NON-PACKAGING APPLICATIONS OF LTCC TECHNOLOGY

MÁRIO RICARDO GÓNGORA-RUBIO,

Instituto de Pesquisas Tecnológicas do Estado de São Paulo

IPT, SÃO PAULO, BRAZIL

Panamerican Advanced Studies Institute

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THIS IS A COLLABORATIVE EFFORT WITH

- UNIVERSITY OF SÃO PAULO-LSI-DMI
- AUTONOMOUS UNIVERSITY OF BARCELONA
  - SENSORS AND BIOSENSORS GROUP
- UNIVERSITY OF PENNSYLVANIA

Penn Engineering

PRESENTATION OUTLINE

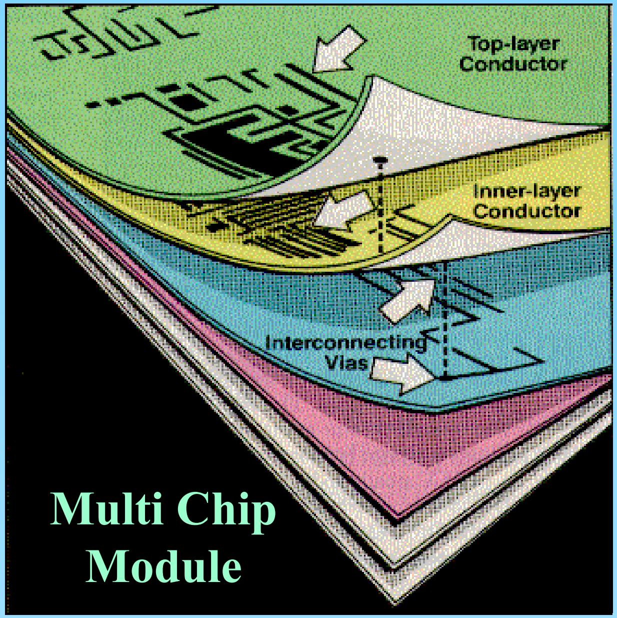
1. Introduction to LTCC Technology
2. LTCC Processing
3. Modular System Interfaces
4. LTCC Devices for MEMS/MST
5. Meso Systems Applications
6. Conclusions

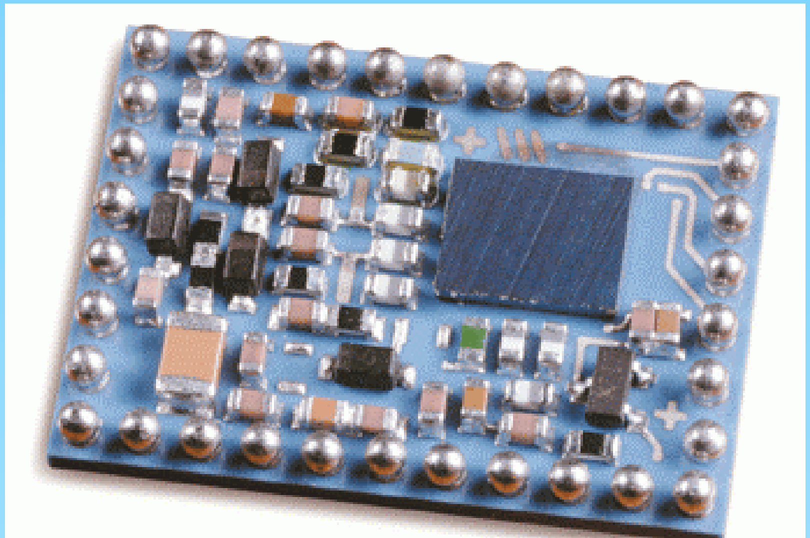
WHAT IS LTCC ?

–LTCC was originally developed by Hughes and DuPont for Military Systems.

– The (LTCC) technology can be defined as a way to produce multilayer circuits with the help of single tapes, which are to be used to apply conductive, dielectric and / or resistive pastes on.

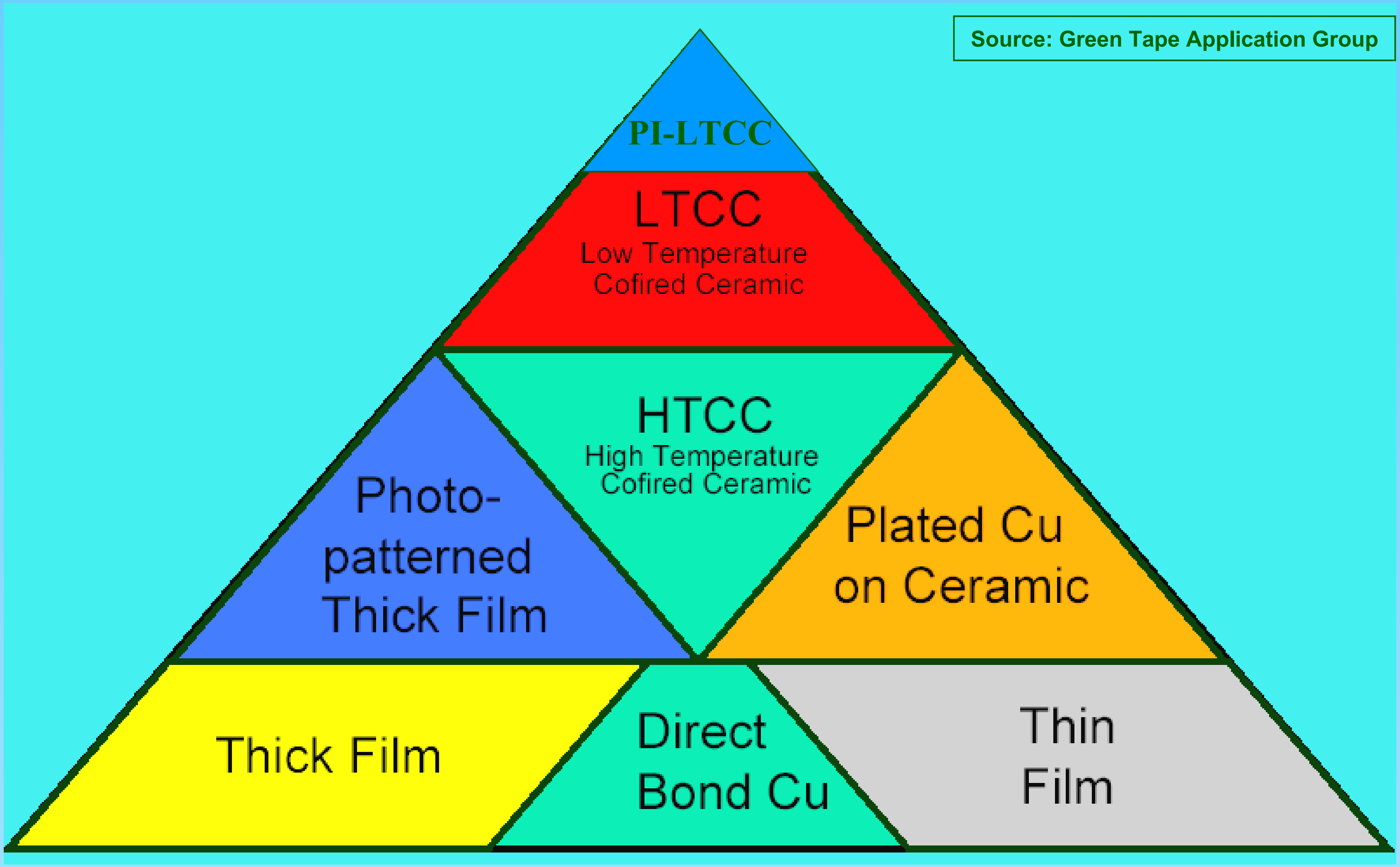
–These single sheets have to be laminated together and fired in one step all.



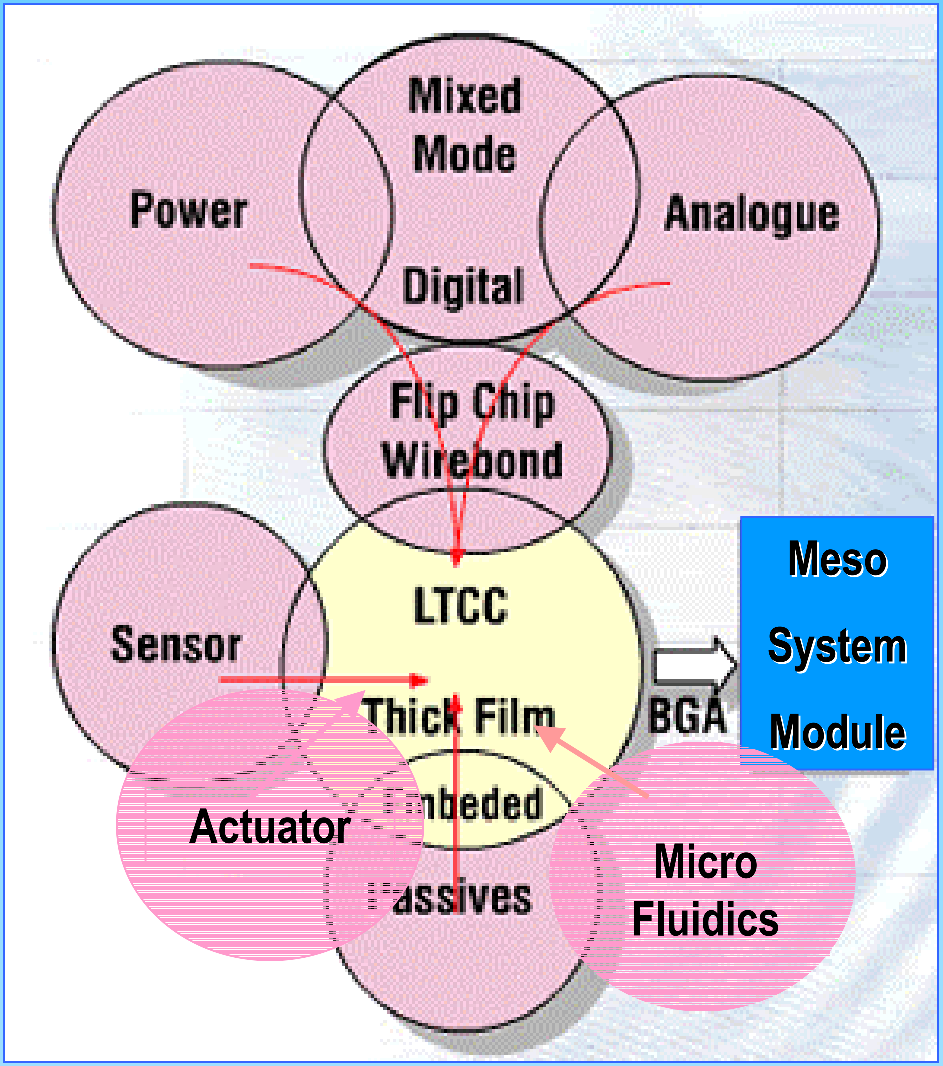


Bluetooth Interface (National)

CERAMIC INTERCONNECT TECHNOLOGY



TECHNOLOGY VISION



2. LTCC PROCESSING

– Materials

– Processing steps

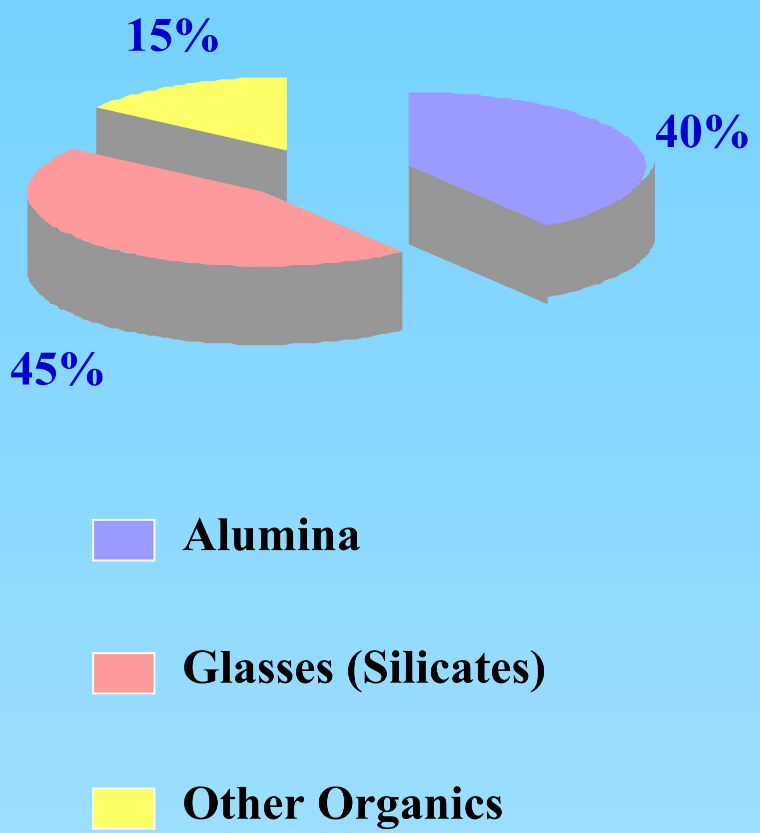
– Lamination

– Sintering

– Tape Machining

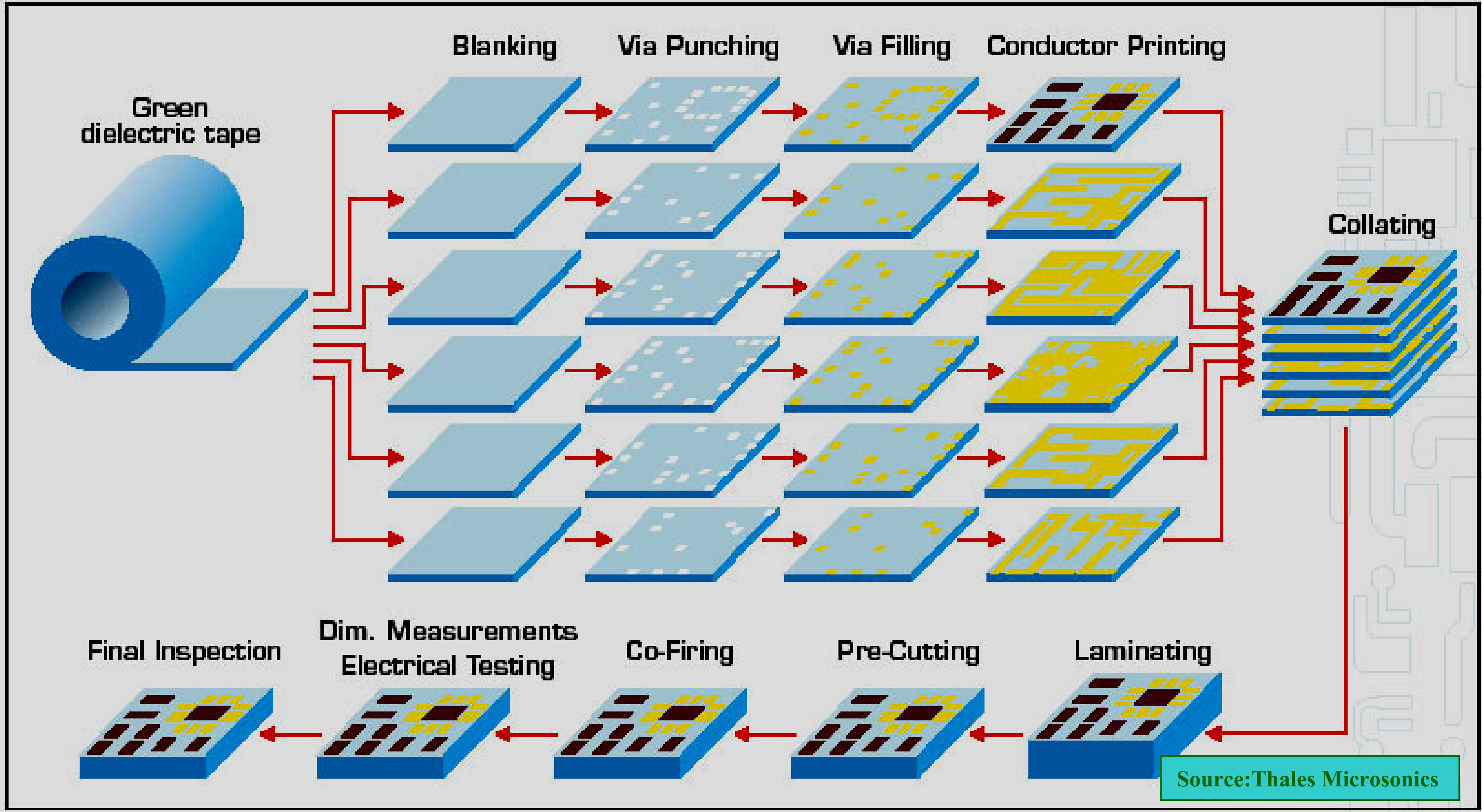
LOW TEMPERATURE CO-FIRED CERAMICS (LTCC)

LTCC-951 Composition



- Glass-ceramic composite materials
- The ceramic filler is usually alumina, Al_2O_3
- The usual composition also includes a glass frit and an organic binder (plasticizer and anti-flocculant)
- Called green tape before firing and sintering

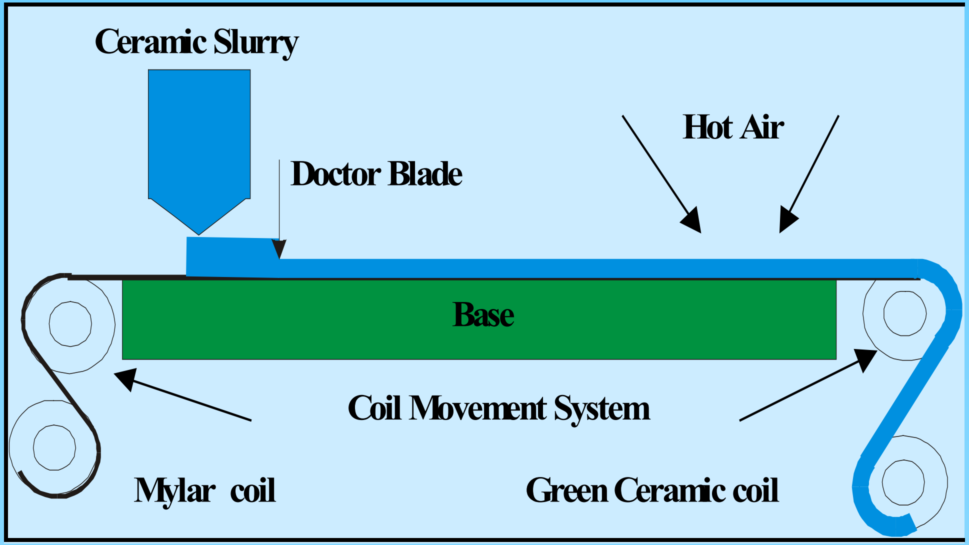
LTCC PROCESSING SCHEDULE

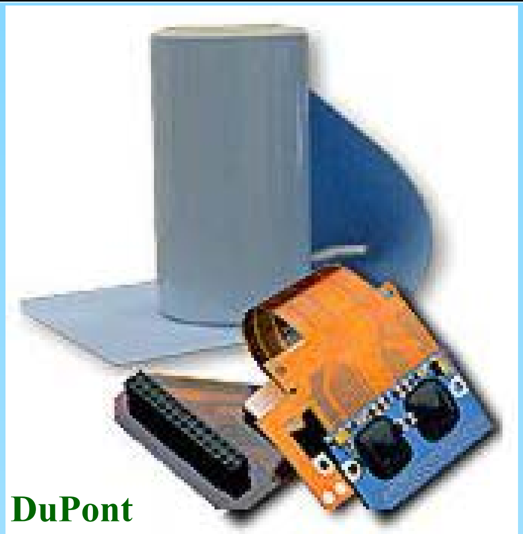


Source:Thales Microsonics

LTCC MANUFACTURING PROCESS (1)

- **Materials Preparation**
  - –LTCC Ceramic tape materials are prepared by milling precise amounts of raw materials into a homogeneous slurry.
  - –This mixture is principally of ceramic/glass powders with controlled particle sizes with fluxes and small amounts of organic binders and solvents.
  - –This slurry is poured onto a carrier and then passed under a blade to produce a uniform strip of specific thickness.
  - –When dried, this strip becomes a ceramic-filled “Green ceramic tape” which is easily handled in rolls or sheets for unfired processing.



