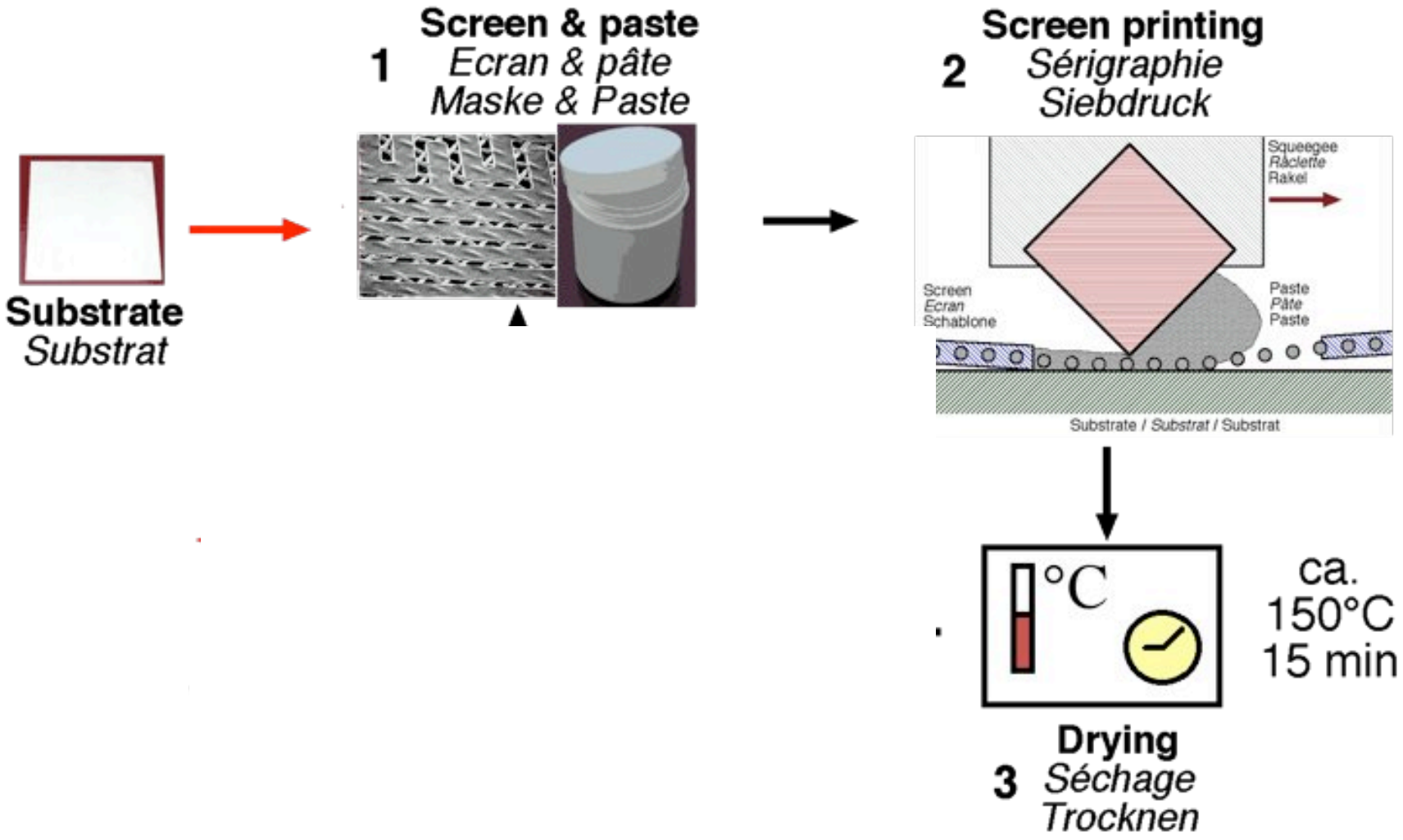

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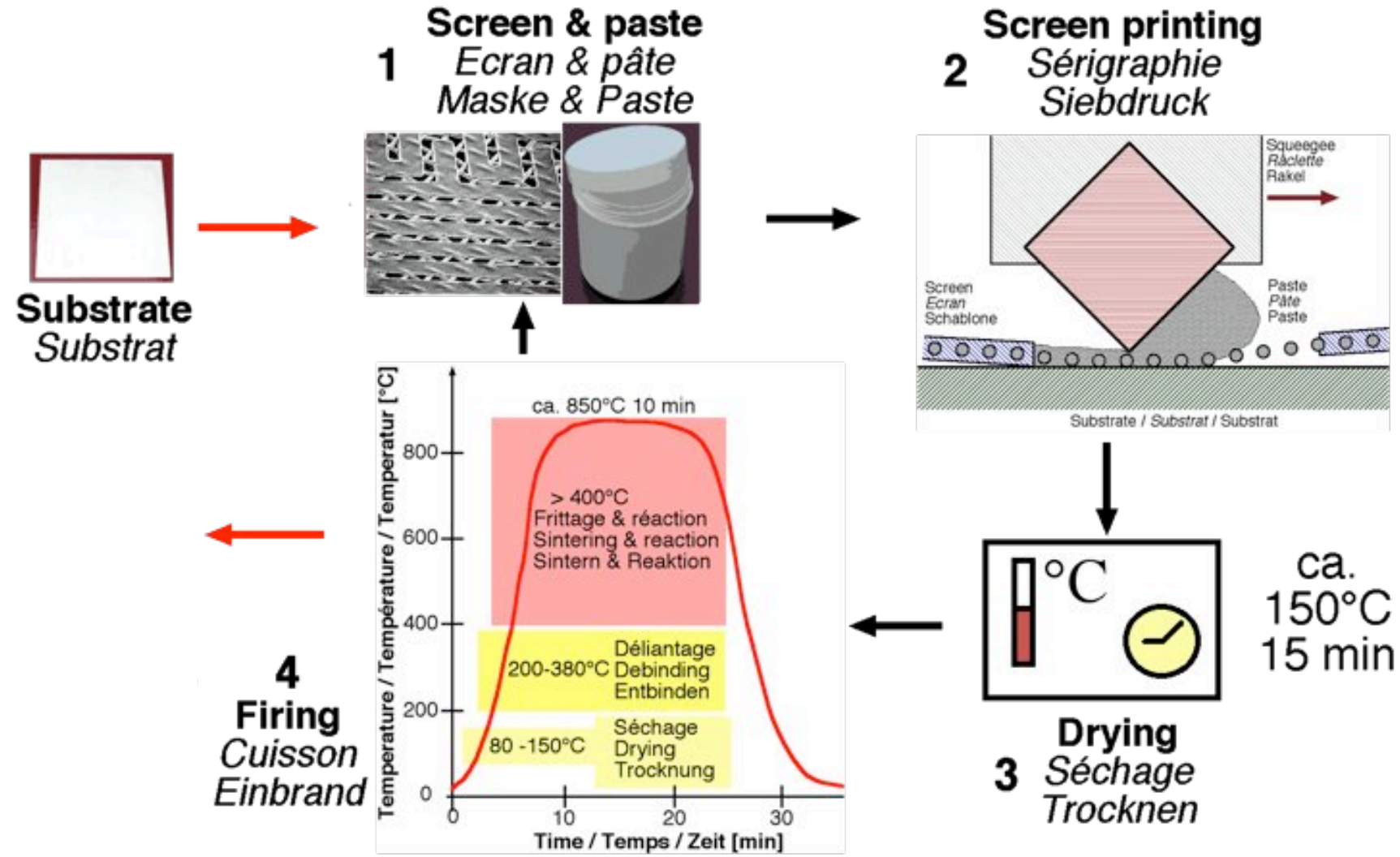

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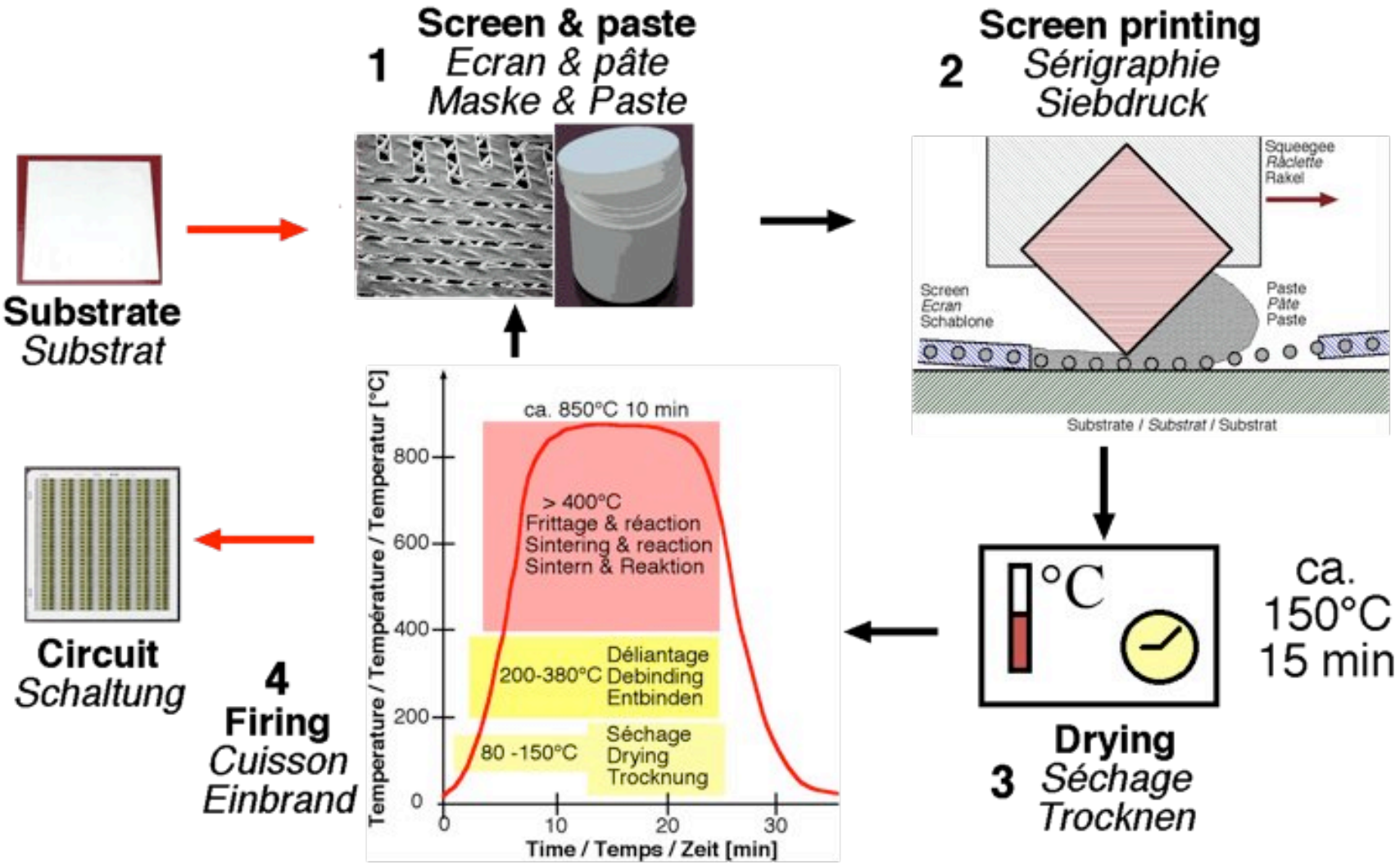

1. Introduction - LTCC

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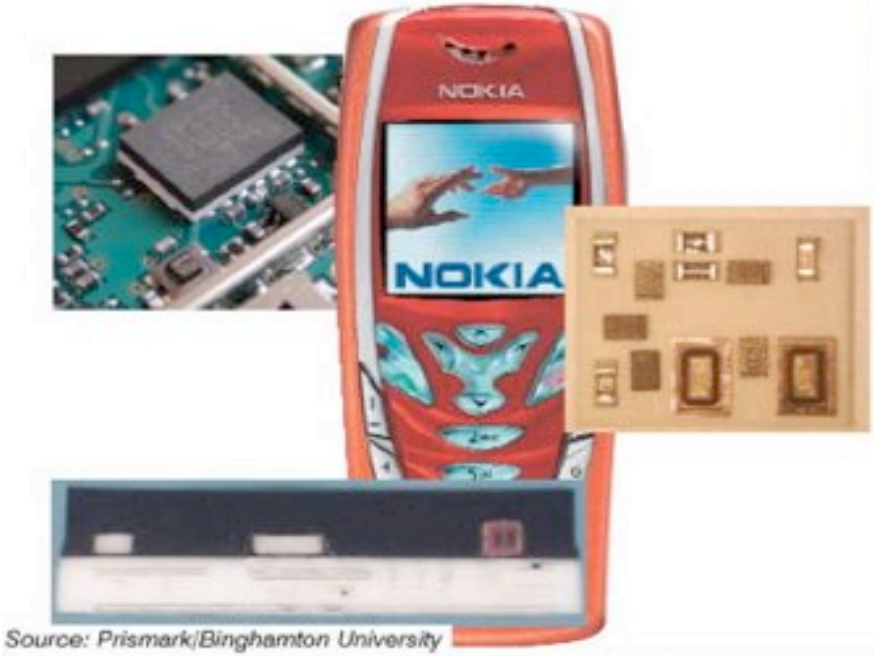
What is LTCC?

- LTCC stands for « Low-Temperature Co-fired Ceramic ».
- It is an evolution of standard thick-film technology.
- The ceramic is a silicate material + Al_2O_3 with outstanding chemical and thermal stability.

How is it made?

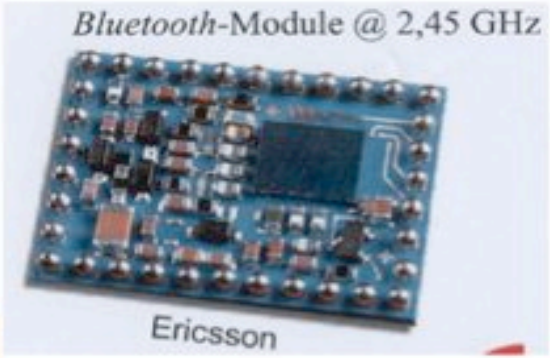
- LTCC comes as unfired « green » sheet (tape) of various thicknesses (ceramic powder with polymer binder).
- Each sheet is shaped & screen-printed with conductive, resistive, or other pastes.
- Finally, the sheets are pressed & fired together.

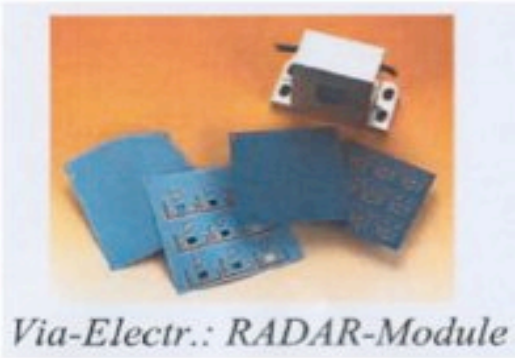
1. LTCC application examples

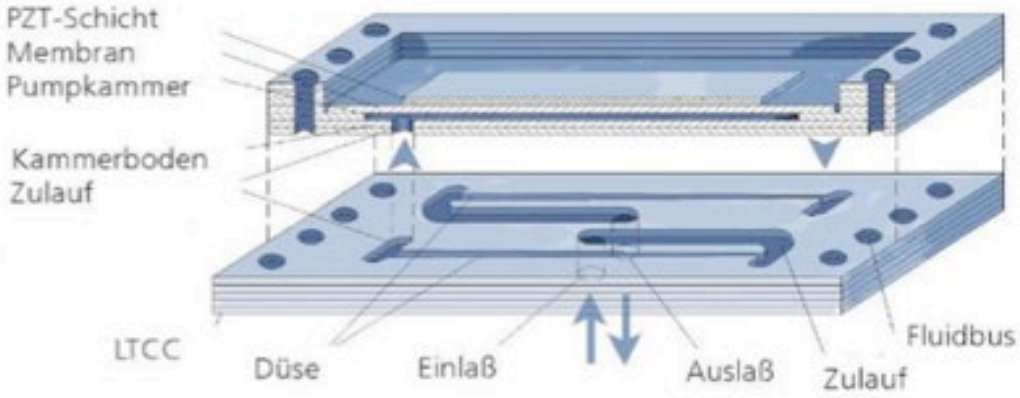


Source: Prismark/Binghamton University

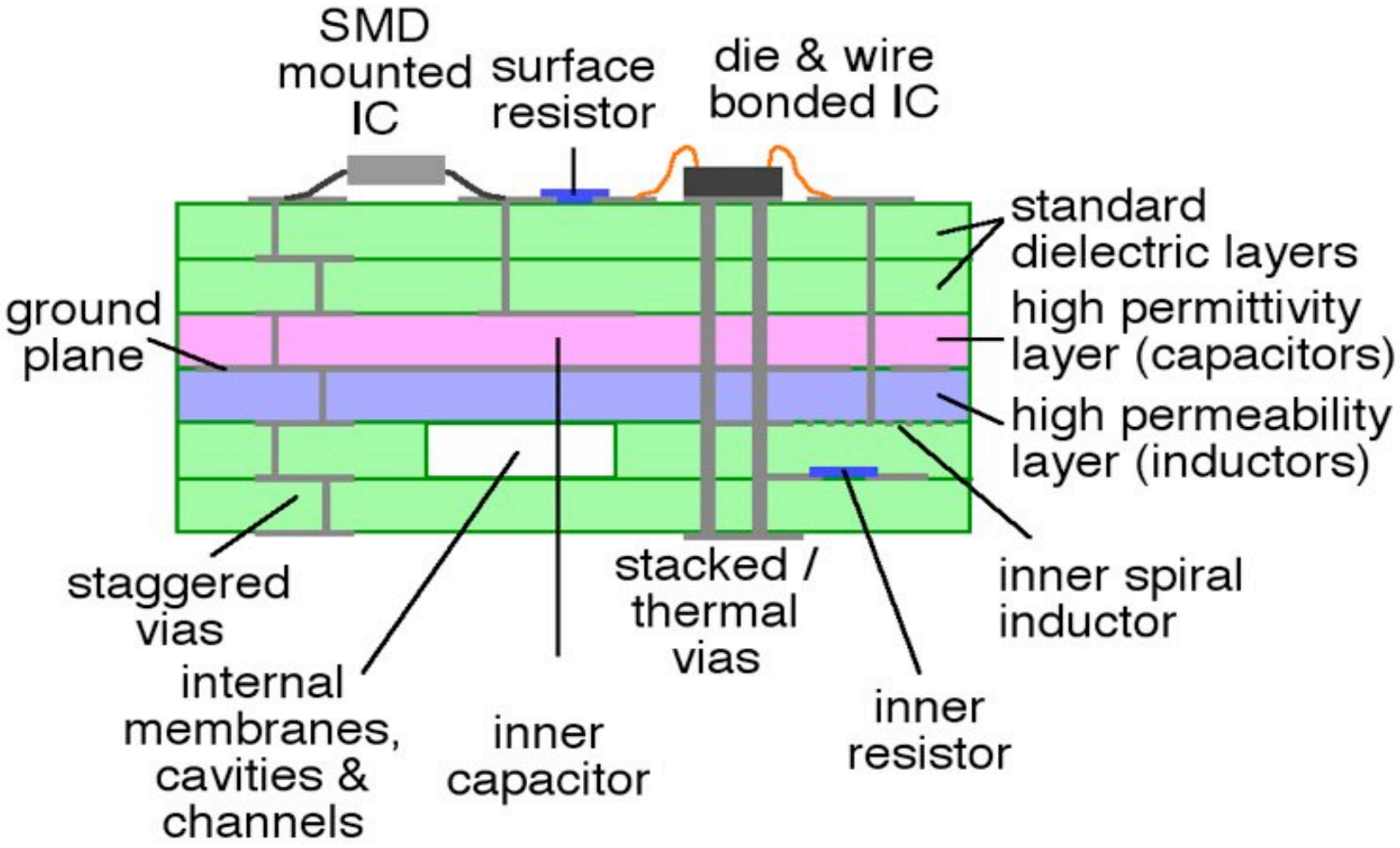
EPCOS FRONT END MODULE
- Key component in new Nokia mobile phone architecture
- Integrates diplexer, switching, LC and SAW filters
- Analysis of LTCC integrates passives and SAW filter packages



