ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Integrated Microfluidic Devices Based on Low-Temperature Co-Fired Ceramic (LTCC) Technology

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Introduction

What is LTCC?

- LTCC stands for « Low-Temperature Co-fired Ceramic ».
- The ceramic is a silicate material + Al_2O_3 with outstanding chemical and thermal stability.

How is it made?

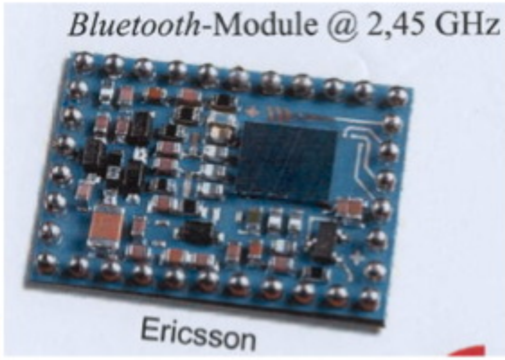
- LTCC comes as unfired « green » sheet (tape) of various thicknesses (ceramic powder with polymer binder).
- Each sheet is shaped & screen-printed.
- Finally, the sheets are pressed & fired together.

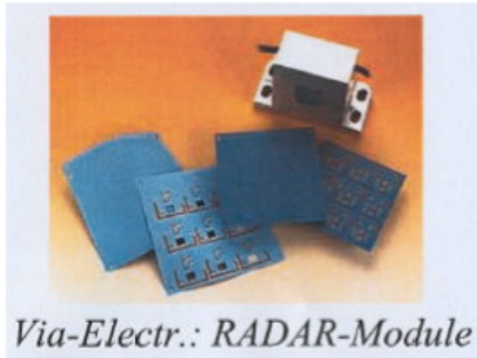
Application examples

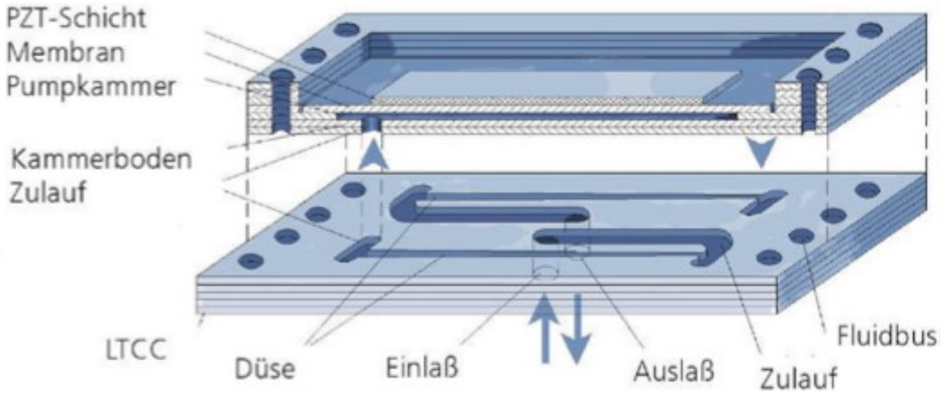
Source: Prismark/Binghamton University

EPCOS FRONT END MODULE

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



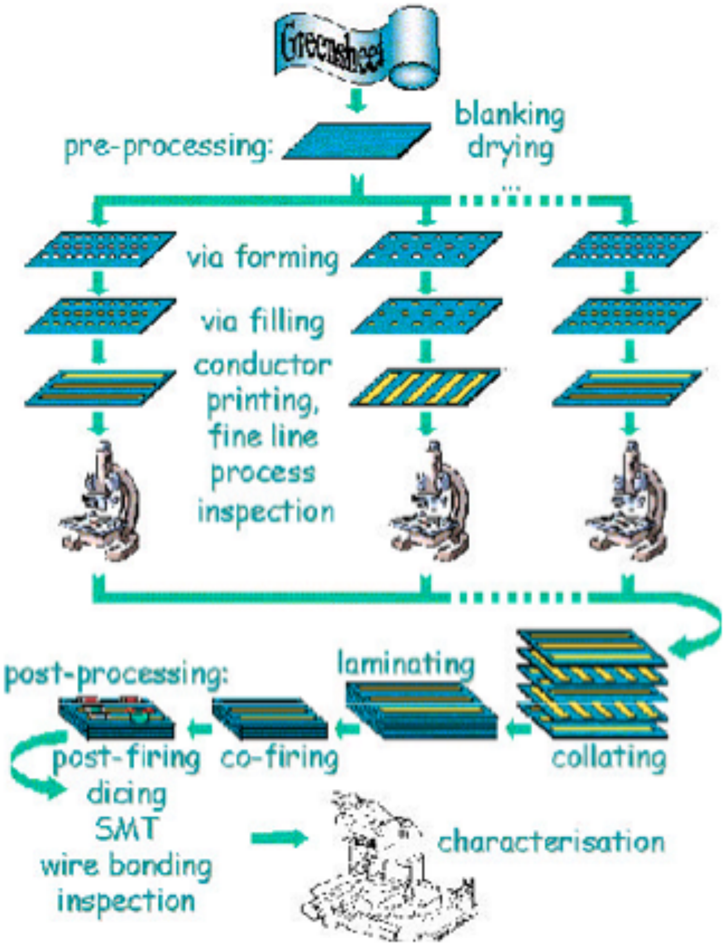




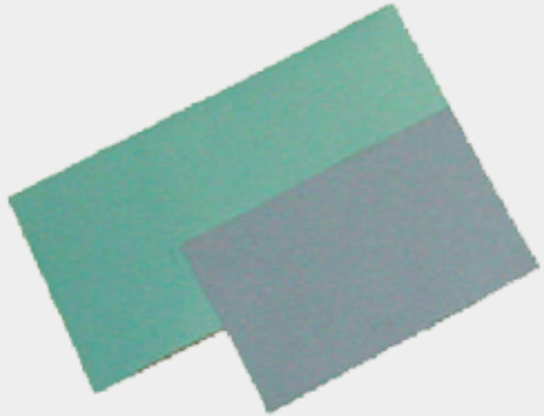
LTCC materials system

	COMPONENTS		
	SUBSTRATE	**PASSIVES**	
Components	**Tape**	**Conductor**	**Resistor**
Function	Dielectric layer	Thick-film paste	Thick-film paste
Functional group	Dielectric powder	Precious metal, fine size powder	Conductive oxide, fine size powder
Glass	✍ Lowers T_{firing}, ✍ increases dielectric strength and density	✍ Lowers T_{firing}, ✍ increases adhesion to substrate and density	✍ Lowers T_{firing}, ✍ increases density ✍ surrounds conductive powder
Organics	Binder, solvent, dispersant for appropriate rheology		