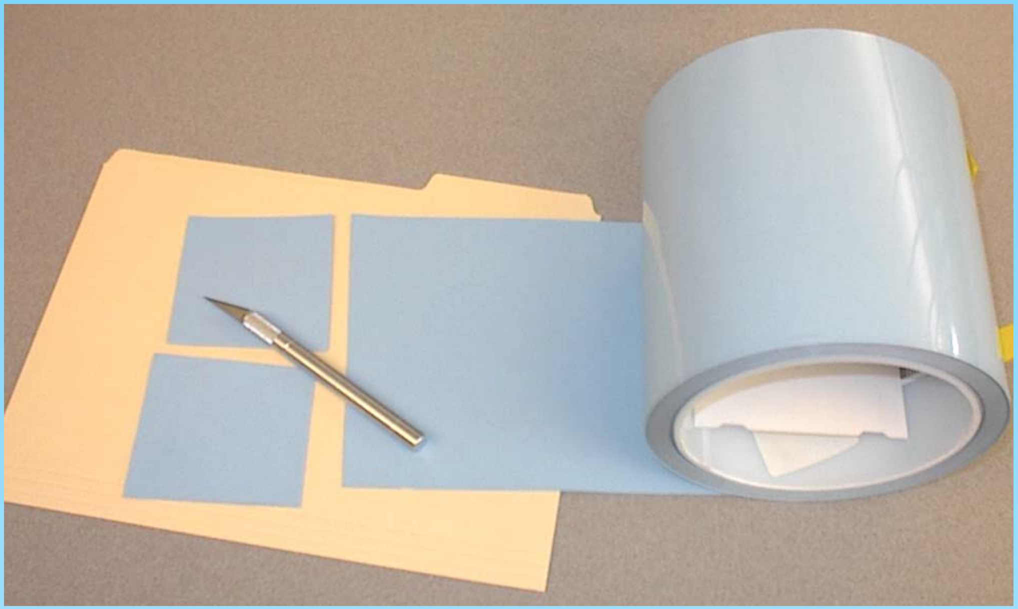


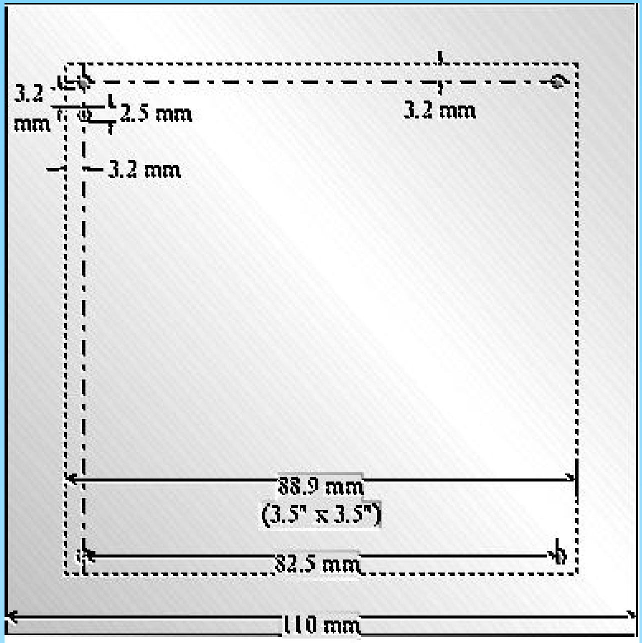
DuPont

LTCC MANUFACTURING PROCESS (2)

- Tape Preparation
  - –Cutting tape
  - –Pre-Conditioning in the furnace
  - –Punching or burning registration holes
  - –Removing Mylar-tape

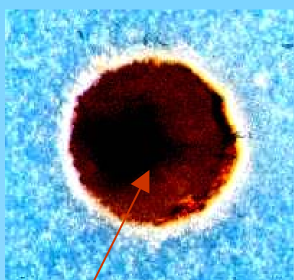
- Blanking
  - –A blanking die is used to create orientation marks and the final working dimension of the green sheets.





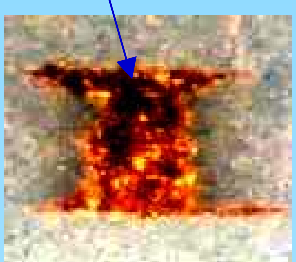
LTCC MANUFACTURING PROCESS (3)

- **Via Machining**
  - **–Using high-speed mechanical punching with a matrix tool, Laser System, CNC or JVE.**

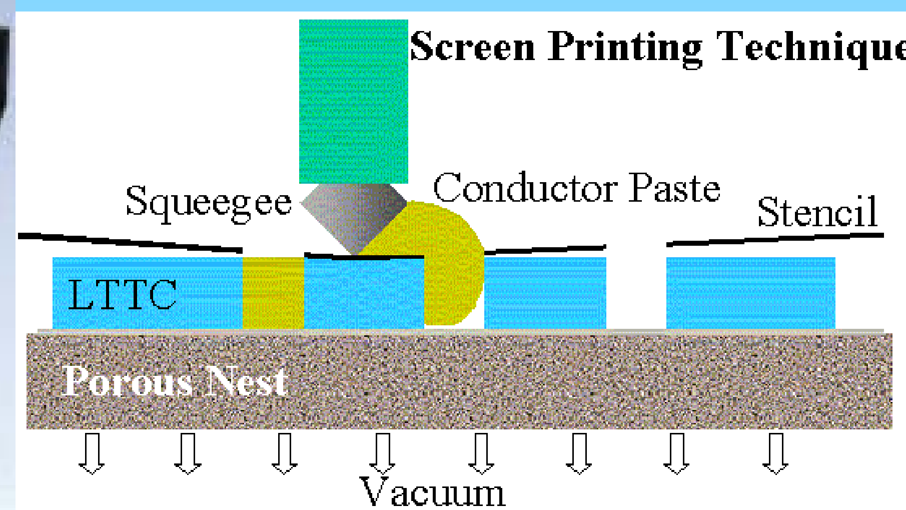


Via Hole

Metal

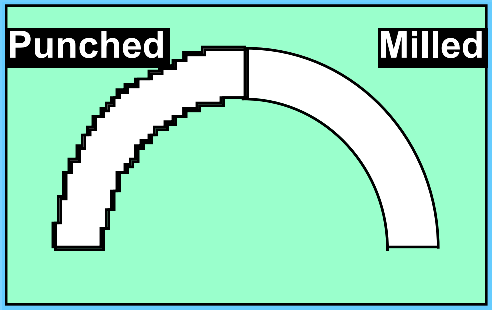


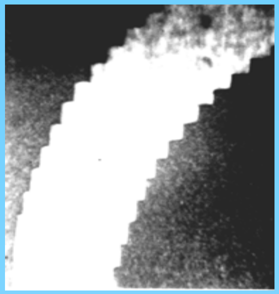
- **Via Filling**
  - **–Performed using an thick film screen printer with a stencil metal mask.**
  - **–Registration is performed using a vision system.**



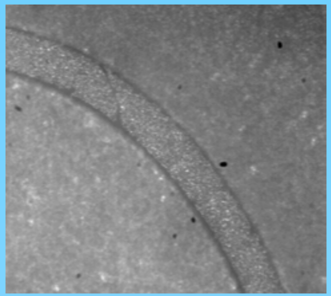
MECHANICAL MACHINING OF CERAMIC TAPES

Machined Samples





Punched curve



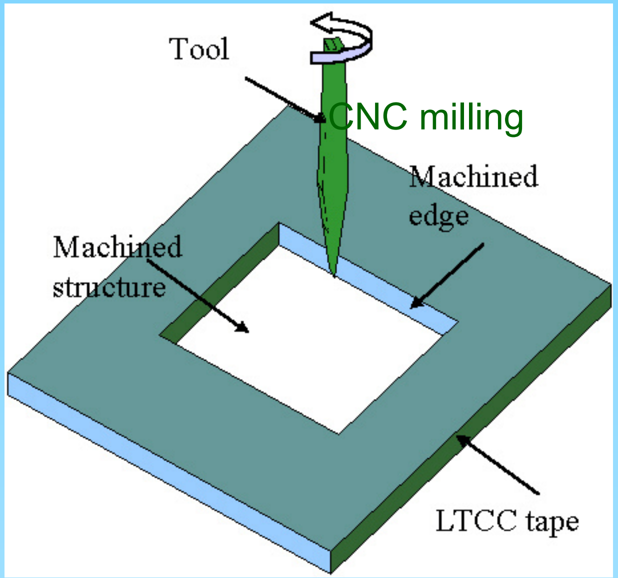
CNC milled curve

PUNCHING

- Circular or square shape
- Smallest size 0.004"(~100microns)
- Machining of curved features is difficult
- Partial depth machining cannot be done

CNC MILLING

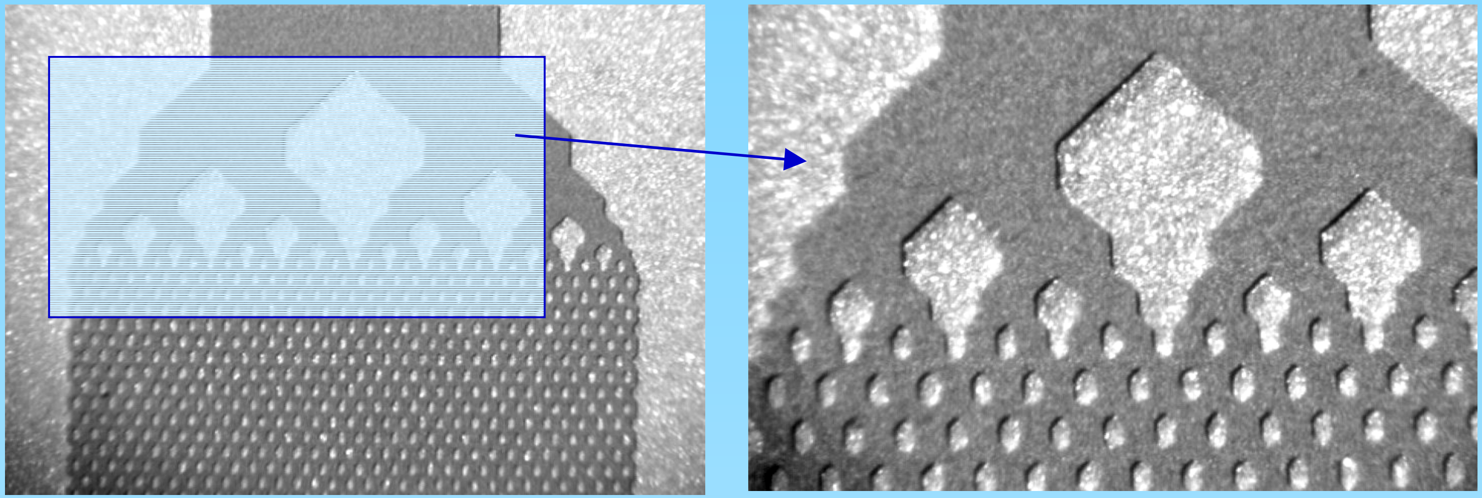
- Smallest size (~150 microns)
- Machining of curved features is easy
- Partial depth penetration facilitating shallow channels and thin membranes
- Vacuum chuck holder or wet tape is used to fix tape



LTCC HOT EMBOSSING

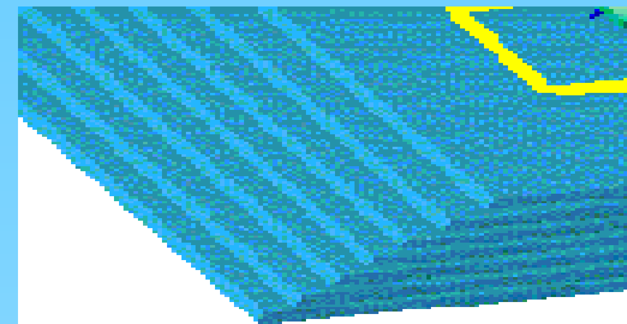
- Small features can be transferred to LTCC layers using Hot Embossing Technique
- Several Molds for complex structures have been constructed
- Development of the technique is on going

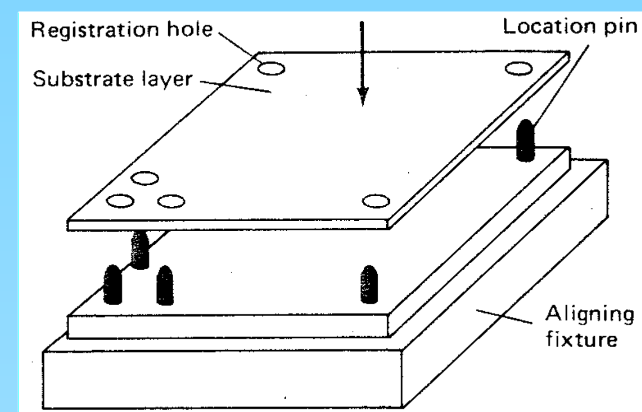
Hot Embossing Mold for Pre-Concentrator

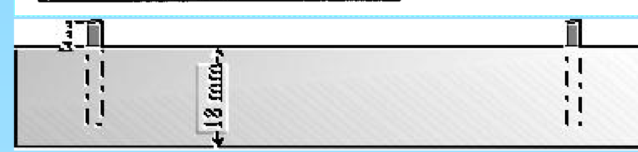


LTCC MANUFACTURING PROCESS (4)

- Paste Printing
  - –Resistor, conductor and dielectrics deposits are performed using an automatic thick film screen printer with mesh screens.
- Collating
  - –All layers will be collated and stacked with a special tool and will be fixed together to avoid misalignment.
  - –Can be performed using a vision system for alignment.



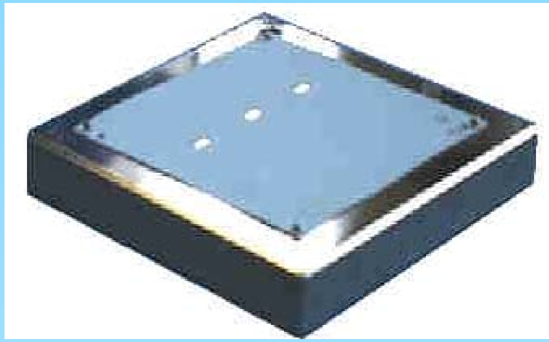




LTCC MANUFACTURING PROCESS (5)

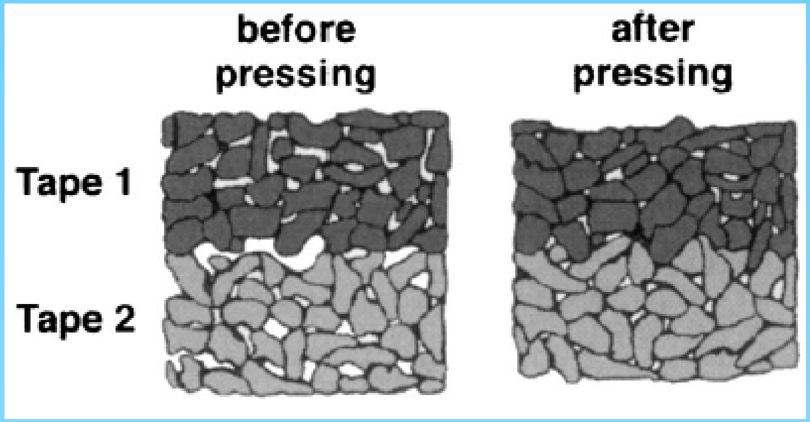
- Laminating
  - Accomplished using uniaxial or isostatic lamination in a specially designed thermal press
  - Temperature for lamination 100 °C
  - Laminating pressure is 3000 PSI
  - Typical cycle time is 10 minutes.

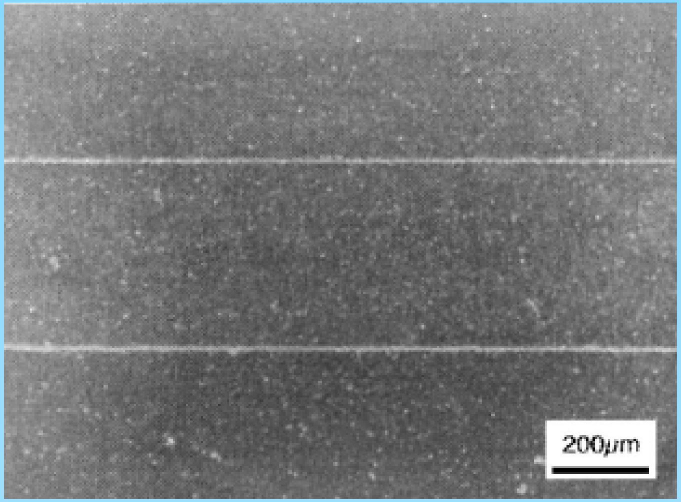
- Pre-Cutting
  - Laminates are pre-cut with a hot blade, meeting the panel drawing specifications.