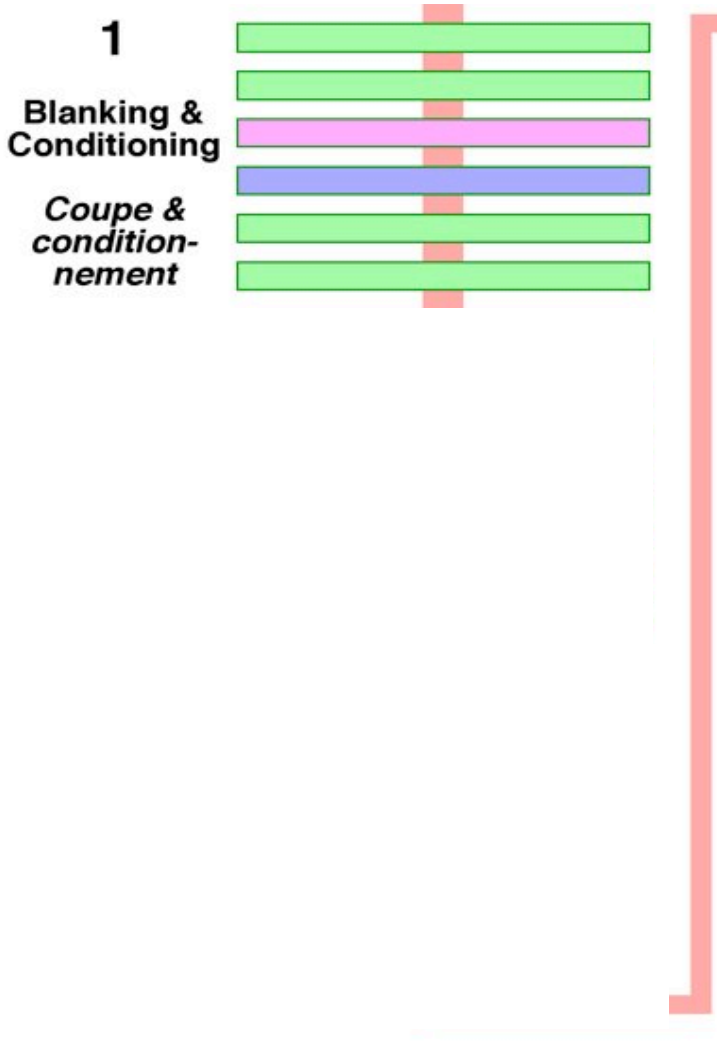




1. 3-D structuration of LTCC



1. LTCC manufacturing process



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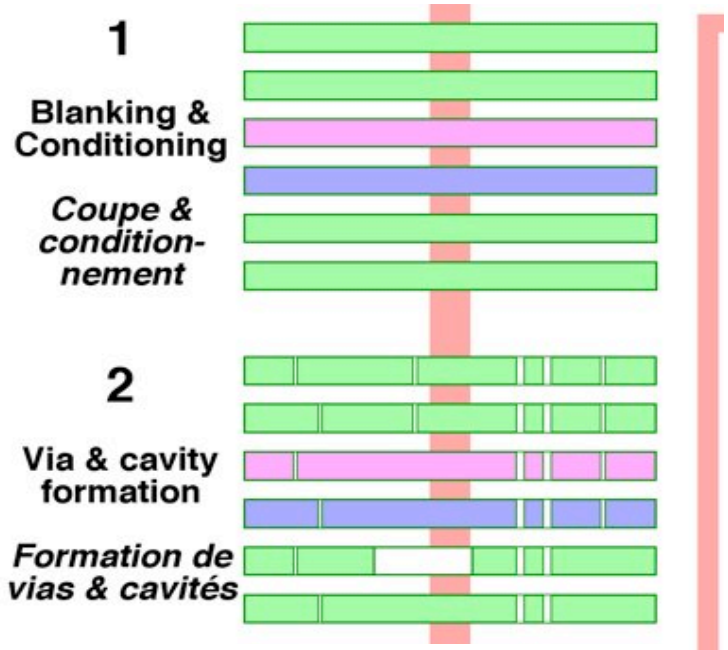

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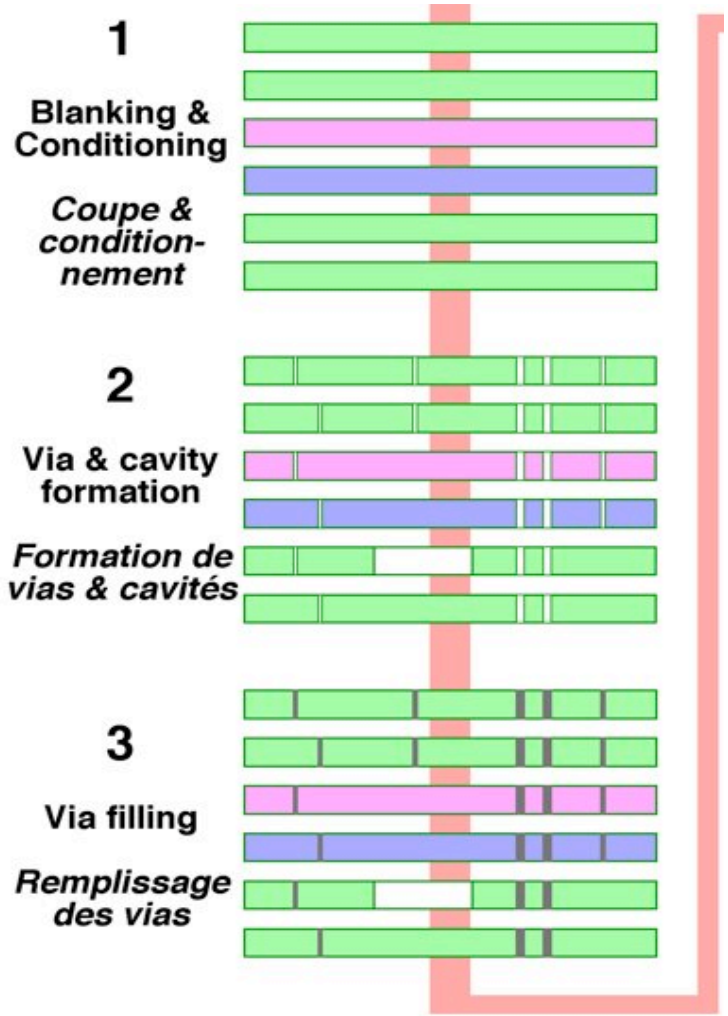

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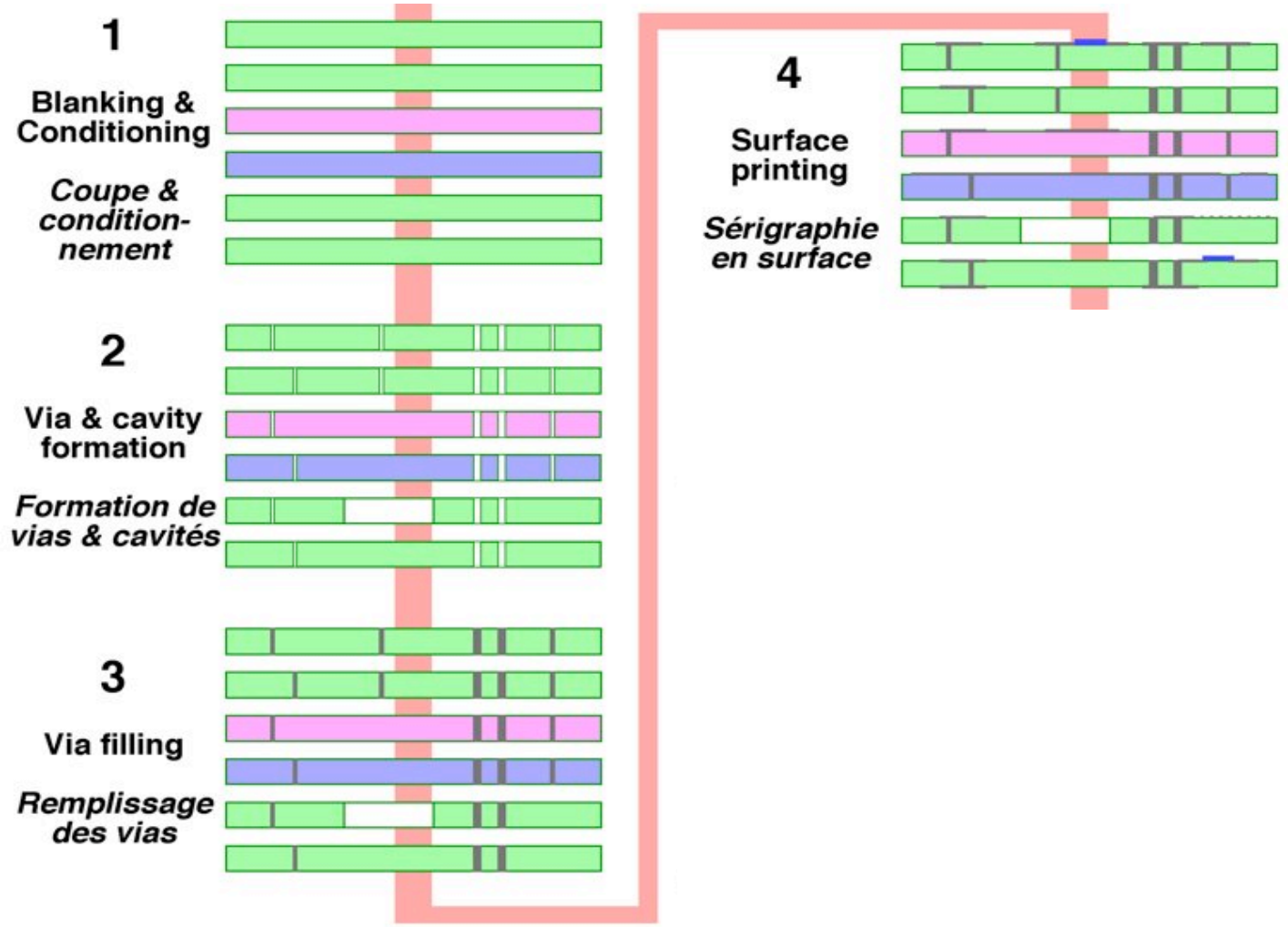

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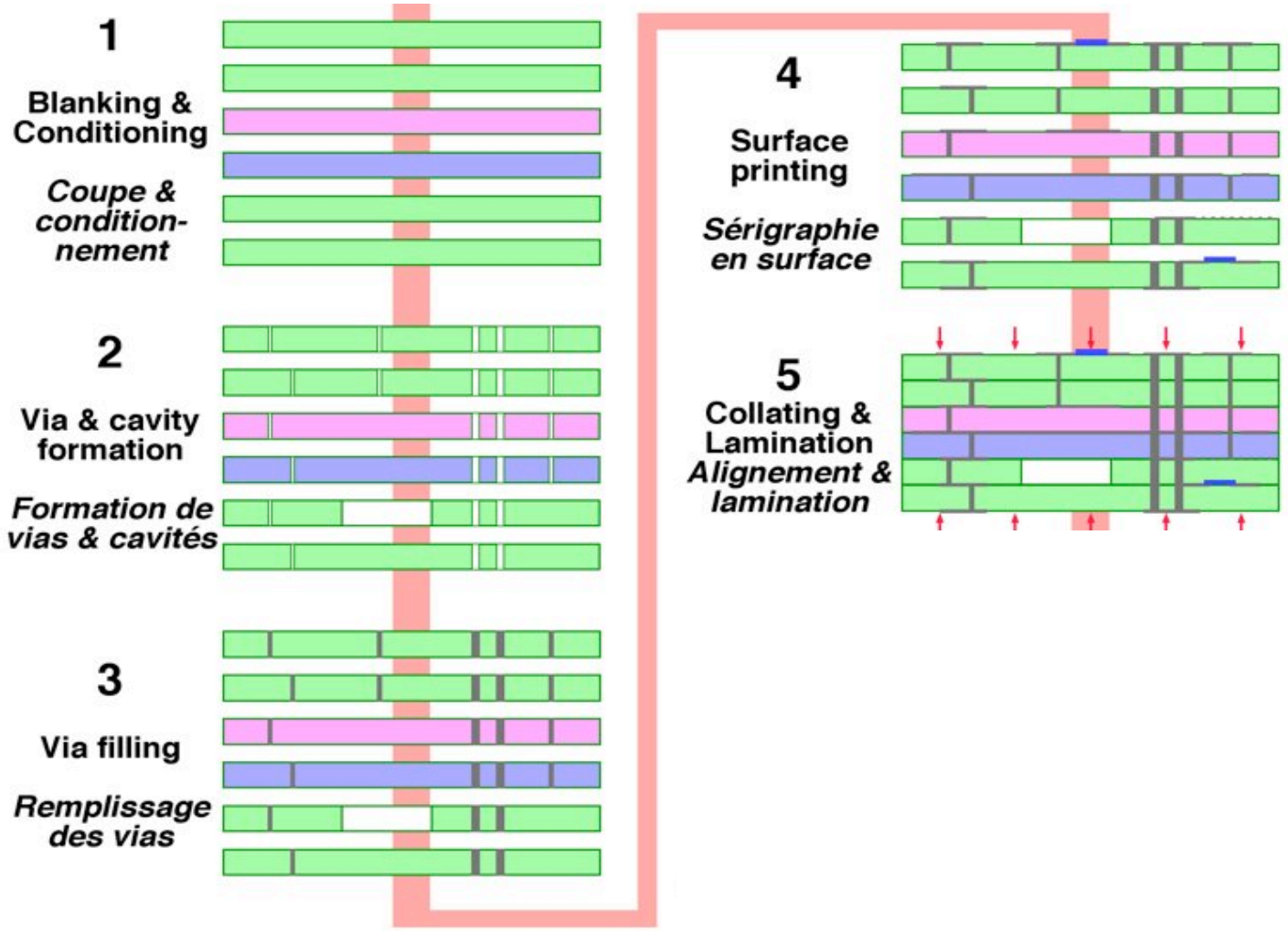

1. LTCC manufacturing process

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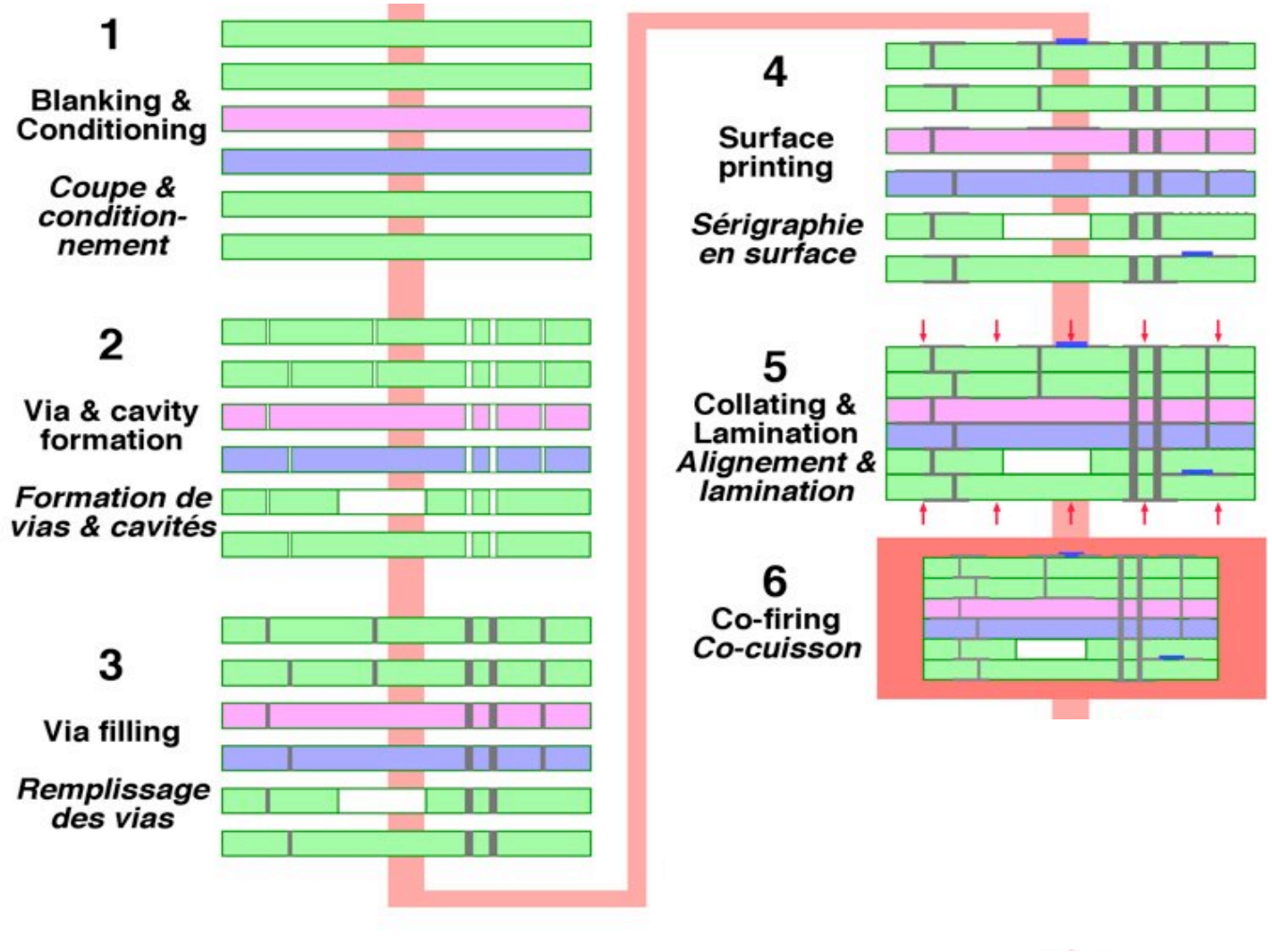

