

# Structuration of LTCC for integrated fluidics and micromechanical devices

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# Outline

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**Introduction**

**Common technological issues**

**Devices**

**Microreactors & mixers - shaping of LTCC**

**Membranes & “resistors” - C sacrificial layers**

**Force sensors - shaping of LTCC**

**Conclusions**

## 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 +  $\text{Al}_2\text{O}_3$  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.

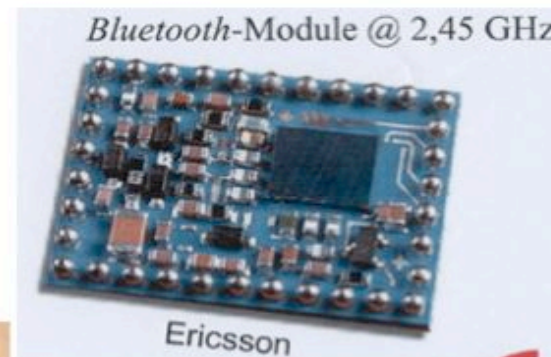
# Application examples



Source: Prismark/Binghamton University

## EPCOS FRONT END MODULE

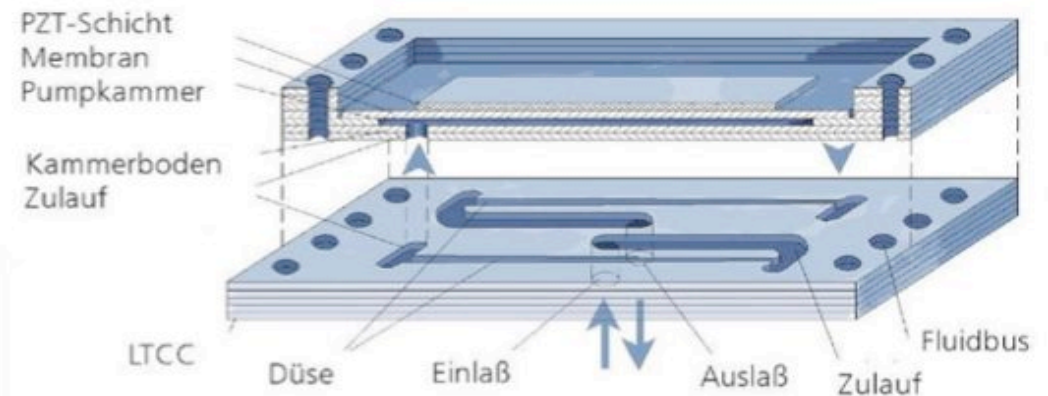
- Key component in new Nokia mobile phone architecture
- Integrates duplexer, switching, LC and SAW filters
- Analysis of LTCC integrates passives and SAW filter packages



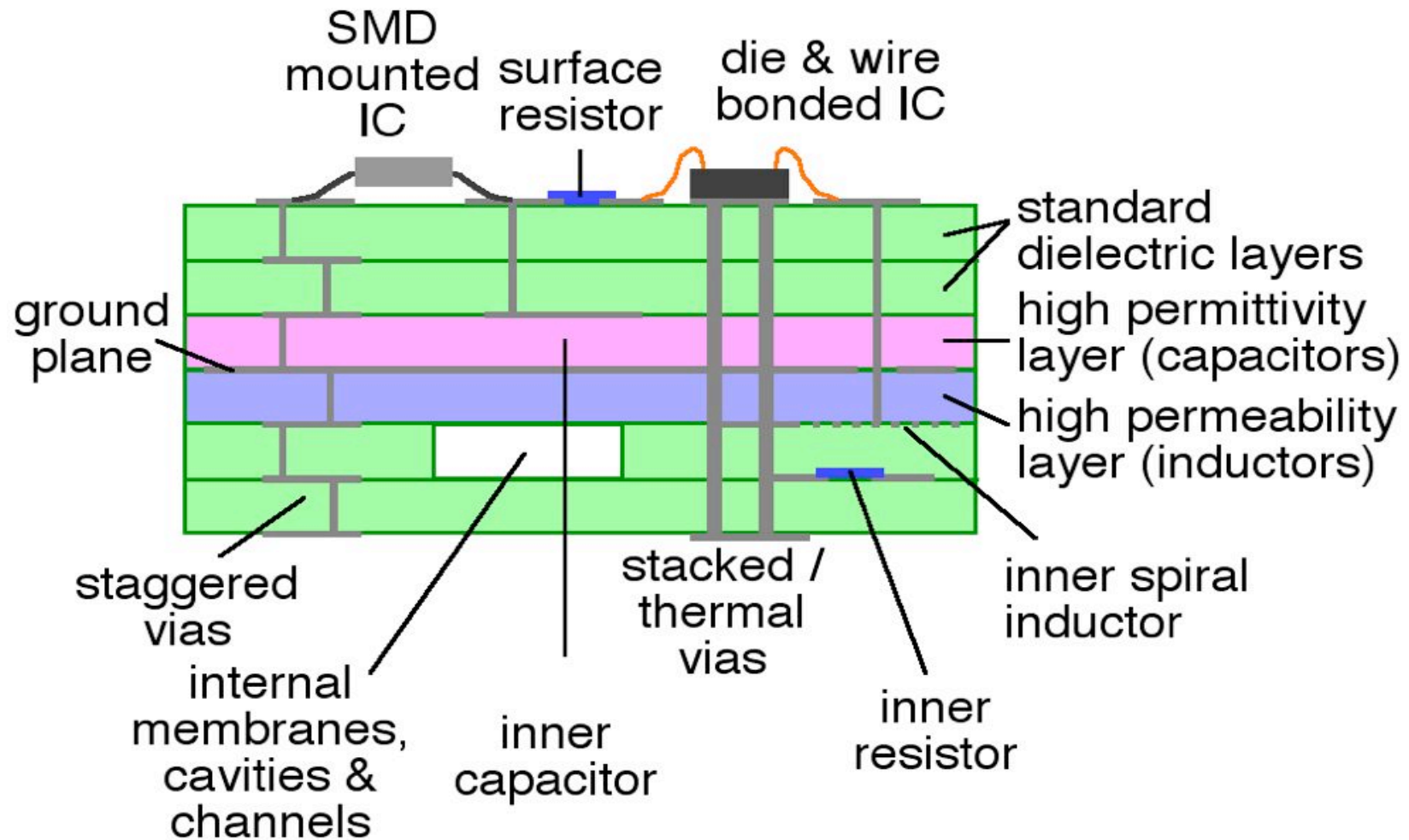
Ericsson



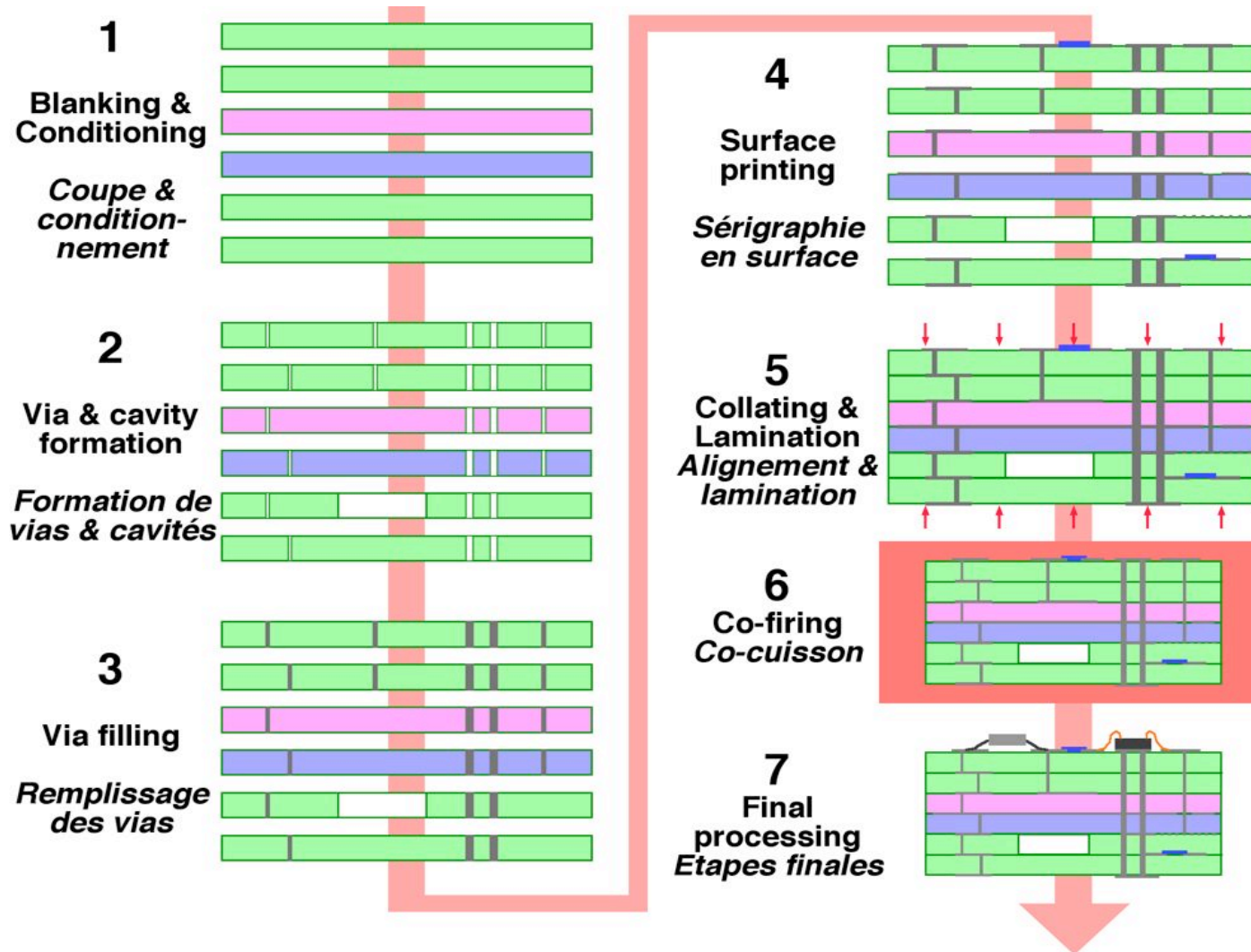
Via-Electr.: RADAR-Module



# 3-D structuration of LTCC



# LTCC manufacturing process





# Processing - advantages

➔  $T_{\text{firing}} < 900^{\circ}\text{C}$  --> allows use of silver conductors

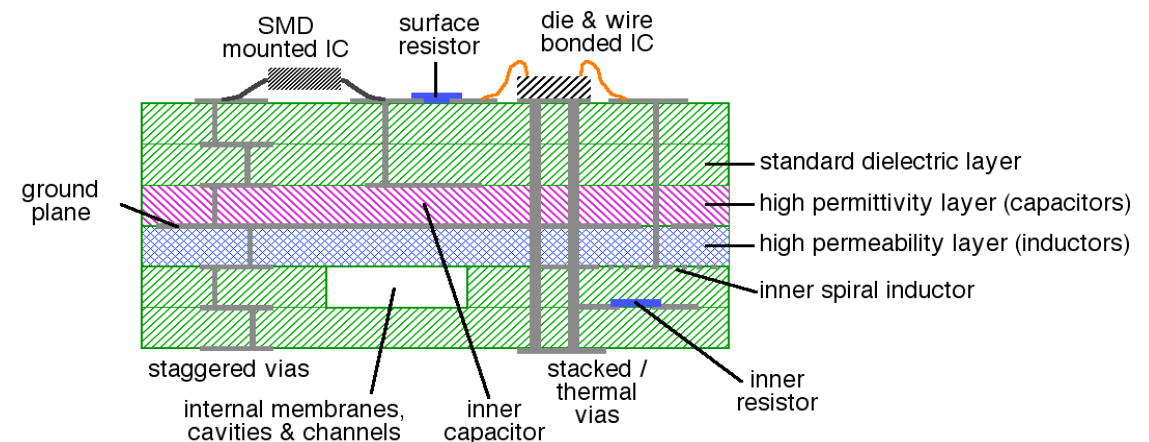
➔ High-density packaging

➔ 3-D structuration

➔ Hermetic structures

➔ Reliable mechanical, thermal and electrical performance

➔ High volume, low cost fabrication



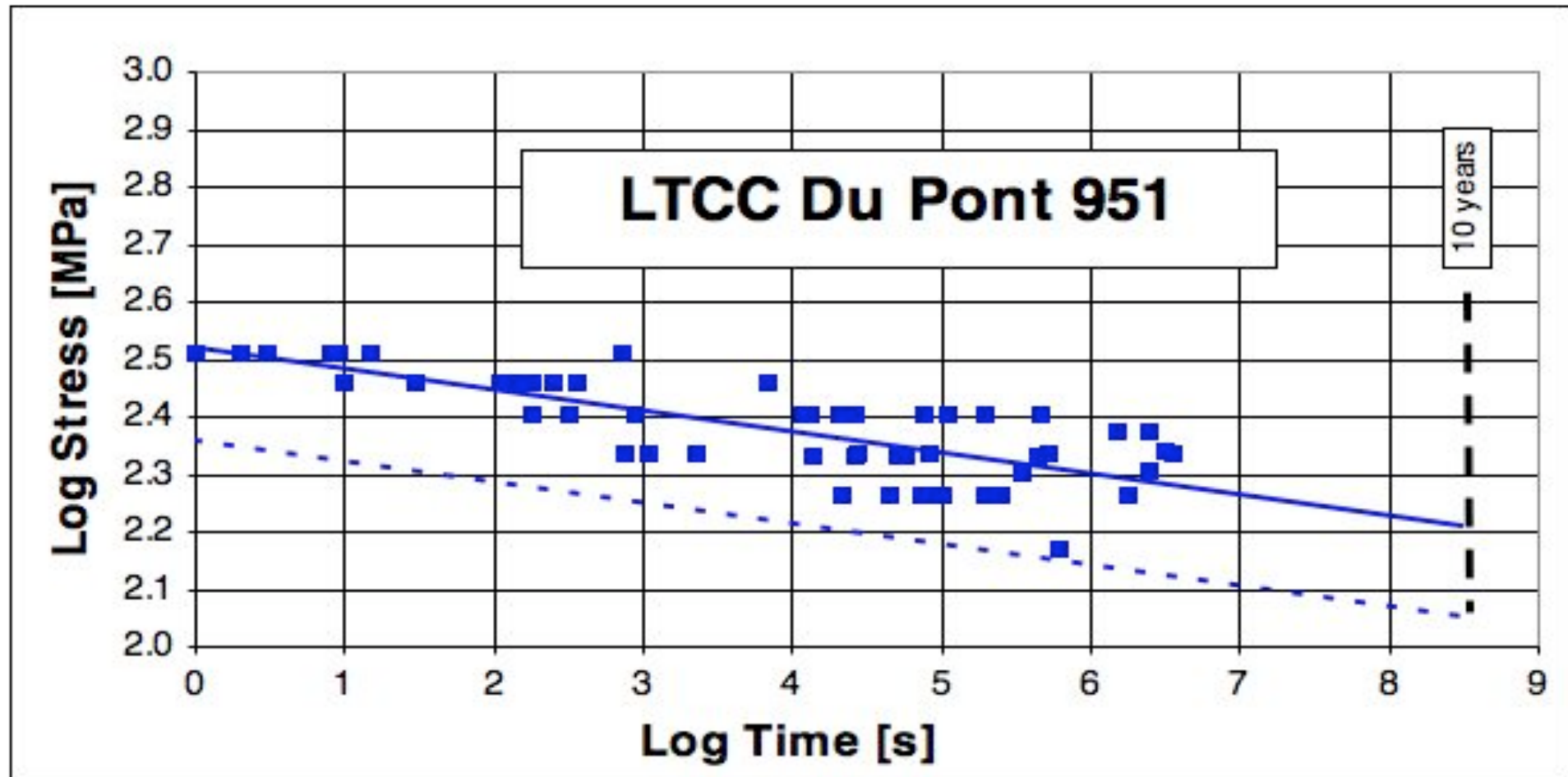
# LTCC vs. alumina

Material	LTCC (DP 951)	Al <sub>2</sub> O <sub>3</sub> (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 <sup>-1</sup> ]	5.68	0.11	53
Thermal resistance [K/W]	8'333	235	35