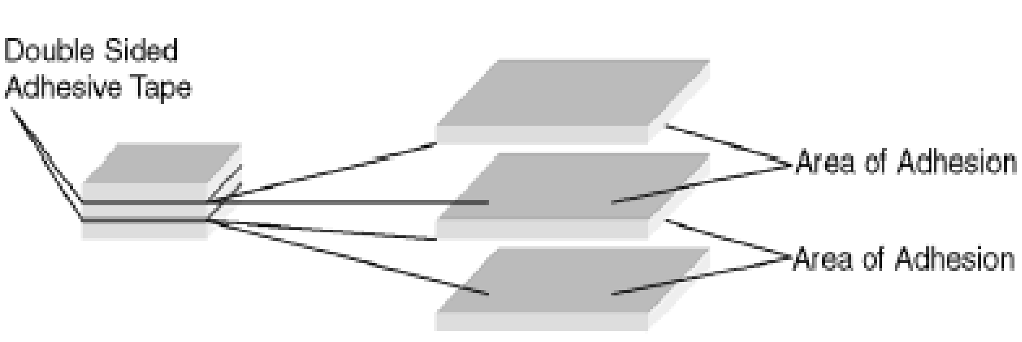
LAMINATION PROCESS

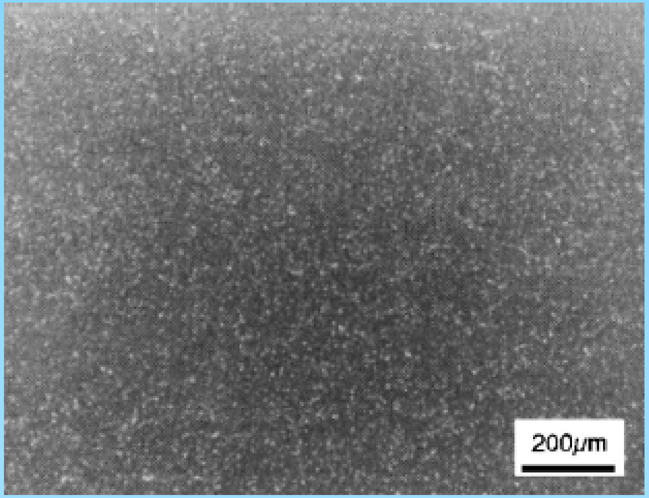
Thermocompression





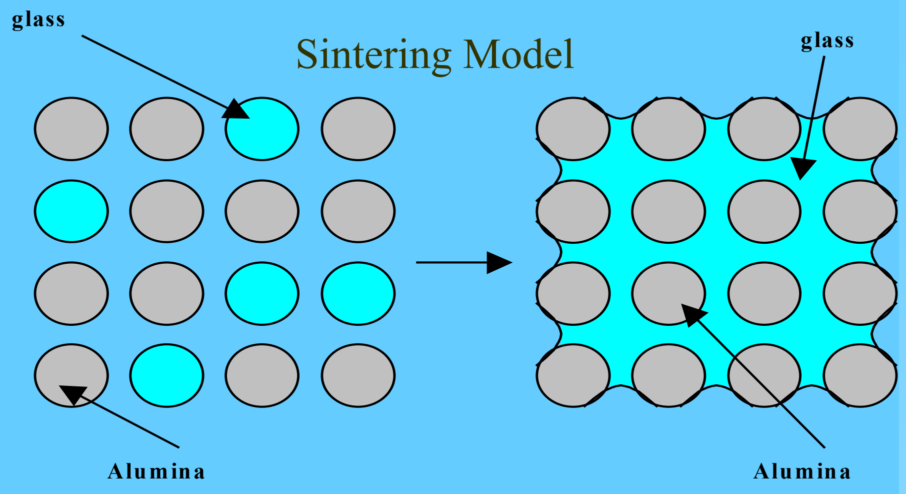
Cold Low Pressure

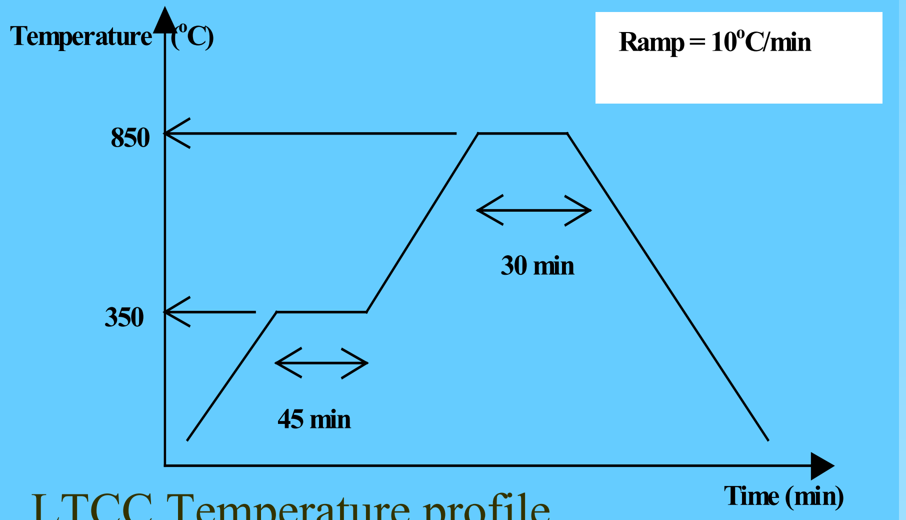




LTCC MANUFACTURING PROCESS (6)

- Co-Firing
  - –Made in a belt or special furnace at a peak temperature of 850°C and a dwell time of 30 minutes.
  - –The typical cycle time is 3 hours.

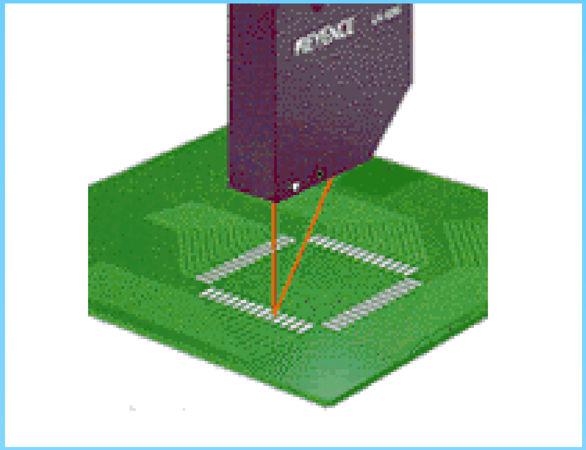




LTCC Temperature profile

LTCC MANUFACTURING PROCESS (7)

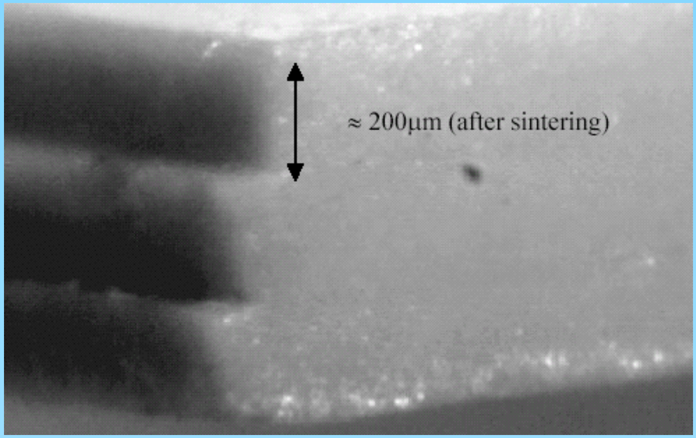
- Dimensional Measurements /Electrical Test:
  - **Panel and circuit size can be checked with automatic measurement vision system. Electrical resistance test is performed with an automatic system with probe card.**
- Final Inspection:
  - **Optical, Laser and acoustic inspection techniques are performed on completed parts in accordance with the applicable standards.**



PROCESSING DIFFICULTIES IN MST APPLICATIONS: LAMINATIONS

An often encountered problem in MST applications is the lamination at low uniaxial or hydrostatic pressures, as to avoid the collapse of internal voids, channels and cavities in the green. Several possibilities are available, the two that we have pursued in recent times are: cold low pressure lamination (Erlanger's CLPL method) and Lamination using organic fluids.

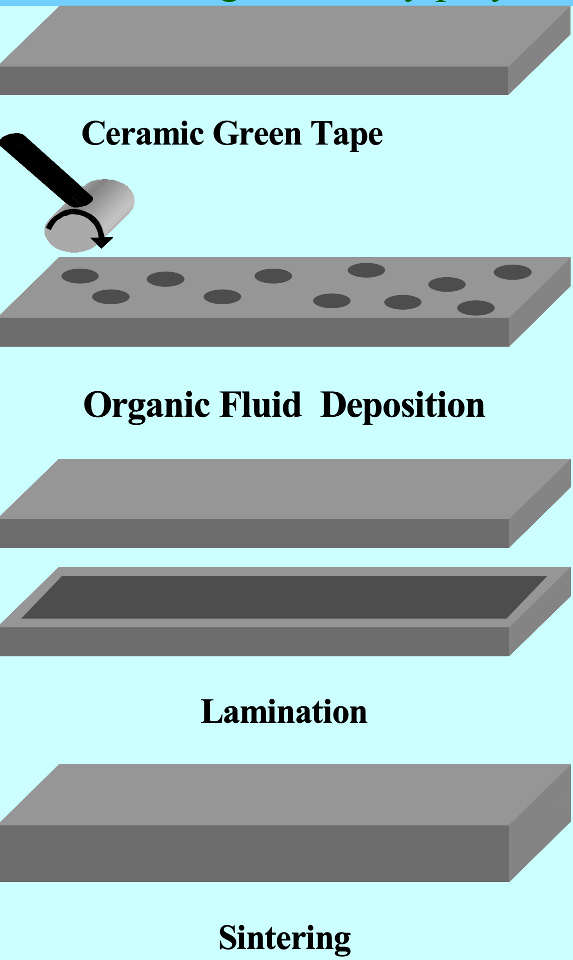
Cavity deformation after thermo-compression lamination

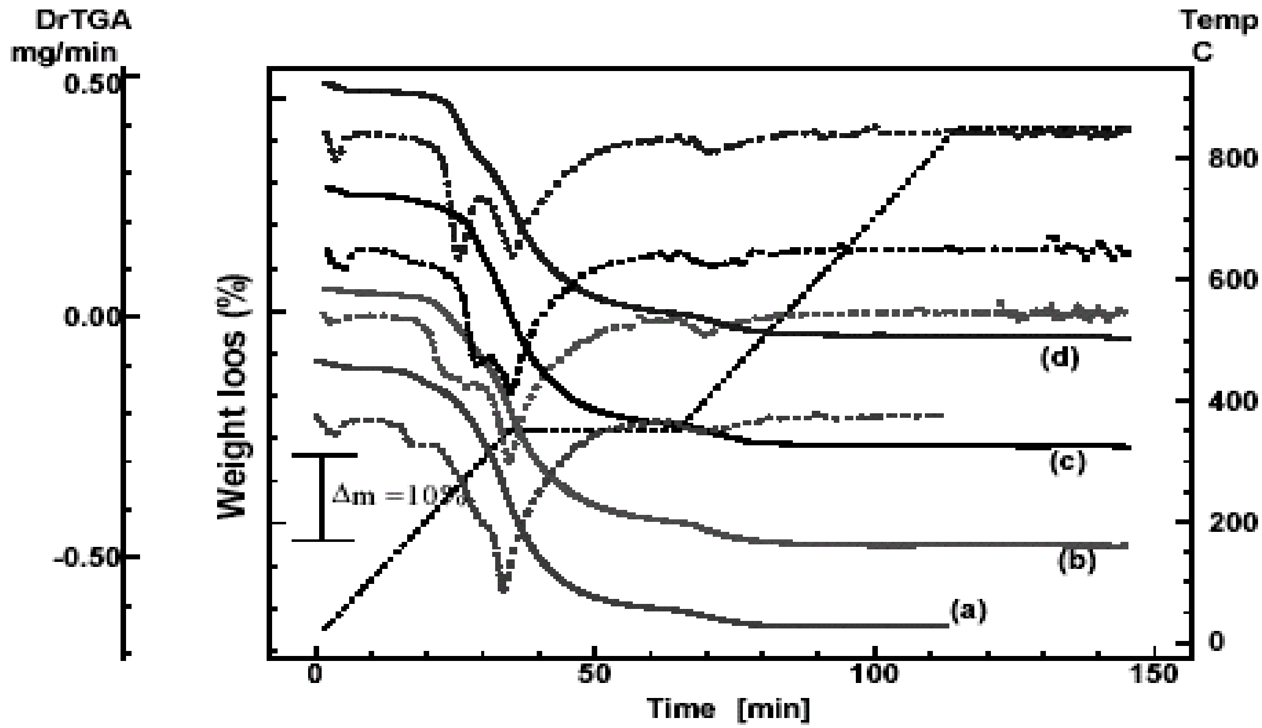


Three layer lamination using organics

PROCESSING DIFFICULTIES IN MST APPLICATIONS : LAMINATION

High viscosity polysaccarides (sugars) used as laminating vehicles for LTCC tapes





(a) Fructose lamination;
(b) Sucrose lamination;
(c) Glucose lamination;
(d) Maltose lamination.

Thermo-gravimetric studies of the different laminating vehicles “burn-off” compared to a typical 951 series LTCC tapes sintering cycle.

PROCESSING DIFFICULTIES IN MST APPLICATIONS: LAMINATION

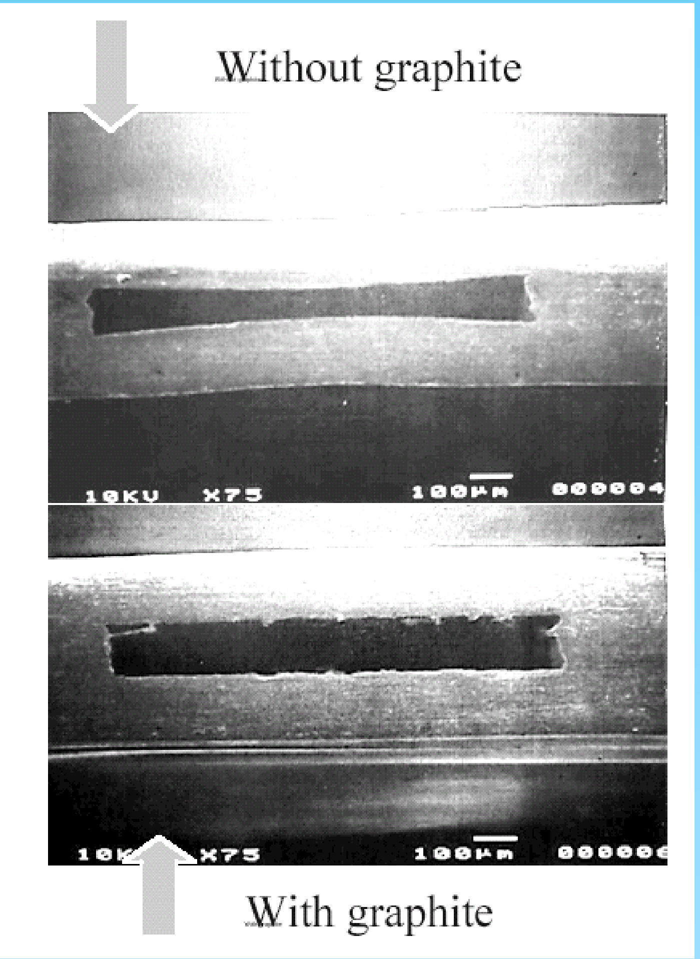
- Advantages of lamination using organic fluids :
  - –Excellent gluing function and easy tapes alignment in room temperature due to their high viscosity;
  - –Low pressure and temperature process;
  - –No pressure gradients in laminate;
  - –Easy method of deposition, allowing lamination of complex shapes and non-uniform surfaces;
  - –Sintering temperature profile with high heating rate compared with CLPL method;
  - –Organic fluid deposition can be realized by dipping, screen printing or dispensing techniques;
  - –-Inexpensive and readily available.

PROCESSING DIFFICULTIES IN MST APPLICATIONS : SAGGING

The sagging, or the collapsing of the top and bottom (mostly top, due to body forces)of internal voids or channels in LTCC tapes is a common problem for MST and Microfluidic applications.

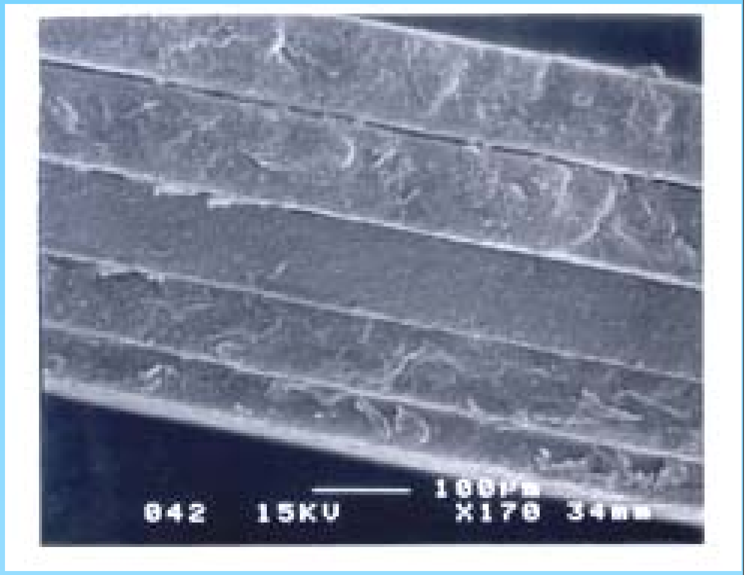
The inexpensive solution is to mix graphite or carbon black powder with an organic vehicle of high viscosity. This mixture is easy oxidized during the sintering cycle (a fugitive or sacrificial phase).

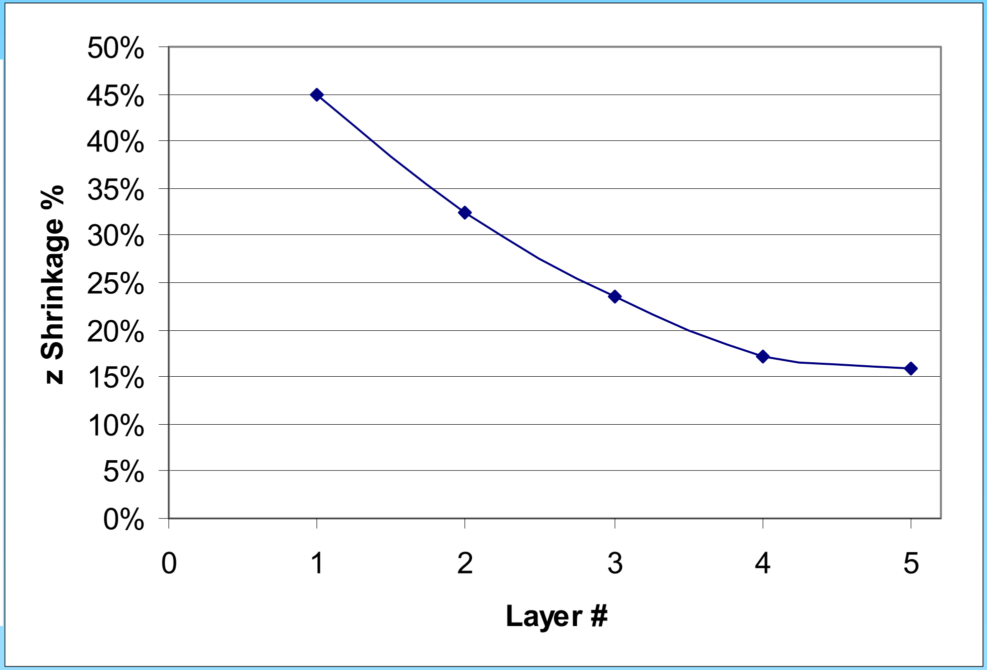
Here is a SEM micrograph of the same size channel sintered with and without the fugitive phase.