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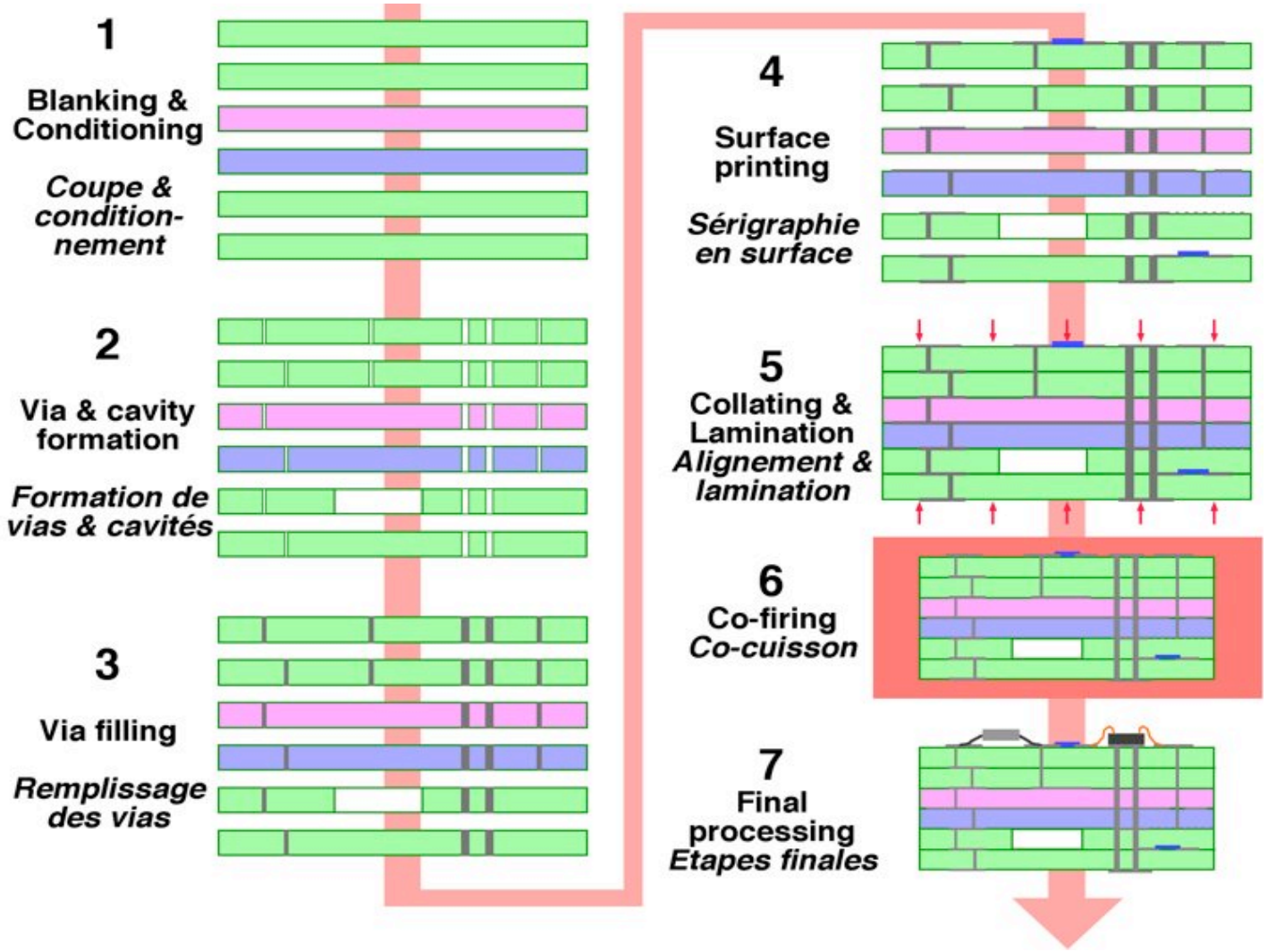

1. LTCC advantages

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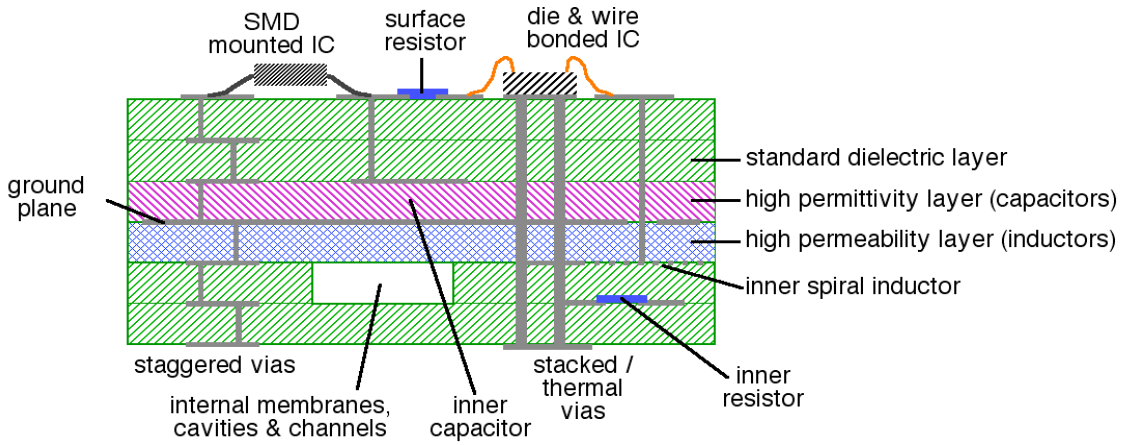
- T_{firing} < 900°C --> allows use of silver conductors
- High-density packaging
- 3-D structuration
- Hermetic structures



- Reliable mechanical, thermal and electrical performance
- High volume, low cost fabrication

1. LTCC vs. alumina for sensors

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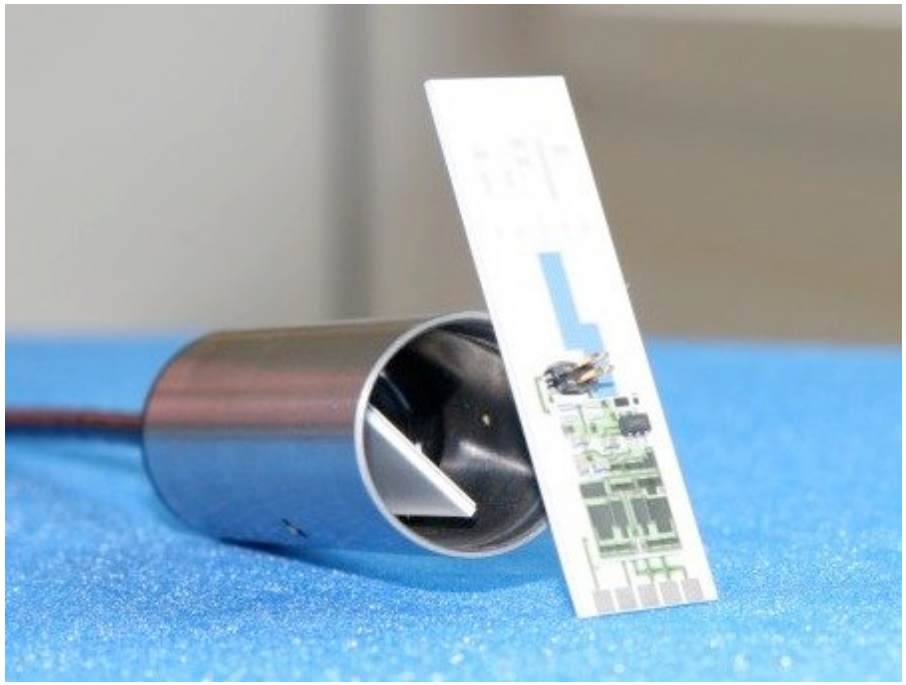
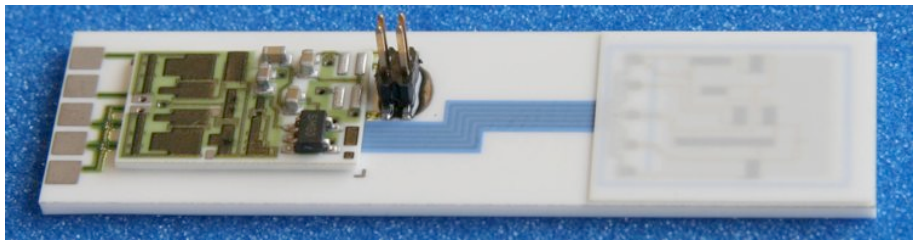
Material	LTCC (DP 951)	Al_2O_3 (96%)	Ratio
Minimal thickness [mm]	0.04	0.17	*0.24*
Short-term strength [MPa]	320	600	*0.53*
10 year strength [MPa]	110	270	*0.41*
Young's modulus [GPa]	110	320	*0.34*
Thermal conductivity [W/m]	3	25	*0.12*
Design strain [ppm]	1'000	800	*1.25*
Flexural sensitivity [kN^{-1}]	5.68	0.11	*53*
Thermal resistance [K/W]	8'333	235	*35*

> Thermal, low-range mechanical sensors

2. Thick-film liquid level sensor

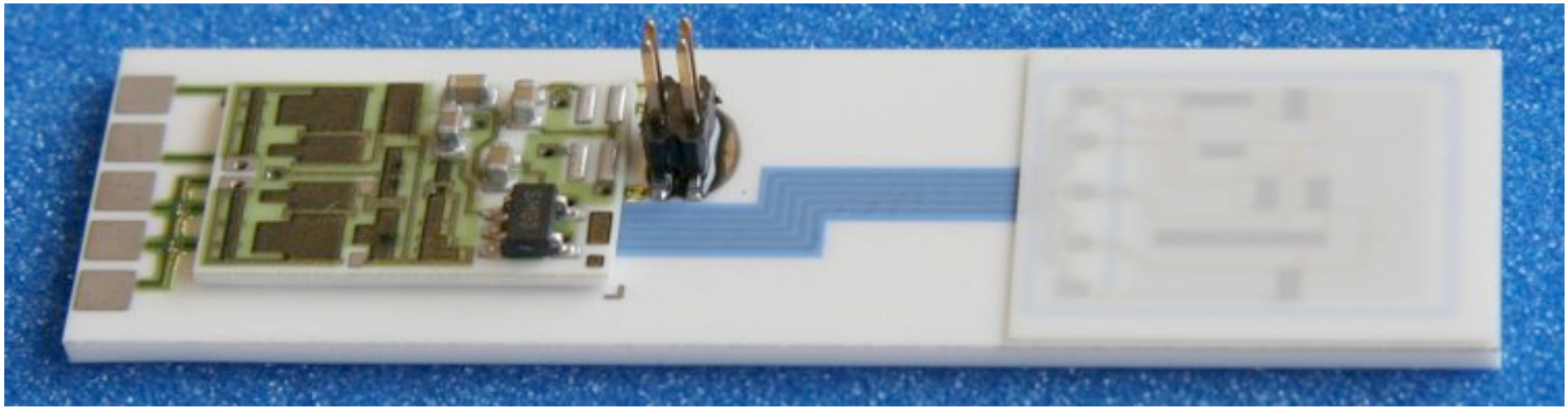




Features:

- Absolute piezoresistive pressure sensor for continuous immersion in water & fluids
- 3 thick-film circuits
  1. Base
  2. Membrane
  3. Electronics
- Membrane side in fluid
- Electronics & cable protected by epoxy potting compound

2. Level sensor - module

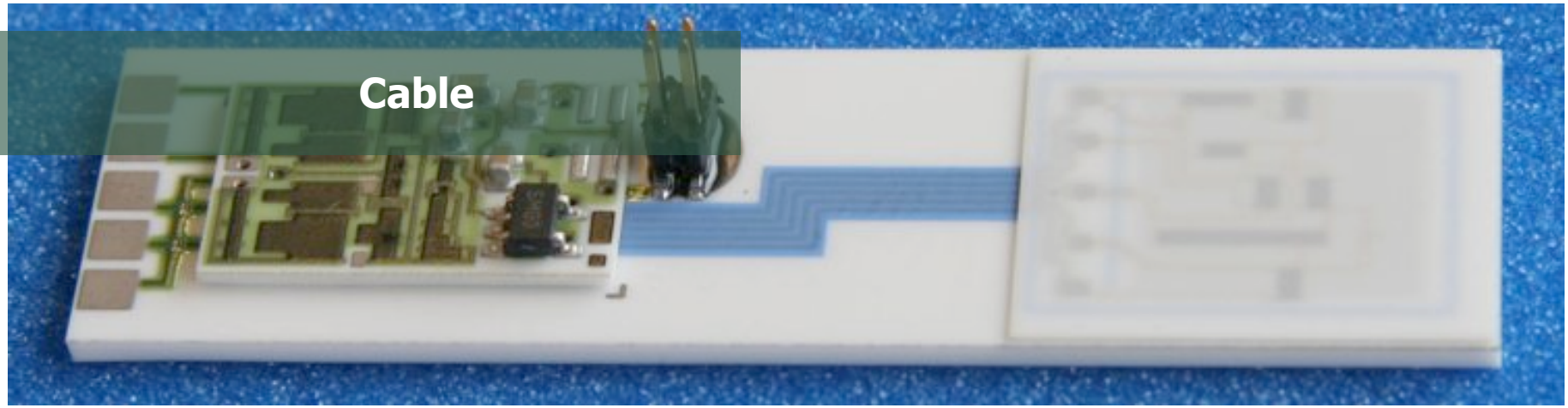


Electronics

Membrane

Membrane free-standing to avoid stress induced by packaging

2. Level sensor - module



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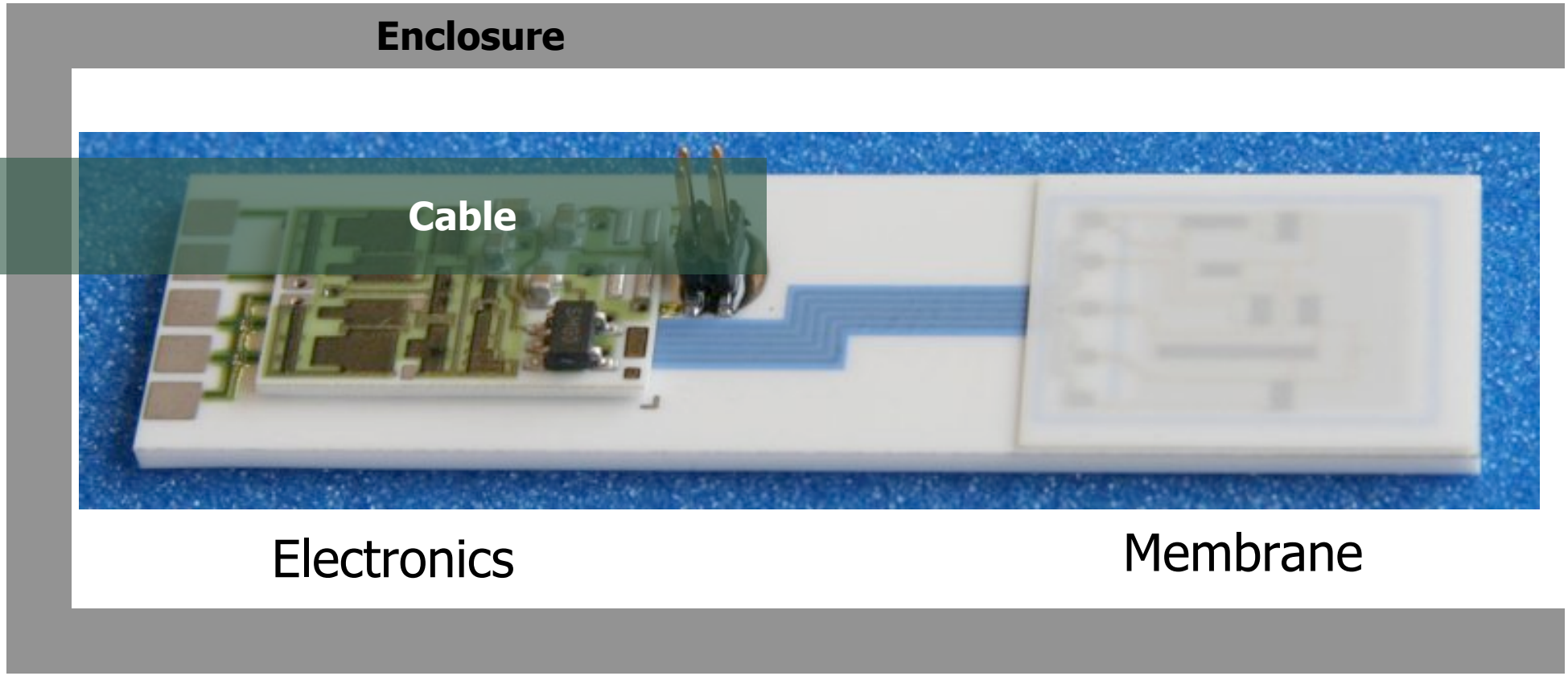