> Thermal, low-range mechanical sensors

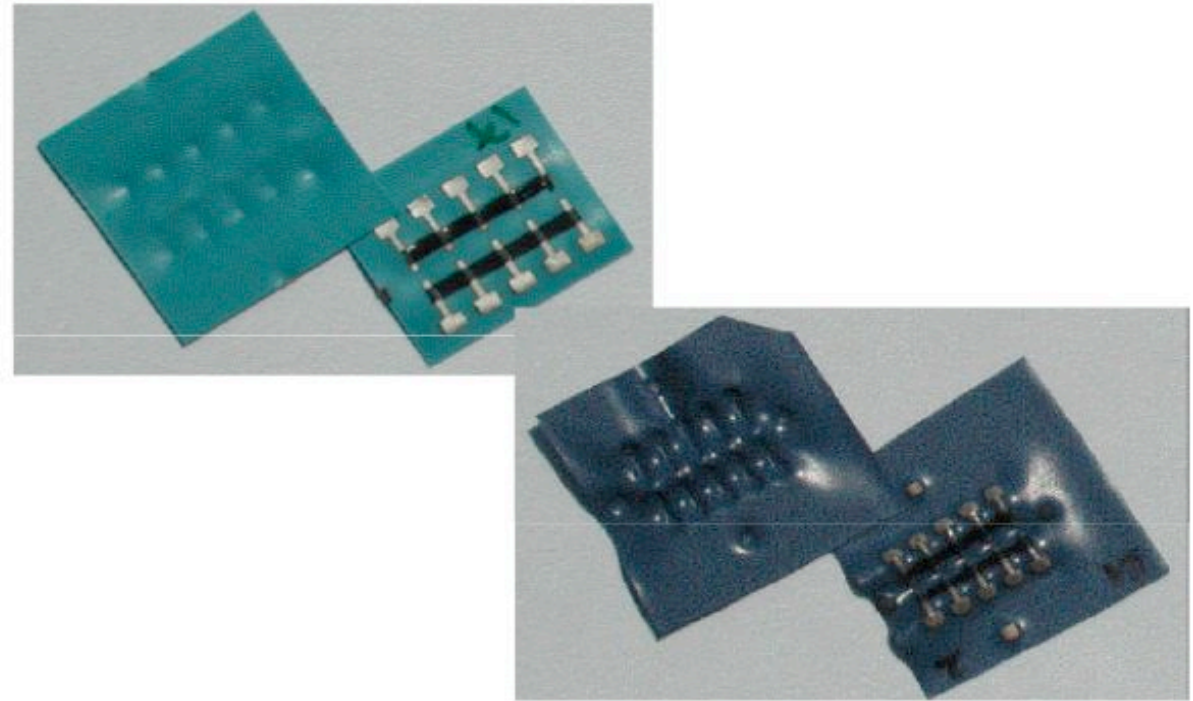
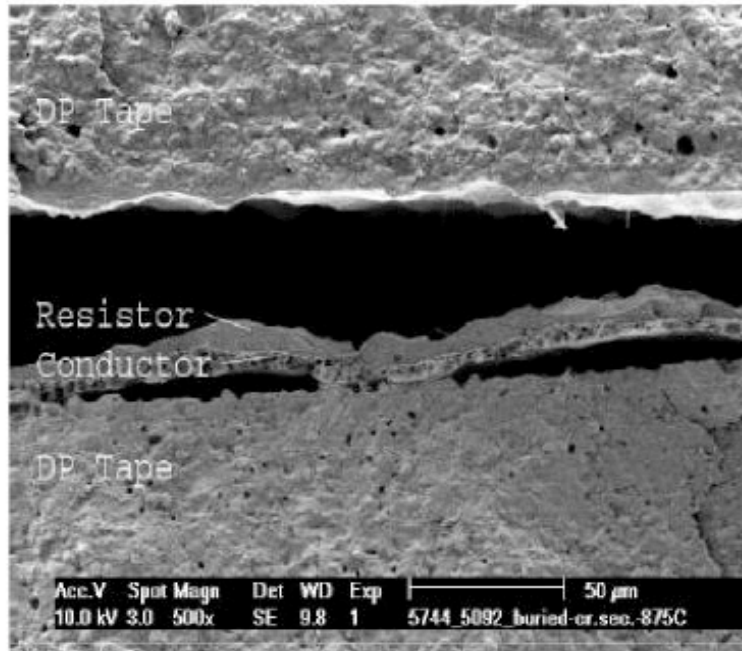


# Design stress - static fatigue



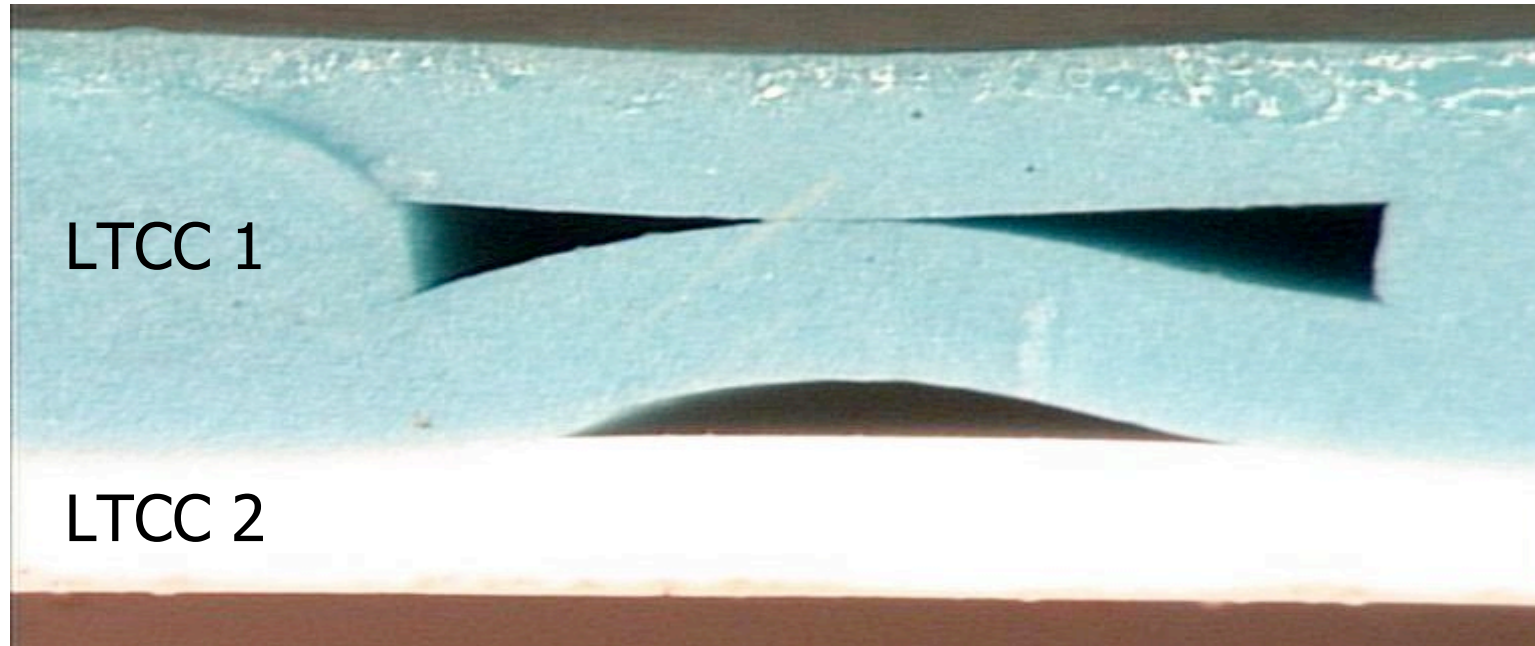
Maeder et al., 2005

# Physical issues during firing



- Evolution of gases during debinding
- Lamination issues (thickness of layers)
- Differential sintering shrinkage

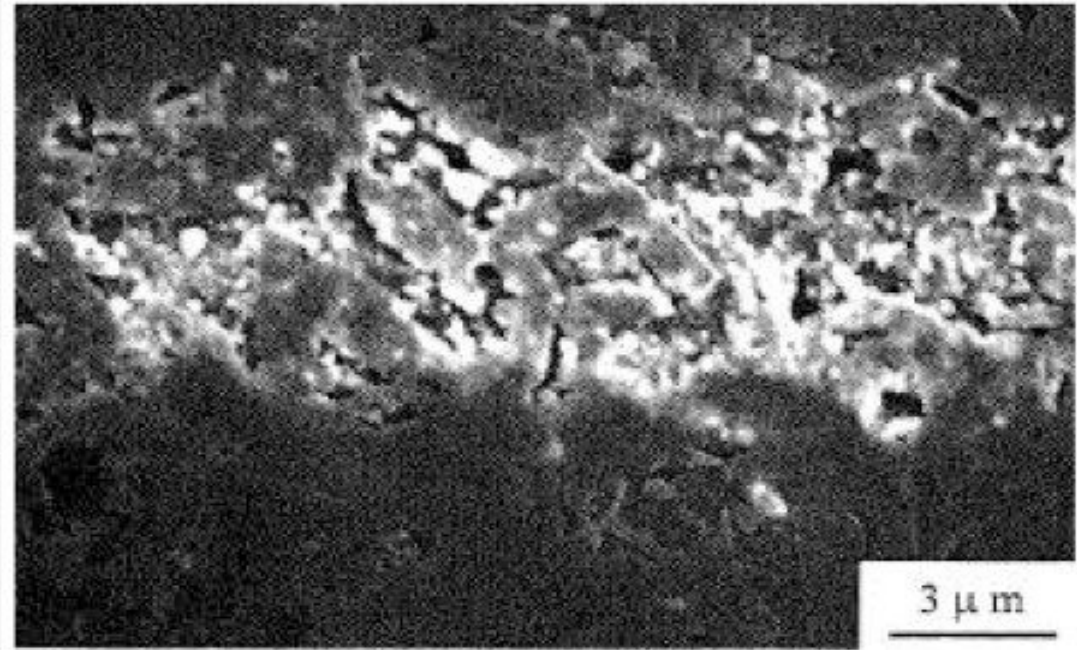
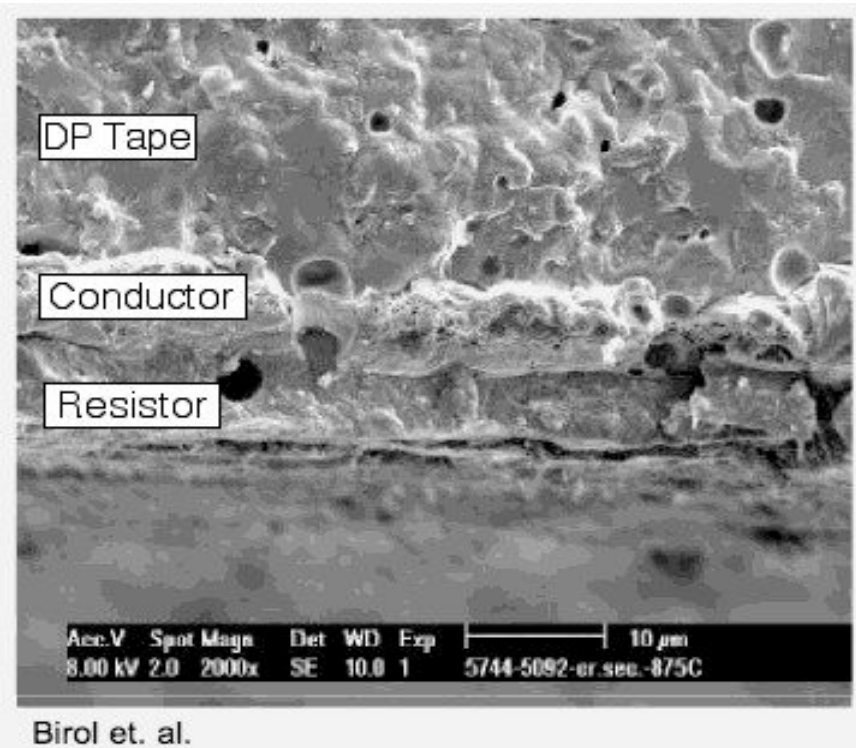
# Physical issues during firing (3)



- Channels by cutting & stacking
- Different LTCC compositions
- --> Illustration of differential shrinkage