PROCESSING DIFFICULTIES IN MST APPLICATIONS: CONSTRAINT LAMINATION

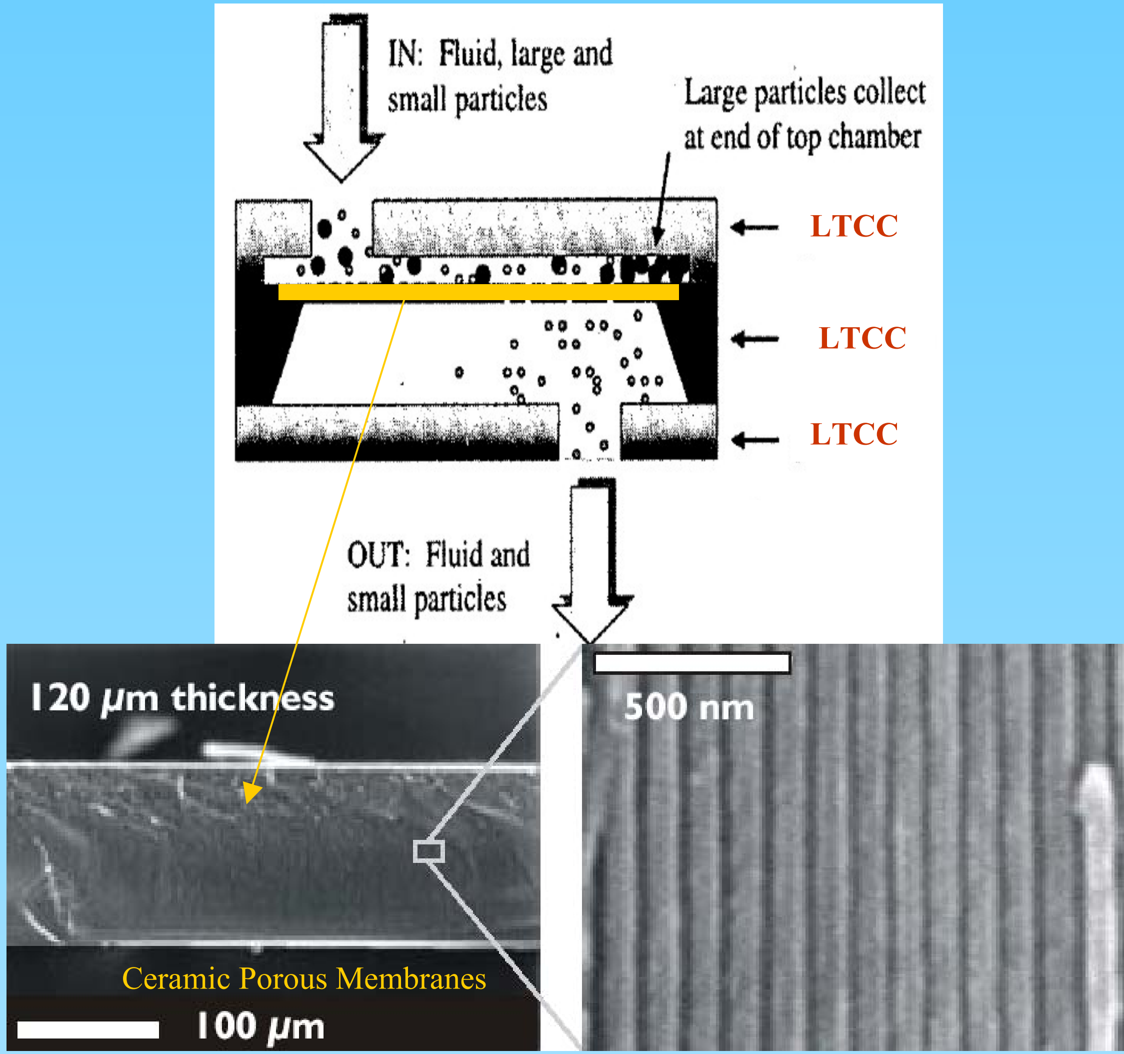
- Before firing the green tapes are laminated to a rigid substrate. z-shrinkage must be considered during the device design.



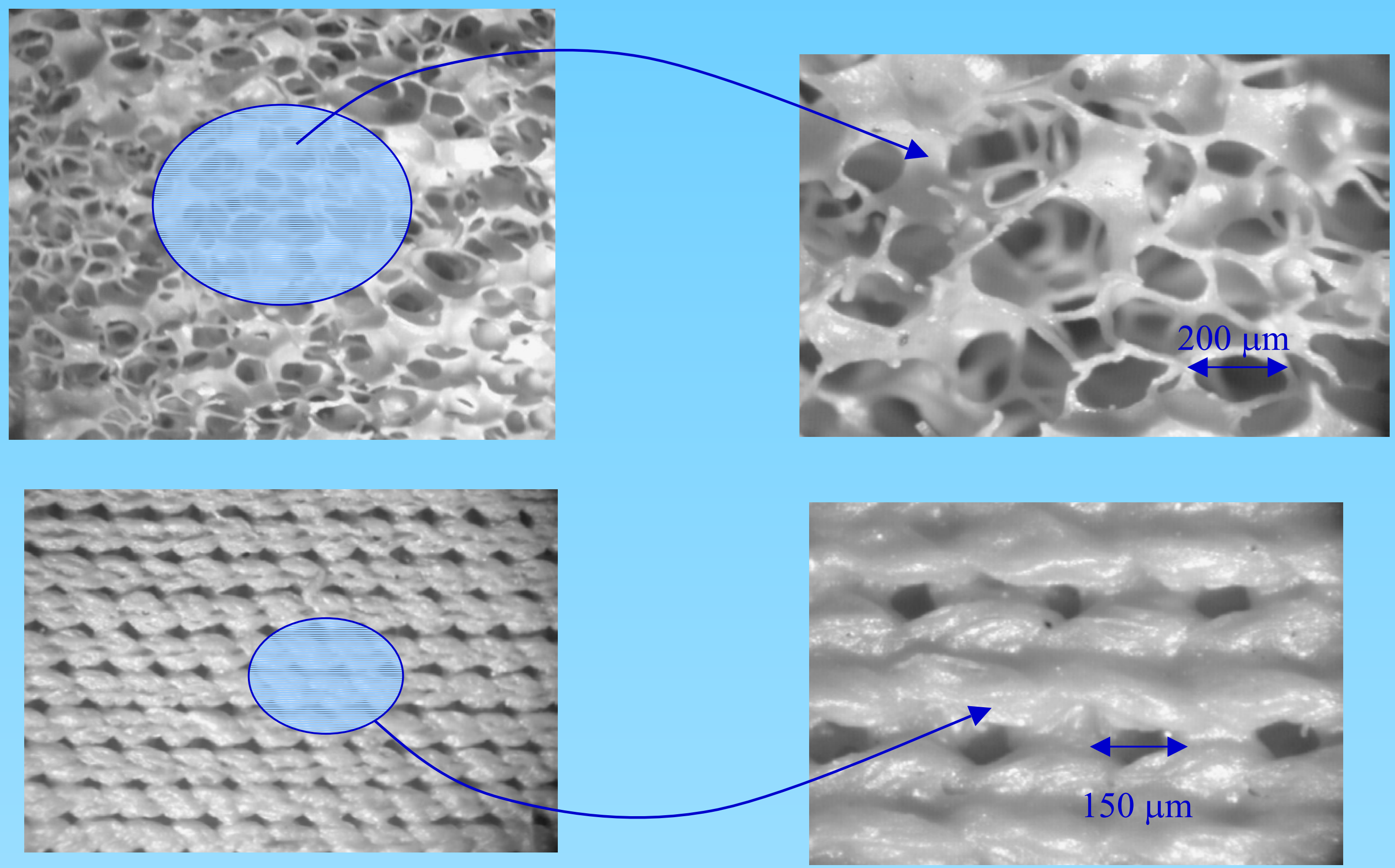


LTCC STRUCTURES FOR MICROFILTERING

- Need to integrate a Microfiltering stage into LTCC Microfluidic system
- Possibility of create structures for Catalytic material deposition for Fuel Cells
- Possibility of creating high area for biological seeds.



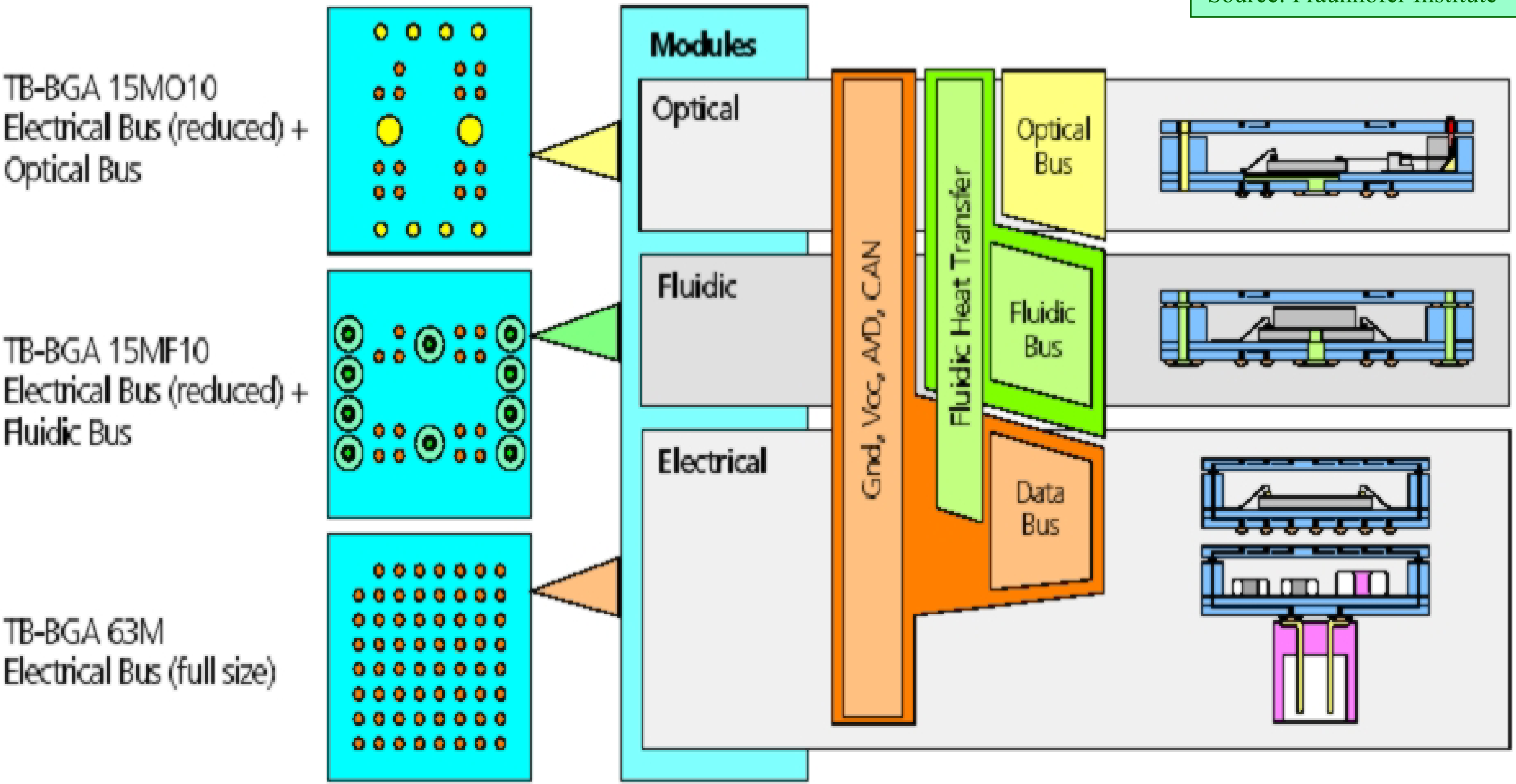
POROUS LTCC



3. MODULAR SYSTEM INTERFACES

MODULAR SYSTEM INTERFACES

Source: Fraunhofer Institute



LTCC-TB-BGA (TOP-BOTTOM- BGA)

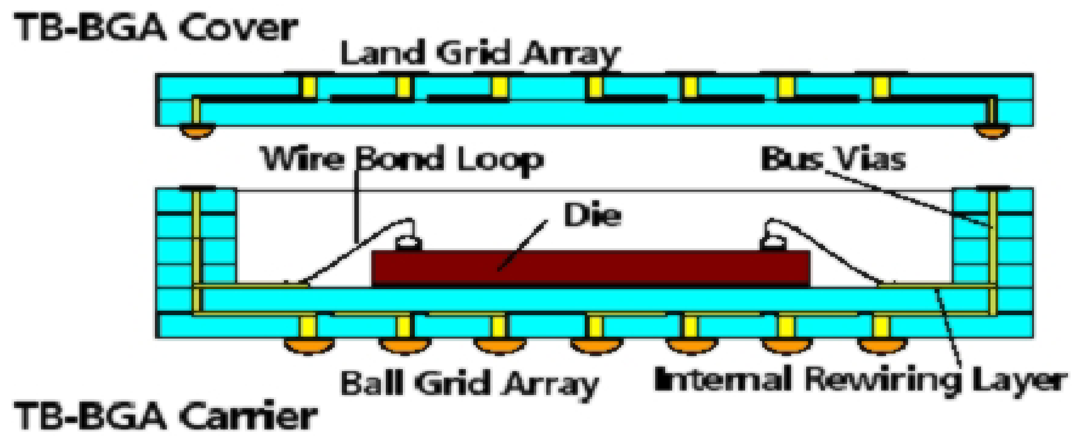
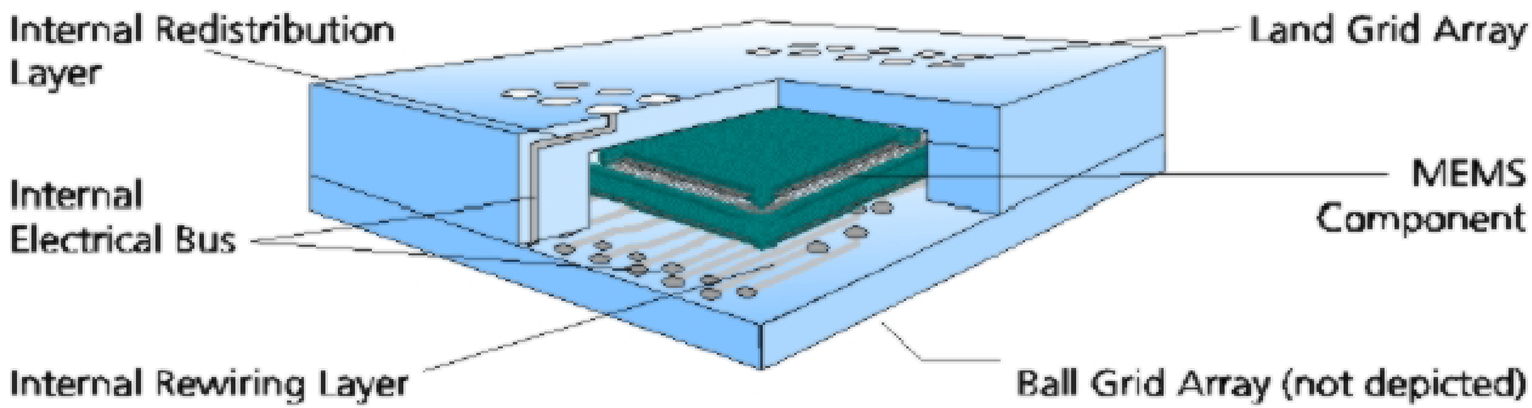
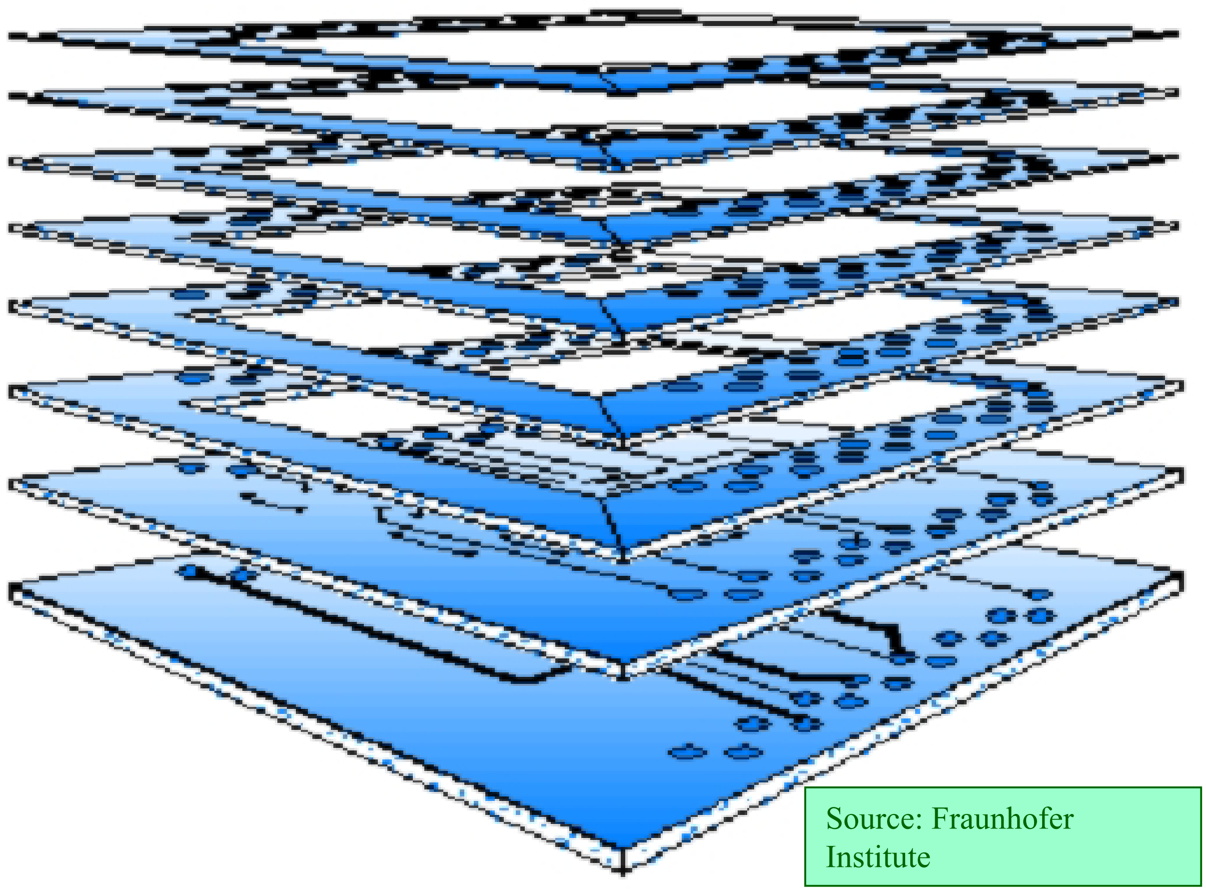