Membrane free-standing to avoid stress induced by packaging

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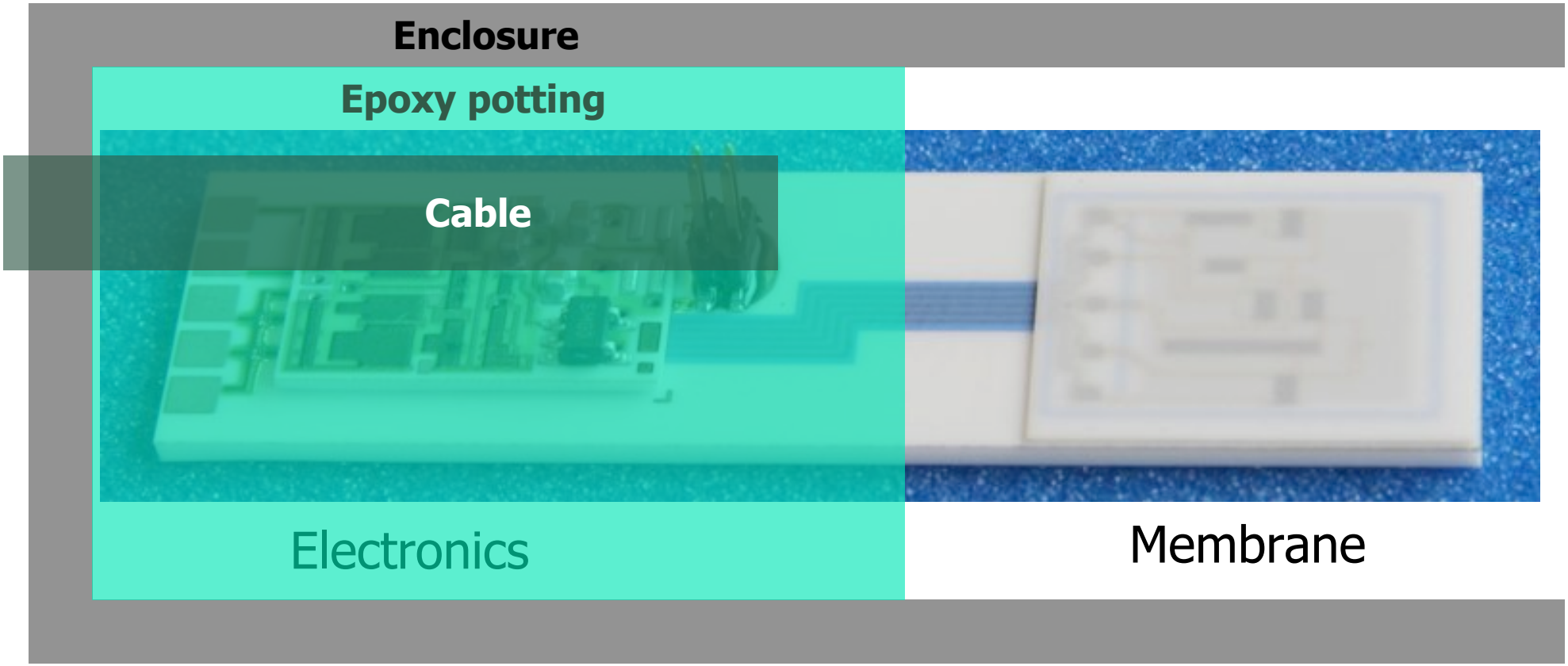
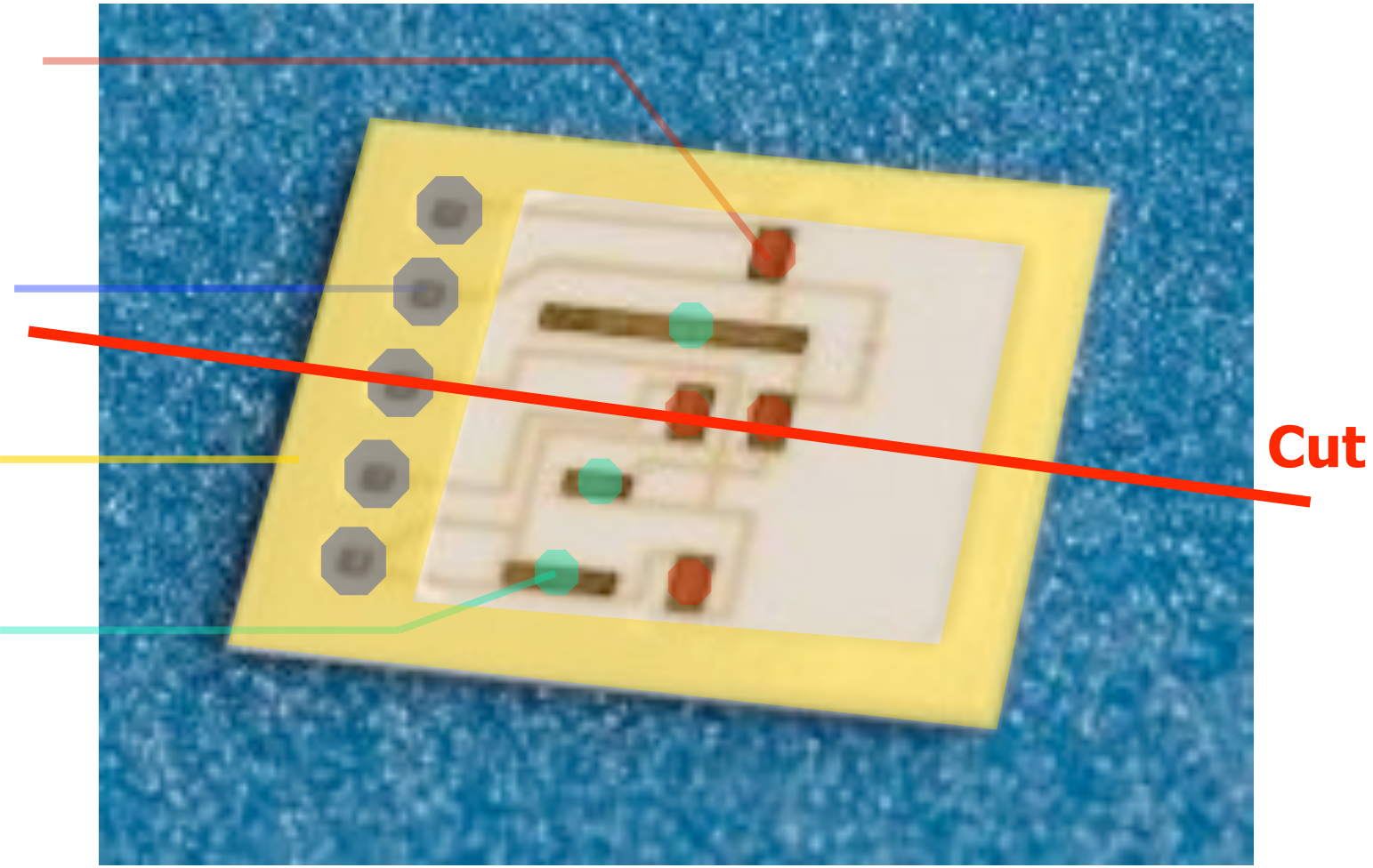
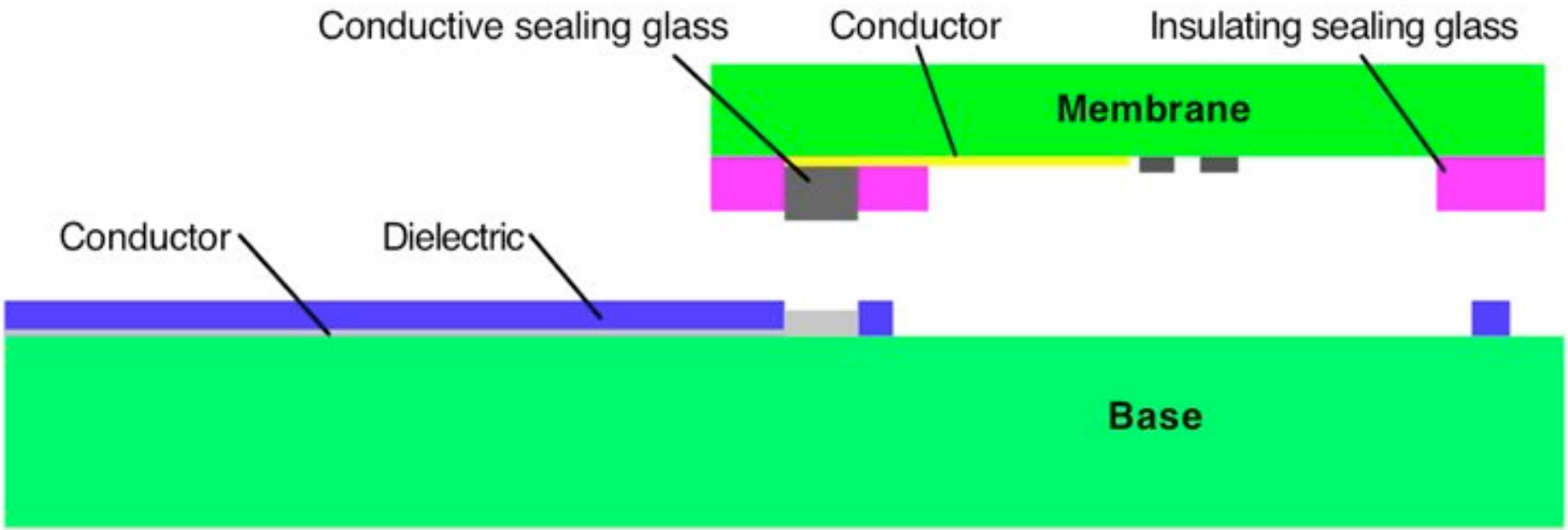


Membrane free-standing to avoid stress induced by packaging

2. Level sensor - membrane



2. Level sensor - seal



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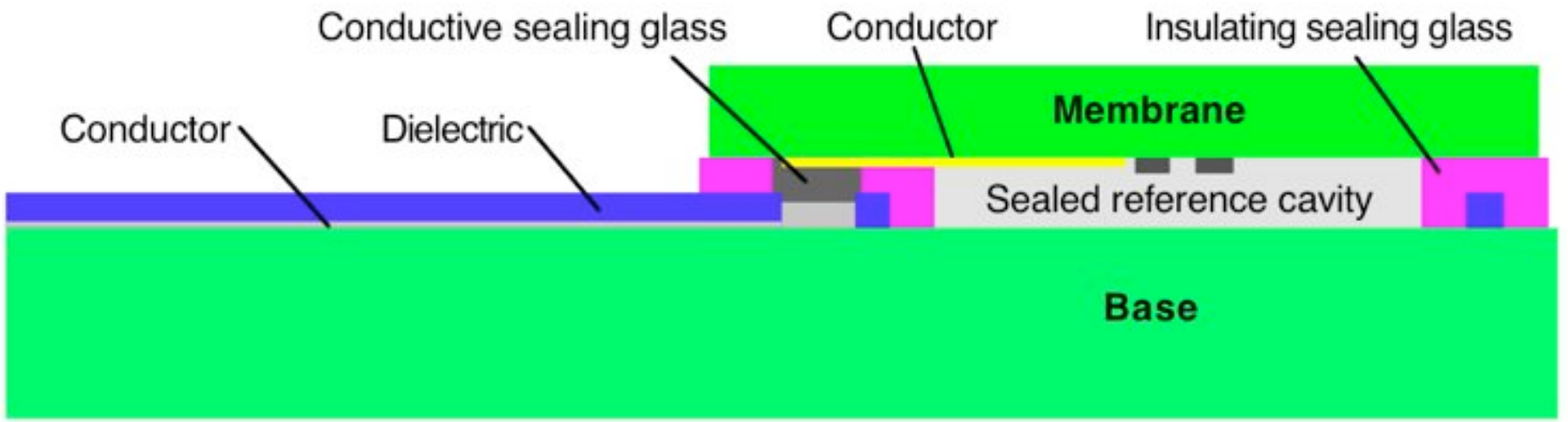

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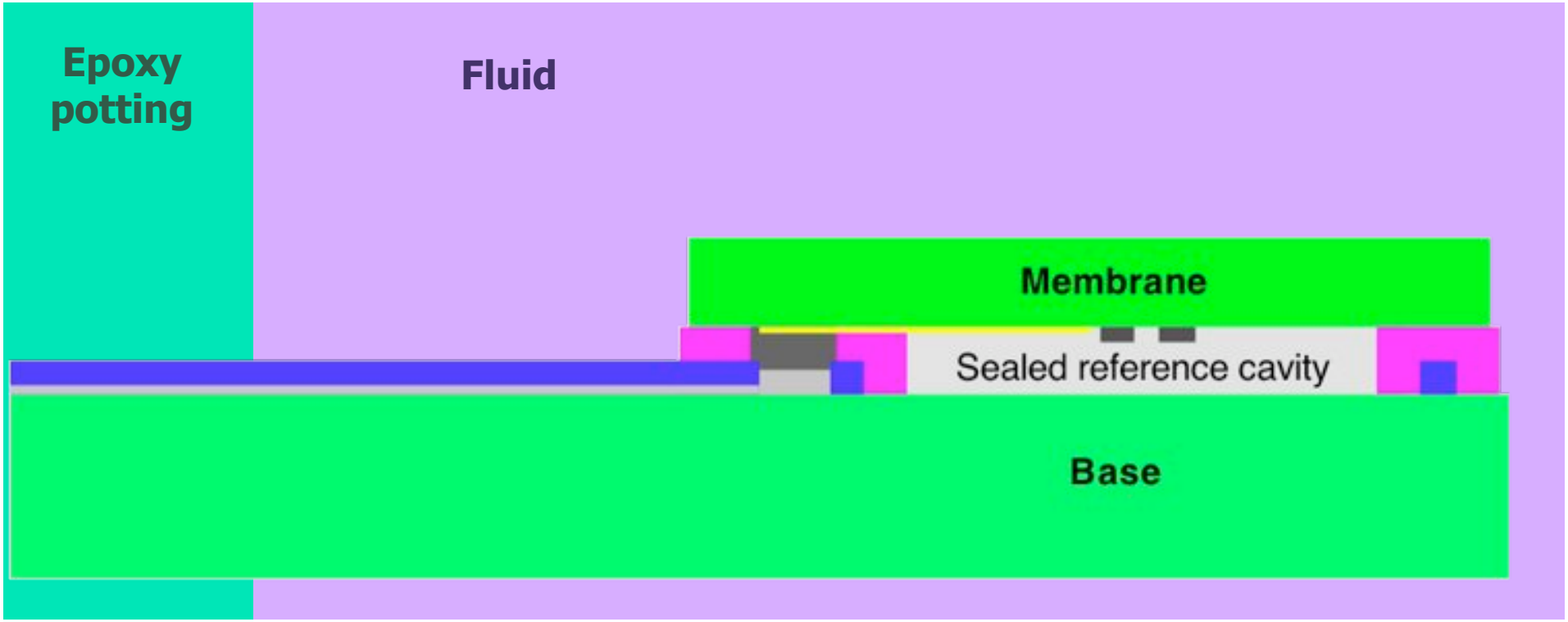
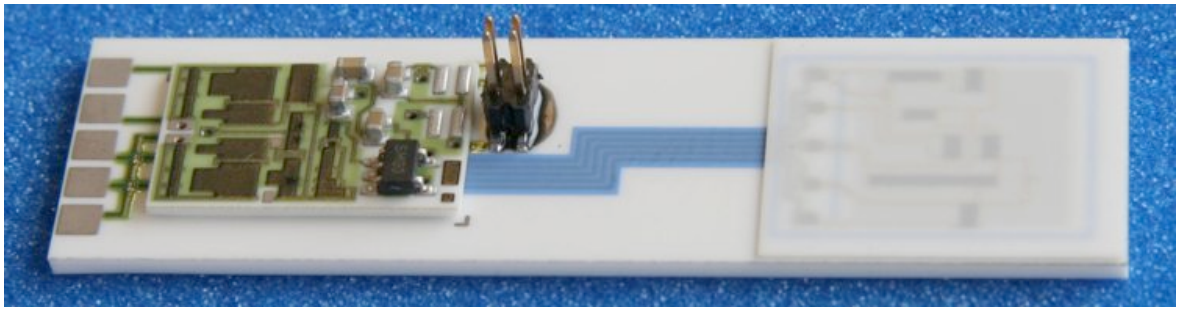


2. Level sensor - conclusions



- Full media separation achieved
- Compatibility with fuels & mildly aggressive aqueous solutions

  (critical points : sealing glass & potting compound)
- Absolute sensor for lower cost & increased reliability
- Reference cavity through hermetic glass seal
- Batch production processes

3. Jet engine AMB sensor (L. Burdet)

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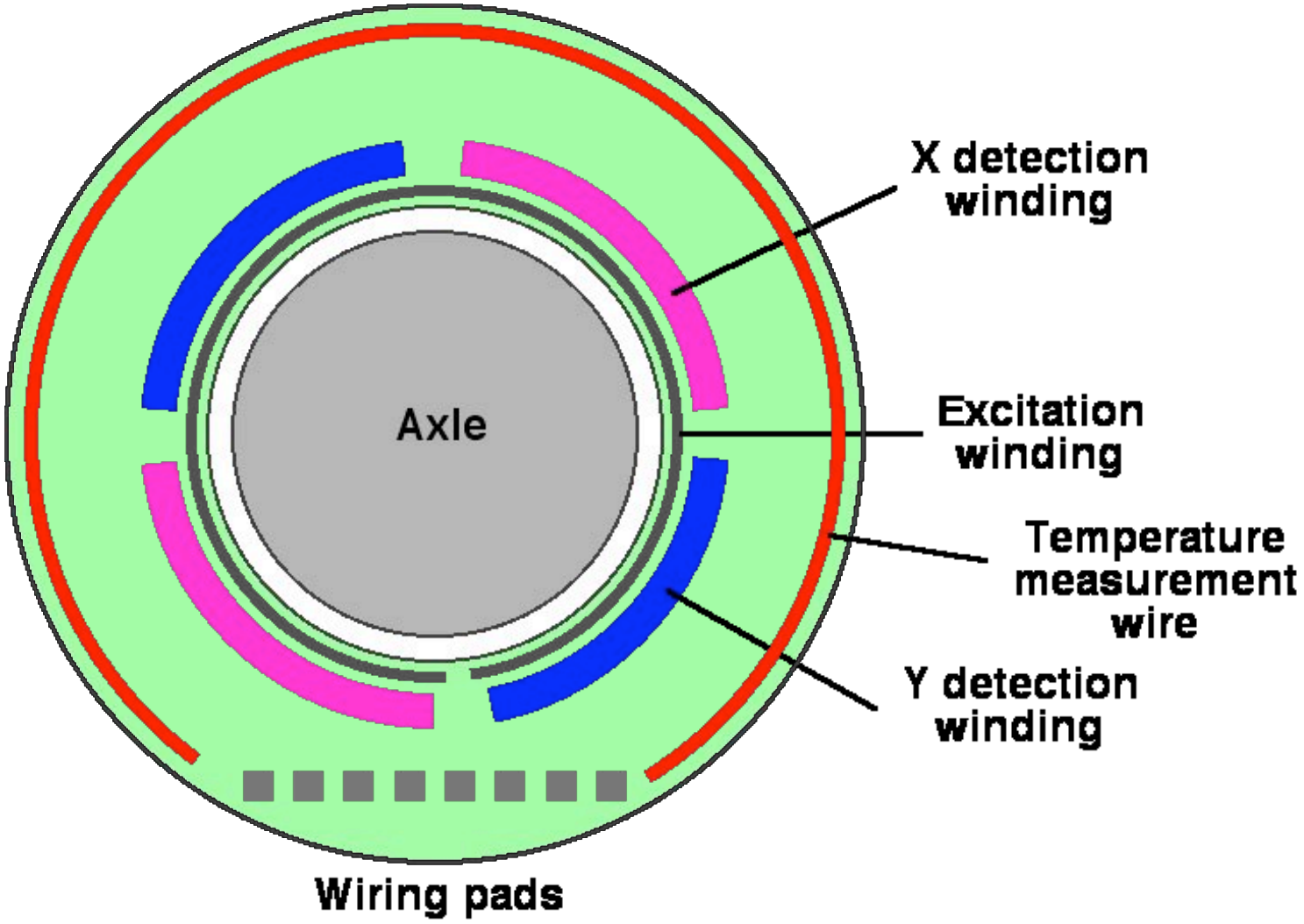
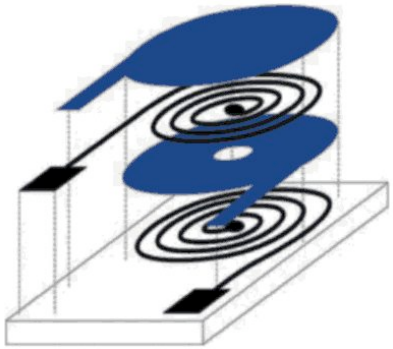
- **A**ctive **M**agnetic **B**earing (AMB) XY position sensor for jet engines
- Magnetic position sensor - eddy currents in rotor
- No mechanical bearings (oil, wear, cooling,…)
- Increased reliability
- Decreased maintenance costs
- Operation @ 550…600°C in aggressive gases
- Thick-film circuit