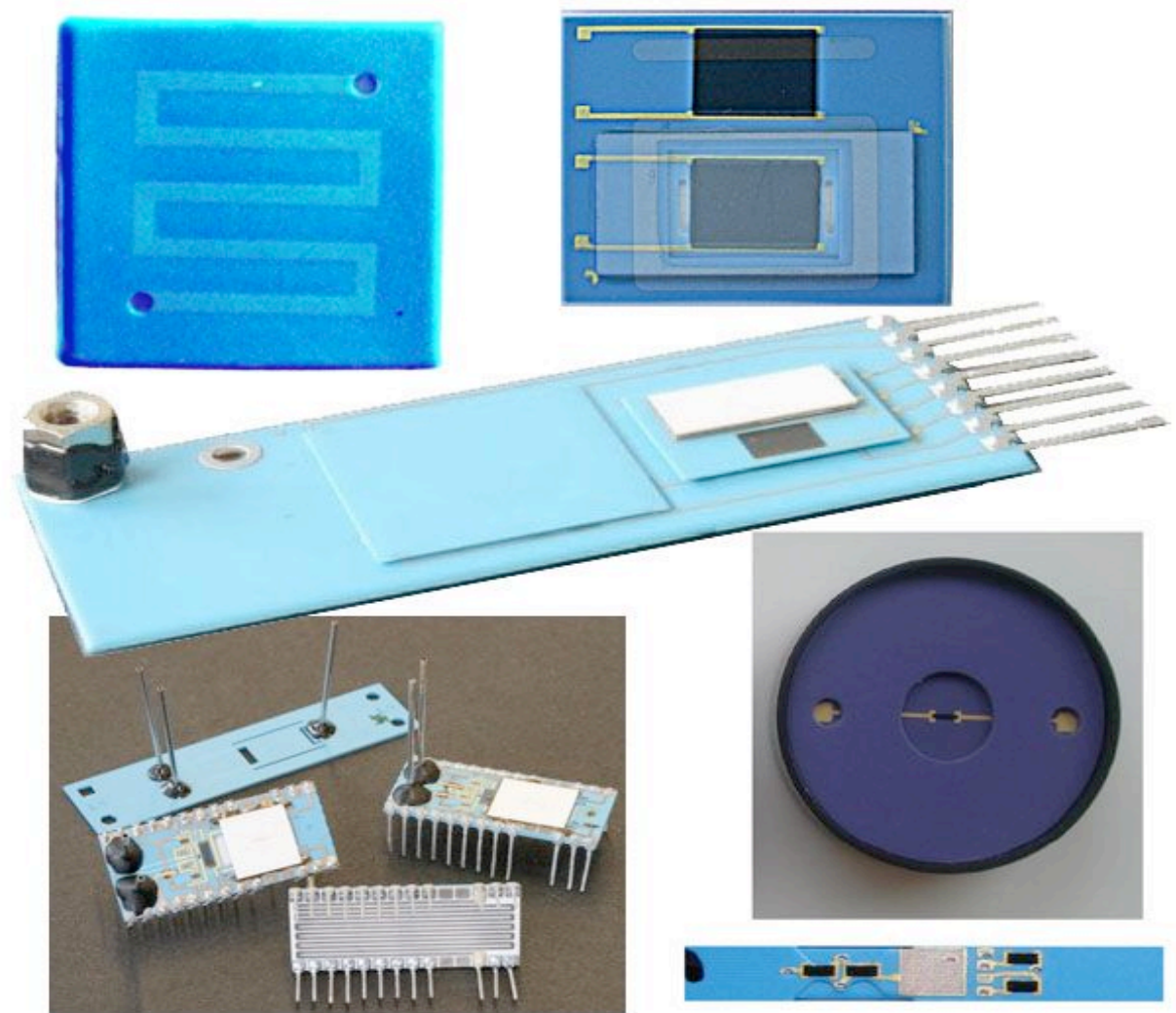
# Chemical issues during firing



- Interdiffusion of layers (esp. glass)
- Reducing / oxidising conditions

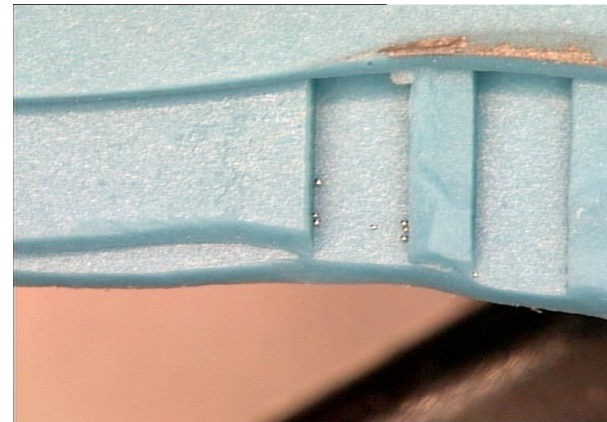
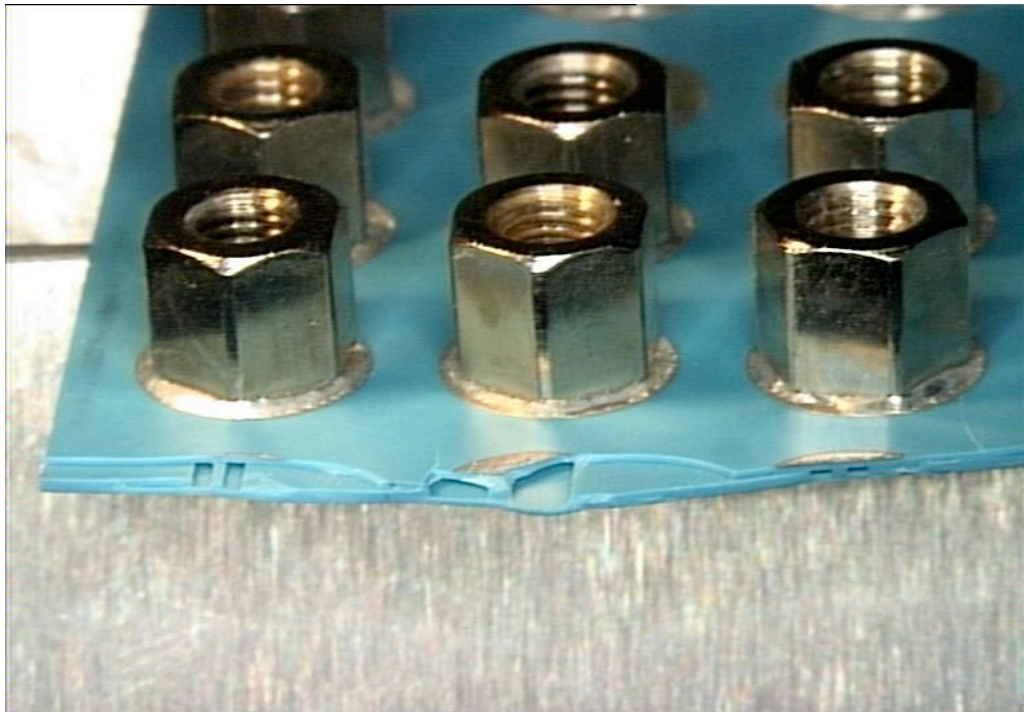
# Microfluidic & mechanical sensors

- Fluidic channels
- Heated cavities
- Reaction chambers
- Local “hot spots”
- Membranes
- Structured cantilevers
- Piezoresistive sensing





# Fluidic circuits





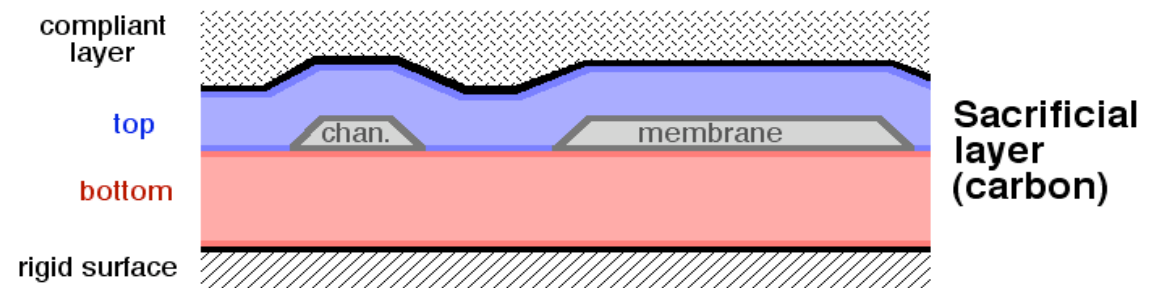
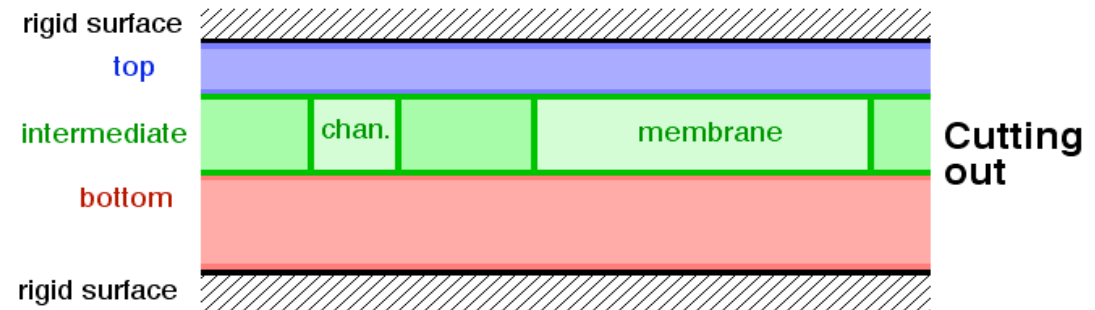
# Structuration - basics

## Features

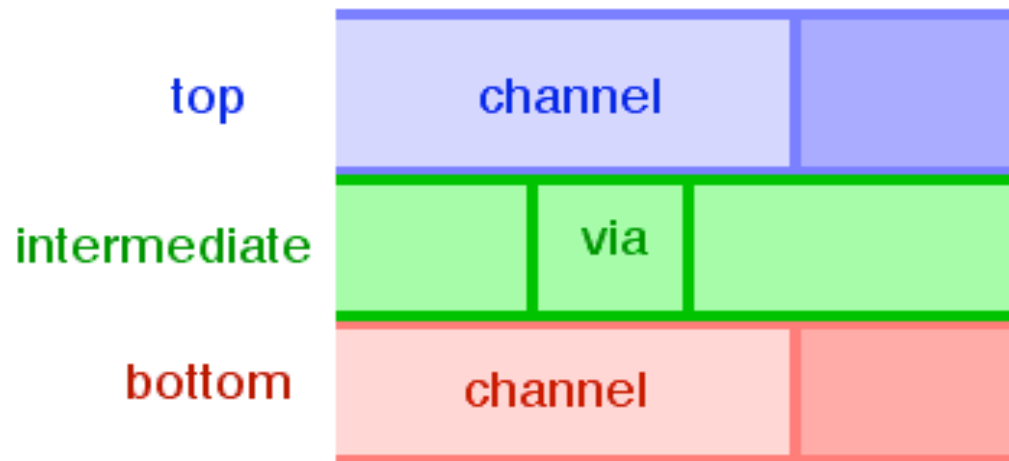
- Vias
- Channels
- Membranes
- Bridges

## Two basic types

- 1) Shaping (cutting, etc.)
- 2) Sacrificial layer



# Structuration - vias

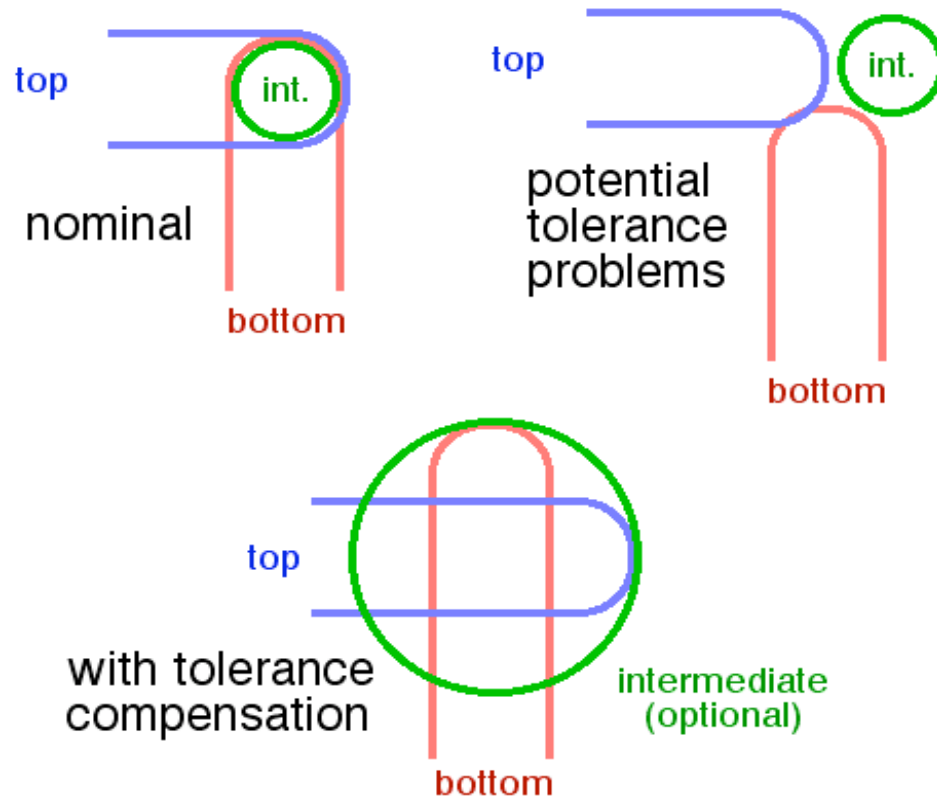


« Explicit » via using  
dedicated intermediate  
layer



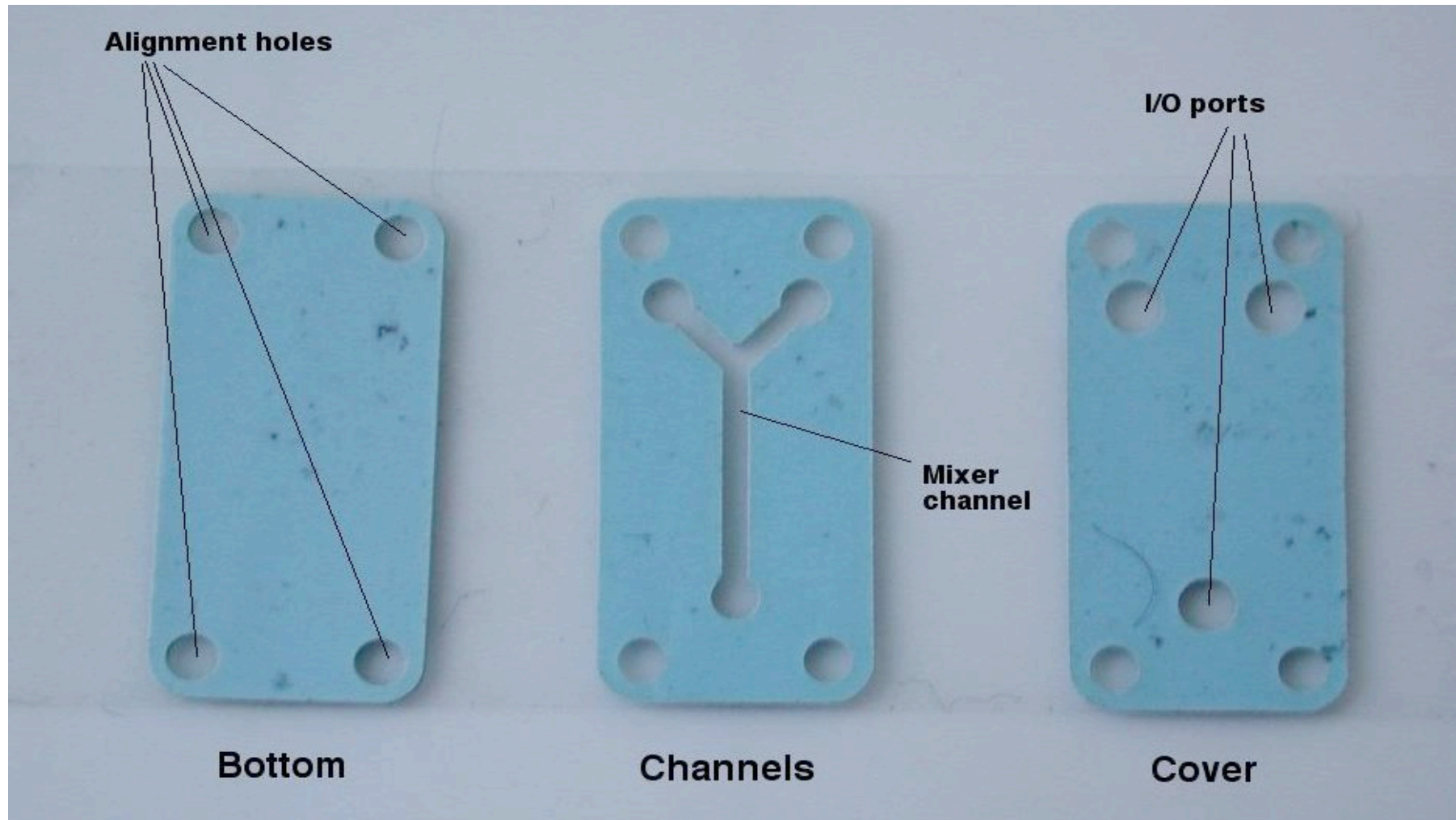
« Implicit » via between  
overlapping channels