Figure 3: TB-BGA Package (Cross Section)

Source: Fraunhofer Institute

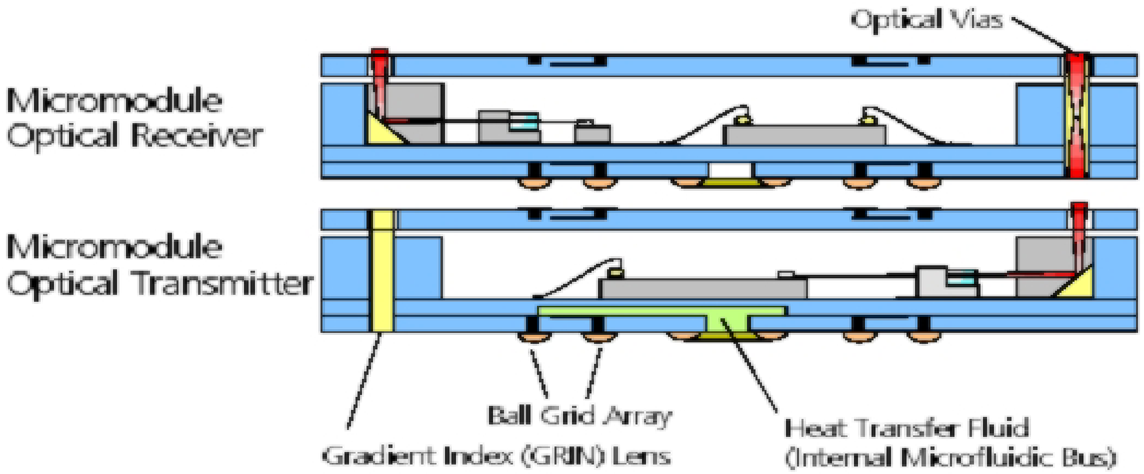


ASSEMBLY OF A LTCC CARRIER

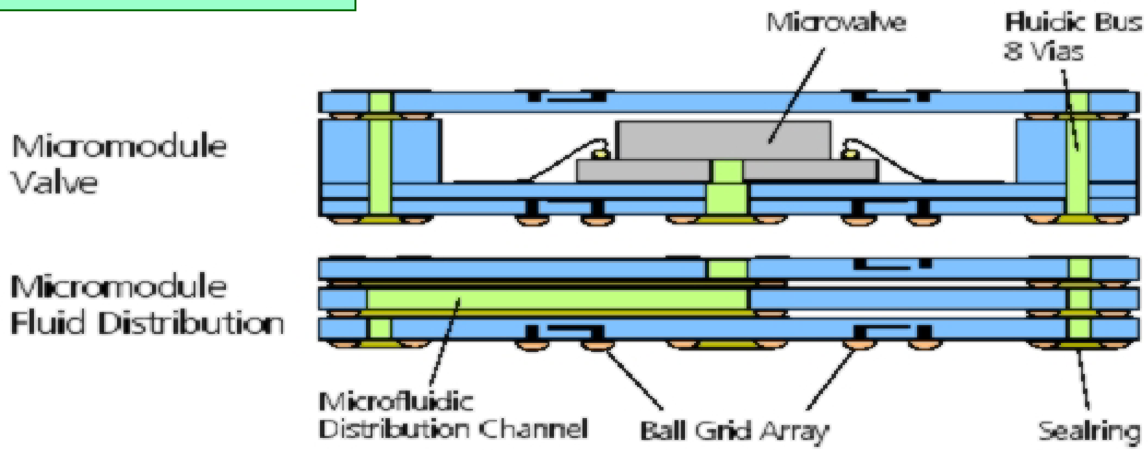


Source: Fraunhofer Institute

OPTICAL & FLUIDIC INTERFACES



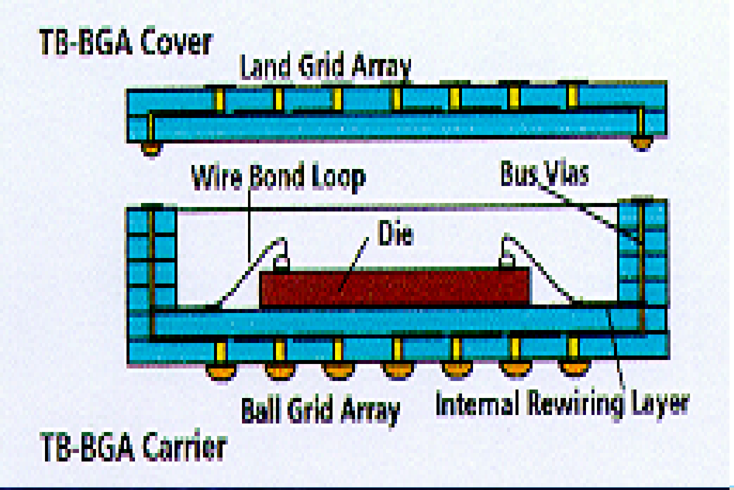
Source: Fraunhofer Institute

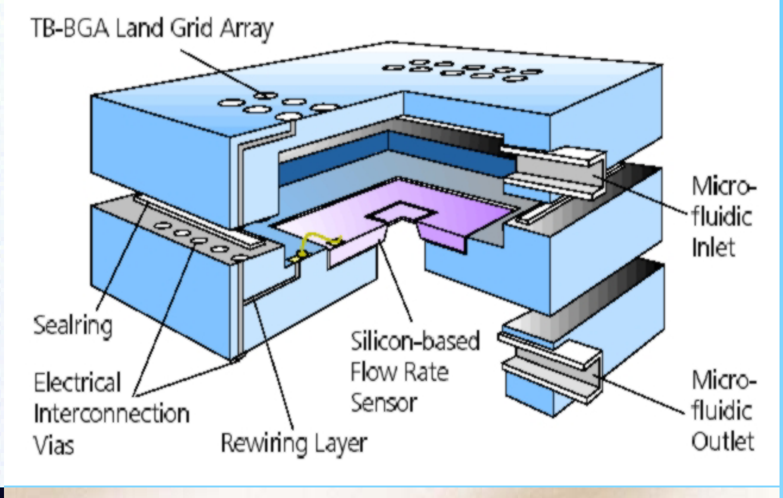


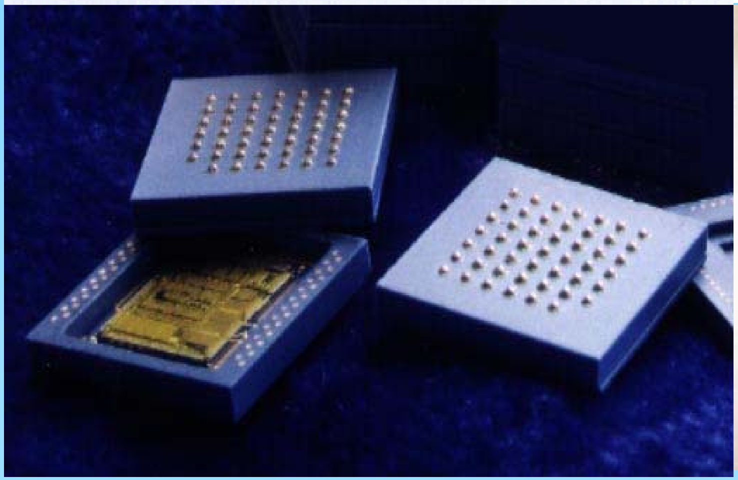
SOME 3D LTCC MODULES

- 16 Bits Microcontroller

Flow Sensor





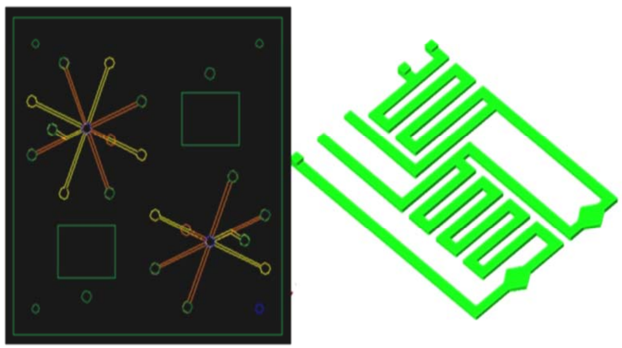


Source: Fraunhofer Institute

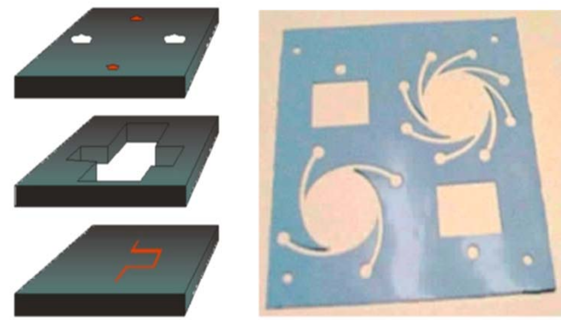
4. LTCC DEVICES FOR MEMS/MST

MANUFACTURING OF MESO SCALE SYSTEMS USING LTCC

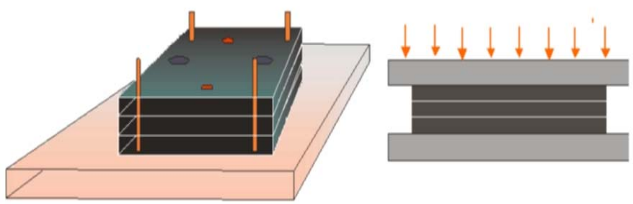
1. COMPUTER ASSISTED DESIGN of the desired structures.



2. COMPUTER NUMERICALLY CONTROL Milling machine are used for the layers fabrication



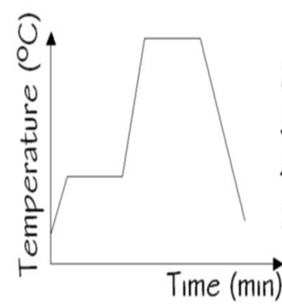
3. ALIGNMENT AND LAMINATION of the tapes.



Thermo-compression:

3 min at 100ºC and 1000 PSI
3 min at 100ºC and 3500 PSI

4. SINTERING PROCESS.



1) 10ºC/min → 350ºC
2) 30min at 350ºC
3) 10ºC/min → 850ºC
4) 30 min at 850ºC
5) Room temperature

SENSORS USING GREEN CERAMIC TAPES

- **Displacement and attitude sensors**
  - LVDT type displacement sensor
  - Attitude sensor using ferrofluids
  - Eddy current proximity sensor

- **Pressure Sensors**
  - Load Cells
  - Differential pressure sensors
  - High temperature pressure

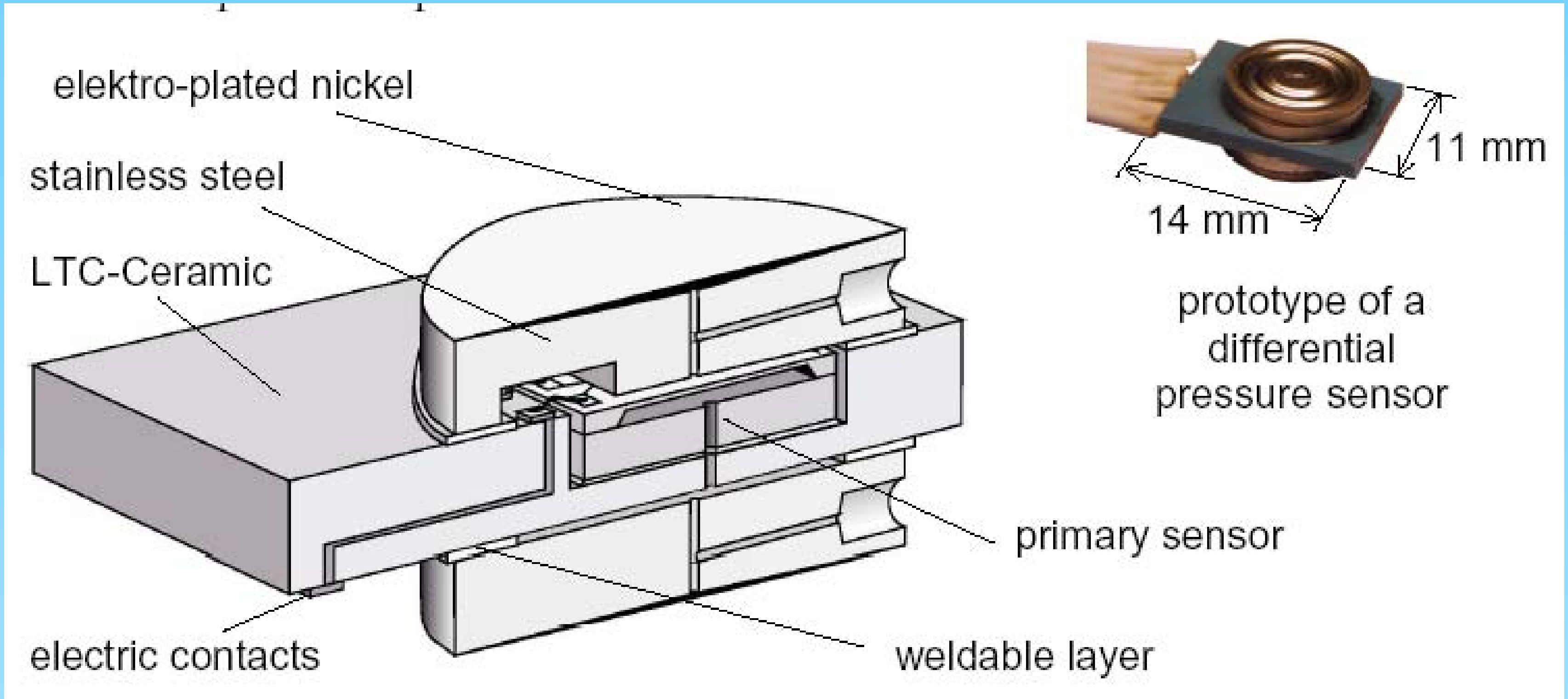
- **Basic Micro-Fluidic Devices**
  - Micro-channels
  - Critical orifices
  - Micromixers
  - Hot Plates
  - Micropumps

- **Thermal Flow Sensor**
  - Flow sensor using thermal loss measurement

- **Chemical Sensors**
  - SNO_2 Gas Sensor
  - PH Sensor
  - Electrochemical Electrodes

PRESSURE SENSORS

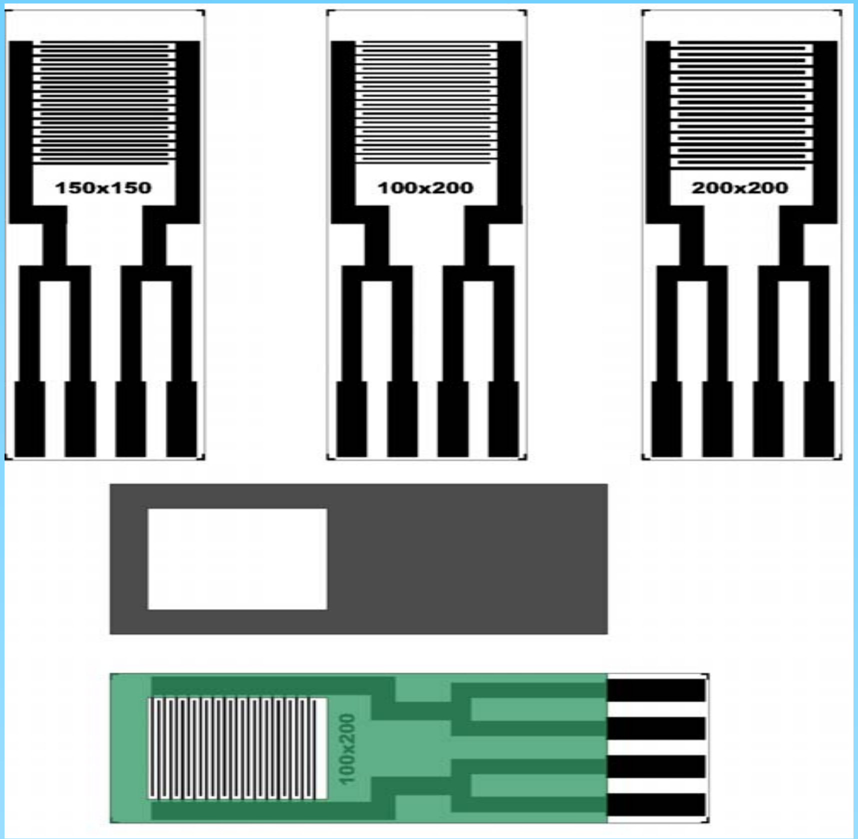
- Pressure sensors for applications, like media isolated devices, were developed using LTCC technology