3. AMB sensor principle



3. AMB sensor circuit build-up



Inductor build-up

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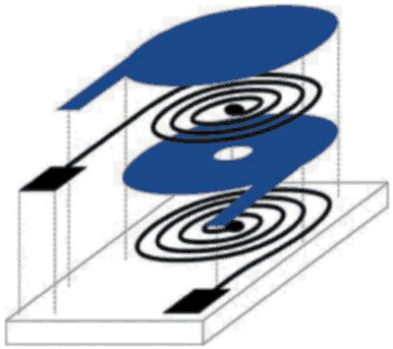

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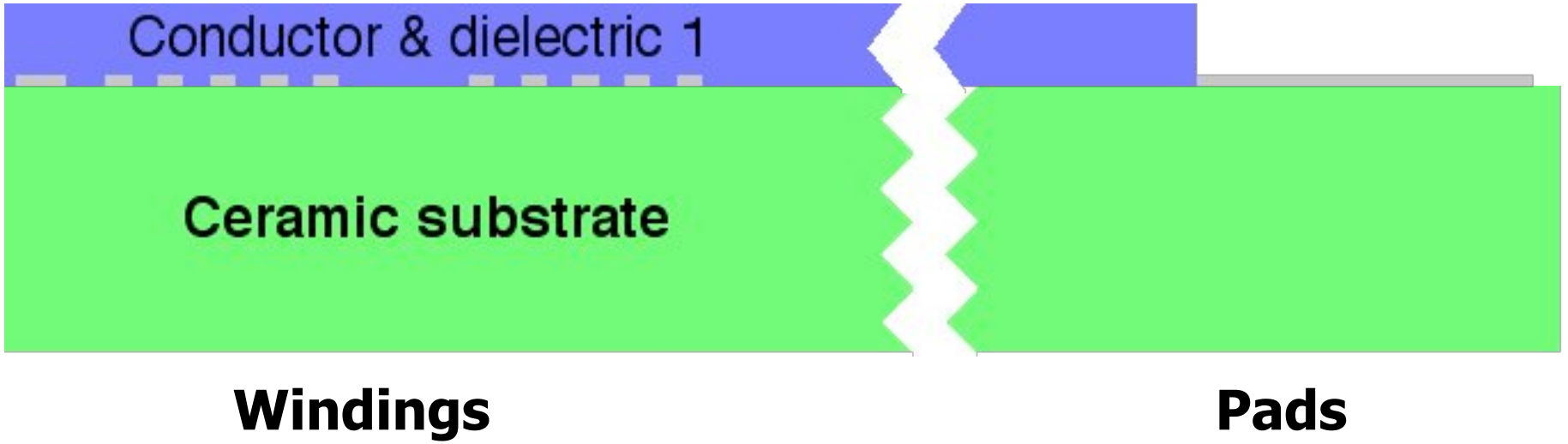

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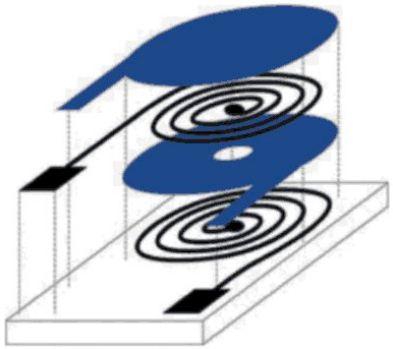

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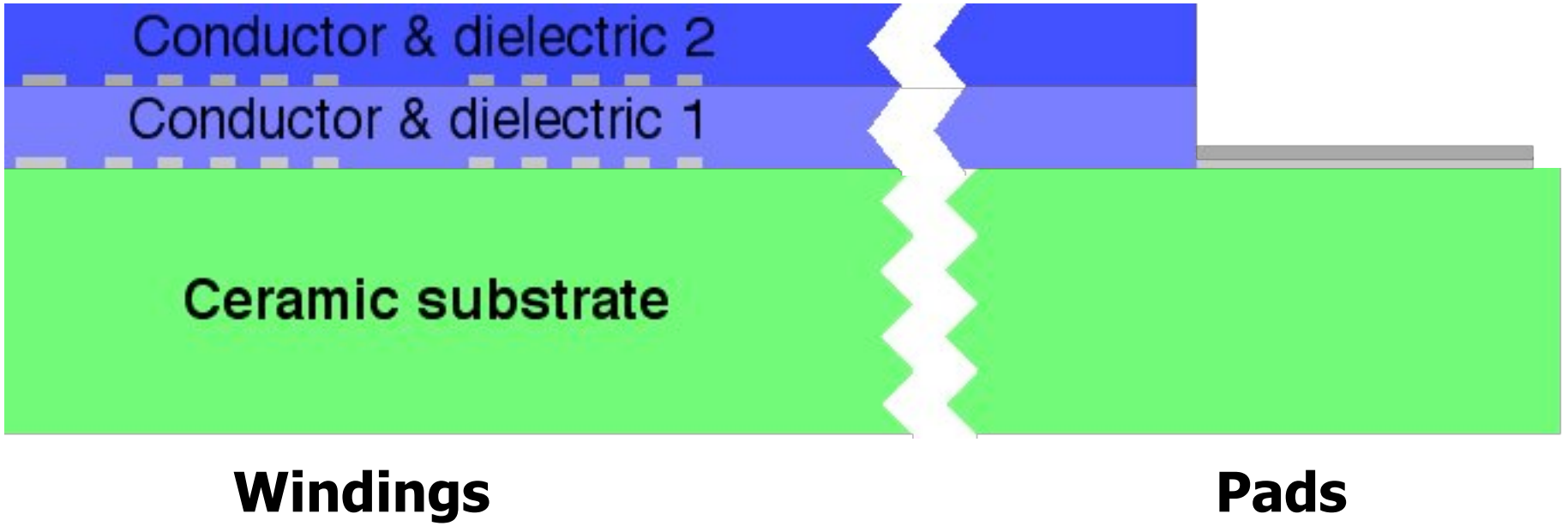

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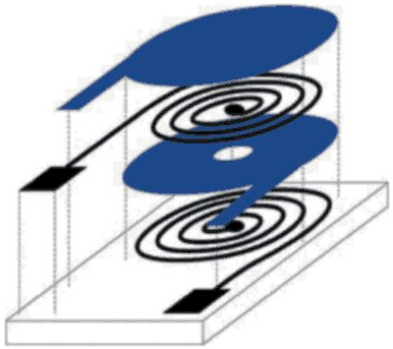

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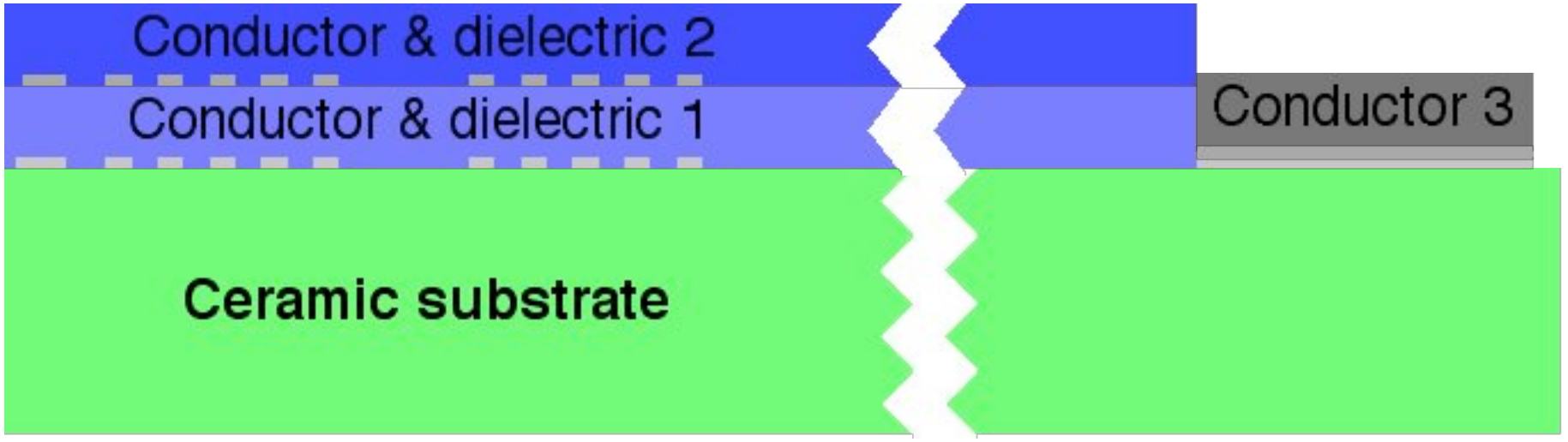

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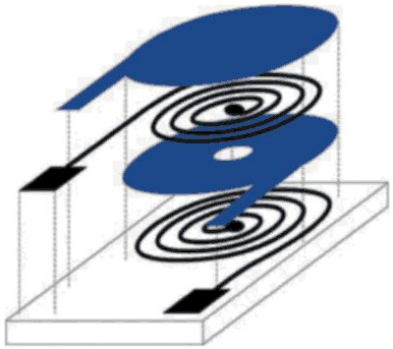

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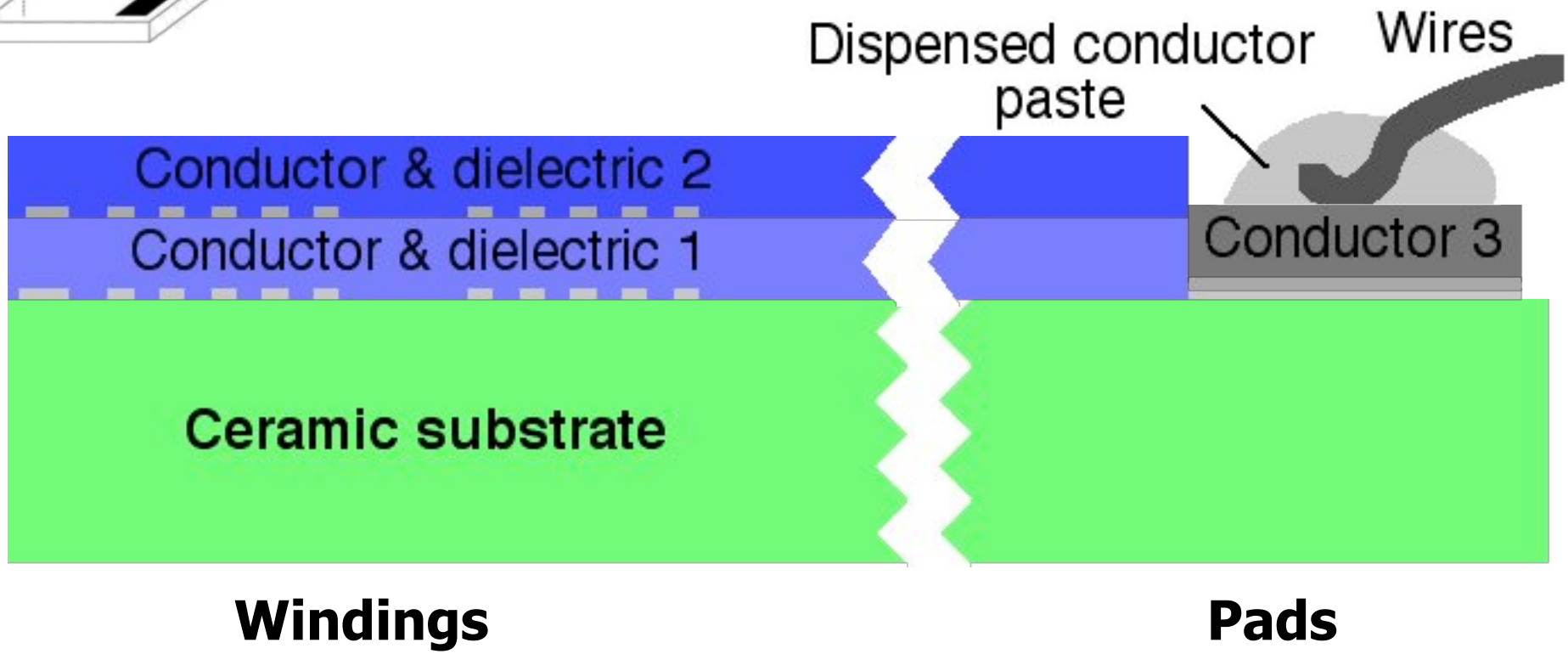

3. Kirkendall effect @ high temp.

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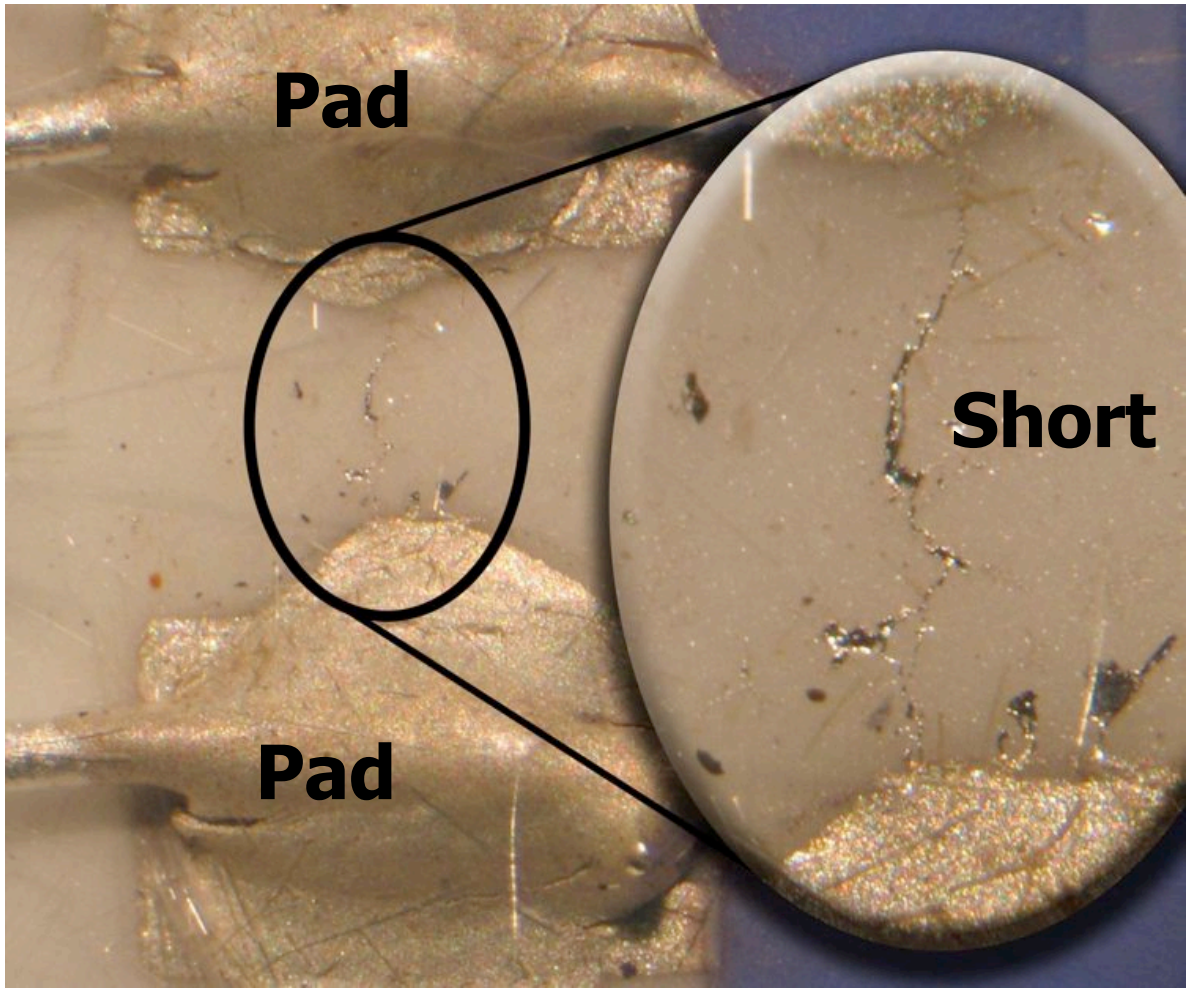
Result of long-term stability (>2'000 hours)

	Au pads (c3)	**Ag pads** (c3)	**Ag:Pd pads** (c3)
Au lines (c1 & c2)	OK	X	X
Ag lines (c1 & c2)	X	OK	X

- Only (quasi) identical metals may be in contact!
- Silver selected for cost & high conductivity

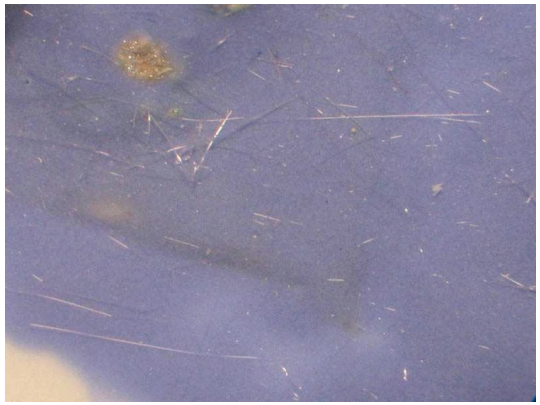
3. Ag electromigration @ high temp.