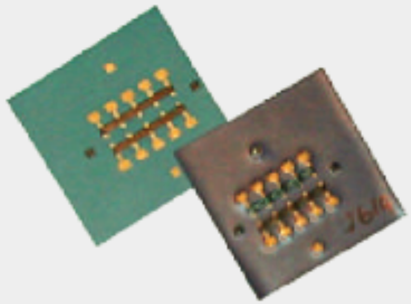
Processing route



Source: www.ltcc.de



LTCC green tapes



Screen-printed and fired

Processing - advantages

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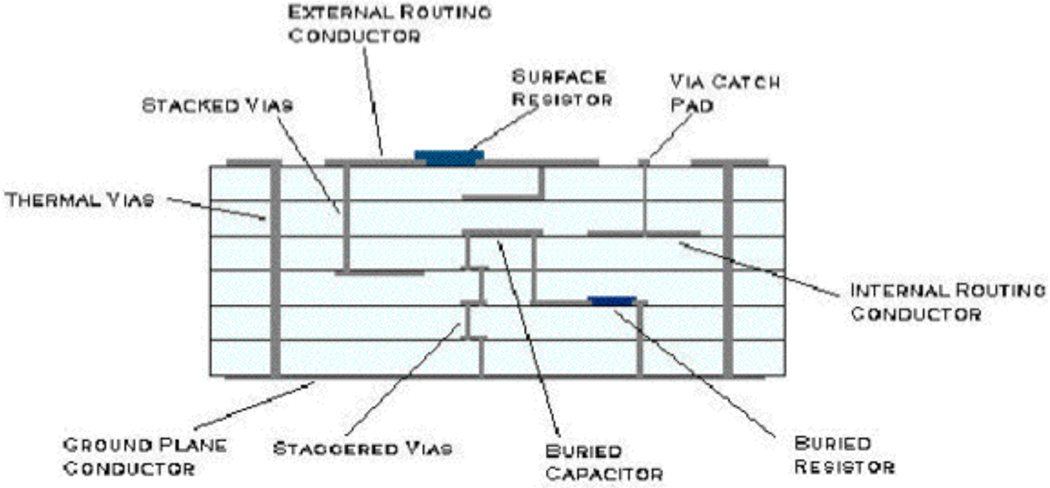
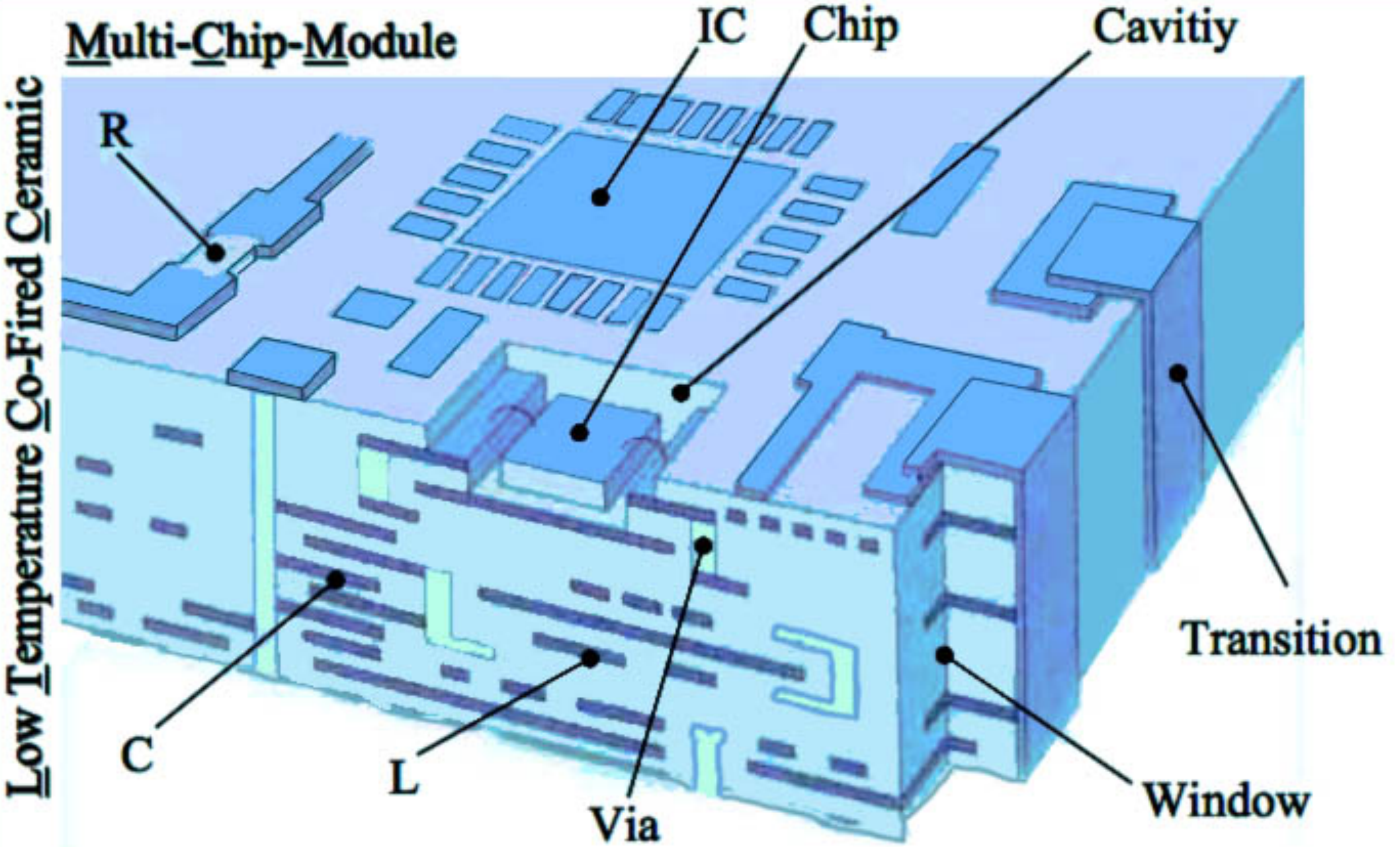
- T_{firing} < 900°C ⇒ permits use of low resistance electrodes
- High density packaging
- 3-D structuration
- Hermetic structures



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

LPM

3-D structuration of LTCC



Source: www.ltcc.de

Classical thick-film technology

M.–A. Schneider et al., 2003

- Microreactor for calorimetric studies
- Microfluidics by classical thick-film technology
- Alumina & sealing glass (seen through glass underside)
- 3-D fluidics difficult
- Difficult to integrate new functions

Simple structure - LTCC mixer

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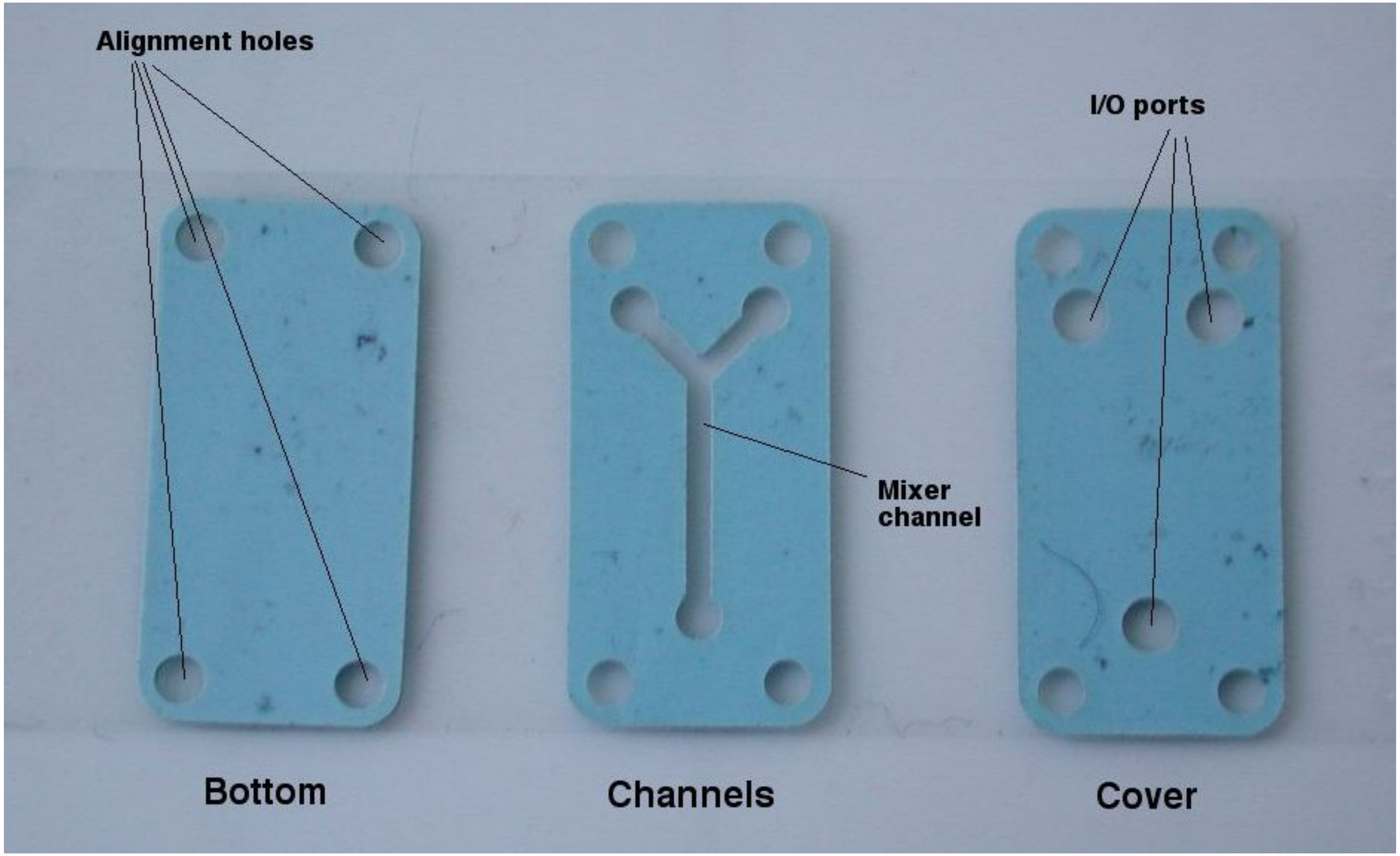