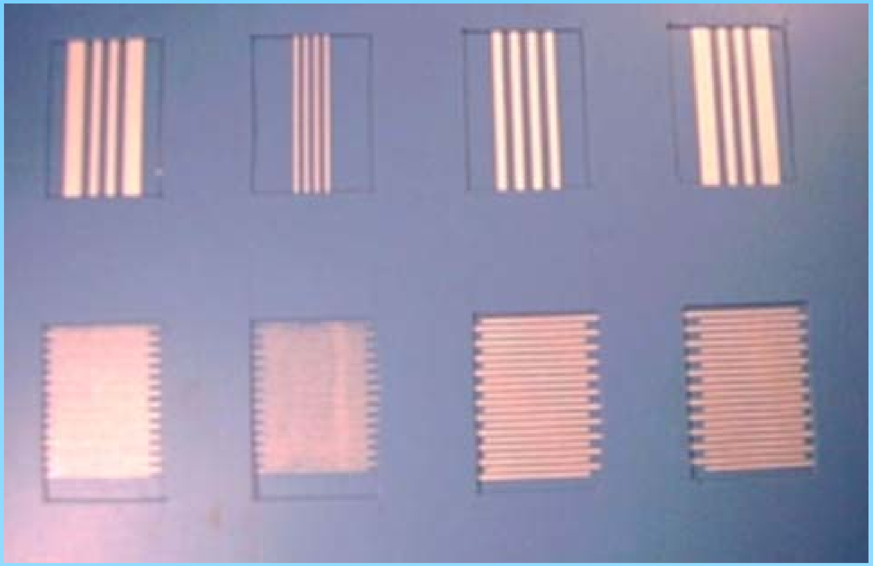
Technical University of Darmstadt

CONDUCTIVITY SENSORS

INTERDIGITAL ELECTRODES



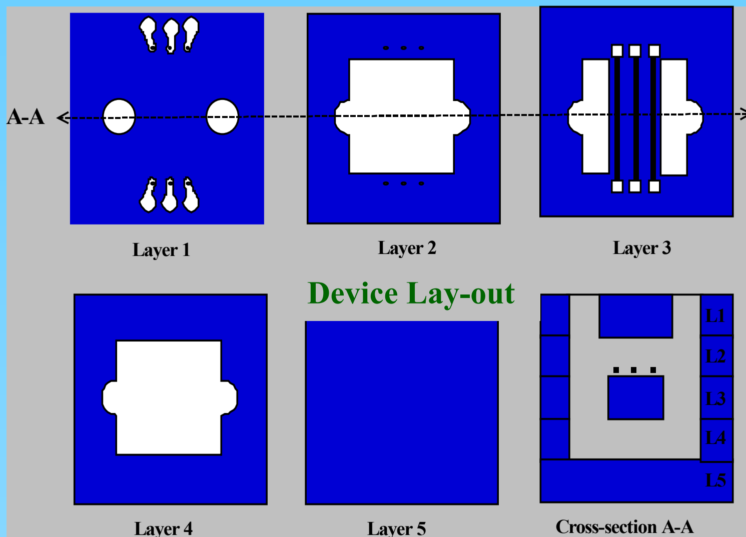
FABRICATED DEVICES

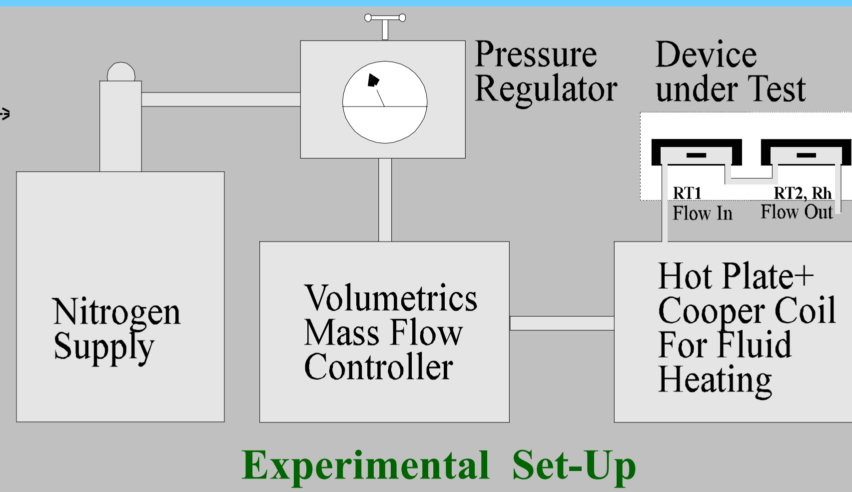


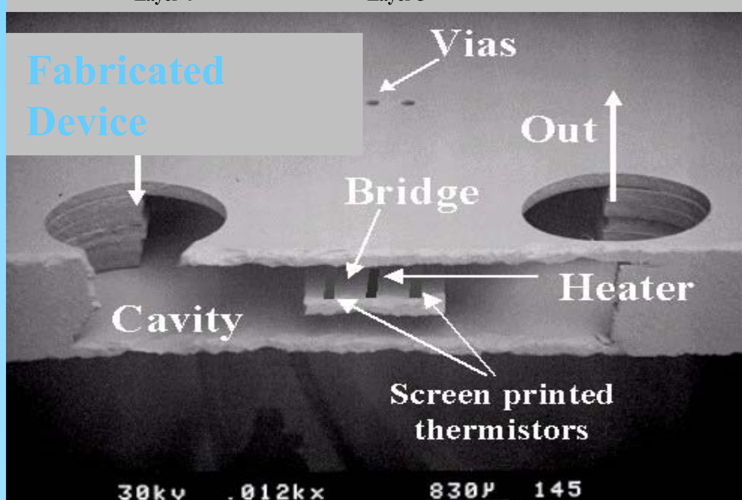
THERMAL FLOW SENSOR WITH LTCC

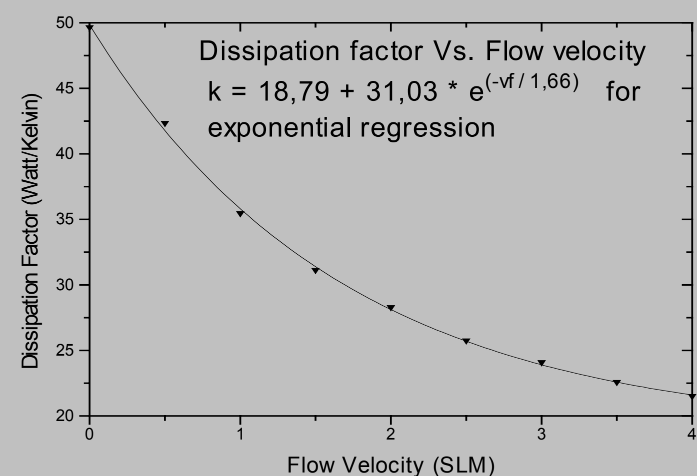
- Thermal methods display some advantages for implementing flow sensors as:
  - –Thermal isolation between structure and support;
  - –Low thermal capacity improving response times;
  - –Small dimension devices;
  - –Integration in a micro-system or MEMS scheme.

LTCC FLOW SENSORS



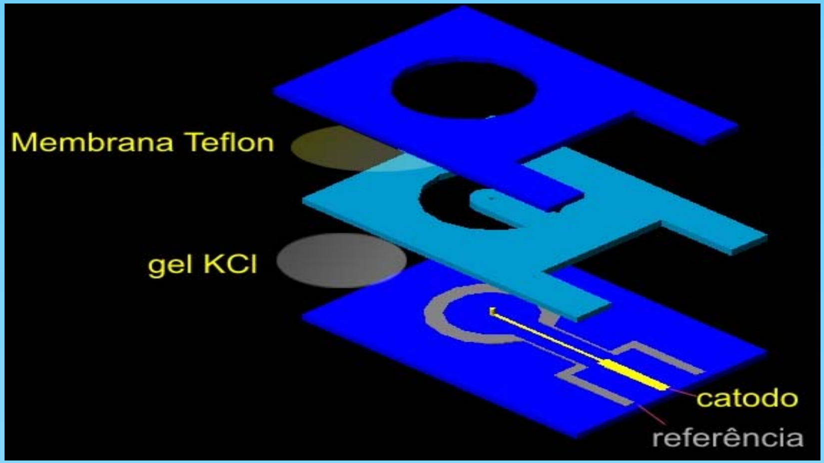


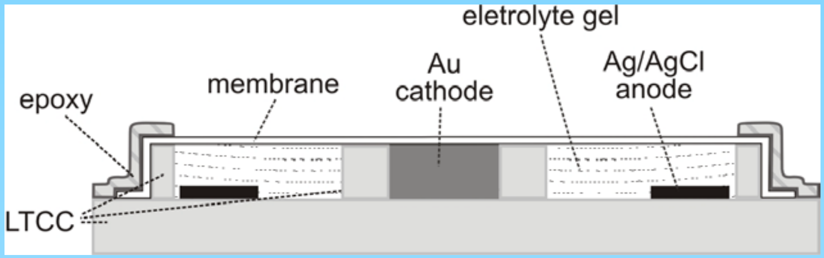


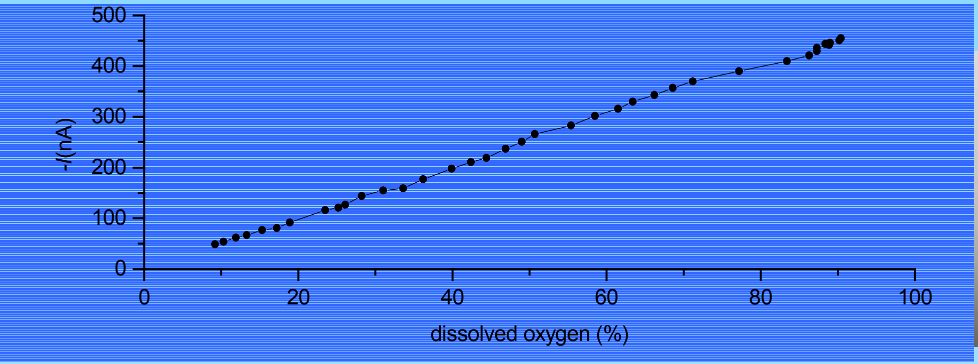


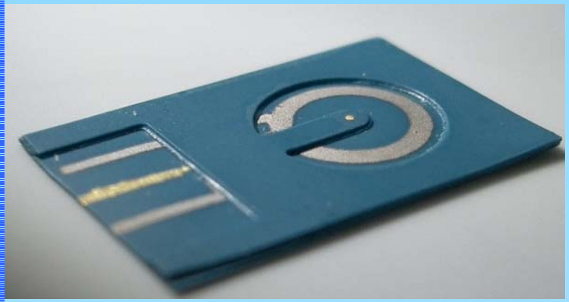
Oxygen Sensors

- The dissolved oxygen (DO) sensor is one of the most important sensors for environmental monitoring.
- A Clark-type DO sensor using (LTCC) targeted for continuous monitoring applications was implemented.



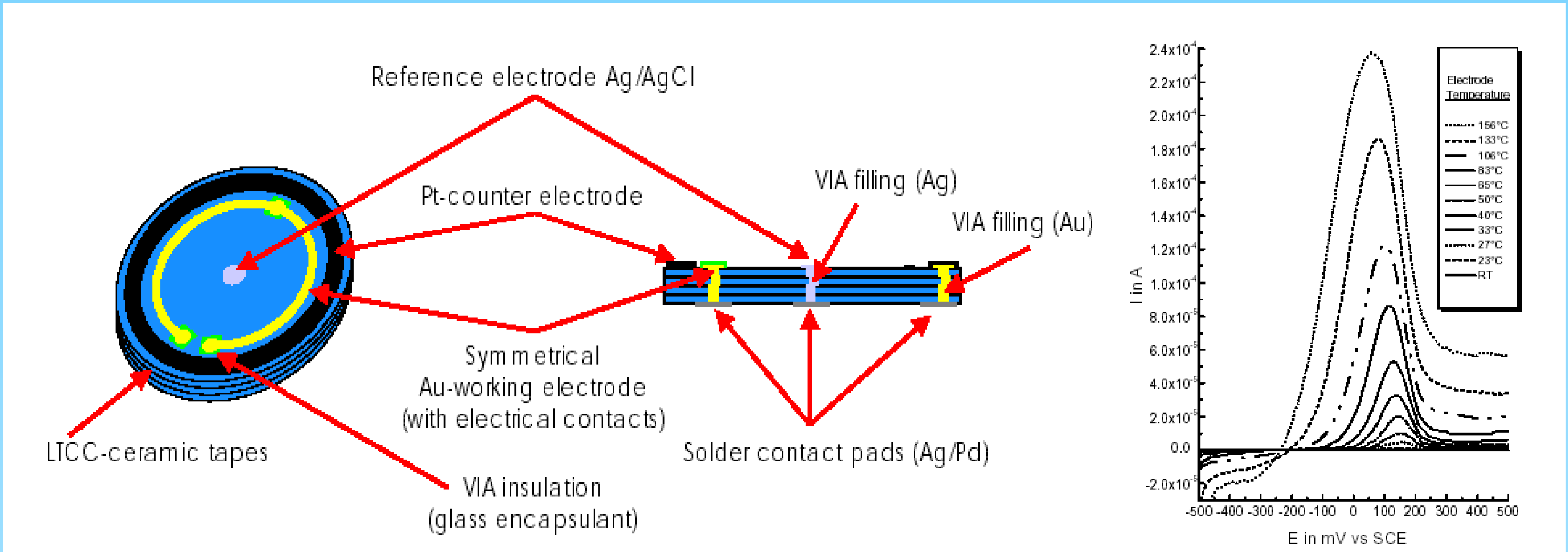






Hot-Layer-Electrochemistry sensor using LTCC

- Chemical application to determine temperature coefficients of redox-couples
- Sampled linear sweep curves for 5 mM K4[Fe(CN)6] in 0.1 M $NaSO_4$ at different Temperatures



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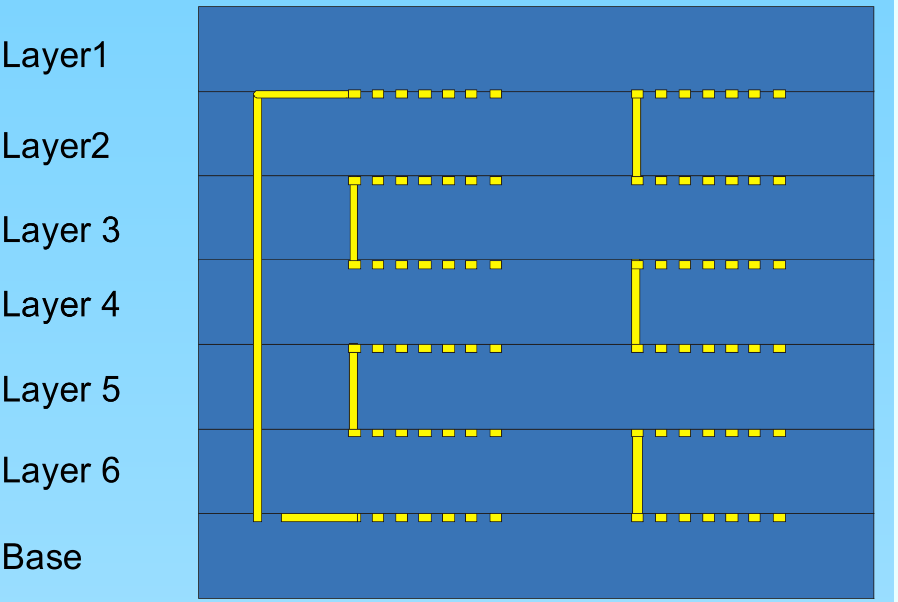
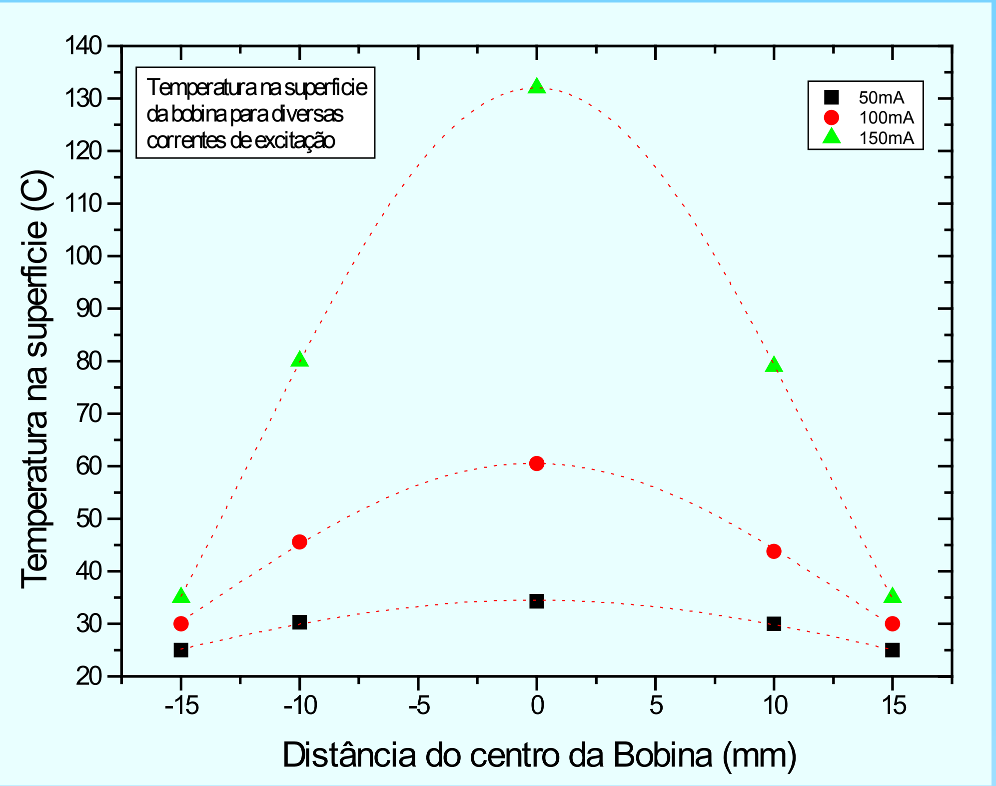
ACTUATORS WITH LTCC

HOT PLATES

- With few layers it is possible to get a simple hot plate.