# Structuration - alignment

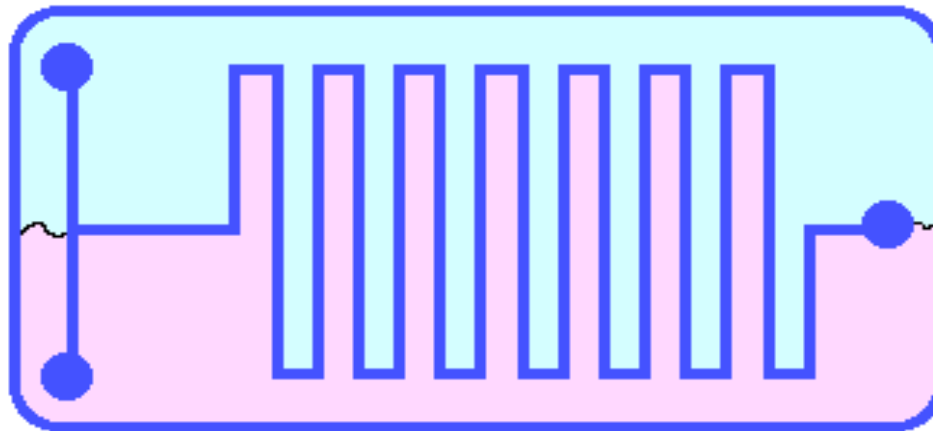


- Tolerances 50...100  $\mu\text{m}$
- Plasticity of LTCC green sheet
- Compensation needed
- Creation of parasitic dead volumes

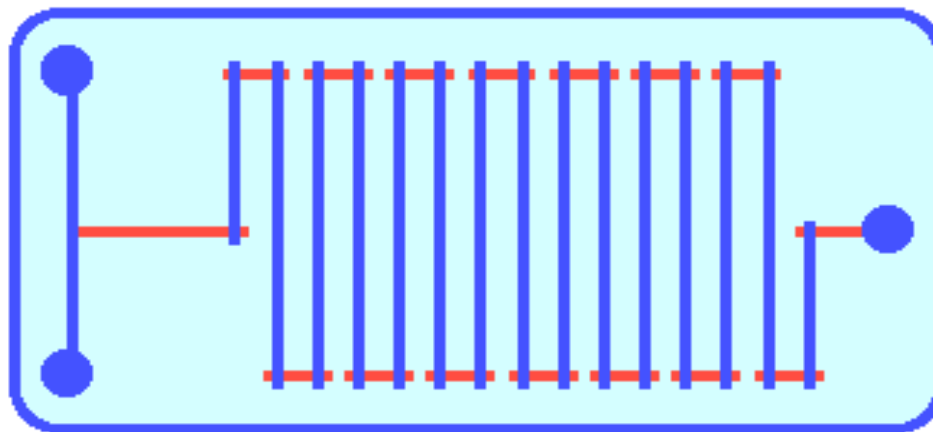
# A simple micromixer



# Fabrication of complex fluidics



- LTCC sheet weak
- Strong risk of clogging

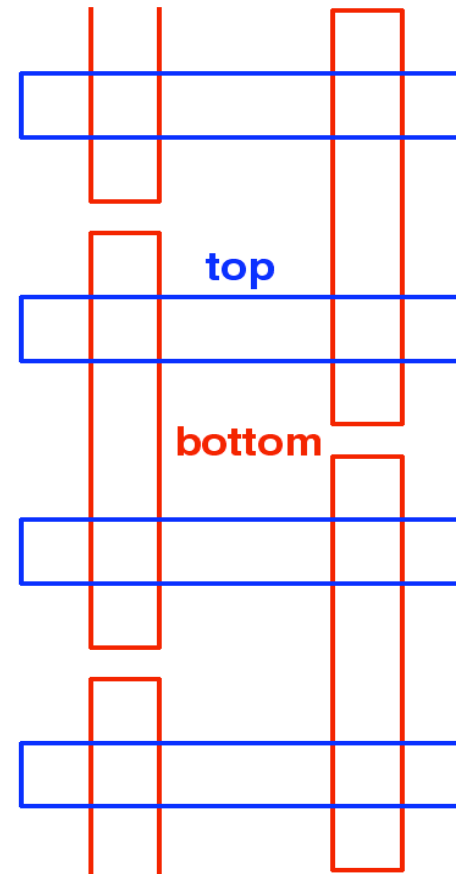
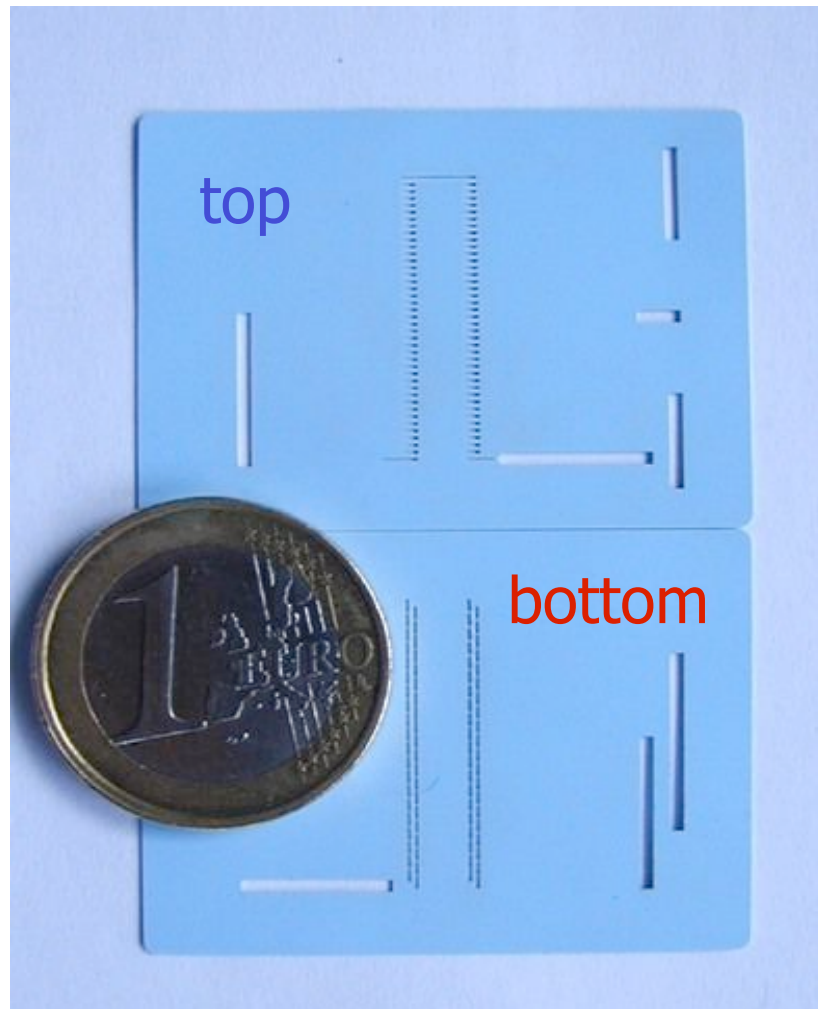


- LTCC sheet stronger
- Less risk of clogging

- Sheet 1 (top)
- Sheet 2 (bottom)

⇒ Avoid long, narrow & windy cuts!

# Complex mixer by cutting

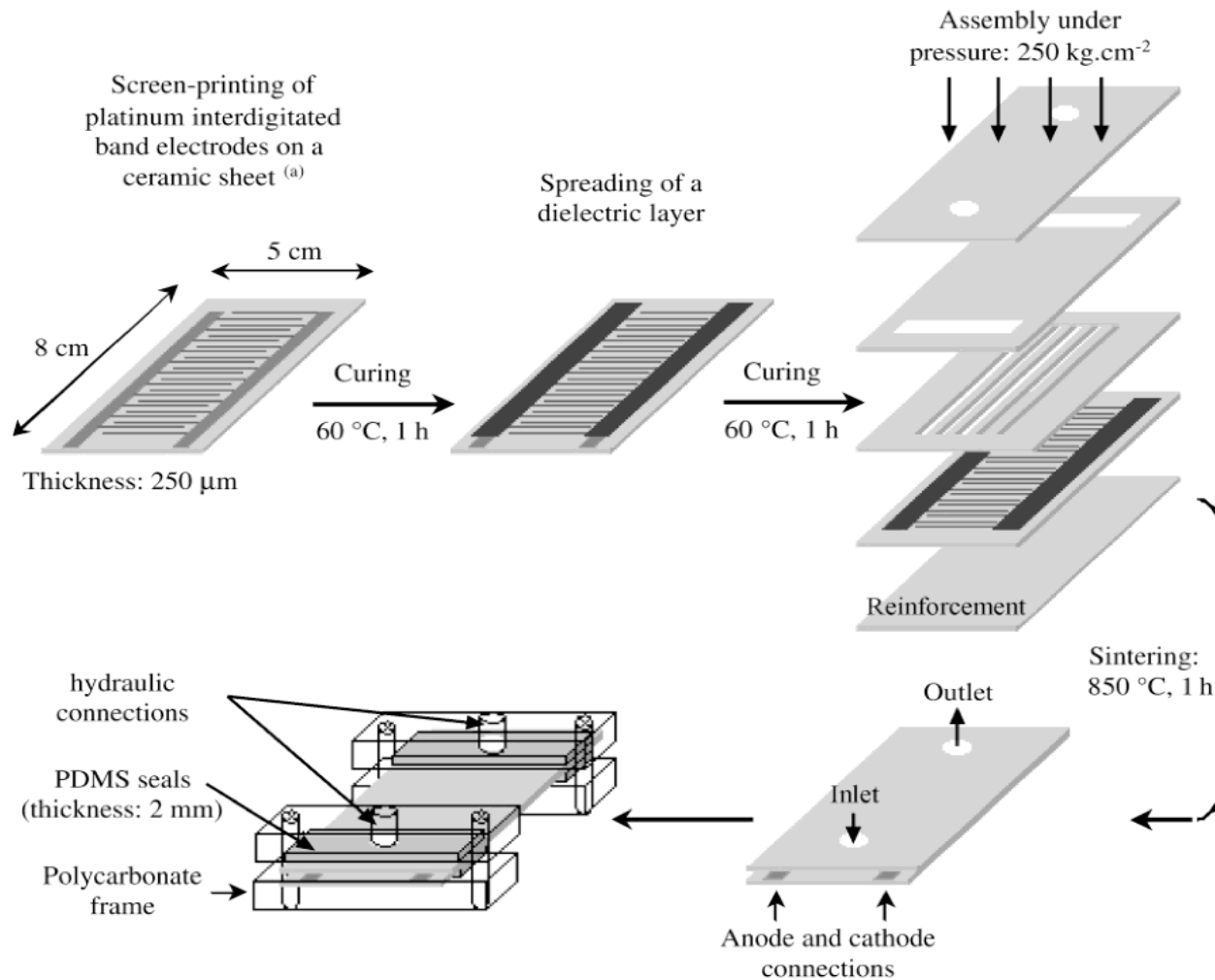


Mengeaud,  
EPFL 2002

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



# Electrochemical microreactor

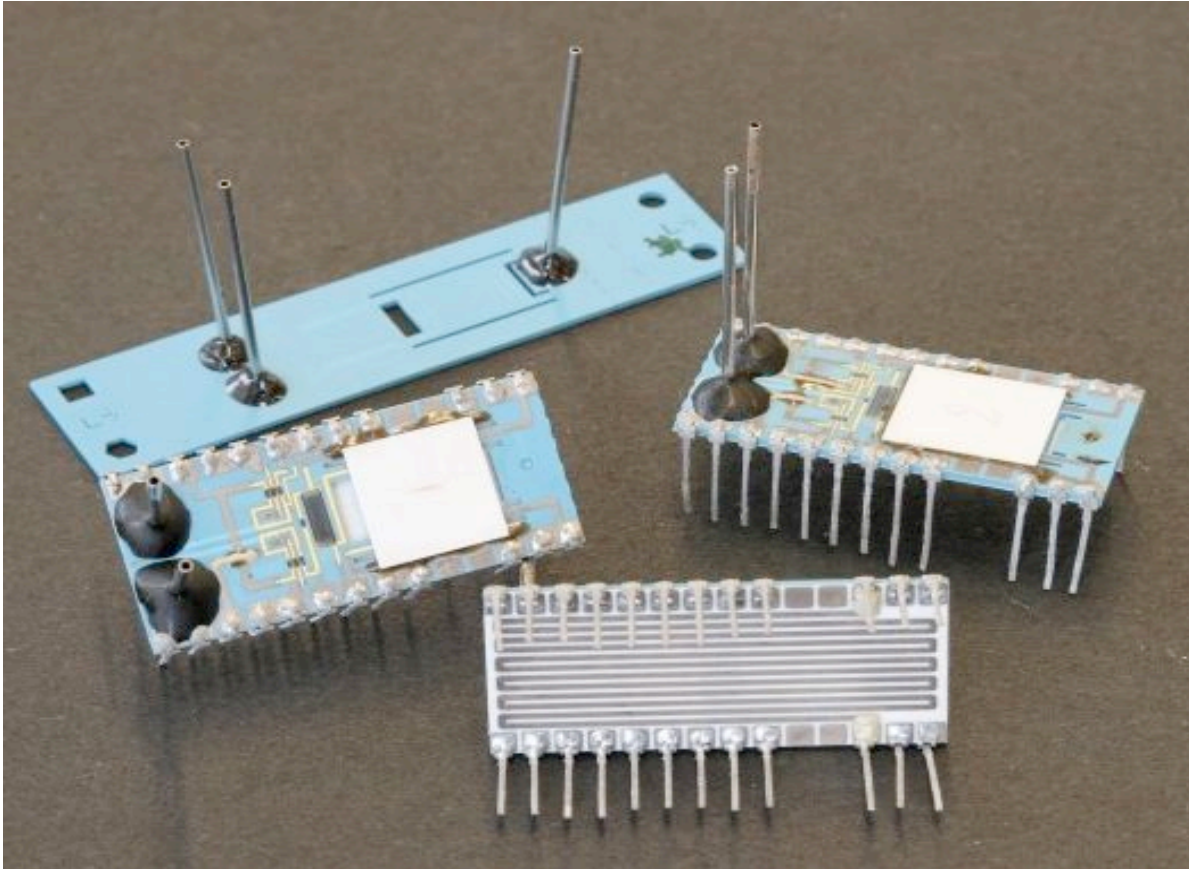


Mengeaud et al., 2001

## Can add:

- Electrodes
- Heaters
- Sensors
- Catalysts

# Chemical microcalorimeter (1/7)

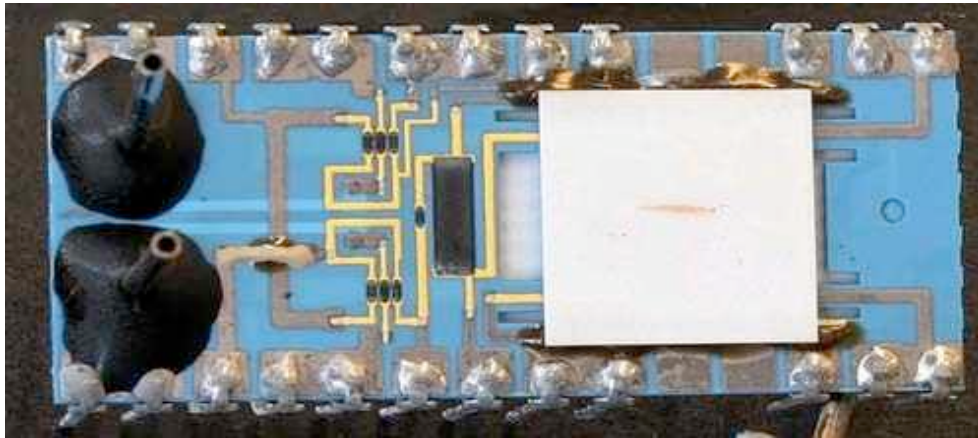


## Features:

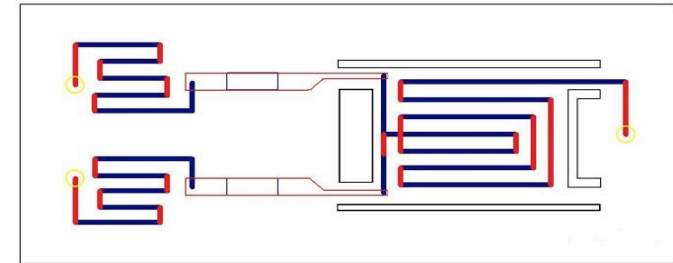
- DIL-24 package
- Global heating track
- Inlet pre-heating zones (meanders)
- Thermally insulated reaction zone
- Microcalorimeter with calibration heater
- Separate flow sensor for each inlet