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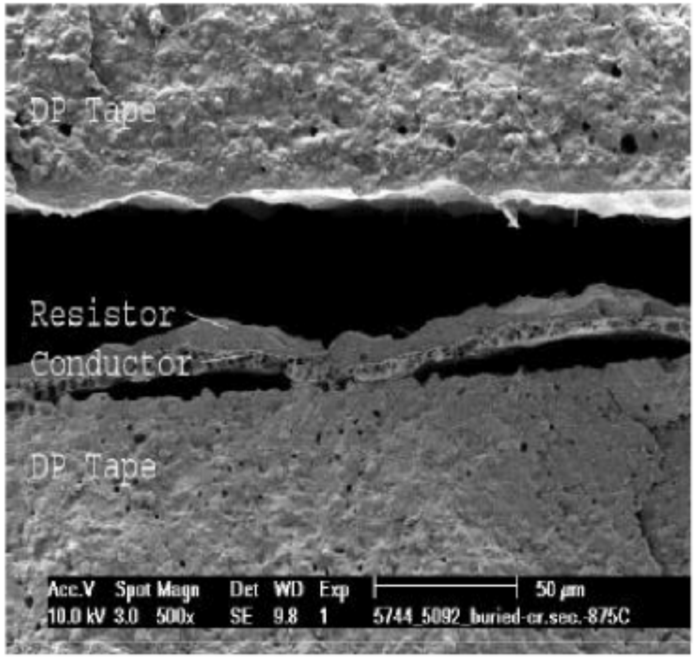
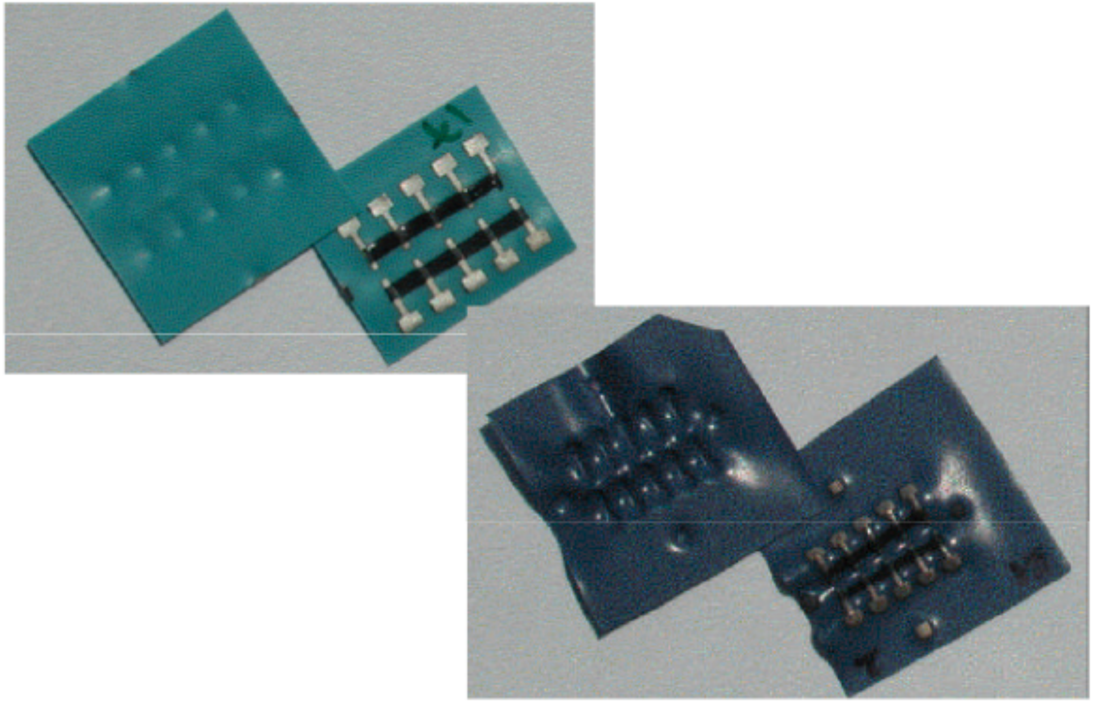
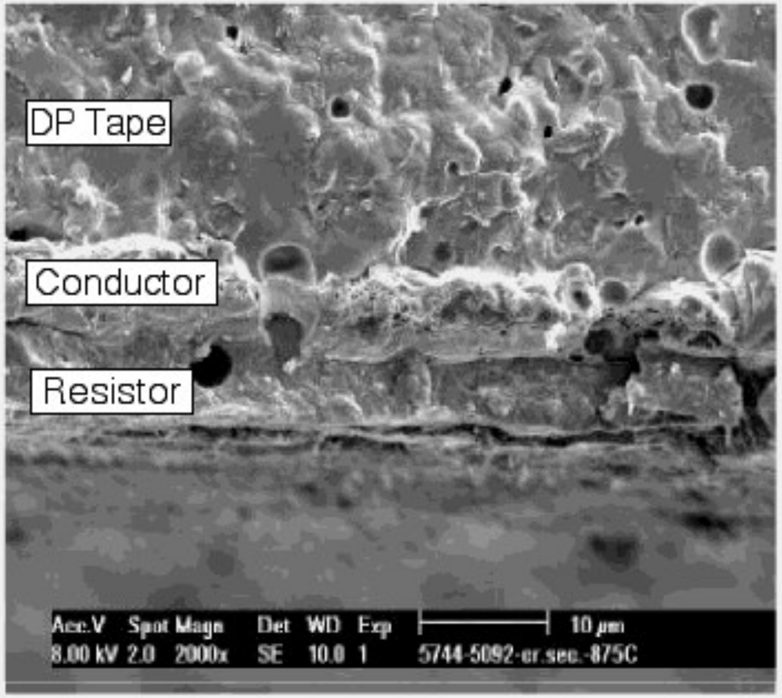
Physical issues during firing



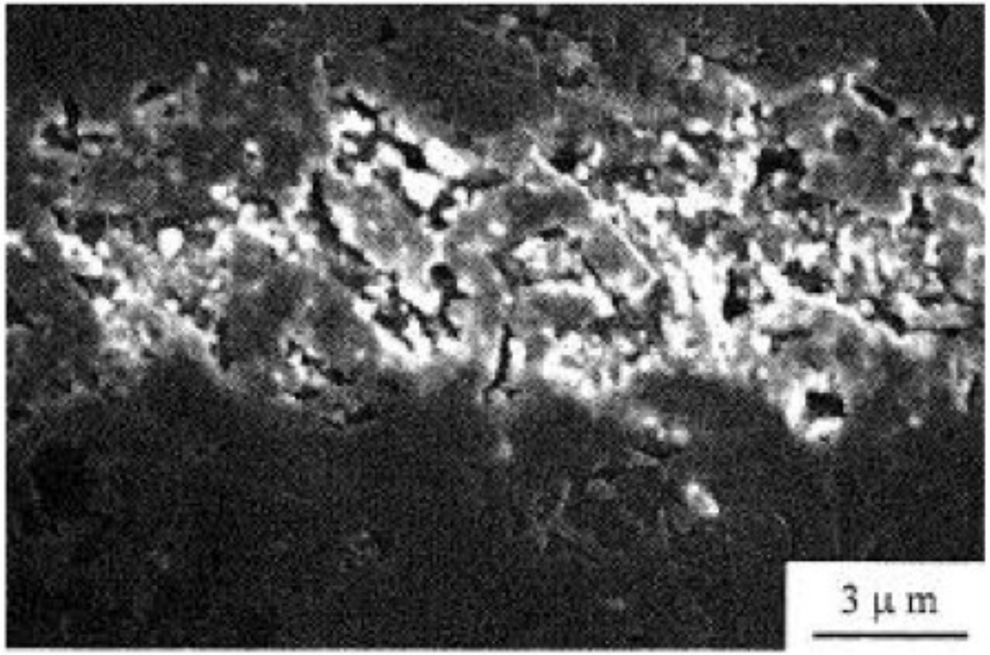


- Evolution of gases during debinding
- Lamination issues (thickness of layers)
- Differential sintering shrinkage

Chemical issues during firing



Birol et. al.