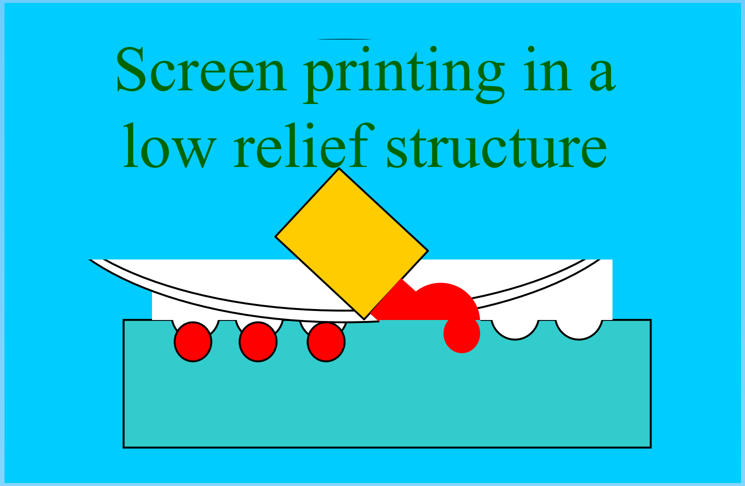
- Surface heating Vs. current in hot plate



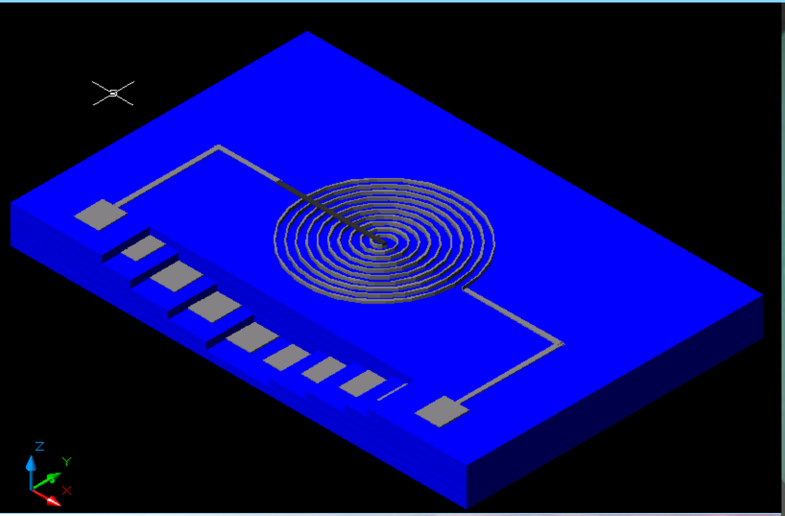


POWER LTCC COILS

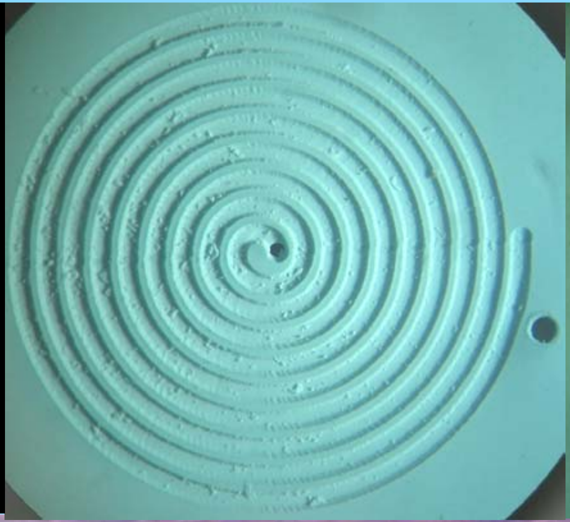
- High current coils can be fabricated in LTCC using a CNC low relief technique



Test Structure



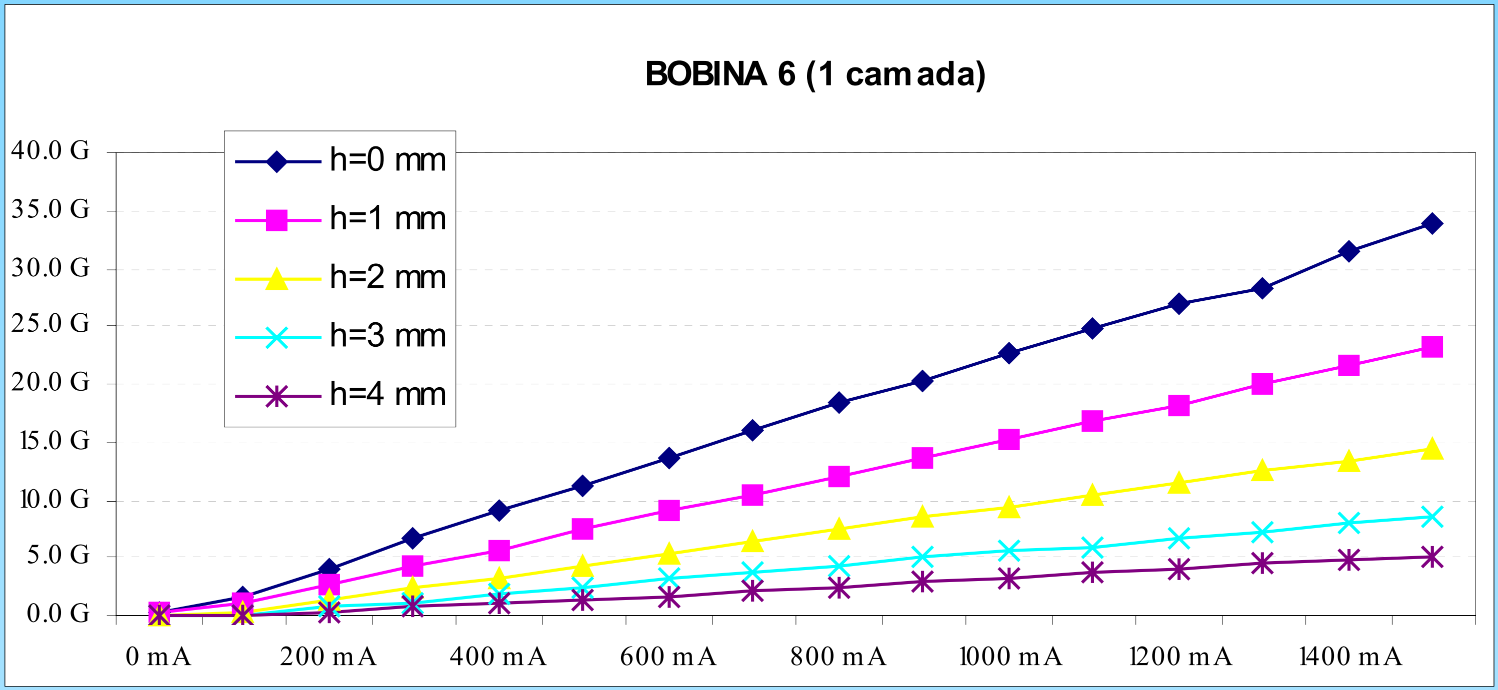
CNC Machined Coil



Printed and Fired coil

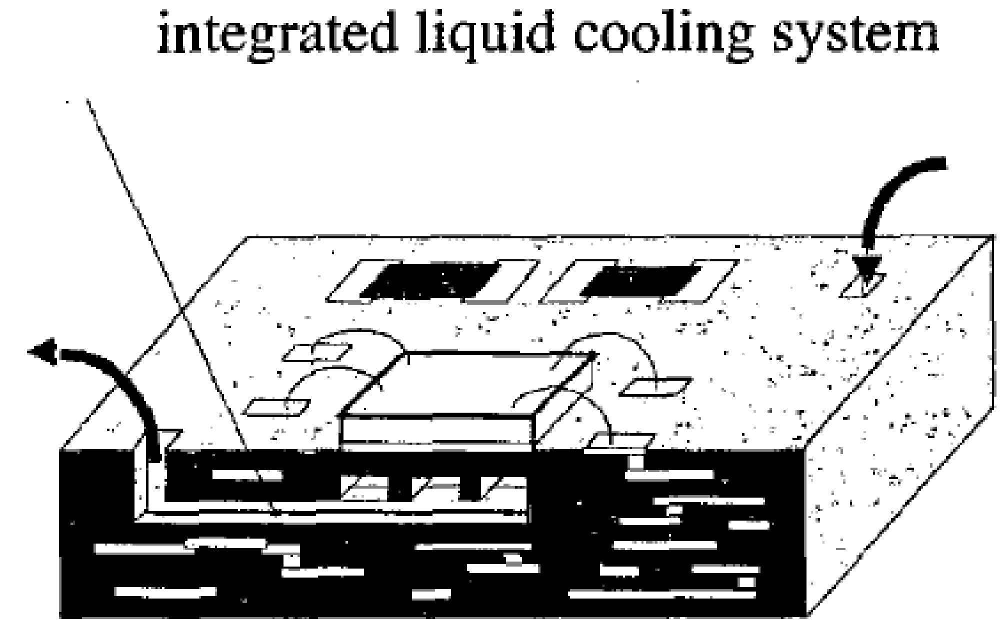
SOME RESULTS

- Coil depth can be defined between 50 to 150 µm, with 150 µm pitch, coils can be done with 5 to 20 number of turns per layer and working layers are: 1 to 6.
- We have found coil layer resistance ranging from 0,1 to 0,4 Ω.



LIQUID COOLING SYSTEMS

- Thermal management is an important problem in electronic packaging.
- LTCC thermal vias and microchannels can deliver liquid cooling systems with thermal dissipation of up to 50 W/cm^2



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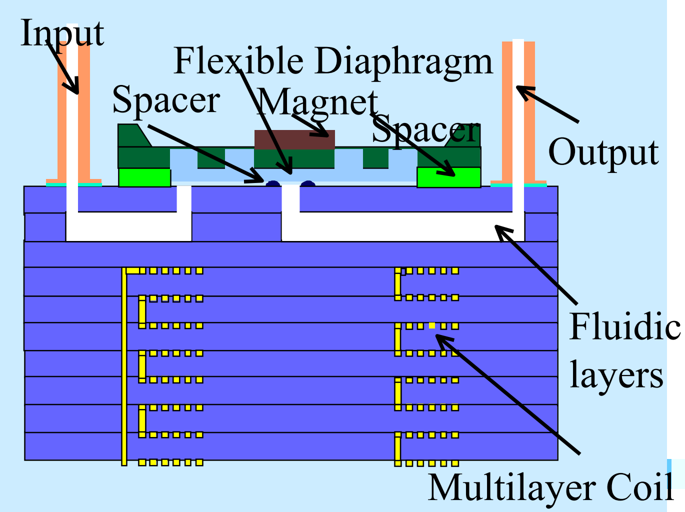
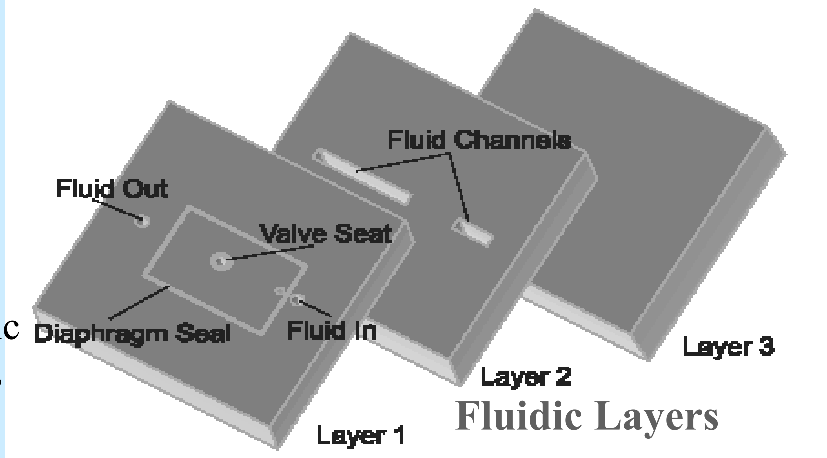
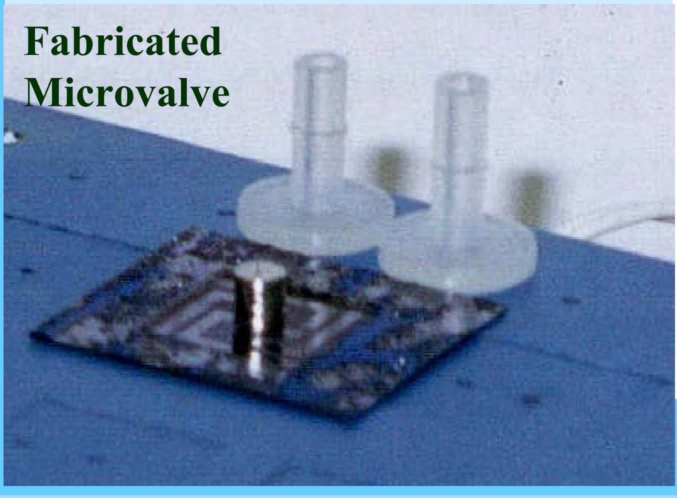
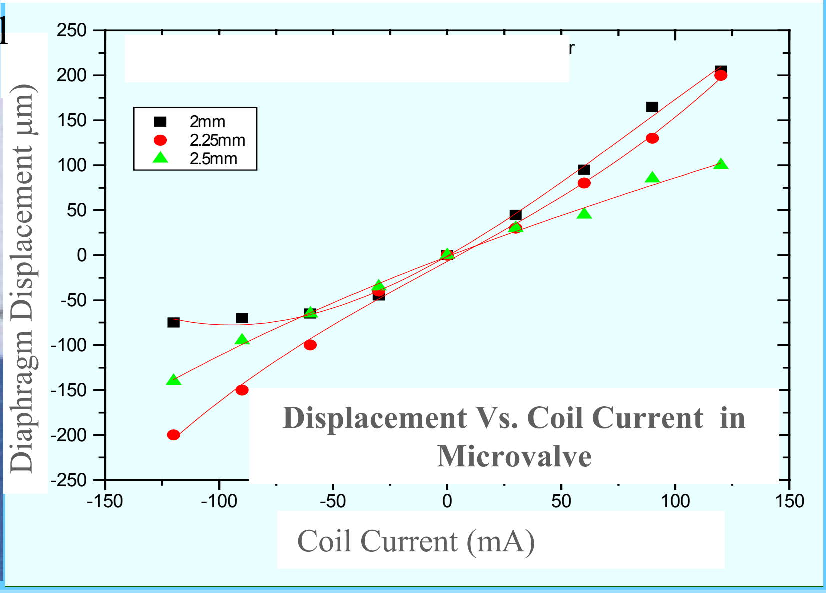
LTCC HYBRID ACTUATORS (MICROVALVE)









In: Gongora-Rubio M.R., Santiago-Aviles J.J. et al., SPIE (1.999), v.3877. p.230 - 239

MESO-SCALE PLASMA GENERATOR

Characteristics of Meso-Scale Plasmas:

- suitable for operation at high pressure (10-760 Torr).
- sofisticated vacuum system is not required.
- high plasma density (10^{13} - 10^{15} cm^{-3})

Advantages of LTCC:

- easy to construct 3D structures.
- resistant to high temperature.
- low cost.

Applications of Meso-Scale Plasmas:

- surface treatments / coatings.
- etching of materials.

DEVICE DIMENSIONS & PARAMETERS

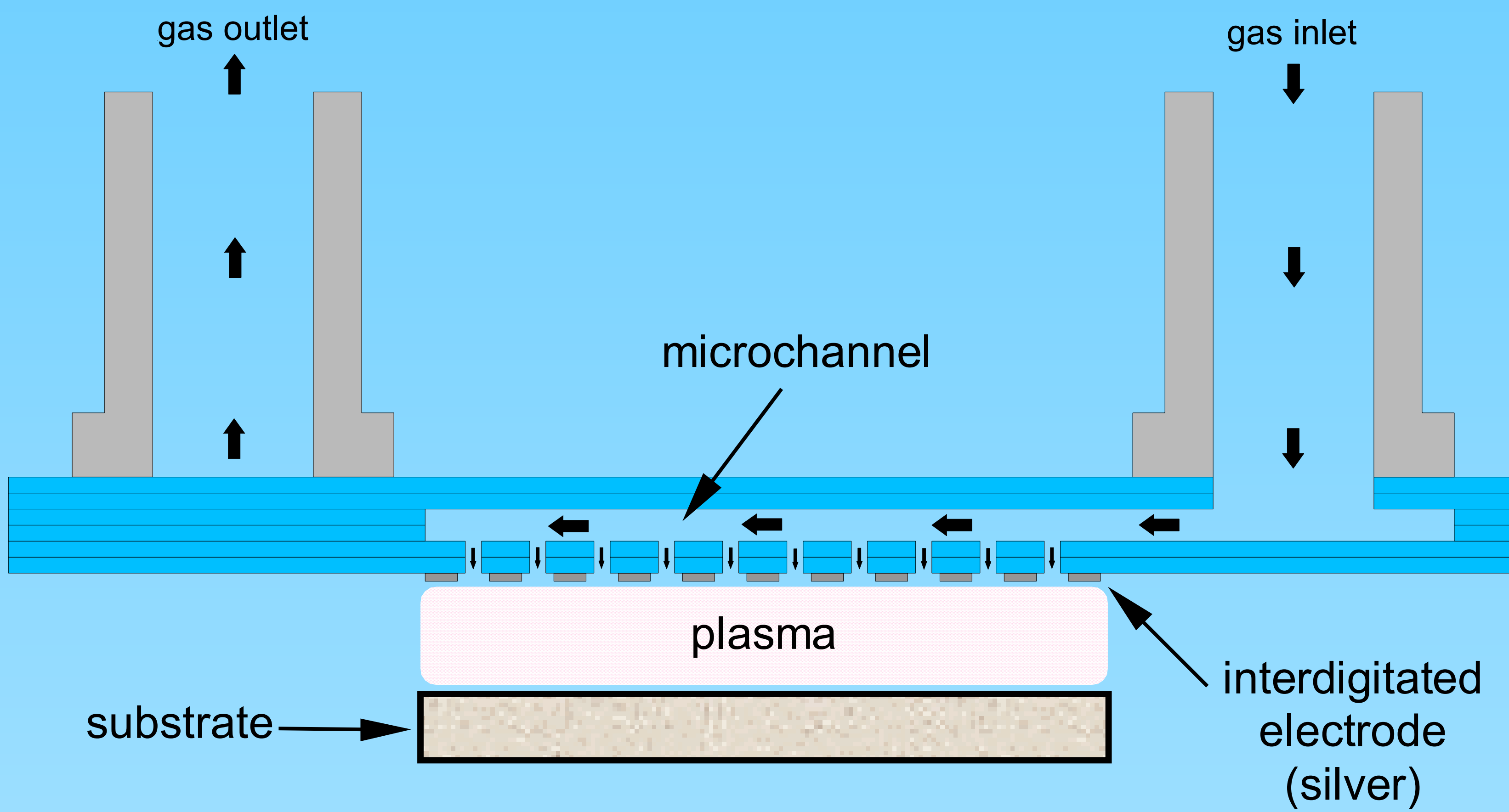
Dimensions:

- Inter-electrode spacing: **500 µm**.
- Area: **10 x 10 mm^2**.
- Green tape thickness: **250 µm** (before firing)
  220 µm (after firing)
- Microchannel cross-section: **500 µm** x **500 µm**
- Gas inlet tube diameter: **2.5 mm**.
- Gas distributor hole diameter: **500 µm**.
- Electrode width: **500 µm**.
- Electrode thickness: **5 µm**.