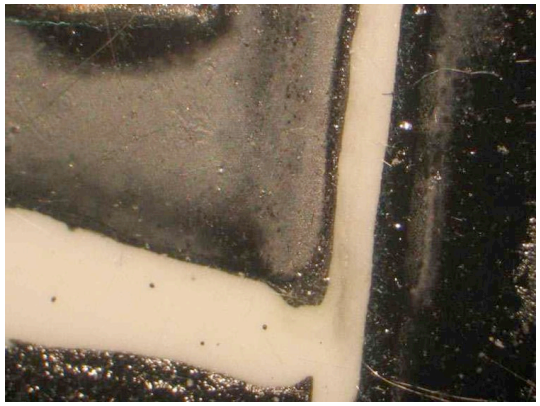
- Shorting of windings after long-term operation at high temperature
- Degradation only observed if voltage applied
- Creation of Ag conductive paths identified at pads
- **High-temperature Ag electromigration!**
- No problems if covered

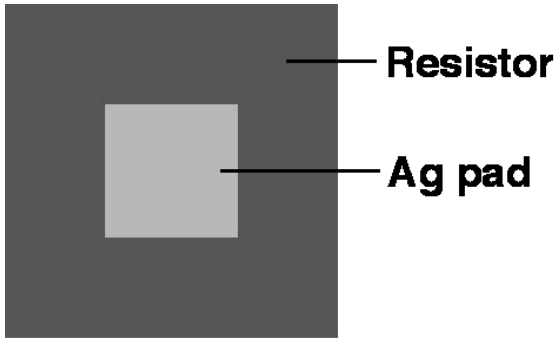
3. Ag electromigration - mitigation

glassy dielectric



cristallising diel.





Resistive guard pad / ring

- Need modern migration-resistant cristallising dielectric!
- Use of resistive guard pad or ring to cancel electric field around pad also possible
- **Extensive long-term qualification of these solutions still needed!**

3. Jet engine AMB - conclusions

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- Control of AMB (Active Magnetic Bearing) achieved
- Operation of thick-film circuit demonstrated @ 600°C !
- Electromigration of silver & Kirkendall effect problematic
- Electromigration stopped with
  - dielectric
  - resistor (conductive) guard ring
- Kirkendall effect avoided by using only pure Ag for conductors & cables

4. Packaging of MEMS microreactor

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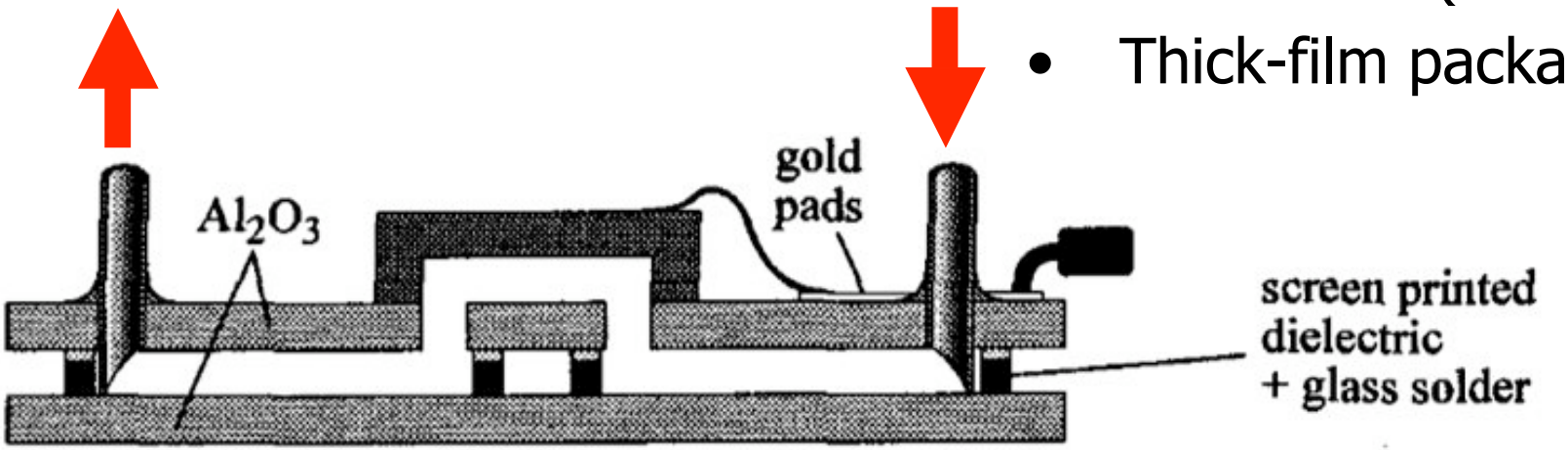
(Ch. Alépée - LMIS, 2000)

$$CH_3OH \rightarrow CH_2O + H_2$$

[Na, 800°C]

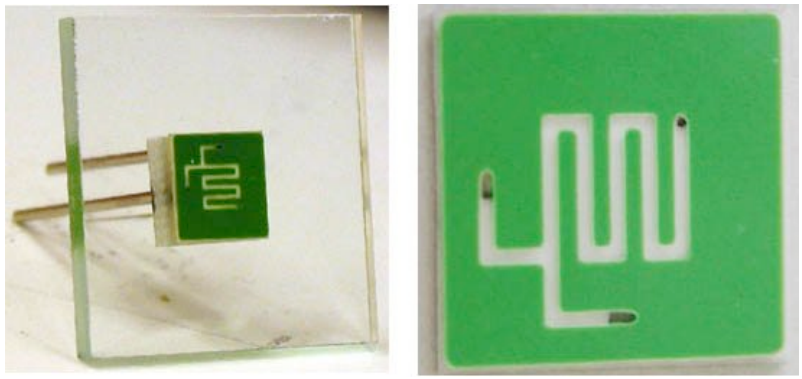
- MEMS microreactor for methanol dehydrogenation into formaldehyde
- Reaction catalysed by Na around **800°C**!
- Inlets / outlets must be at ca. **300°C** (Na vapour)!
- Thick-film packaging



4. Definition of channels (thick-film)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

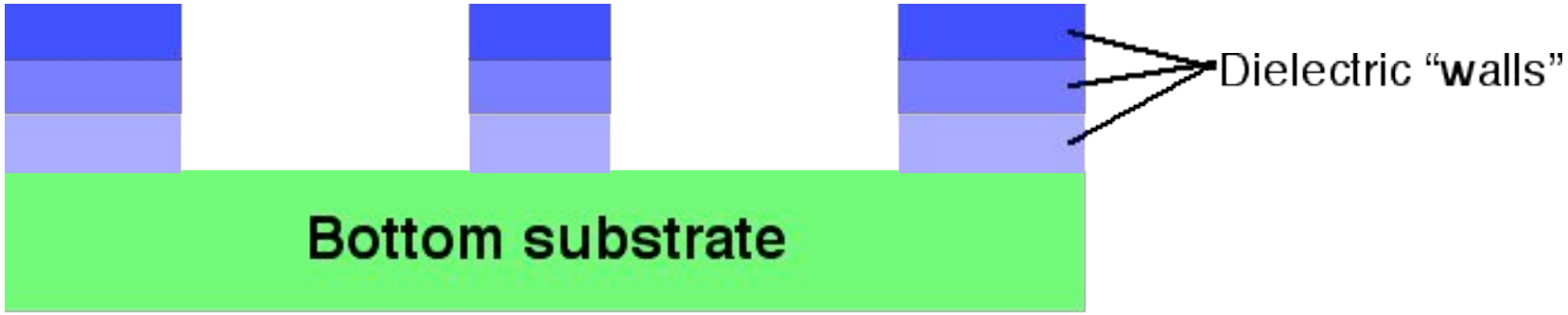
Bottom substrate

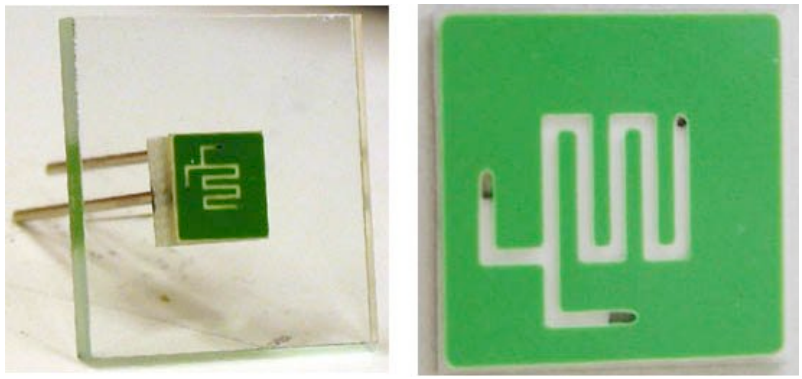


(M.-A. Schneider - 2004)

- Alumina bottom substrate
- Walls built-up by thick-film dielectric
- Final layer = sealing glass
- Glass sealing of top substrate
- Also “old” technique for microreactors

4. Definition of channels (thick-film)





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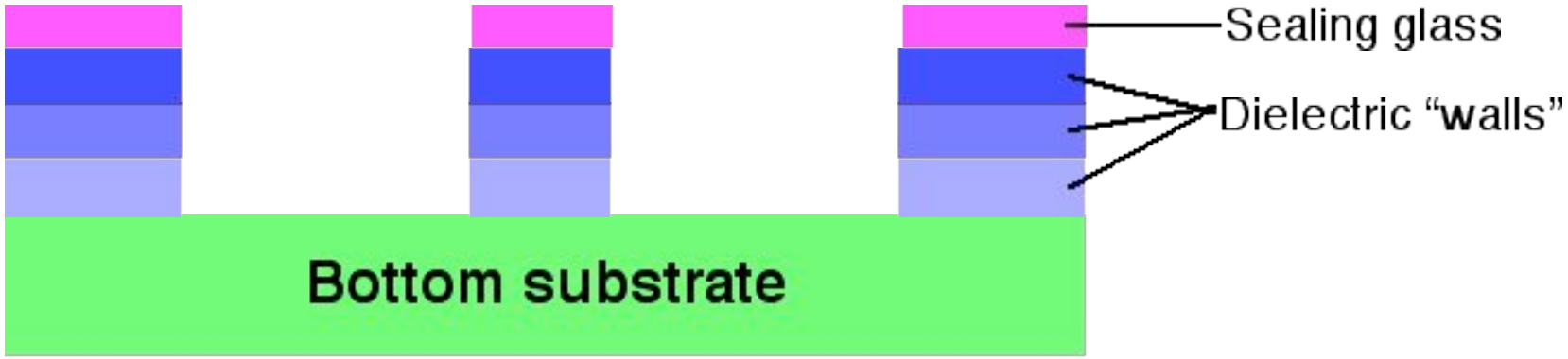

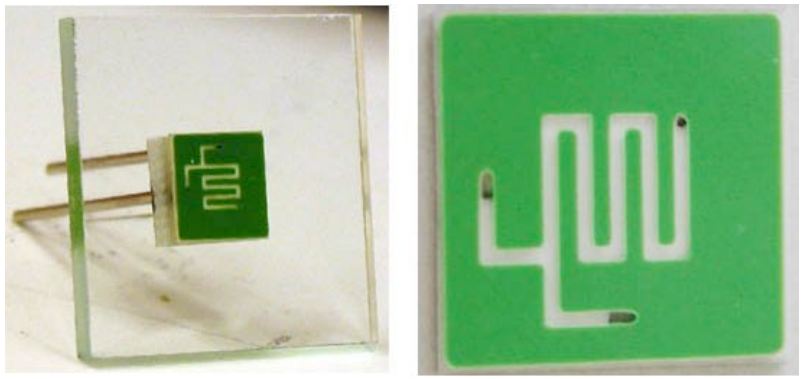

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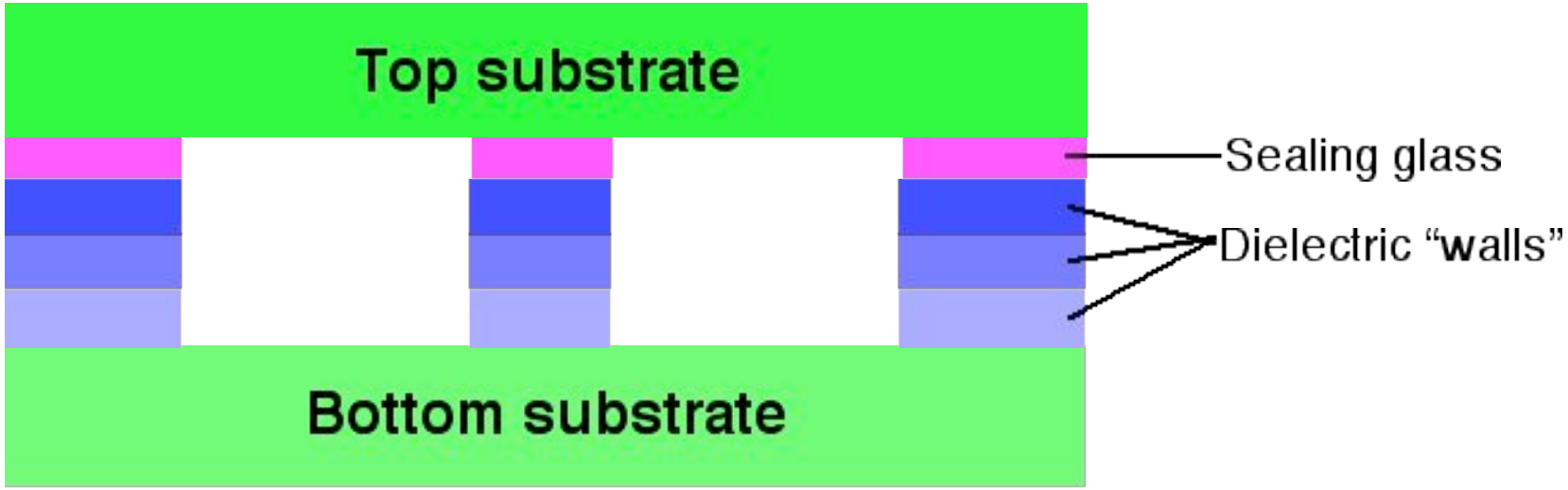

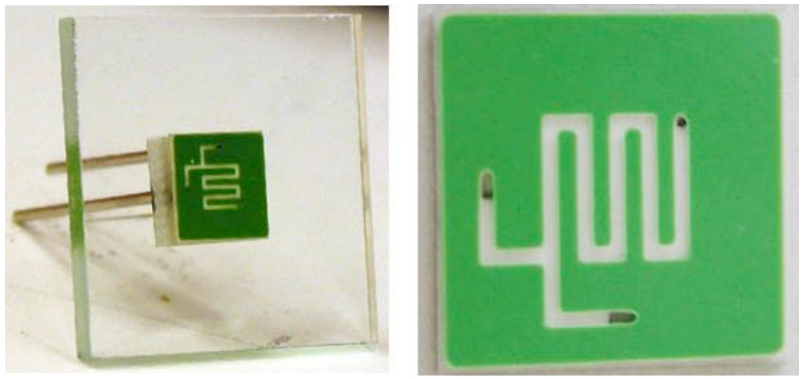

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(M.-A. Schneider - 2004)

4. MEMS µ-reactor - conclusions

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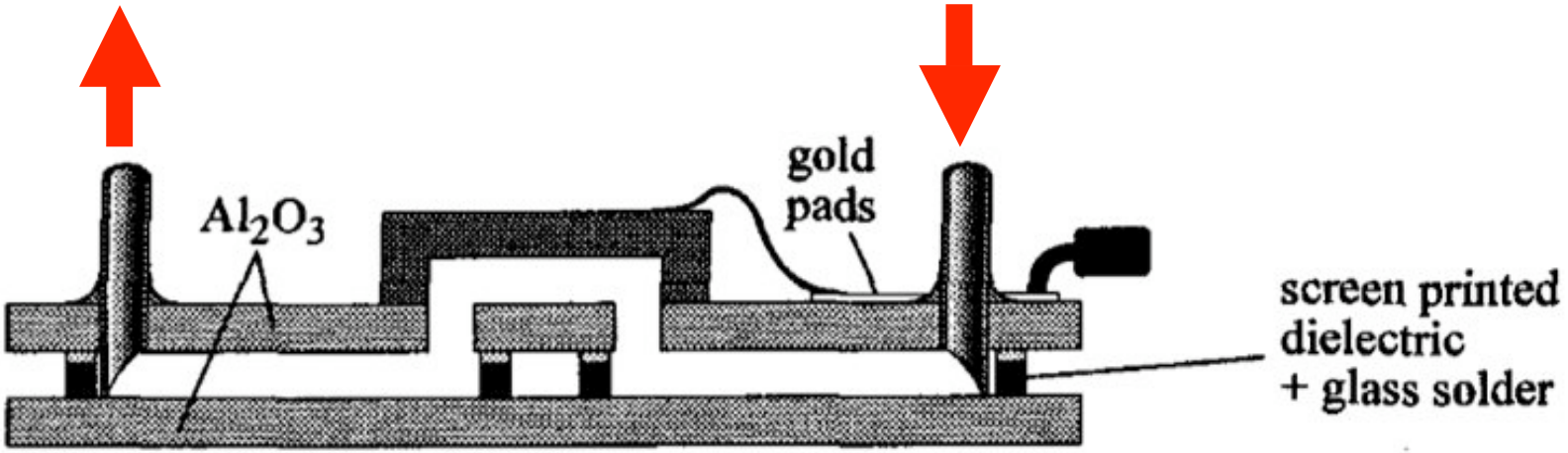
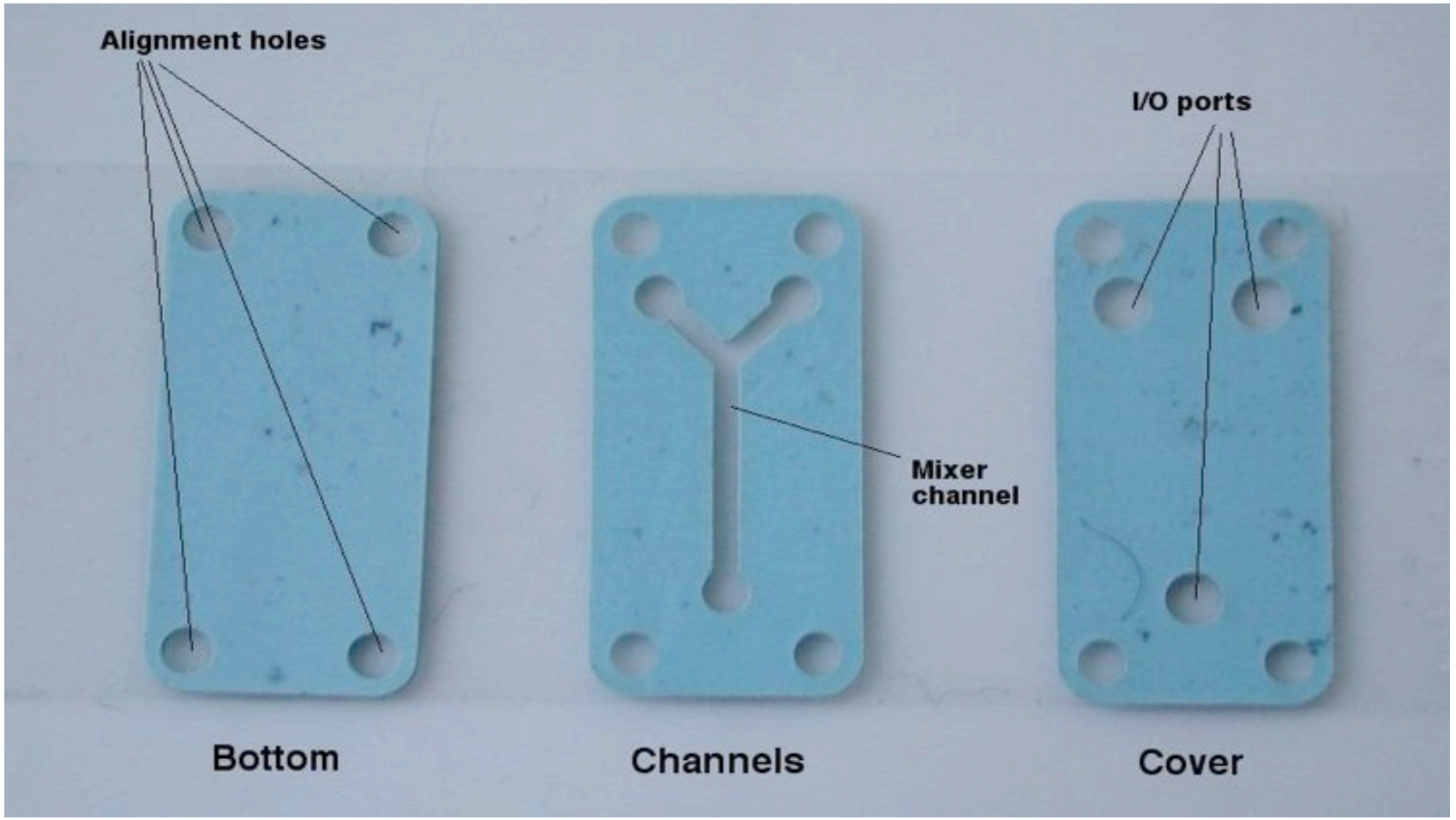
- Medium temperature (300°C) thick-film packaging developed
- Replaced PCB with insufficient thermal stability
- Some stress problems with MEMS mounting
- Would use LTCC today (more suited for fluidics)