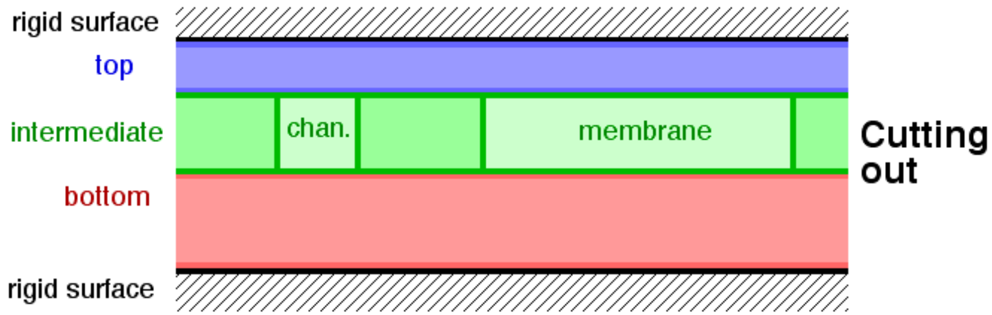


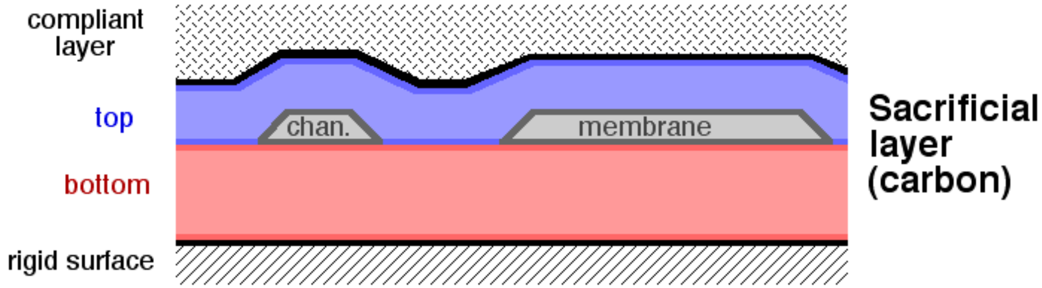
Hsi et. al.

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

Processing of fluidic structures

- Features
  - Vias
  - Channels
  - Membranes
  - Bridges





- Two techniques
  1) Cutting out
  2) Sacrificial layer

Cutting vs. sacrificial layer

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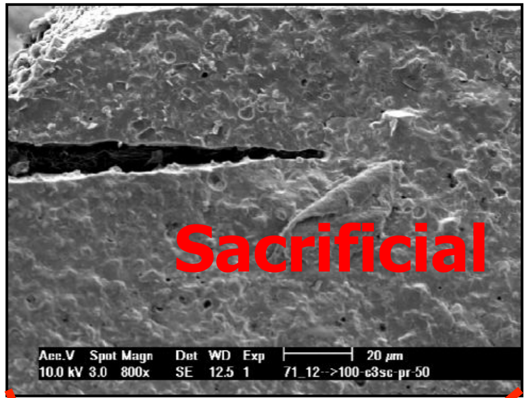
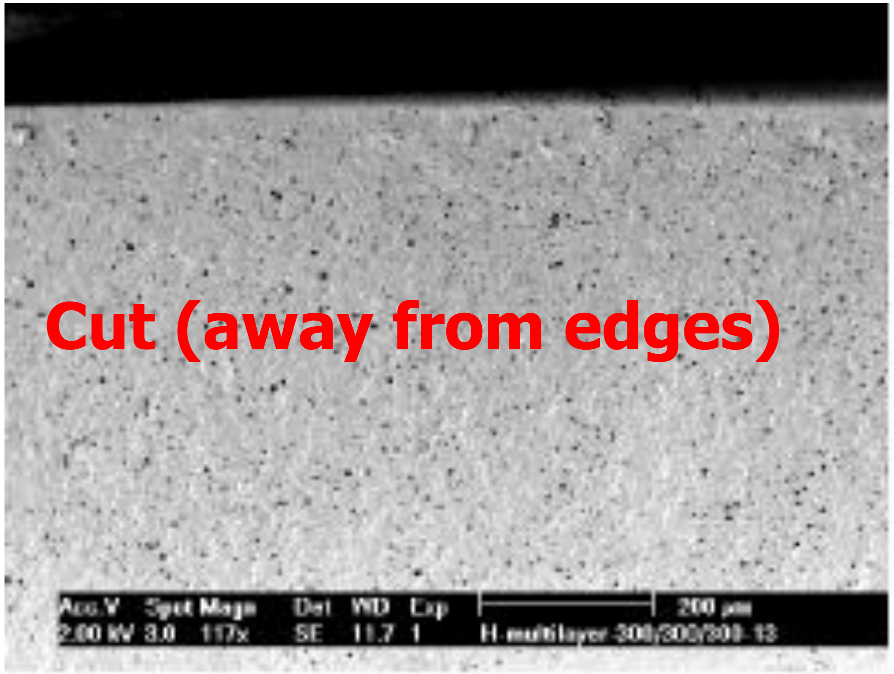
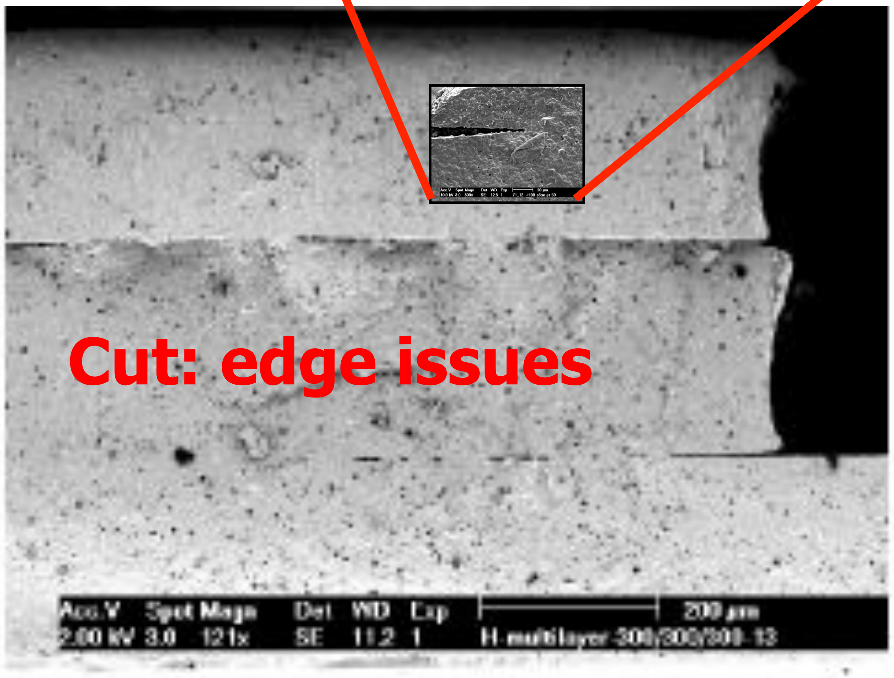
- Gap size: sacrificial max ca. 50 µm
- Complexity: cutting vs. screen-printing
- Edge quality: cut = edge issues







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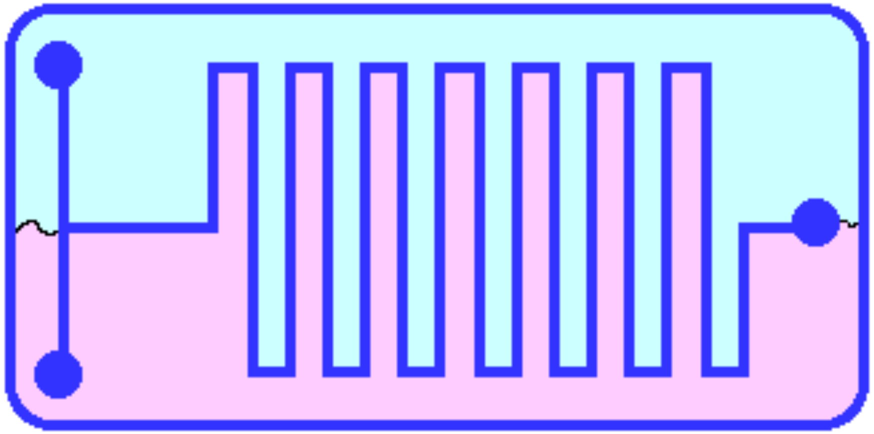
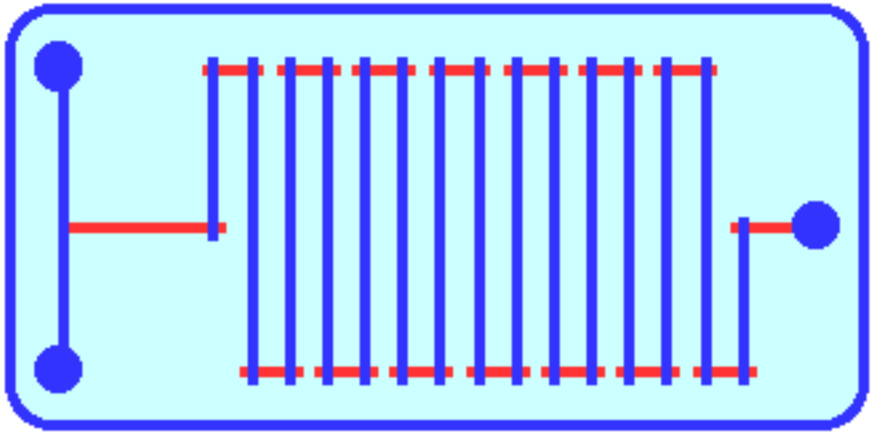
Cutting: distortion of green sheet