Willigens, 2005

# Chemical microcalorimeter (2/7)

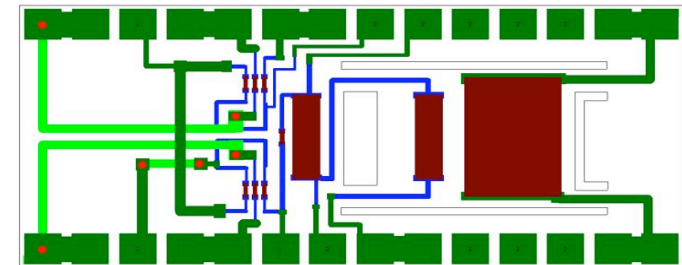


Fluidic layout

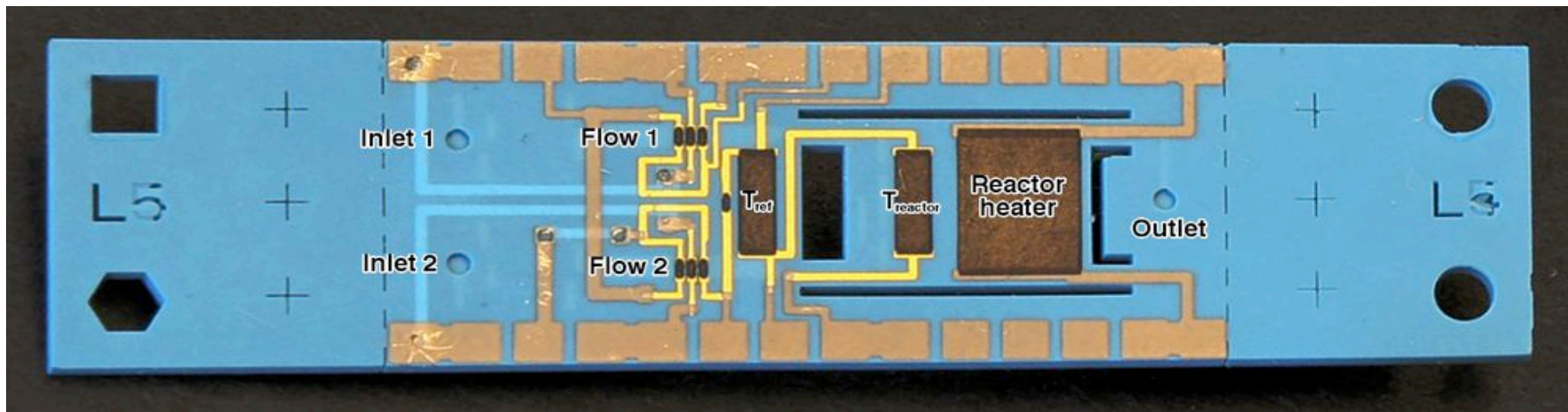


Dimensions : 35.55\*15.25mm

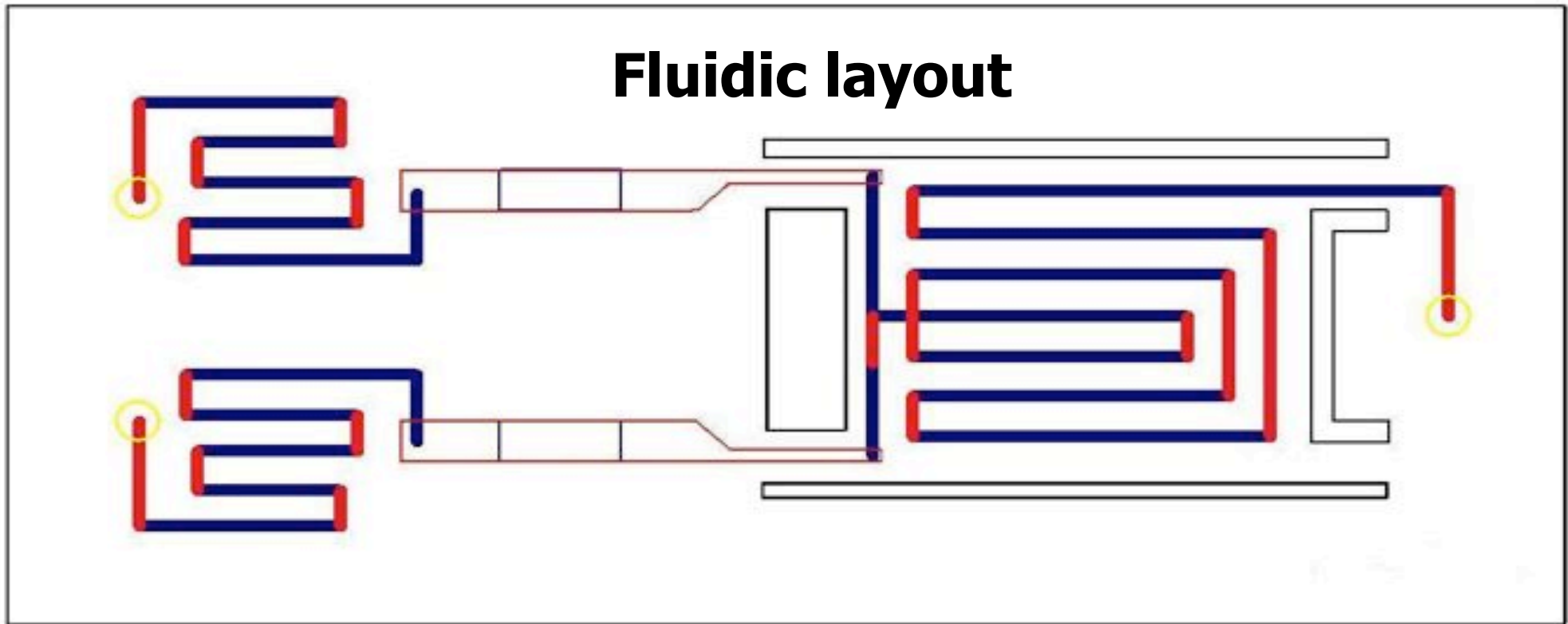
Electrical layout



5mm



# Chemical microcalorimeter (3/7)



*Dimensions : 35.55\*15.25mm*

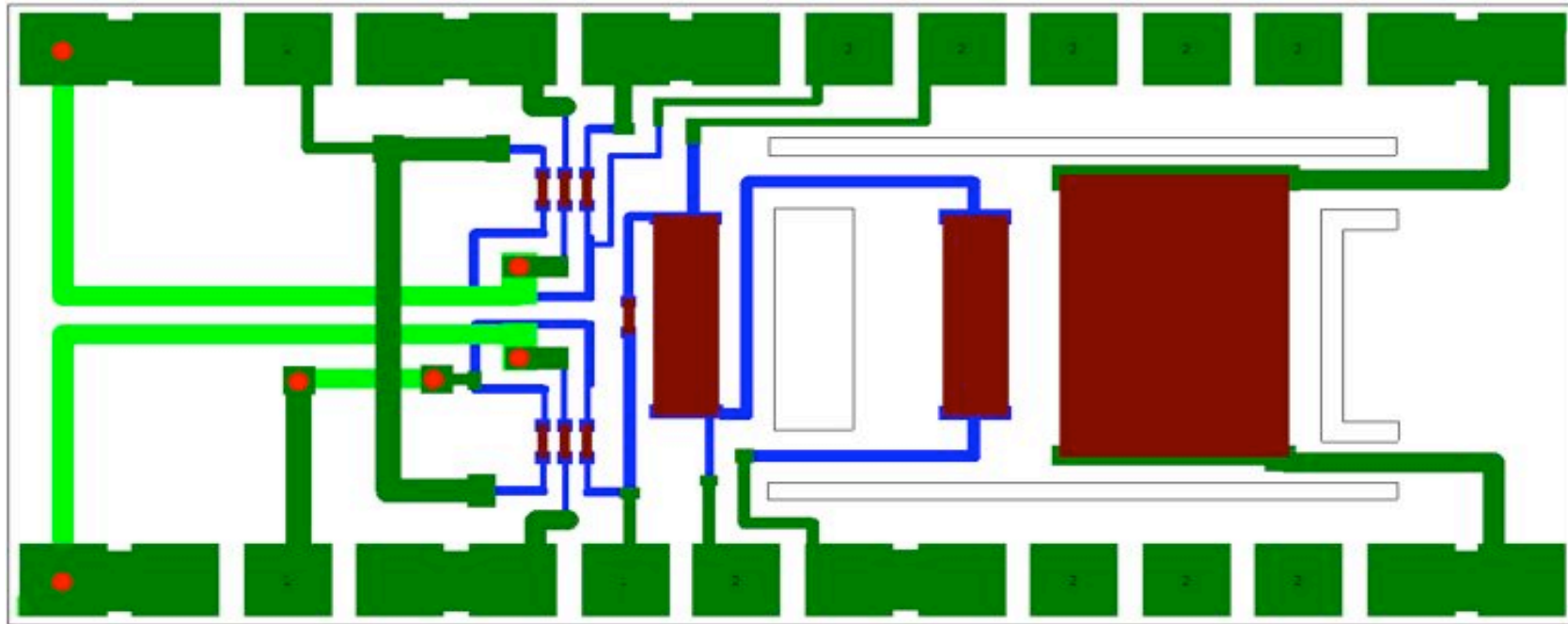
**Preheating  
zone**

**Flowmeters**

**Reactor**



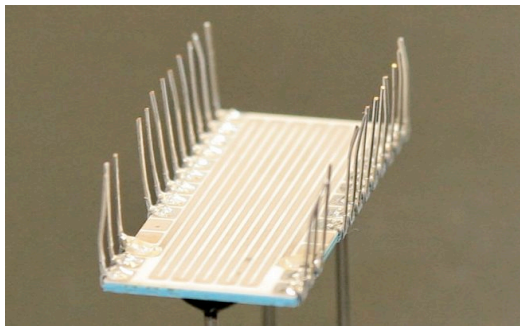
# Chemical microcalorimeter (4/7)



Flowmeters

Reactor

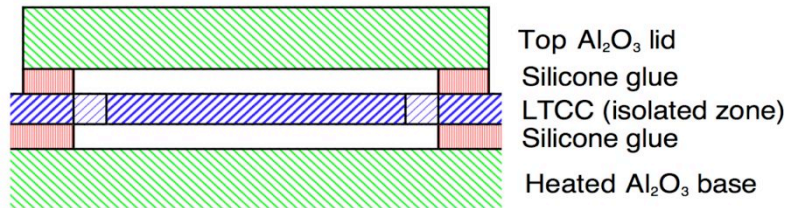
5mm



## Electrical layout

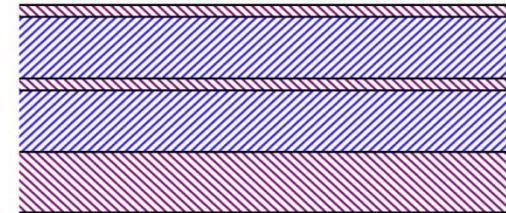
<- General heating + DIL-28 package

# Chemical microcalorimeter (5/7)

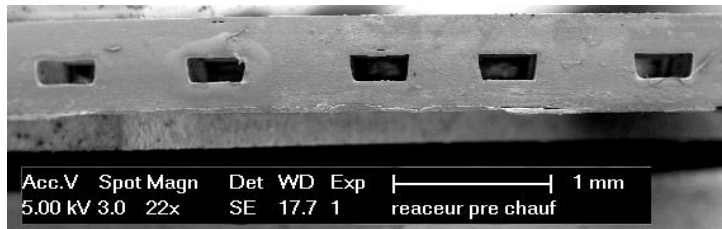


**Global  
layers**

**5 LTCC  
layers**

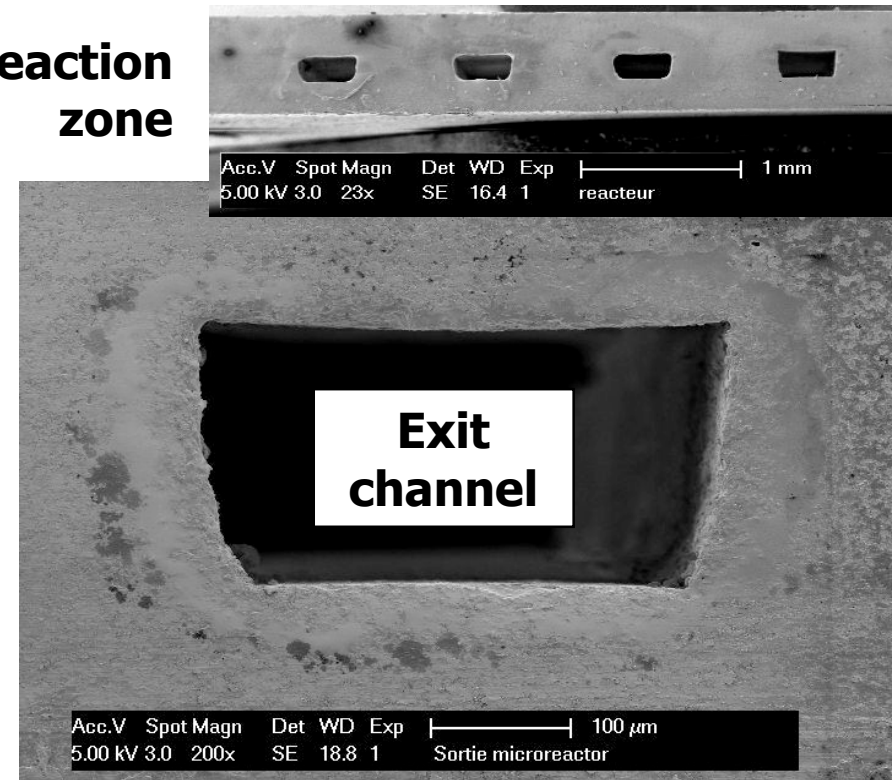


Top lid  
Top fluidic layer  
Separator  
Bottom fluidic layer  
Bottom (base)