5. LTCC microreactor

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

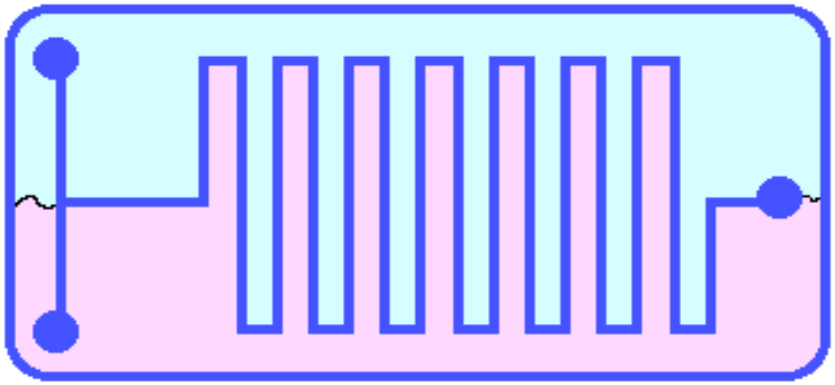
A simple LTCC micromixer



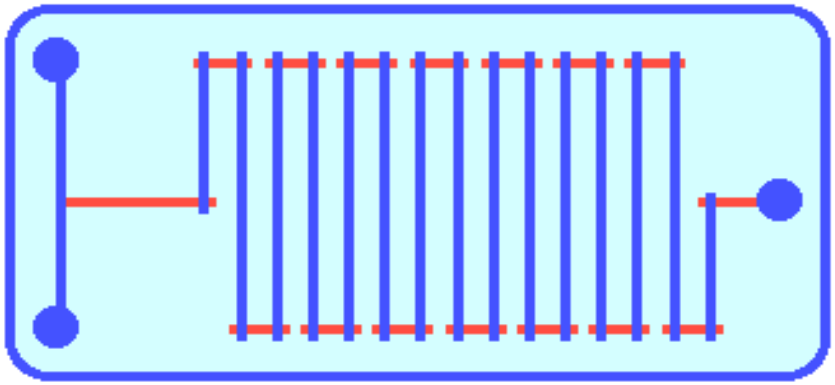
5. LTCC microreactor

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Fabrication of complex LTCC fluidics



- LTCC sheet weak
- Strong risk of clogging



- LTCC sheet stronger
- Less risk of clogging

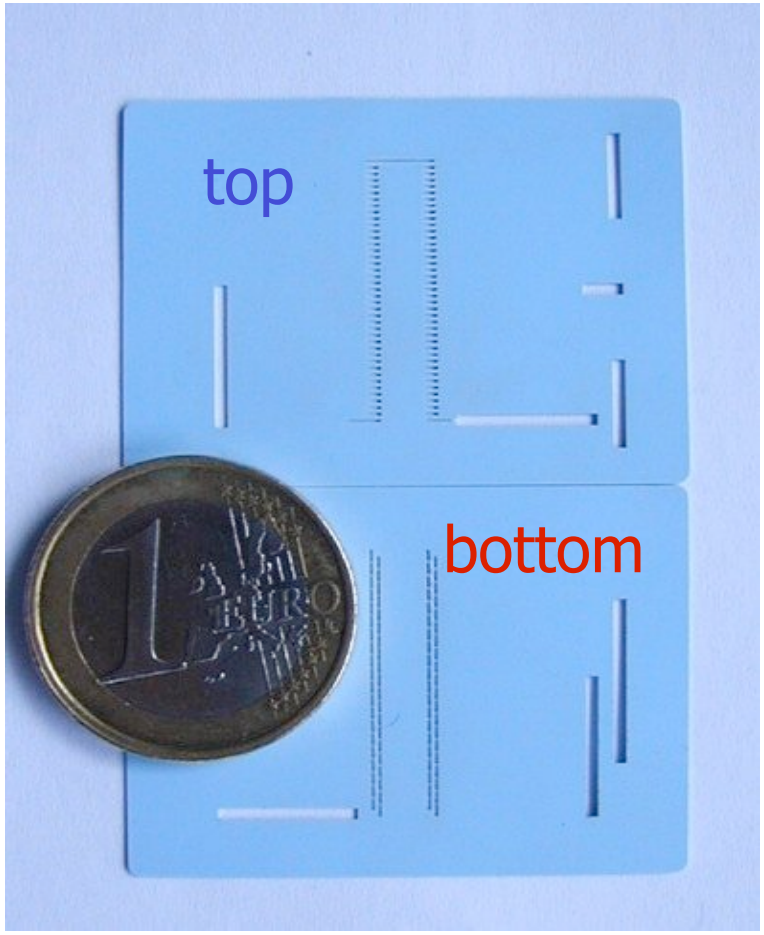
Sheet 1 (top)
Sheet 2 (bottom)

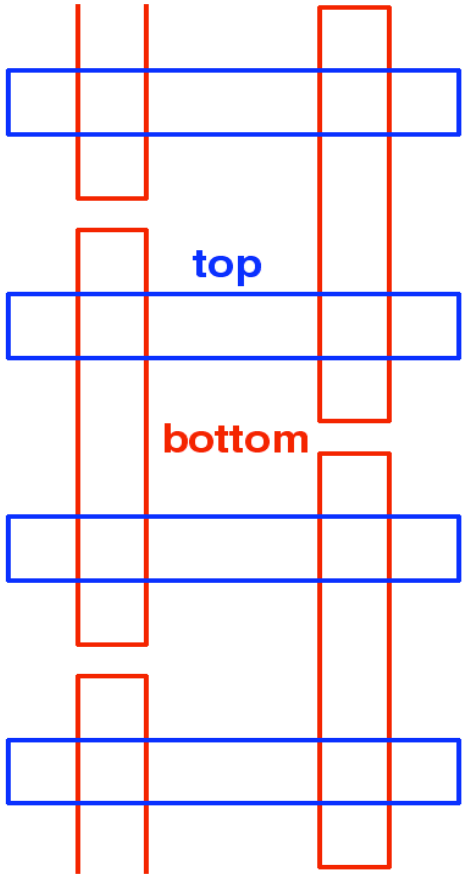
⇒ Avoid long, narrow & windy cuts!

5. LTCC microreactor

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Complex mixer by cutting

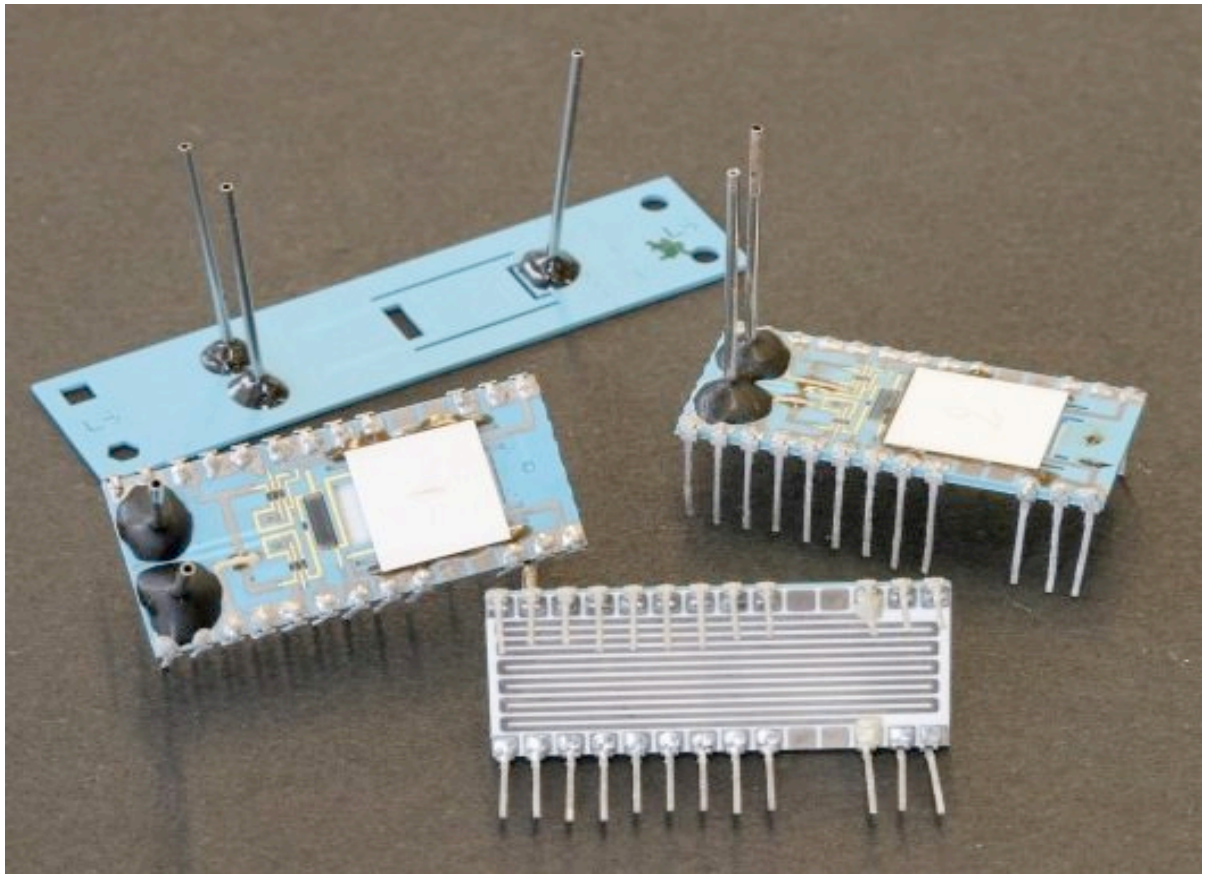




Mengeaud, EPFL 2002

- "Zig-zag" mixer
- Preserves integrity of LTCC layers

5. Chemical microcalorimeter (1/7)



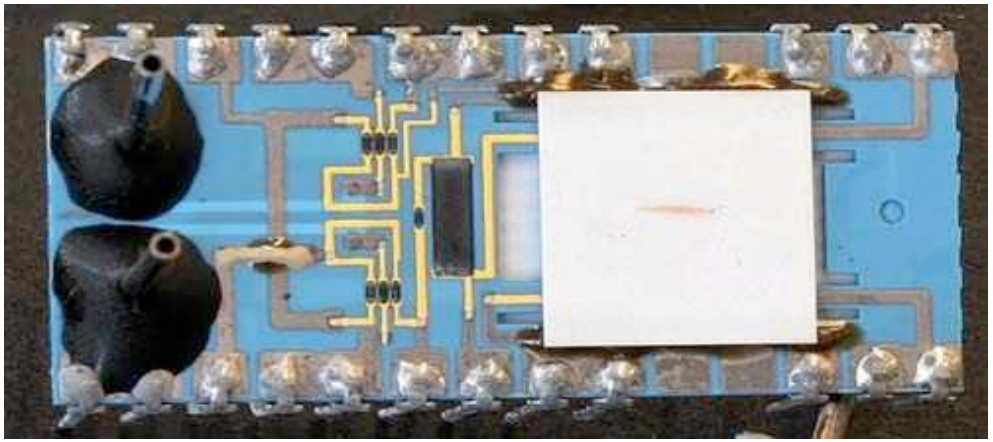
Features:

- DIL-24 package
- Global heating track
- Inlet pre-heating zones (meanders)
- Thermally insulated reaction zone
- Microcalorimeter with calibration heater
- Separate flow sensor for each inlet

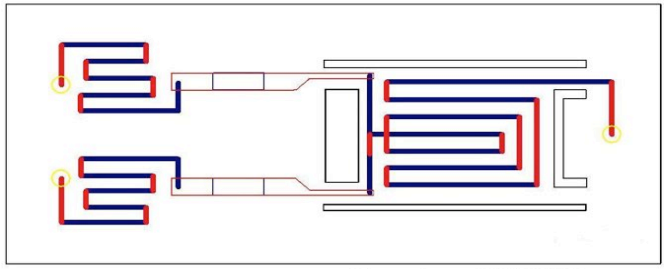
Willigens, 2005

5. Chemical microcalorimeter (2/7)

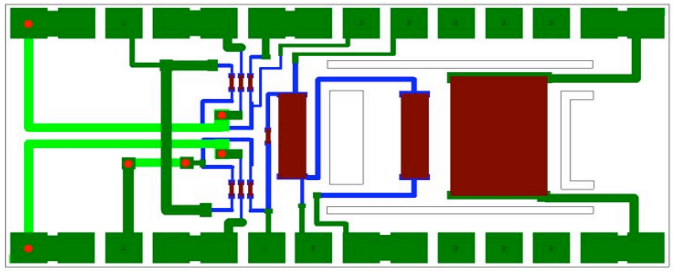
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