- LTCC sheet weak
- Strong risk of clogging

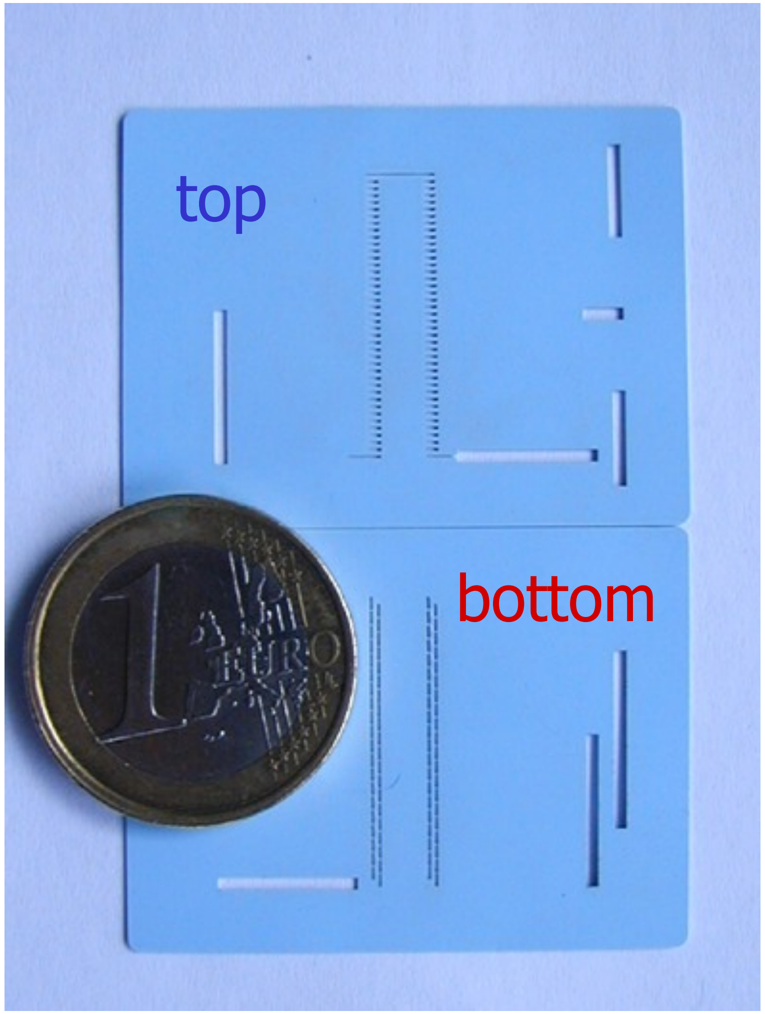


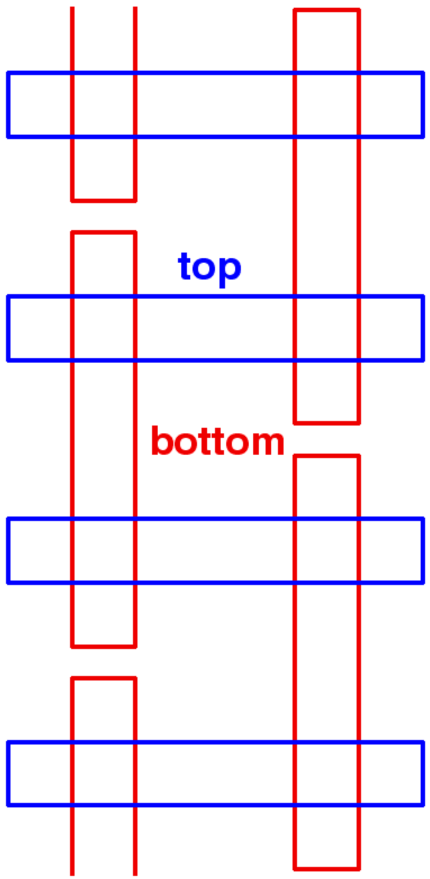
- LTCC sheet stronger
- Less risk of clogging

Sheet 1 (top)
Sheet 2 (bottom)

⇒ Avoid long, narrow & windy cuts!