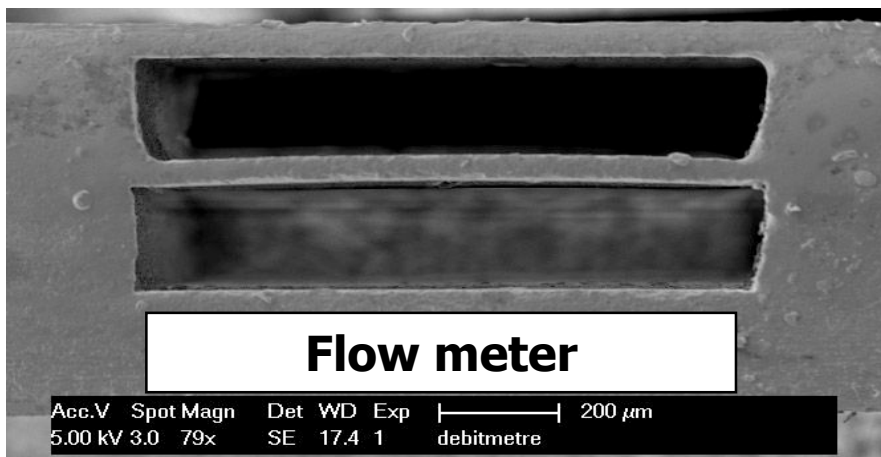


**Pre-  
heating**

**Reaction  
zone**



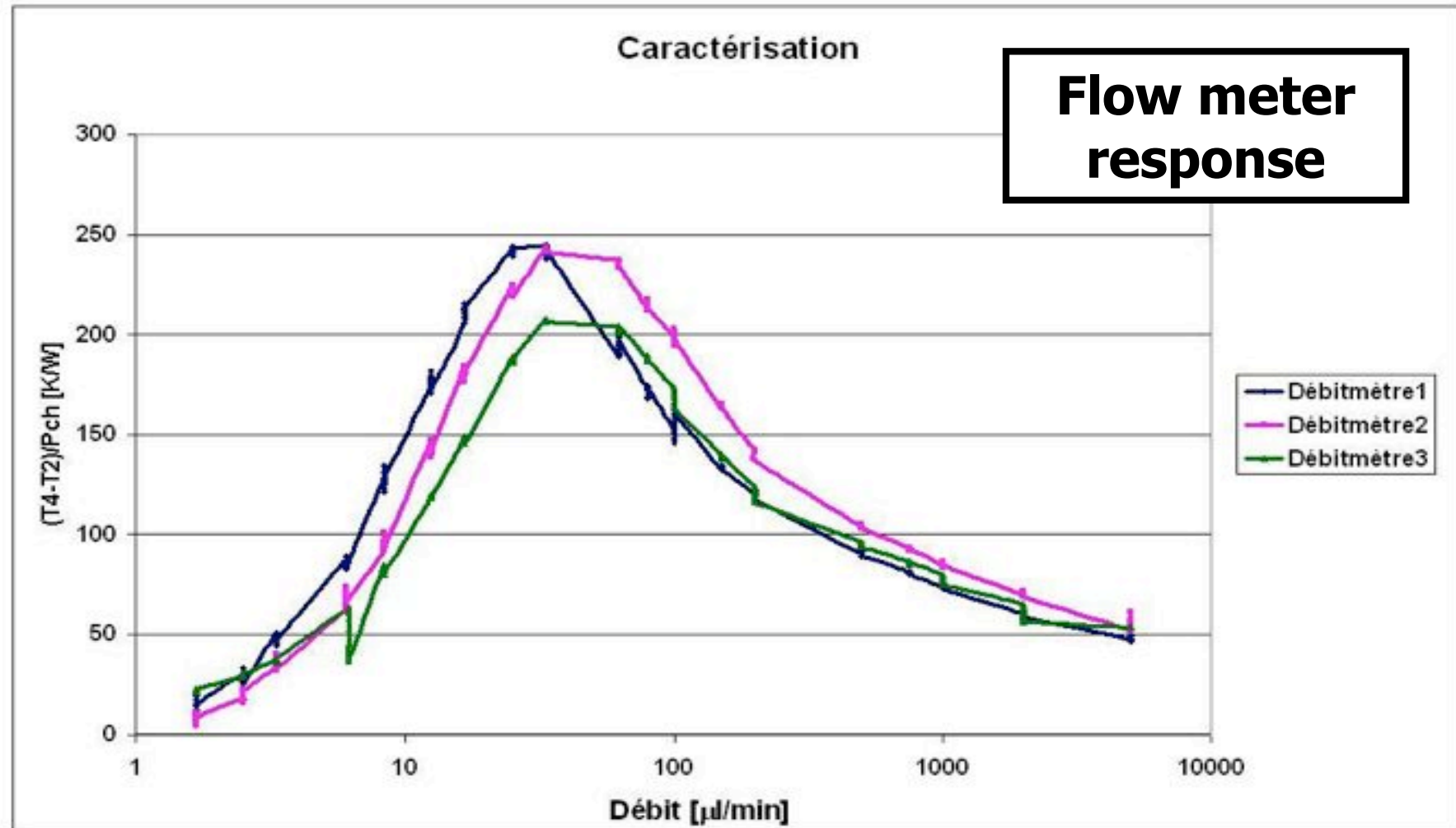
**Exit  
channel**



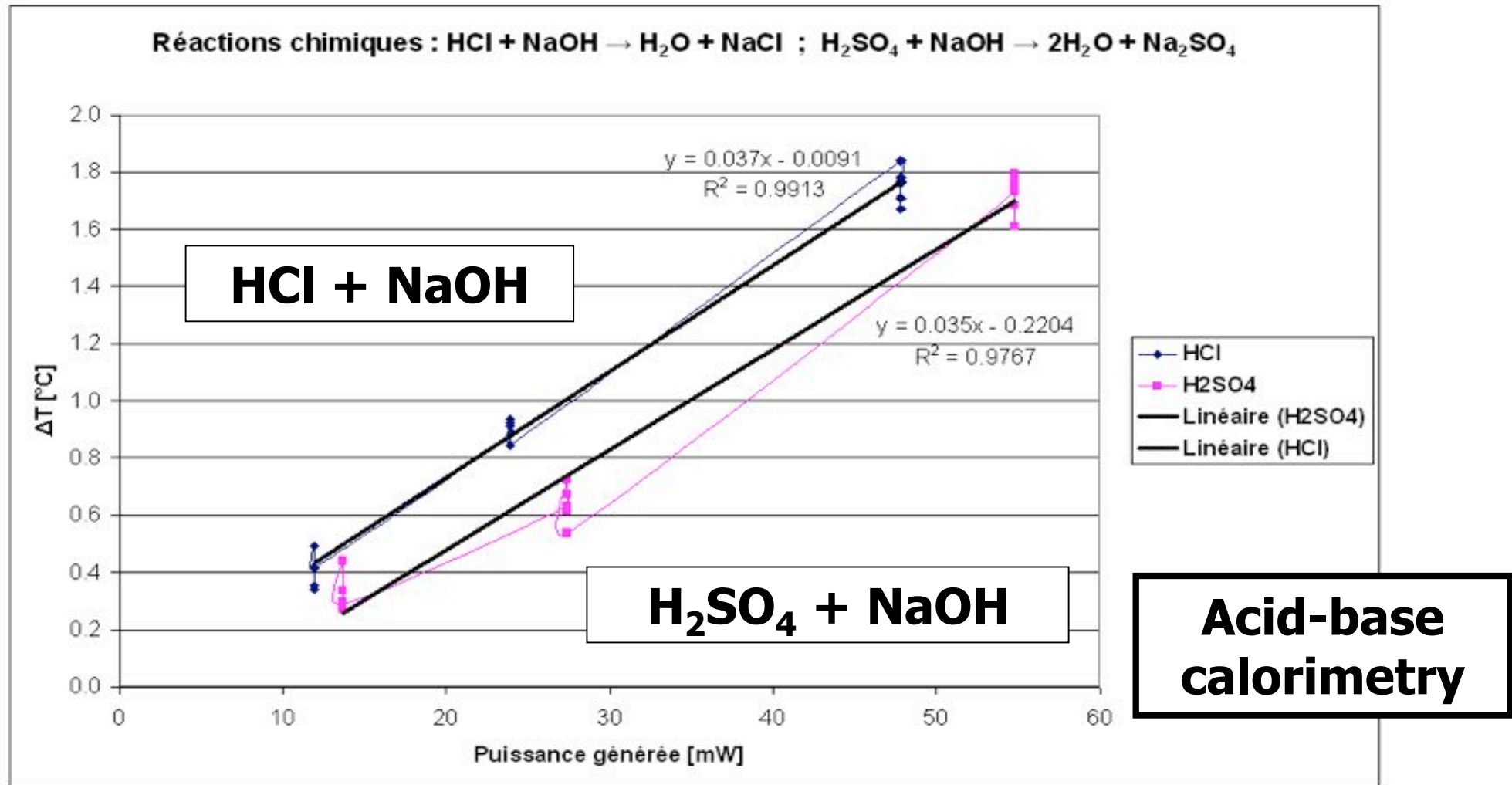
**Flow meter**



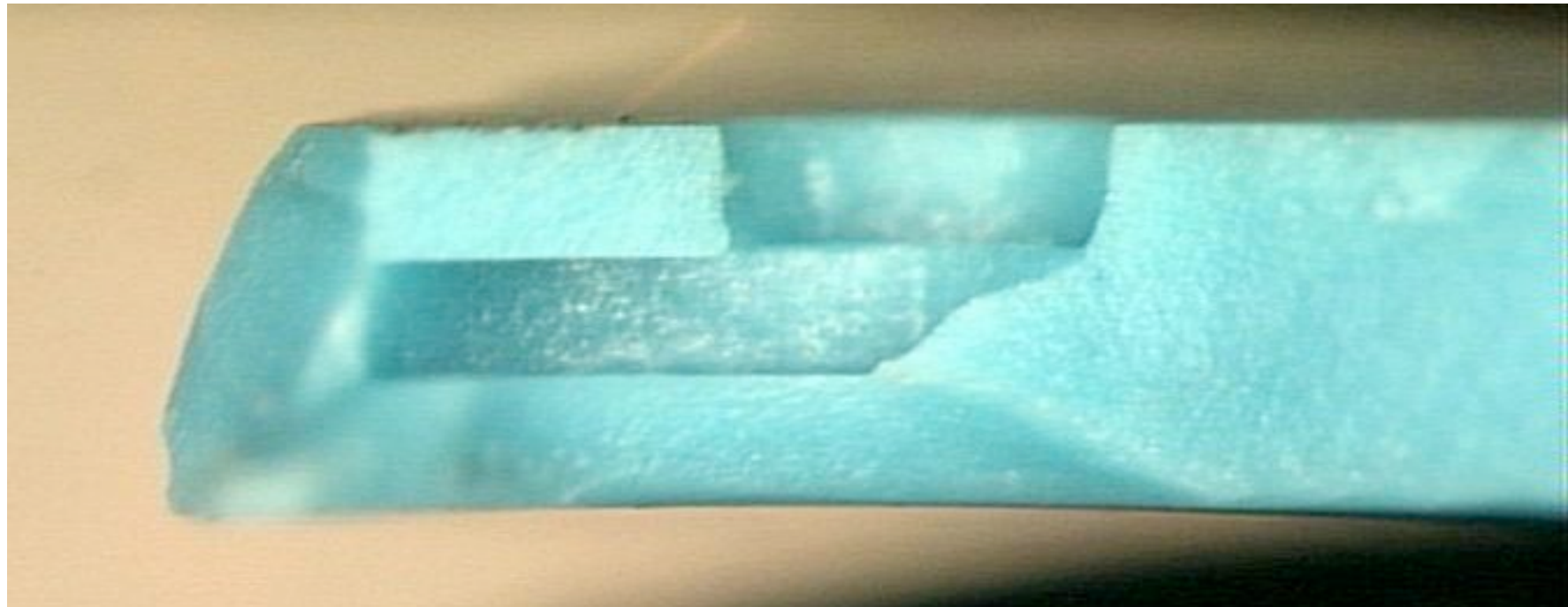
# Chemical microcalorimeter (6/7)



# Chemical microcalorimeter (7/7)



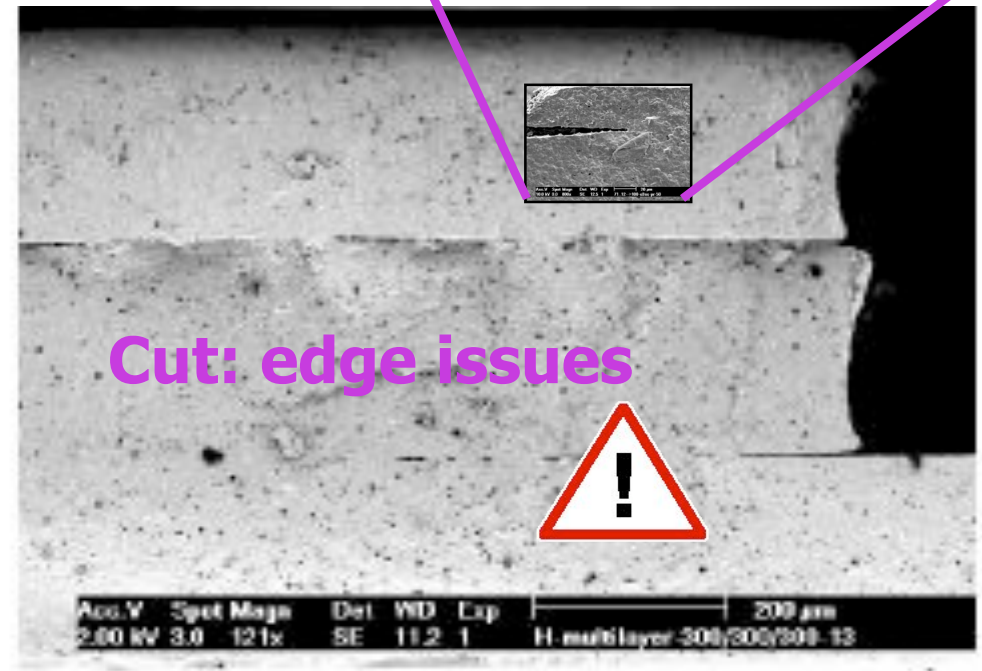
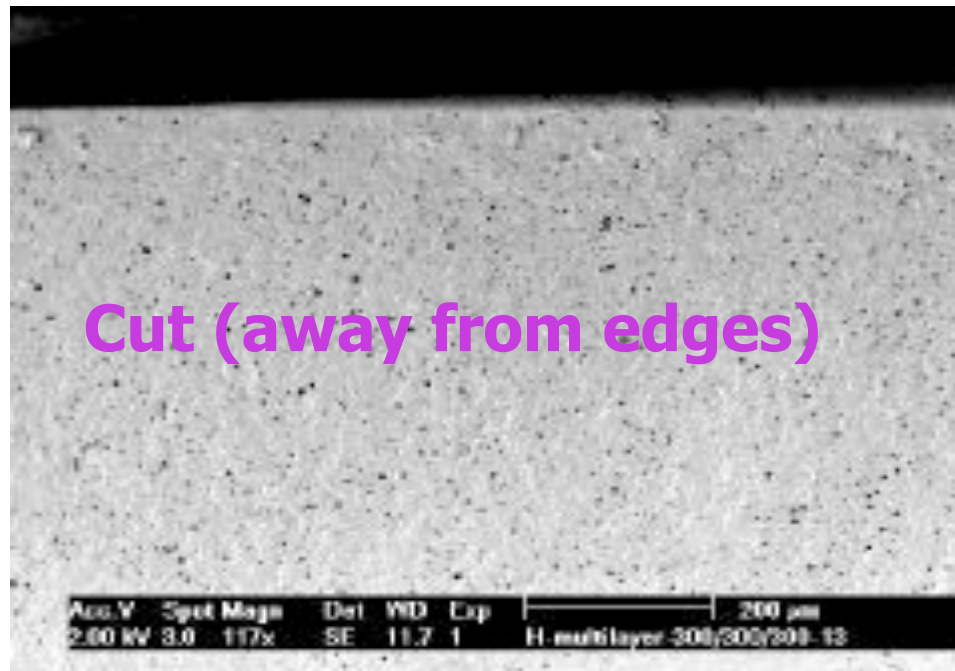
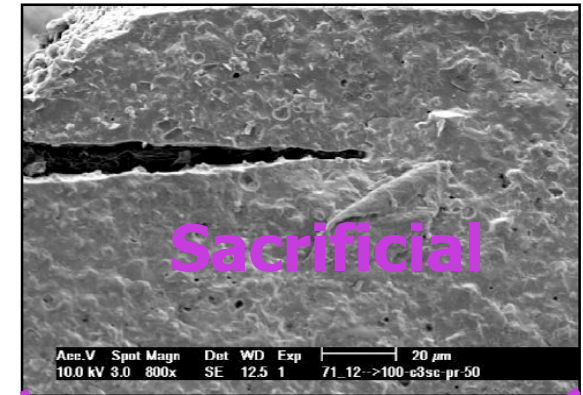
# Physical issues - lamination