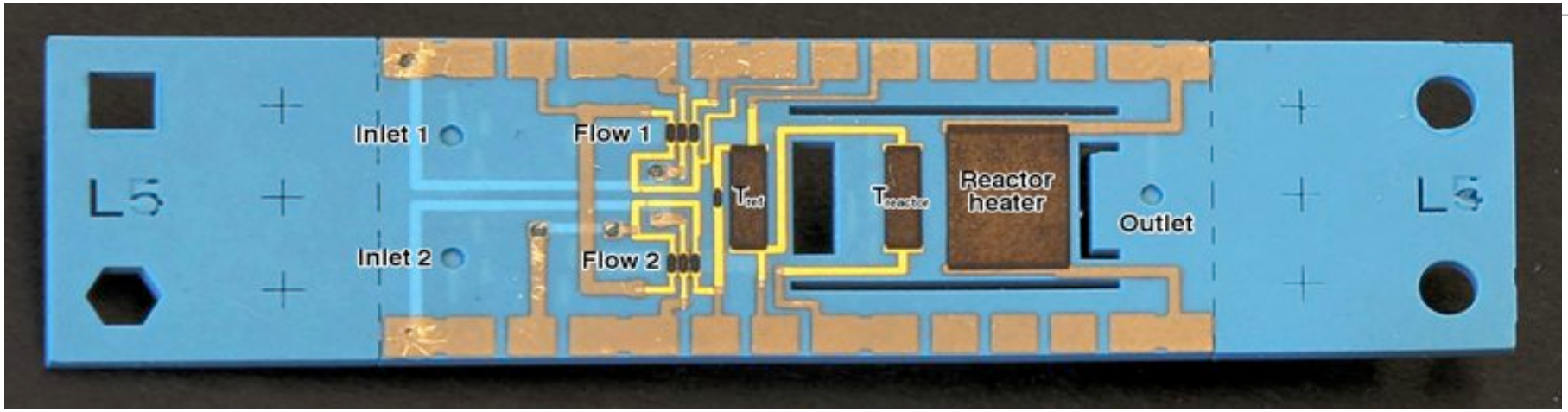


Fluidic layout



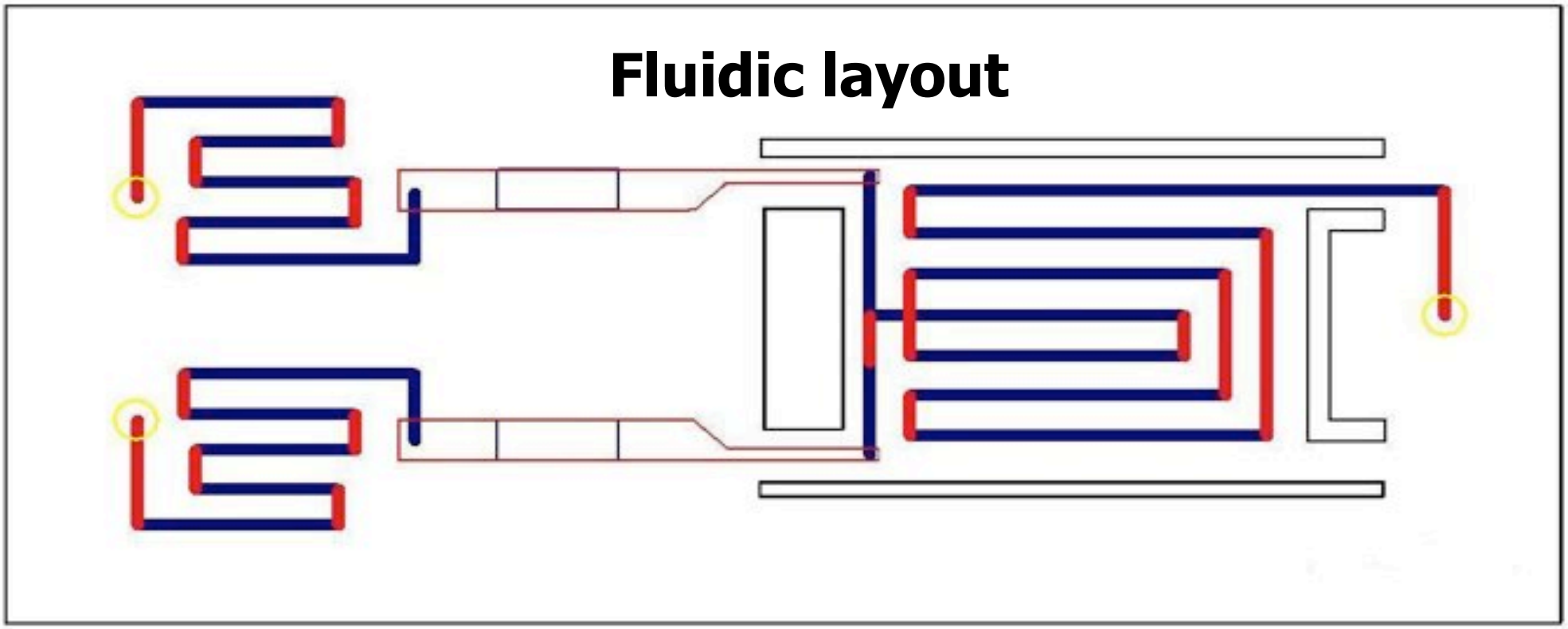
Electrical layout





5. Chemical microcalorimeter (3/7)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



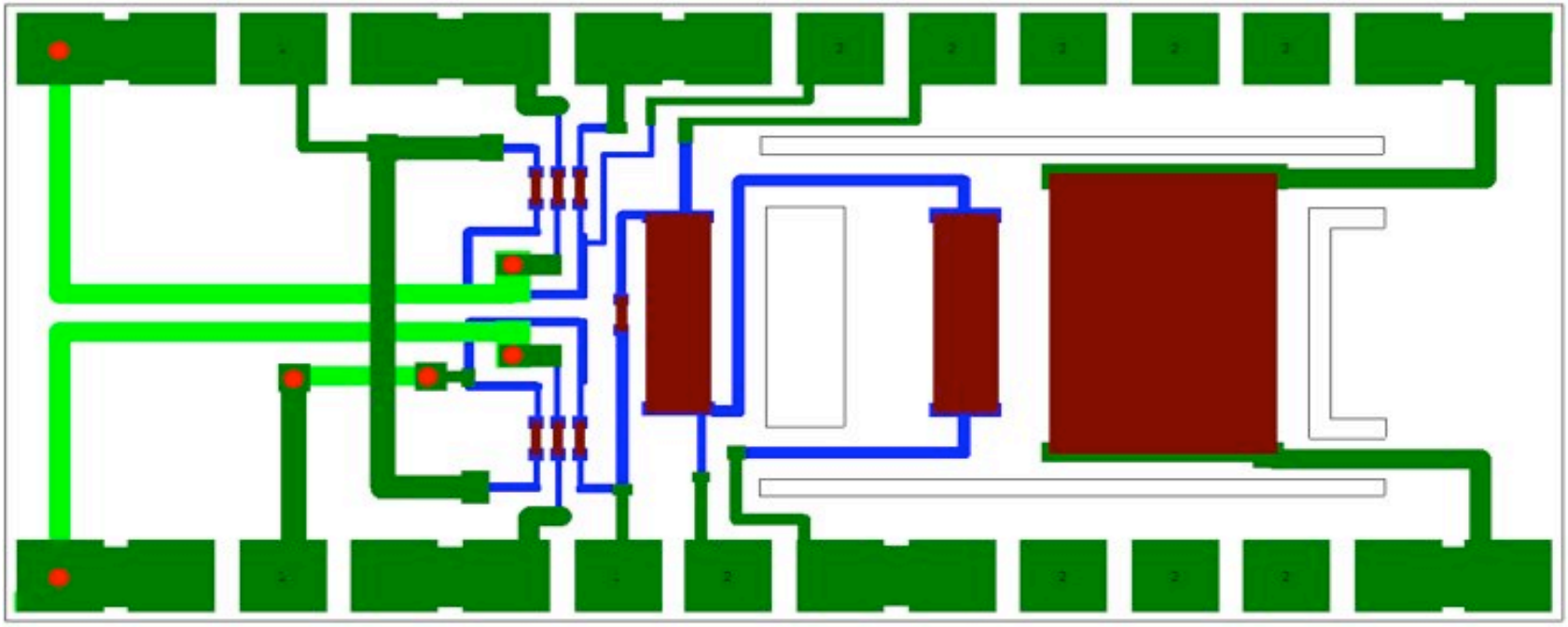
Preheating zone

Flowmeters

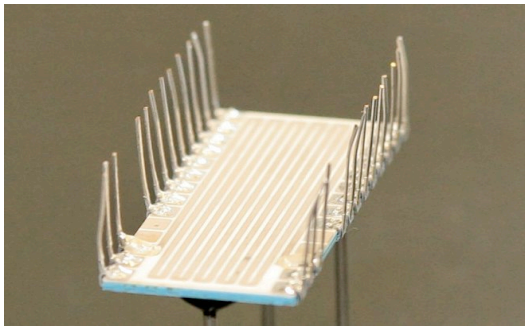
Reactor

5. Chemical microcalorimeter (4/7)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



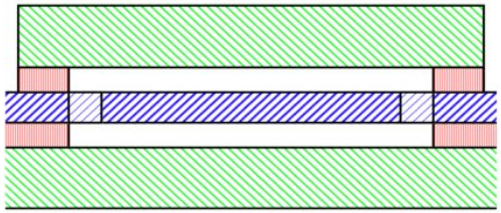
Flowmeters **Reactor** 5mm



Electrical layout

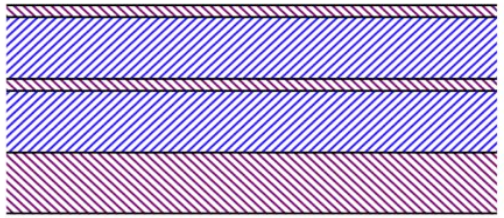
<- General heating + DIL-28 package

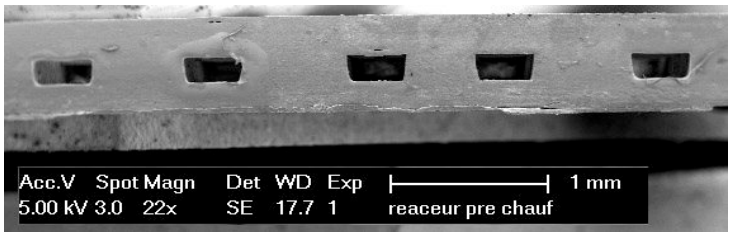
5. Chemical microcalorimeter (5/7)



Global layers

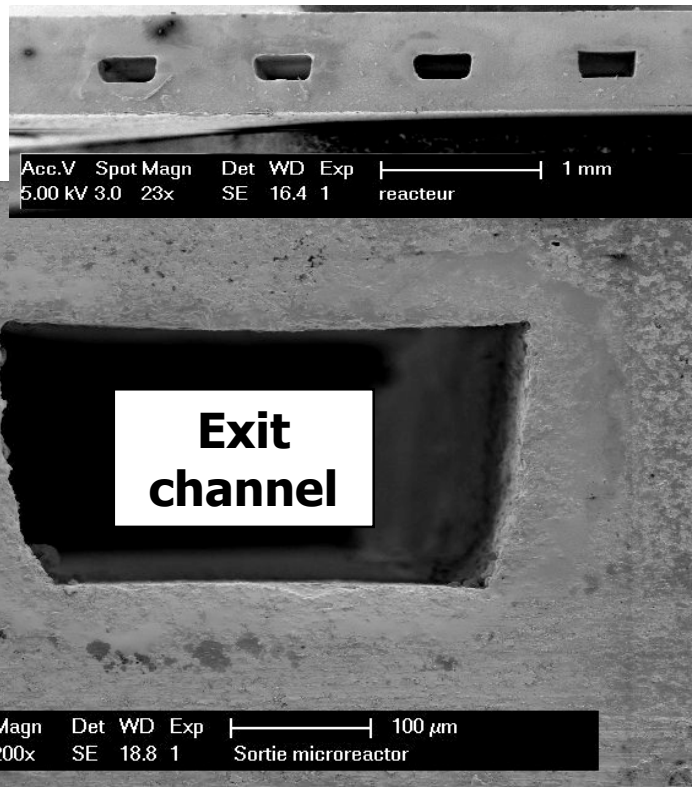
5 LTCC layers

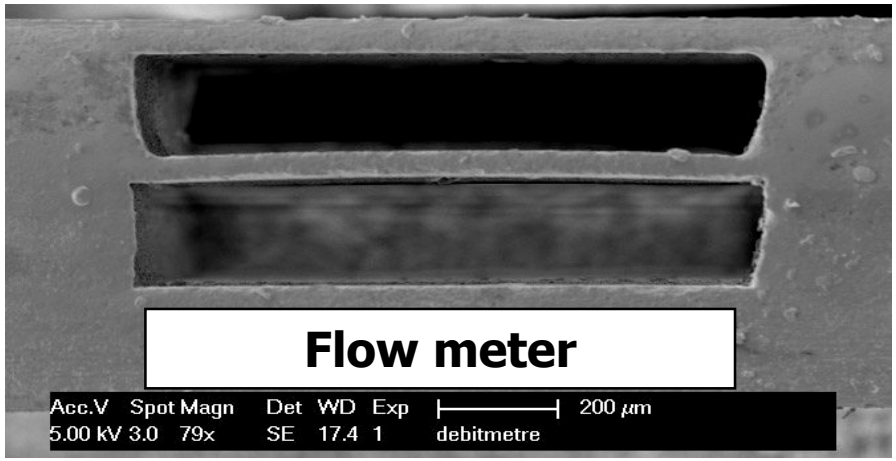




Pre-heating

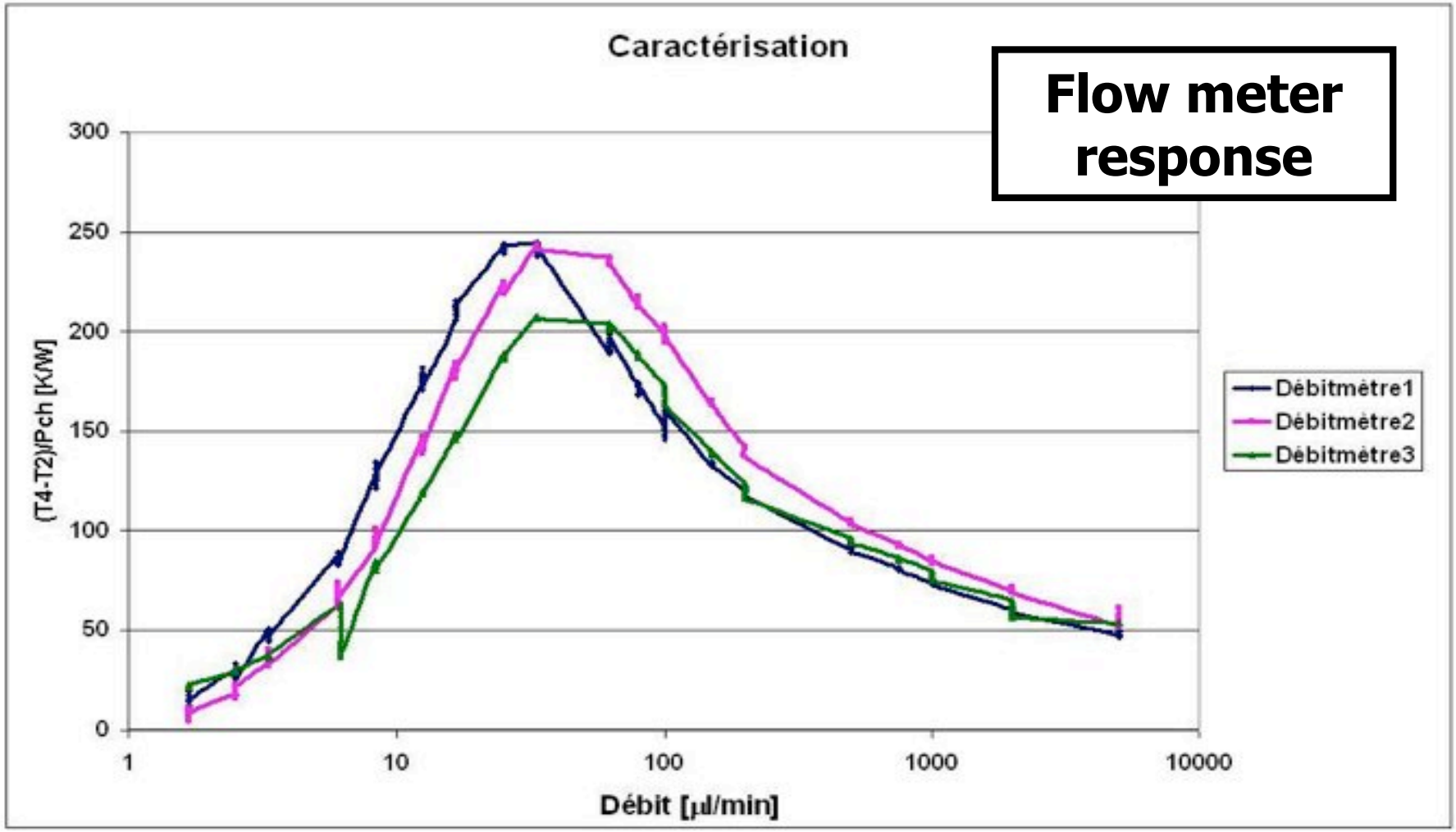
Reaction zone





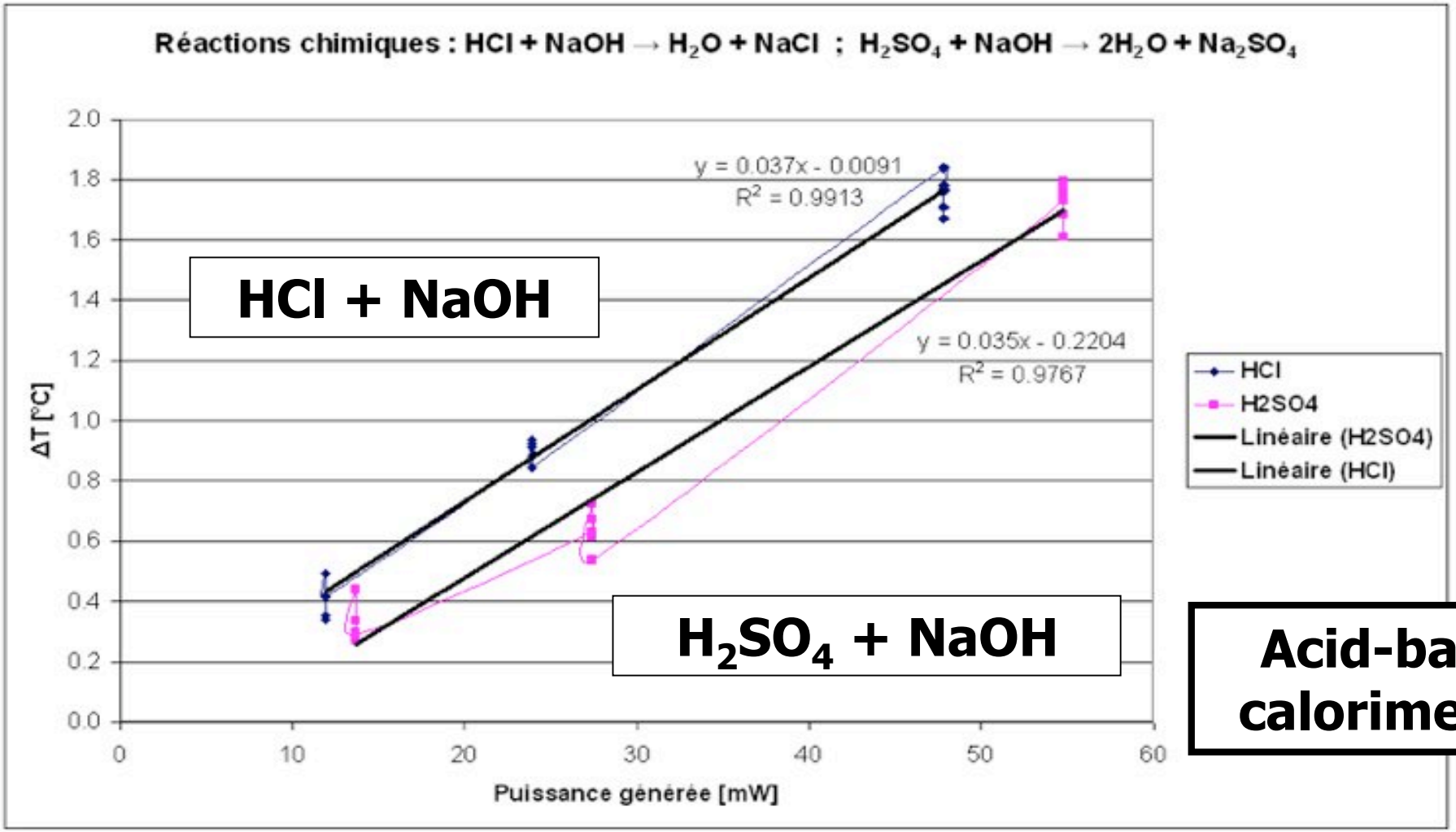
5. Chemical microcalorimeter (6/7)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



5. Chemical microcalorimeter (7/7)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



Acid-base calorimetry

6. Conclusions & outlook

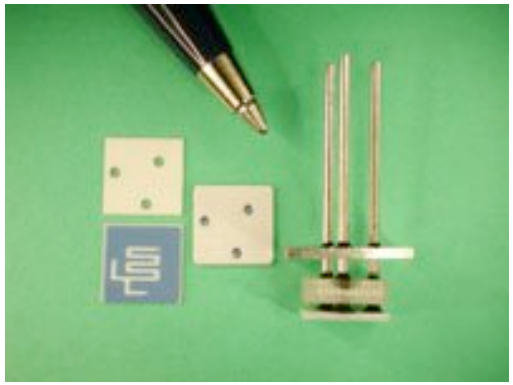
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

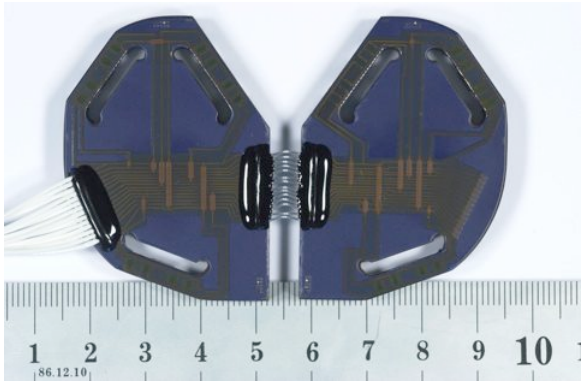
- Proven materials (automotive, aerospace & telecom)
- Very good thermal & chemical stability
- For both sensor & packaging application

- **Many promising development areas:**
  - MEMS packaging & interconnects @ high temperature
  - Interconnects for high-temperature (sensor) electronics
  - LTCC structuration for micromechanical devices
  - LTCC fluidics

Merci

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE





Thank you !