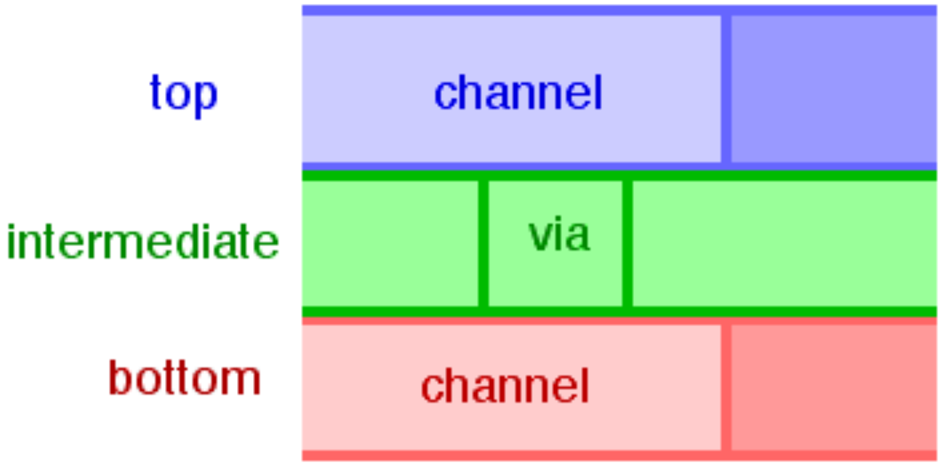
Complex mixer by cutting



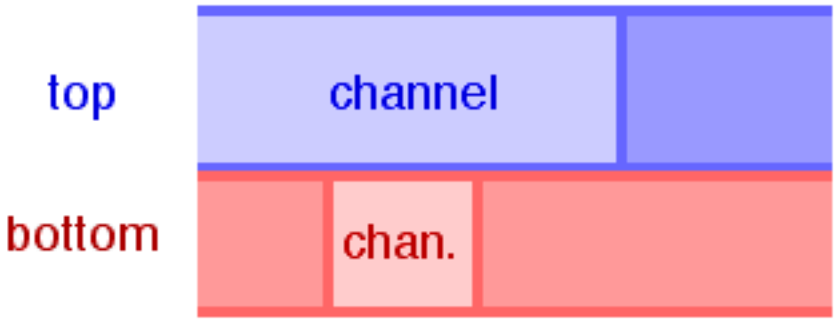


Mengeaud,
EPFL 2002

Making vias

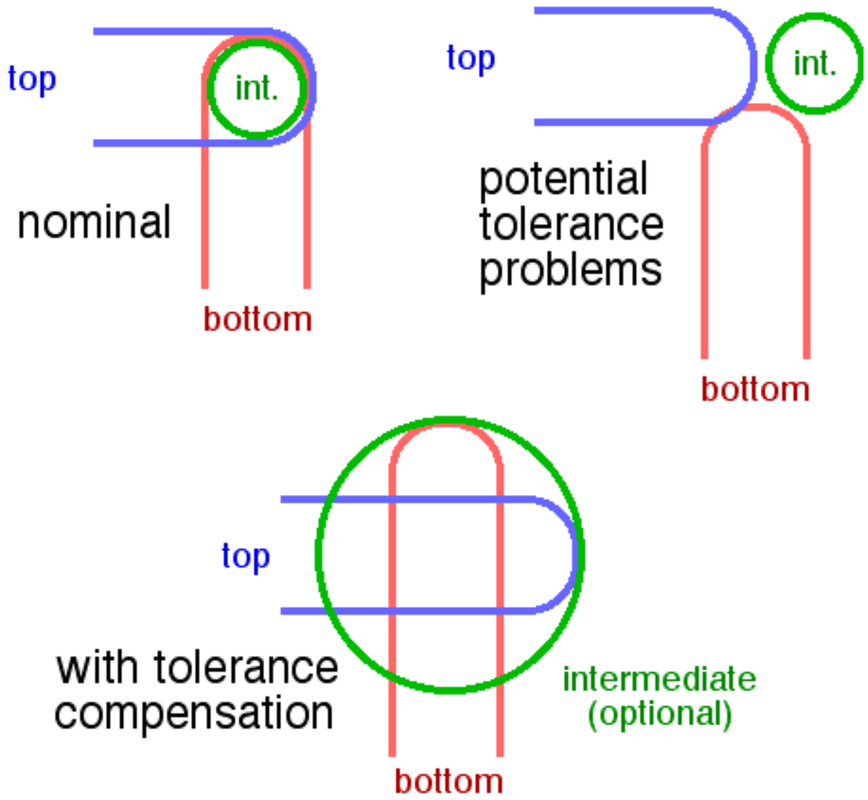


« Explicit » via using dedicated intermediate layer



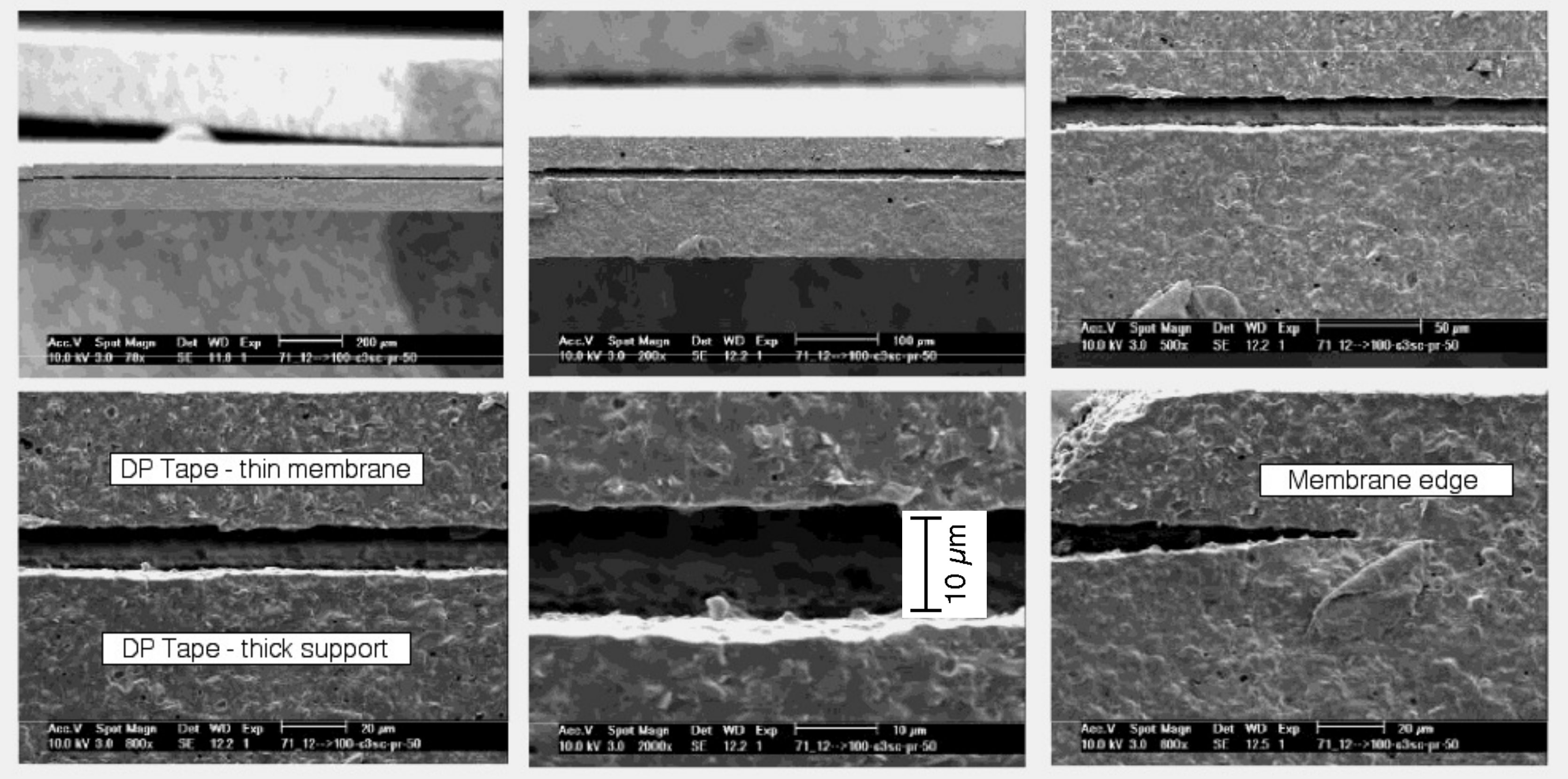
« Implicit » via between overlapping channels

Via alignment tolerance issues



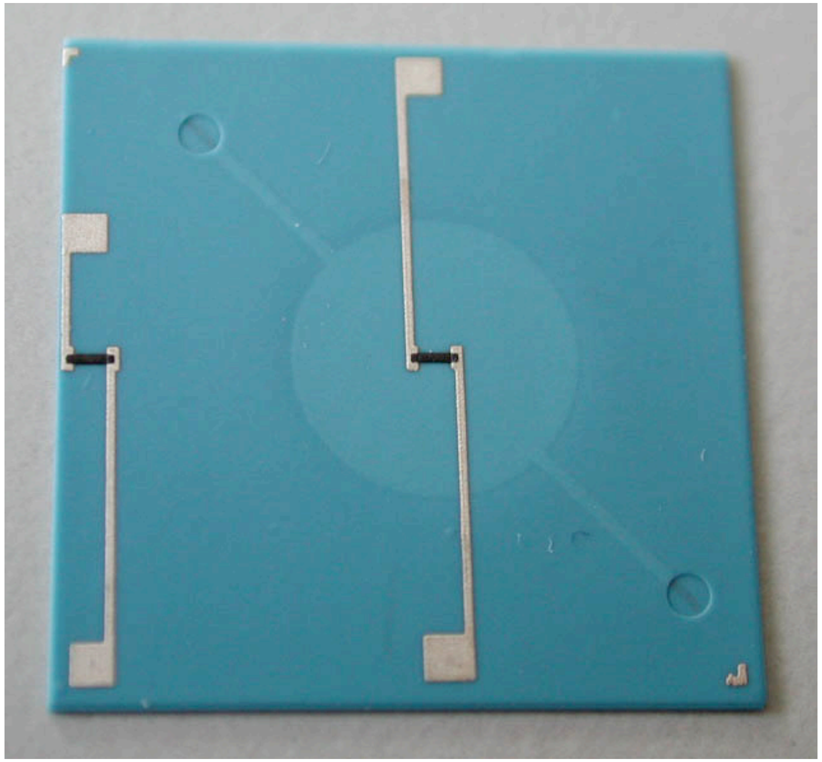
- Tolerances 50…100 µm
- Plasticity of LTCC green sheet
- Compensation needed
- Creation of parasitic dead volumes

Membranes by sacrificial layer



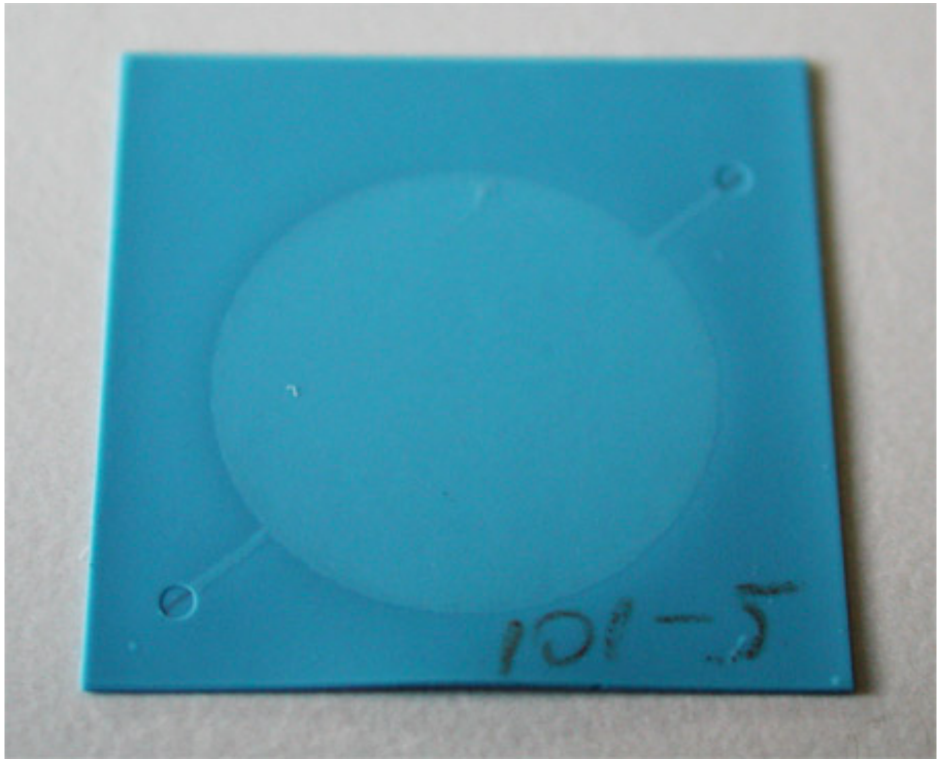
- 3-D structuration using sacrificial C layer
- 7 mm membrane, 40 µm thick, 10 µm spacing