- Channels by cutting & stacking
- Good lamination : well bonded layers

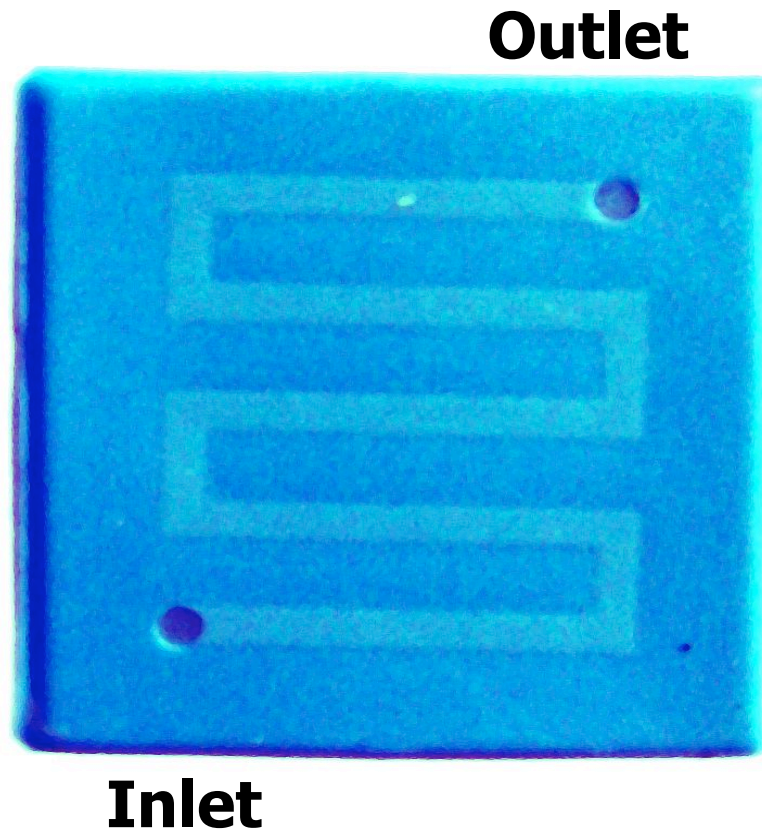
# Cutting vs. sacrificial layer

- Gap size: sacrificial max ca. 50  $\mu\text{m}$
- Complexity: cutting vs. screen-printing
- Edge quality: cut = edge issues





# Fluidic resistive path



- Thickness  $h$ 
  - 5...40  $\mu\text{m}$  : graphite sacrificial
  - $\geq 40 \mu\text{m}$  : cutting
- Width  $b$ : down to 100  $\mu\text{m}$
- Length  $L$ : up to 30 cm /  $\text{cm}^2$
- Fluidics resistance (for small volume change):

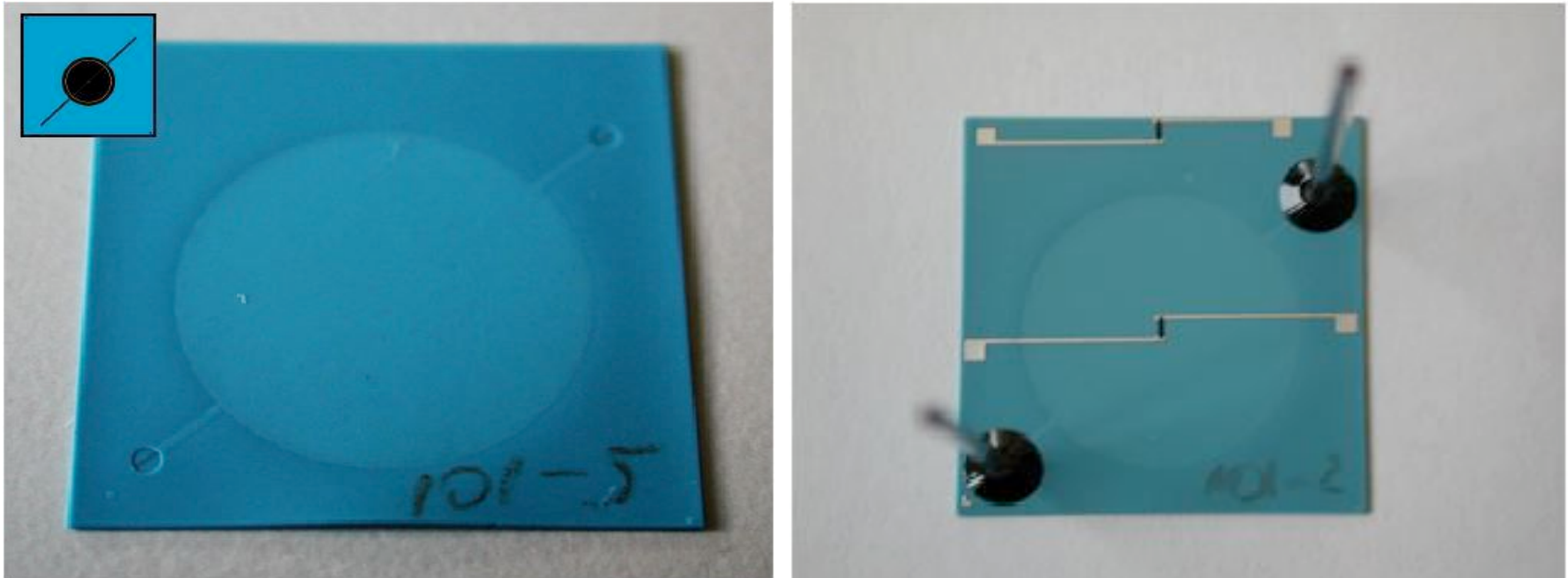
$$R \cong \eta \cdot \frac{12L}{b \cdot h^3}$$

$\eta$  = viscosity

air: 16.58  $\mu\text{Pa}\cdot\text{s}$

water: ca. 1  $\text{mPa}\cdot\text{s}$

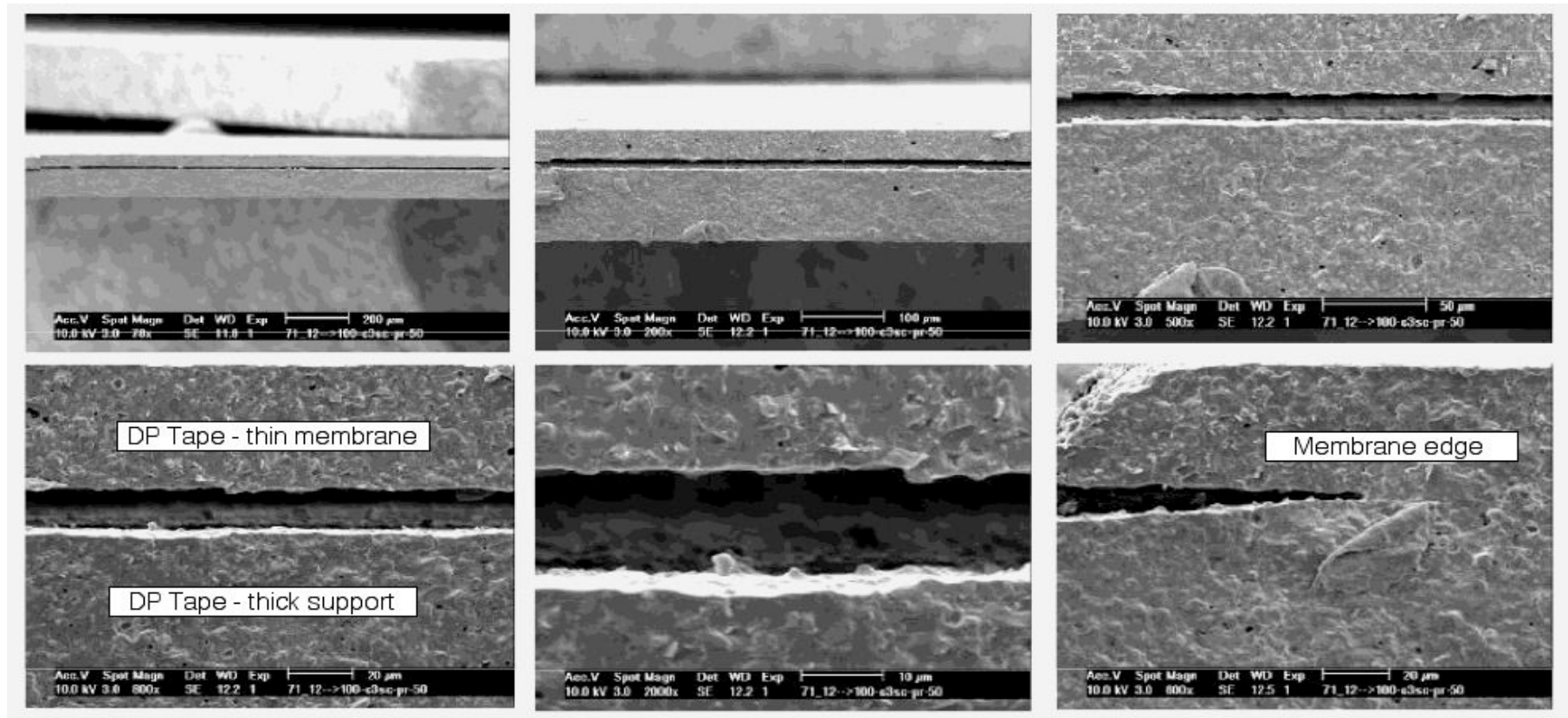
# Thin membranes (1/5)



- 3-D structuration using sacrificial C layer
- 18 mm membrane, 40  $\mu\text{m}$  thick, < 50  $\mu\text{m}$  spacing



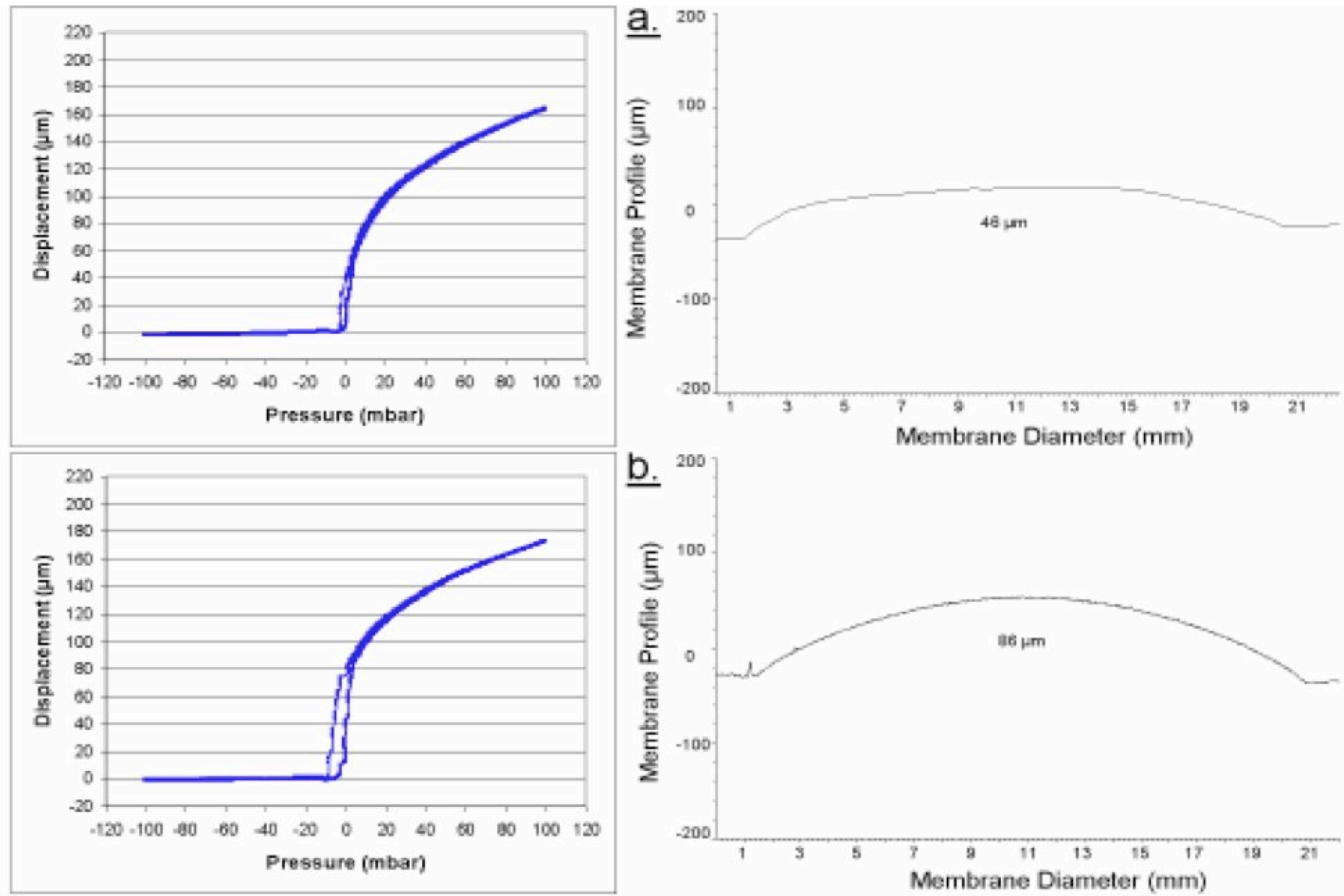
# Thin membranes (2/5)



- Good edge quality
- Control of spacing by process - sensitive!