Membranes by sacrificial layer



- 7 mm membrane, 40 µm thick, 15 µm spacing
- Includes sensing & reference resistors

Membranes by sacrificial layer



- 15 mm membrane, 40 μm thick, 15 μm spacing

LTCC vs. alumina

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Material	LTCC	Al_2O_3
Available thicknesses [mm]	0.04…	0.17…1.5
Strength [MPa]	320	600
Young's modulus [GPa]	150	320
Thermal conductivity [W/m/K]	3	25
Thermal resistance [K/W]	8300	240
Rupture strain [ppm]	2100	1900
Flexural sensitivity [$N^{-1} \cdot m^{-1}$]	100	0.6

⇒ LTCC outstanding for:

- Thermal sensors
- Force & pressure sensors for small ranges

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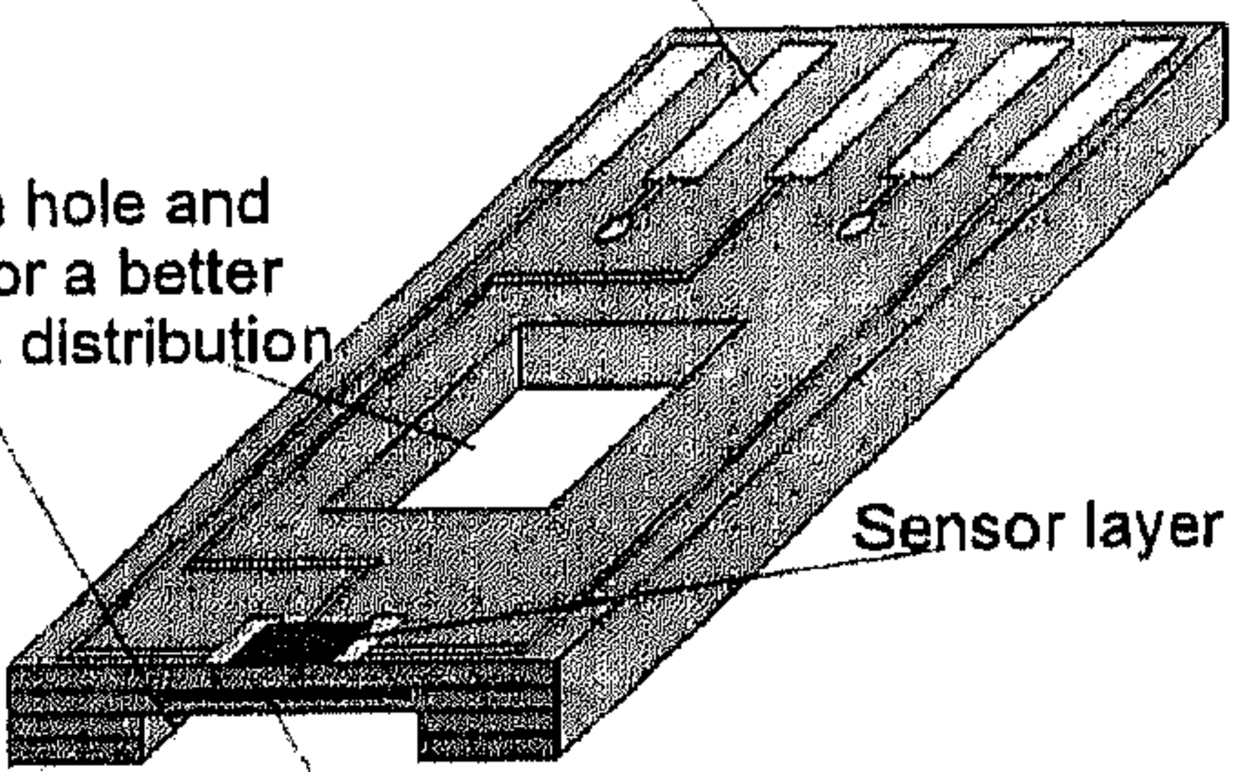
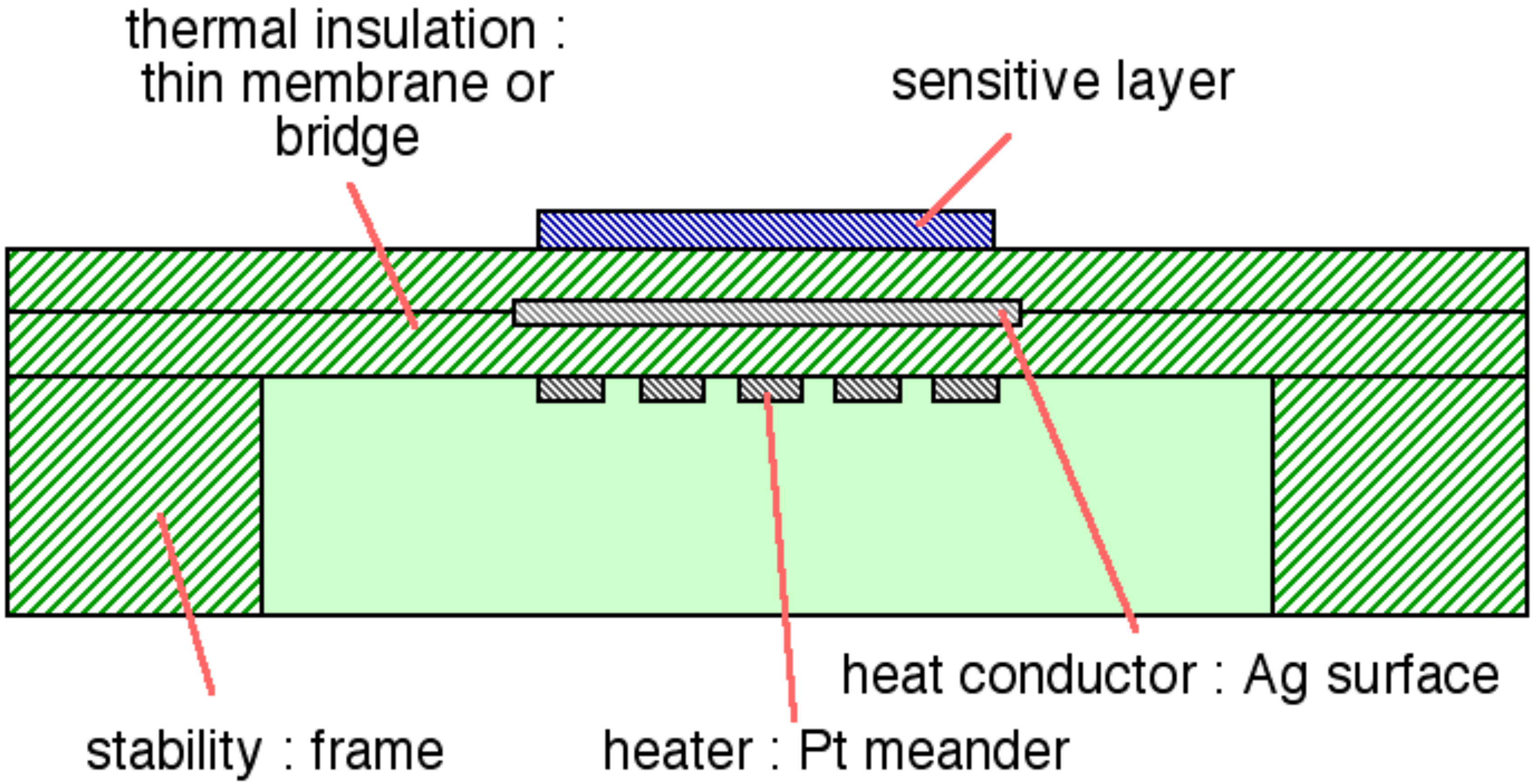
Heated gas sensor