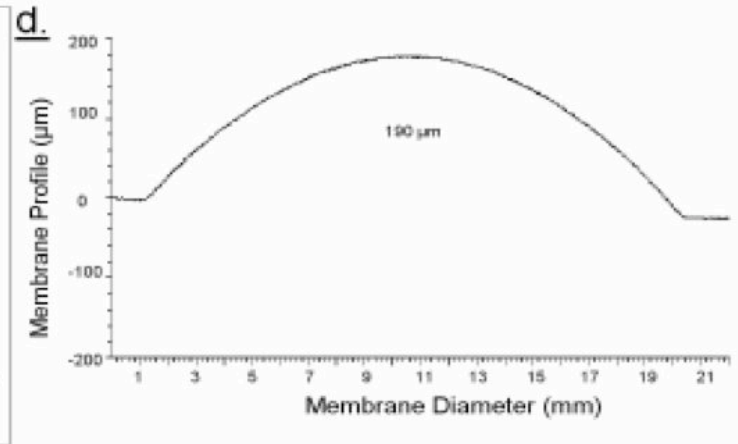
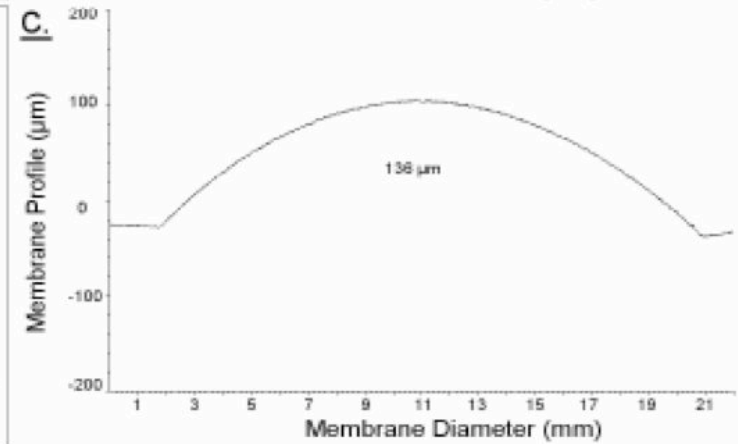
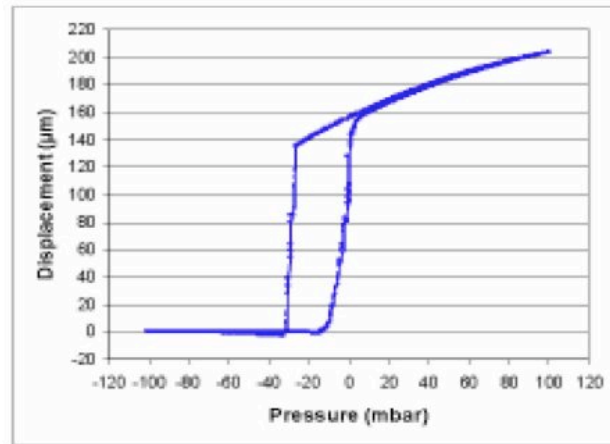
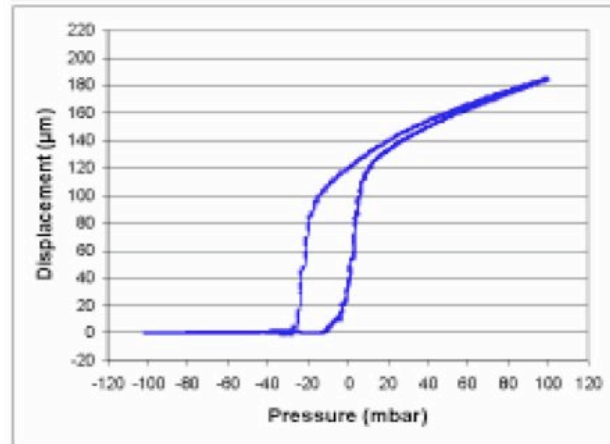
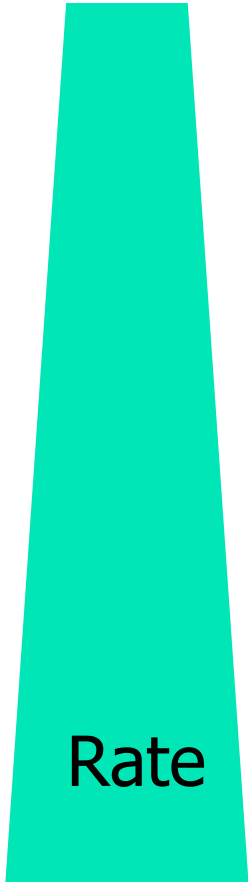
# Thin membranes (3/5)

Rate



Low heating rate / large channels

# Thin membranes (4/5)

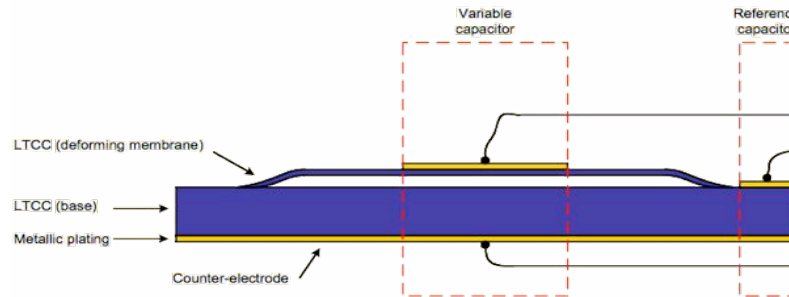
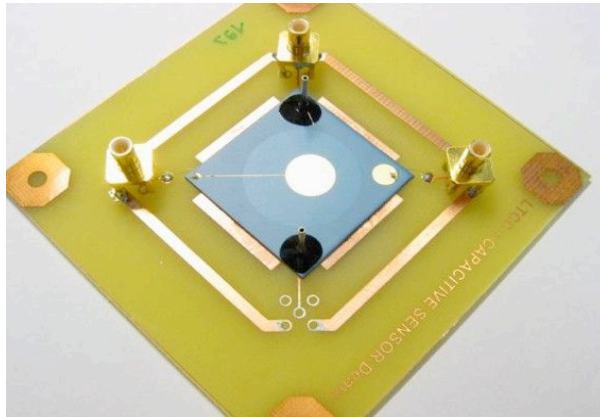


Hysteresis

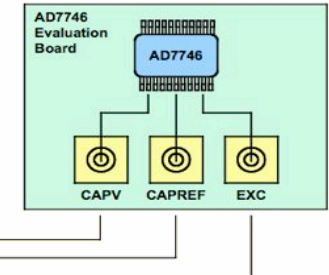
Swelling

High heating rate / small channels

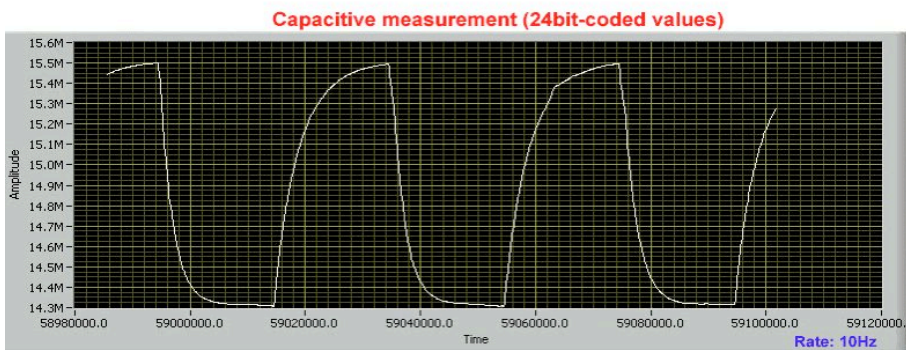
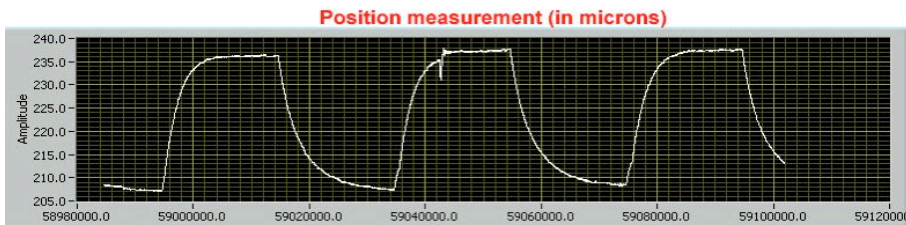
# Thin membranes (5/5)



**LTCC Pressure Sensor  
(with capacitor)**



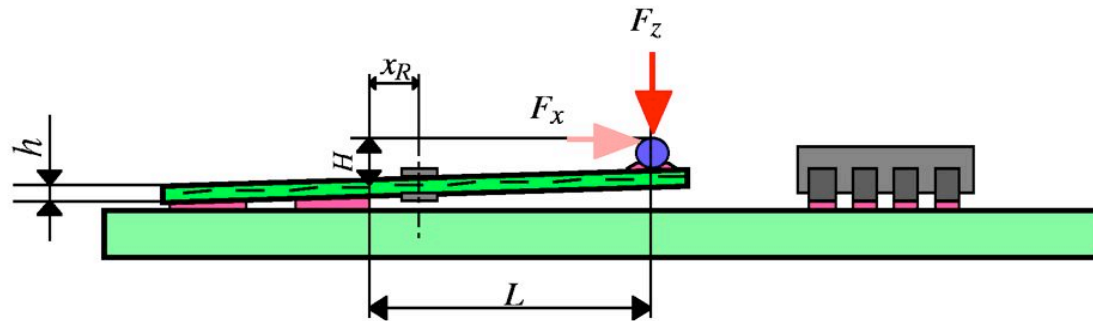
**24-bit Capacitance to  
Digital Converter**



## Capacitive low-pressure sensor

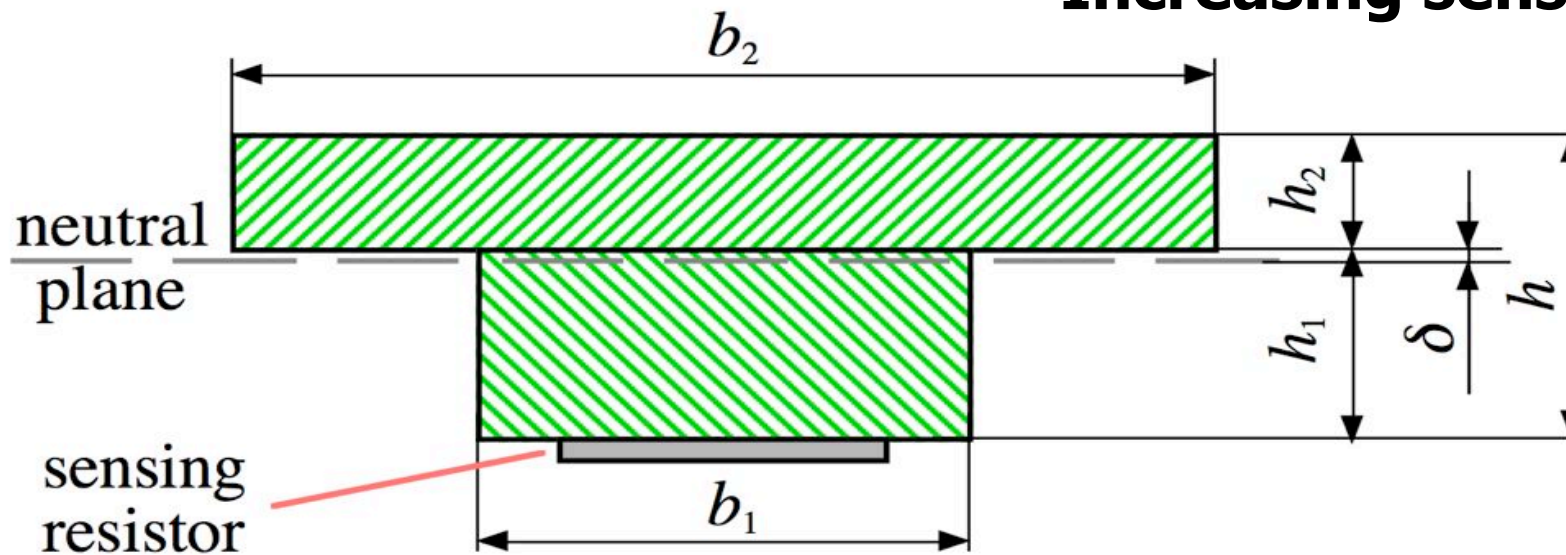


# Structured force sensors

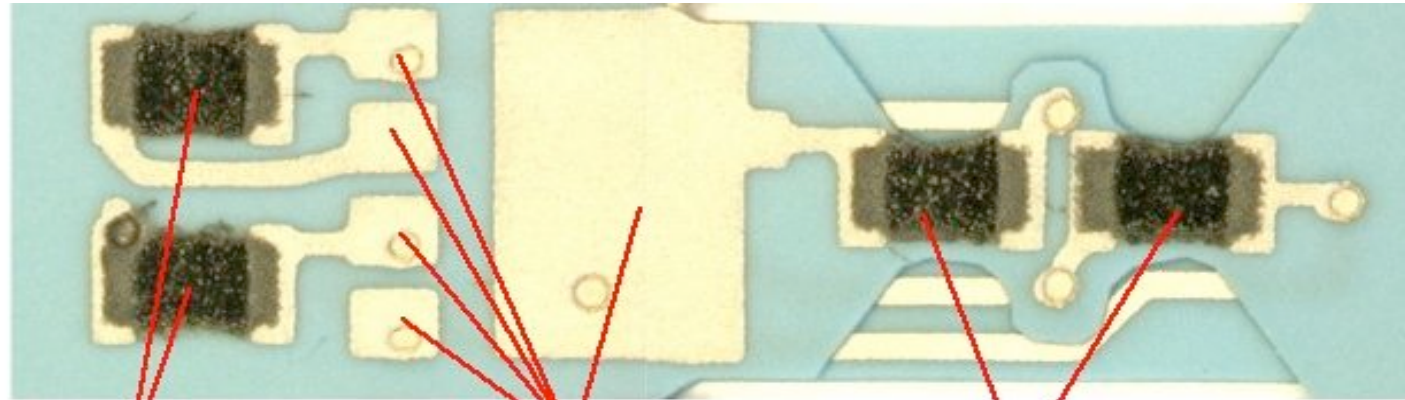


## Principle

## Increasing sensitivity



# Structured force sensors

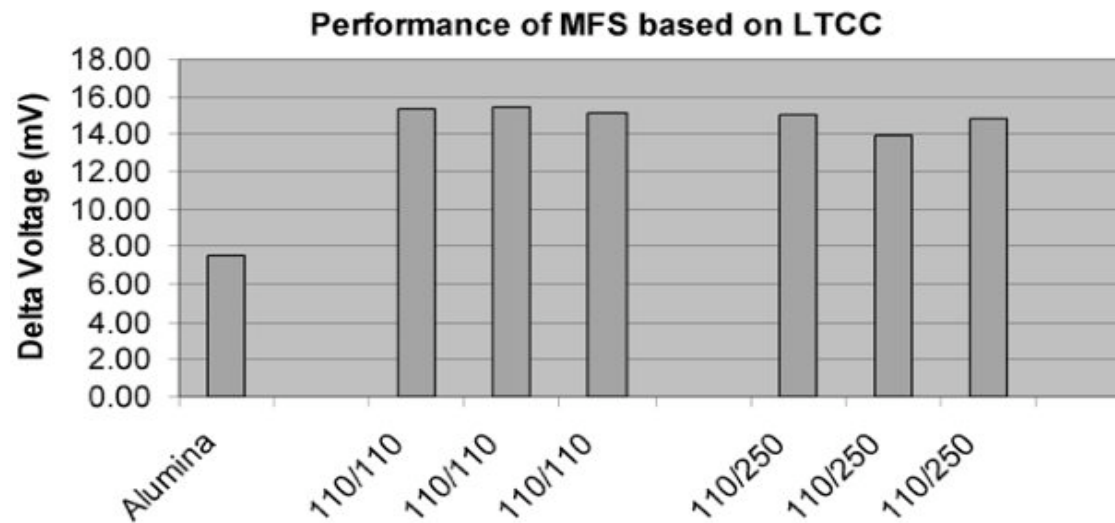


**Sensor**

Passive resistors

Solder pads

Sensing resistors



**Results**

# Conclusions

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- Proven base material (automotive & telecom)
- Easy prototyping and fabrication of 3-D fluidic & electric circuits
- Very good thermal & chemical stability
- Allows sensitive devices
- Functionalisation by appropriate films
- **Processing still needs development:**
  - Co-firing of thin structures
  - Materials compatibility
  - Lower processing sensitivity

**Merci**

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**Thank you !**  
**Danke !**