Golonka et al., 1988

Heated gas sensor - structure

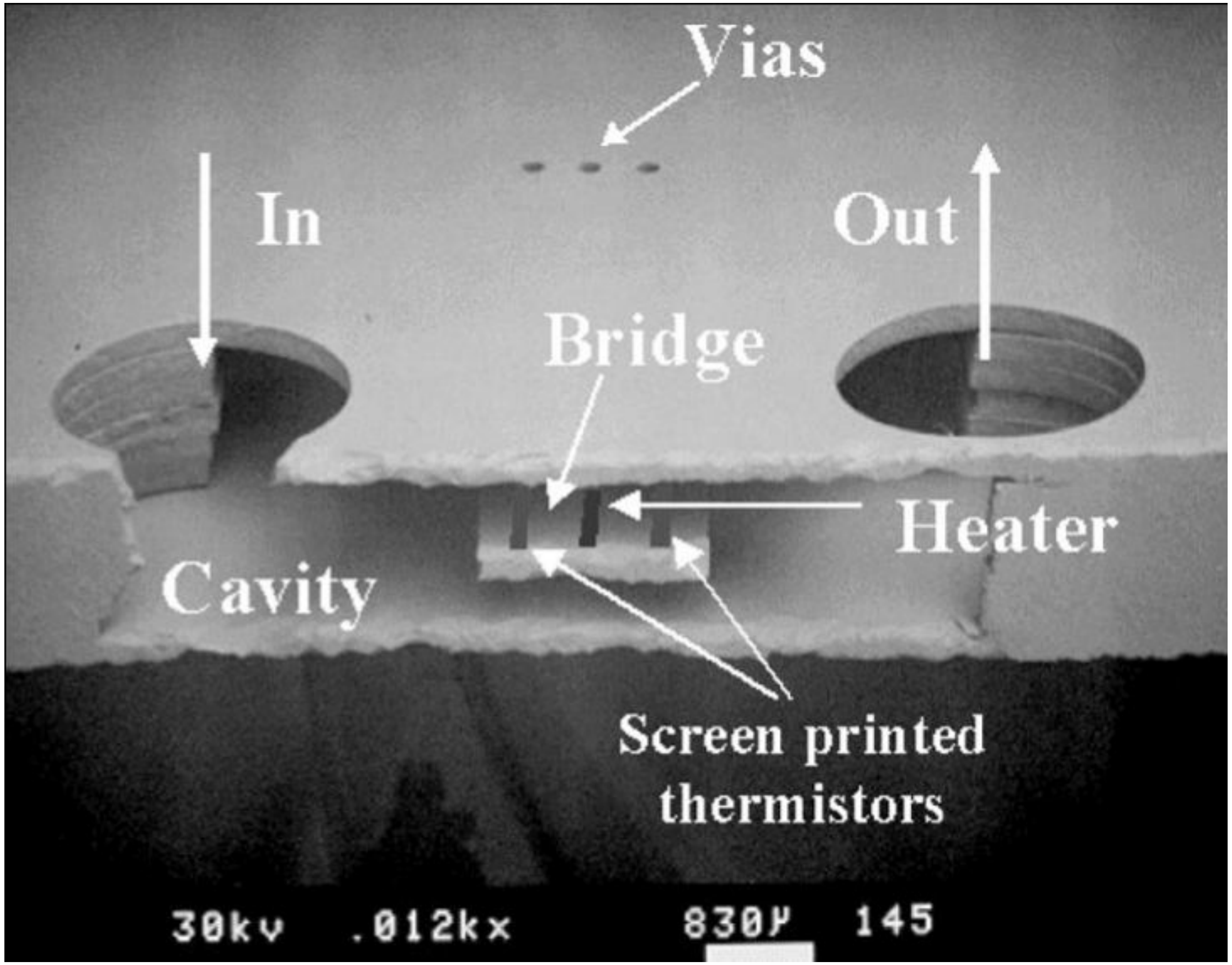


Heated gas sensor - conduction

LTCC Conductivity	3 W/m/K
Ag conductivity	430 W/m/K
LTCC sheet conductance @ 100 µm	0.3 mW/K
Ag sheet conductance @ 10 µm	4.3 mW/K
LTCC conductive loss @ 400°C, 3:1	40 mW

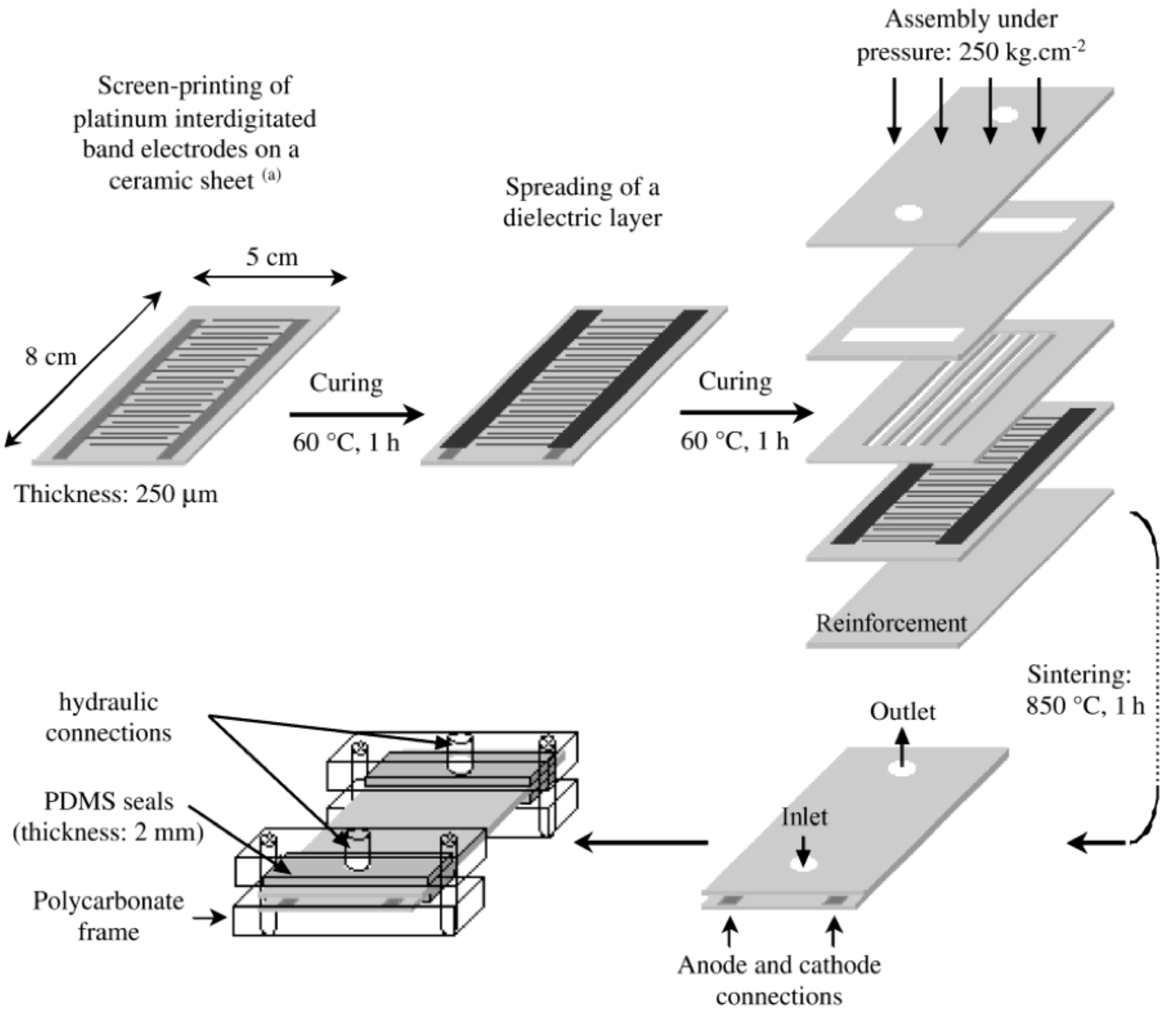
- LTCC allows creation of “hot spots”
- Chemical devices
- Sensors for gas, flow, etc.

Anemometric flow sensor



Gongora-Rubio et al., 2001

Electrochemical microreactor



Mengeaud et al., 2001

Conclusions

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- Proven base material with wide application range - automotive & mobile communications
- Very good thermal & chemical stability
- Easy prototyping and fabrication of 3-D fluidic & electric circuits
- Functionalisation by appropriate films
- Integration of several functions into one device possible - “Lego” design
- Rapidly growing “cookbook”…