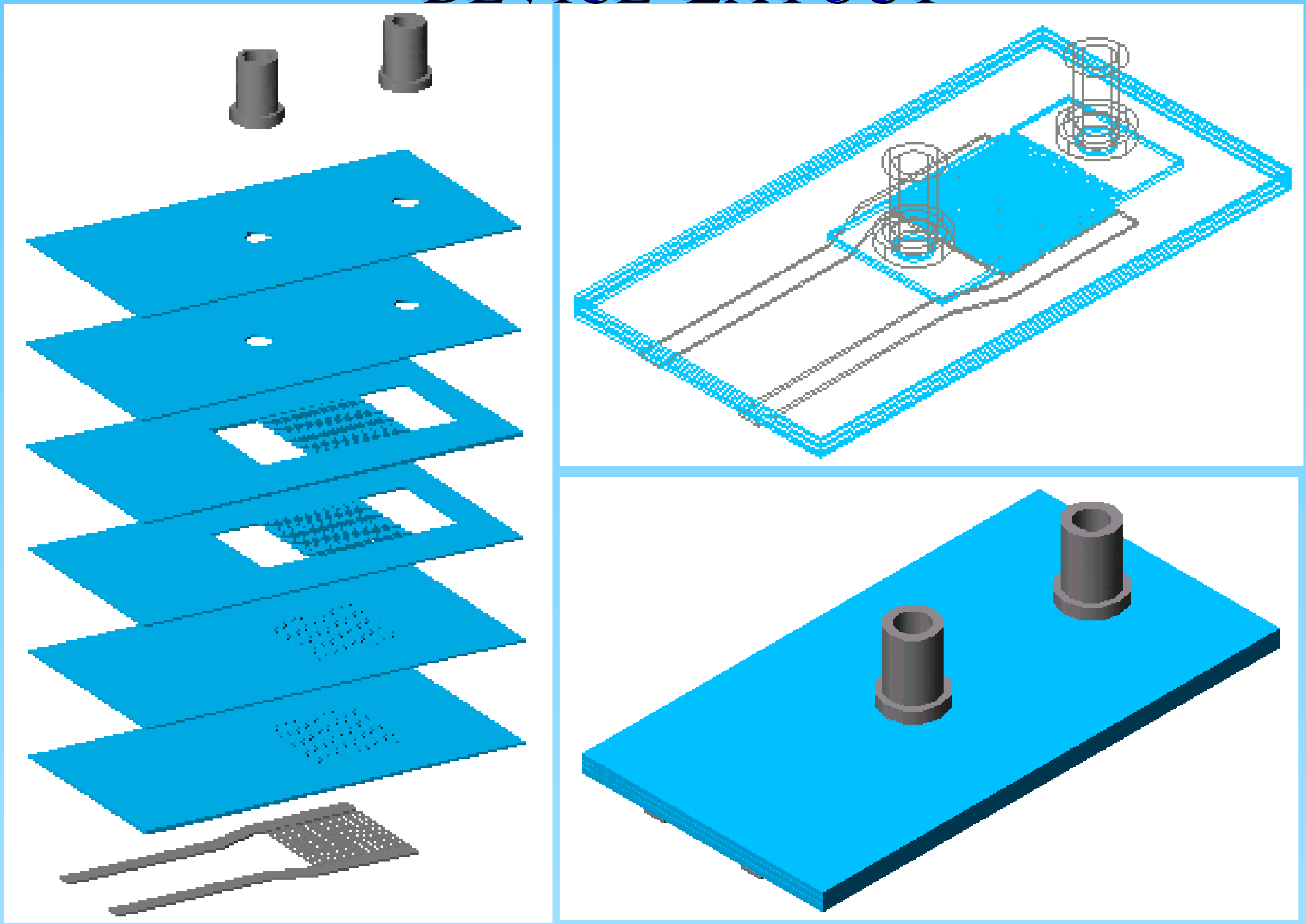
Operation parameters:

- RF frequency: **13.56 MHz**.
- RF power: **10 - 30 W**
- Pressure: **10 - 20 Torr**
- Gas flow-rate: **1 - 10 sccm**.

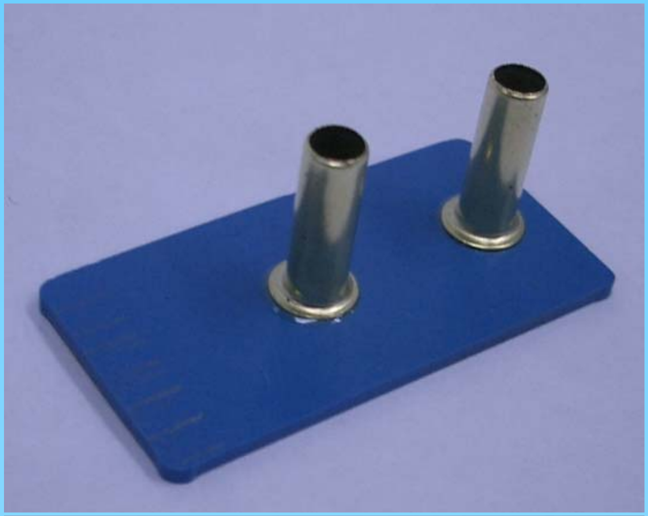
GENERATOR OPERATION

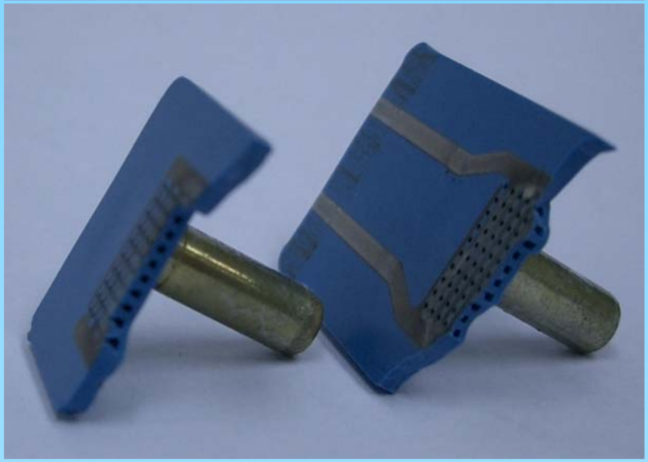


DEVICE LAYOUT



FABRICATED DEVICES

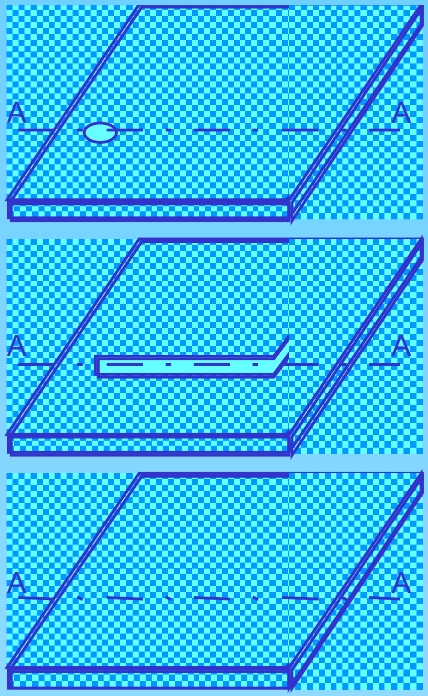


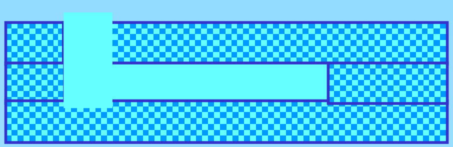


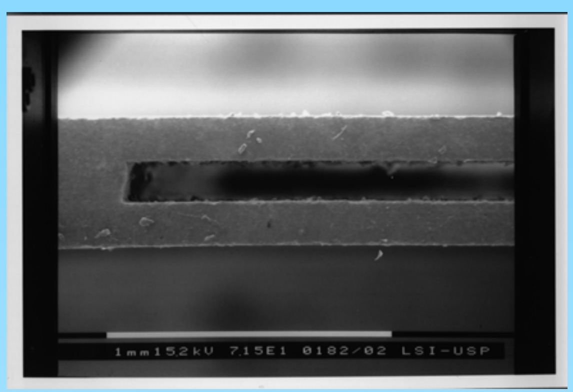
BASIC MICROFLUIDIC DEVICES

MICRO-CHANNELS IN LTCC

- Poiseuille equation relates linearly pressure drop with flow in reduced geometry channels.
- LTCC can be easily used for implementing channels.



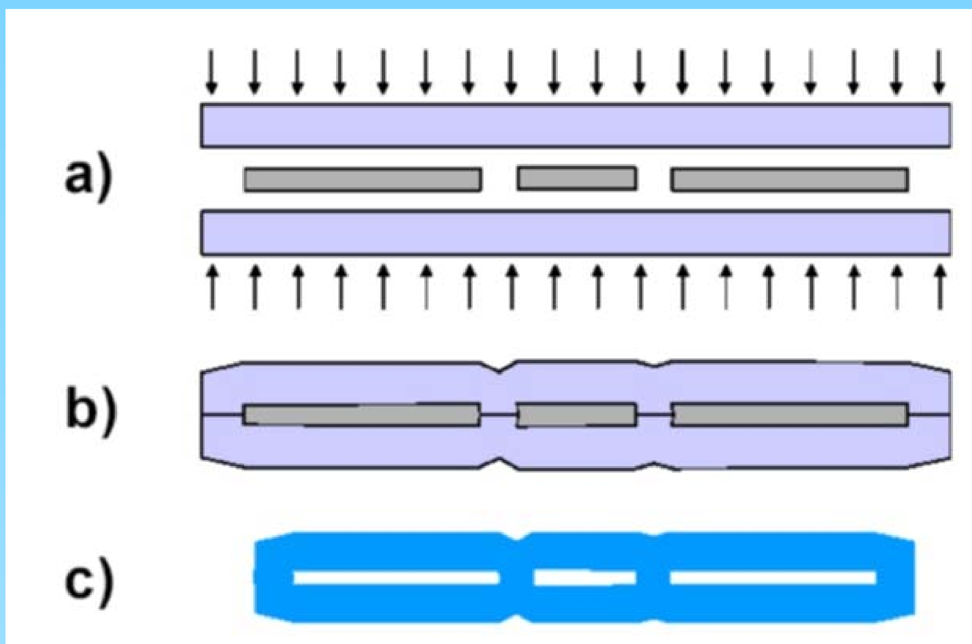


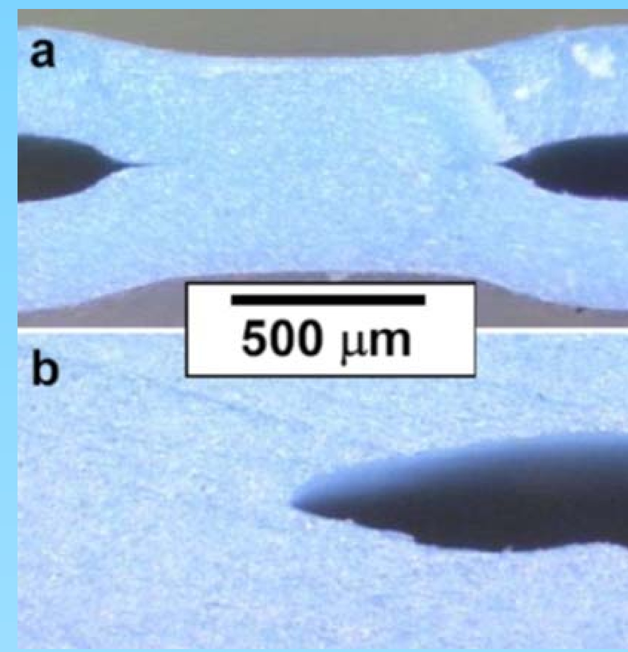


Corte A-A

NEW MICROCHANNEL FORMING TECHNIQUE

- Sacrificial volume technique is used to create microchannels during lamination by deformation of the unfired tape.

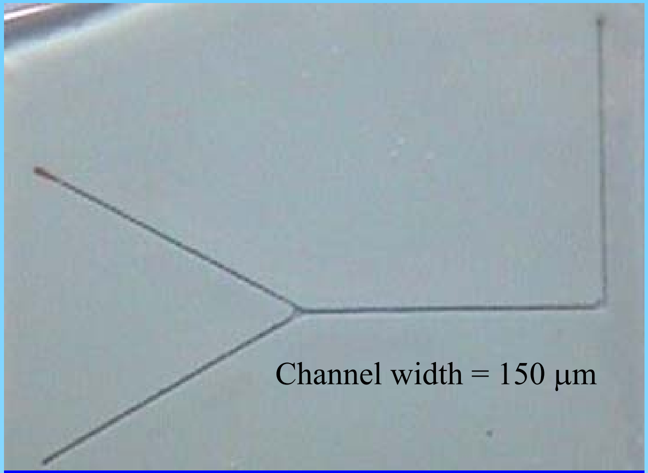


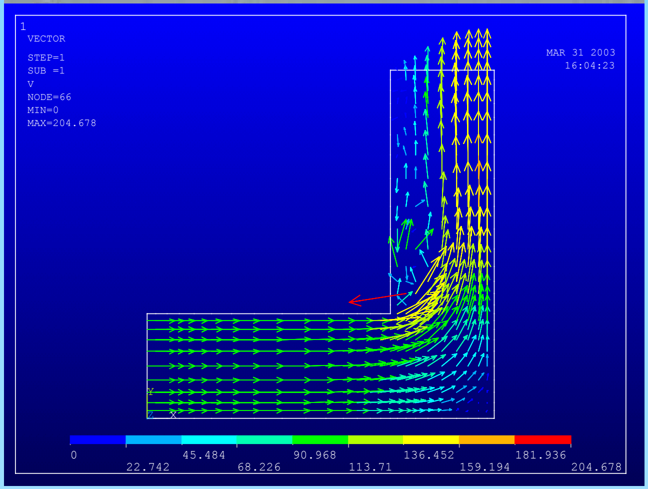


Sandia Labs

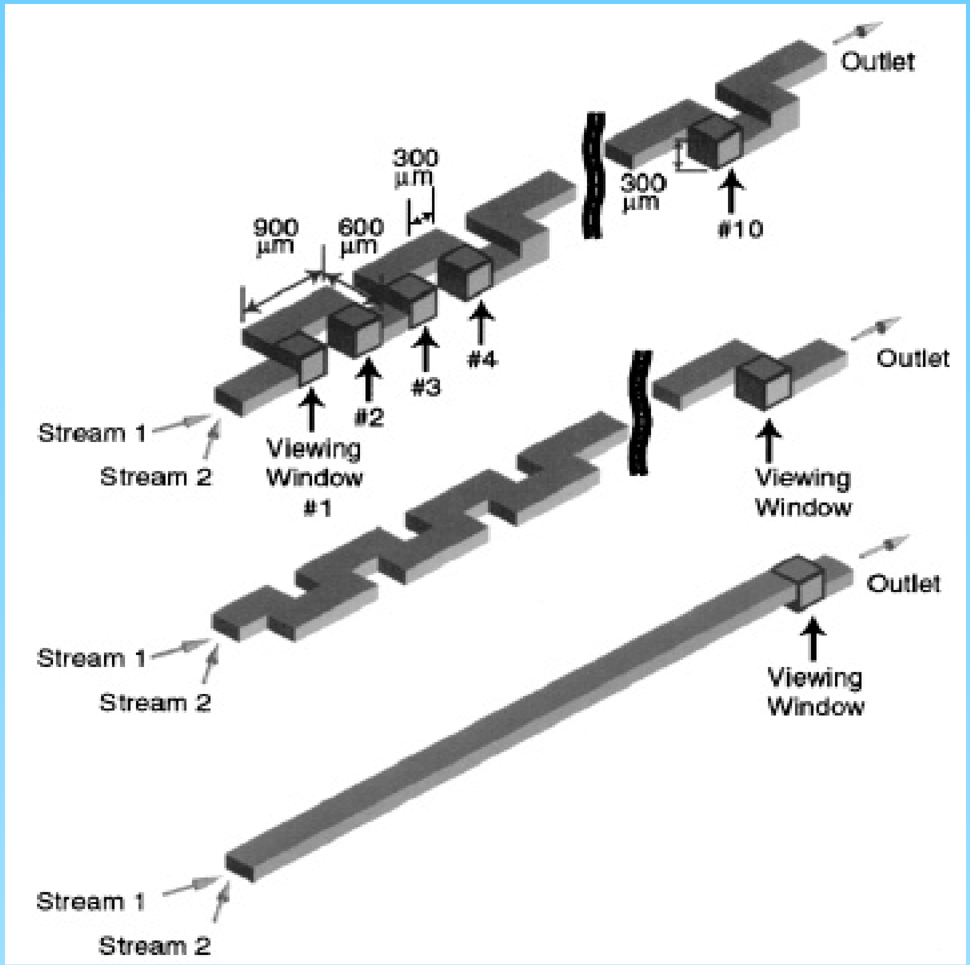
MICROCHANNELS FOR MIXING

- In Microchannels of minute dimensions result in very low Reynolds Number, making difficult liquid mixing.
- Microchannel corners can be used as chaotic advection generators for mixers





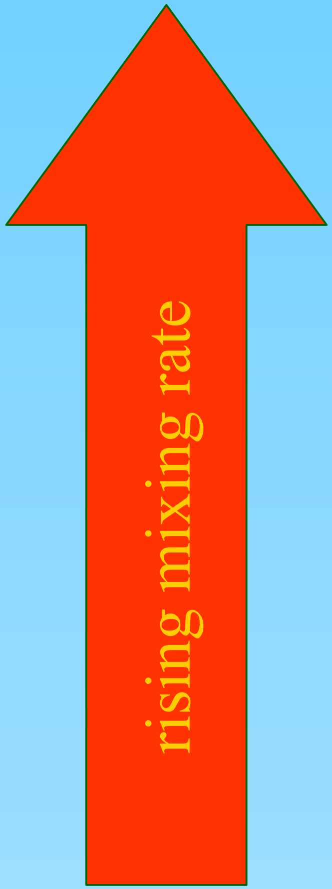
PASSIVE MIXING
CHAOTIC ADVECTION BY CHANNEL EDGES



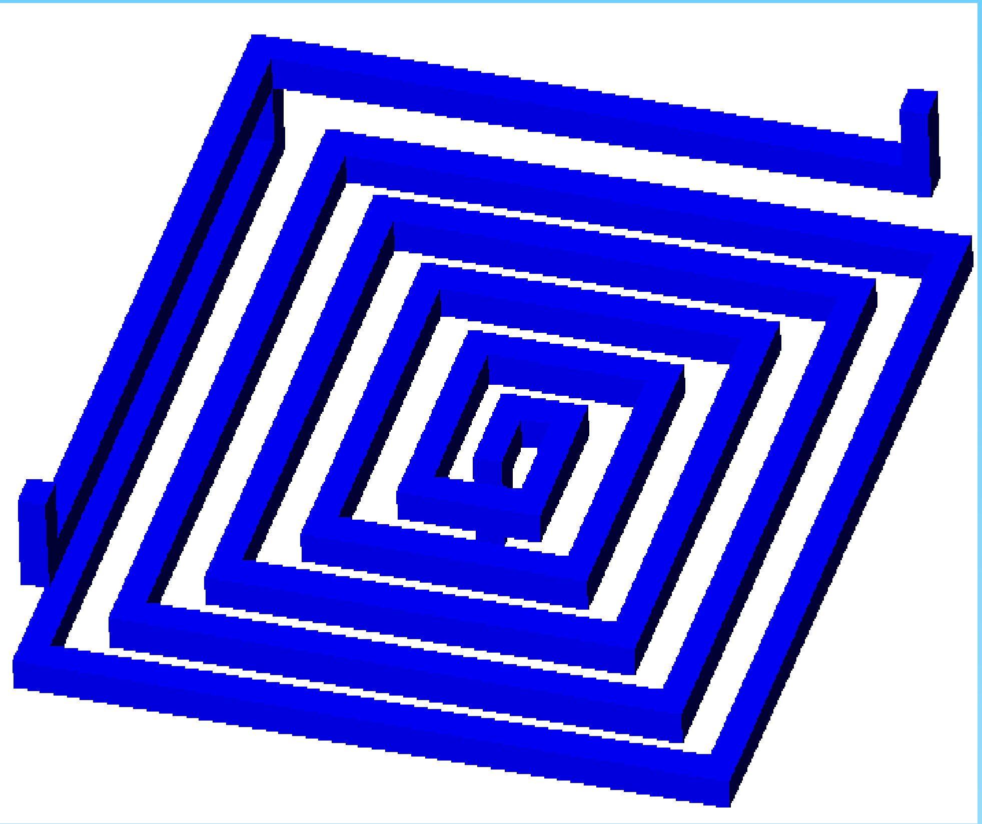
Serpentine channel

Square channel

Straight channel



PASSIVE MIXING
CHAOTIC ADVECTION BY CHANNEL EDGES



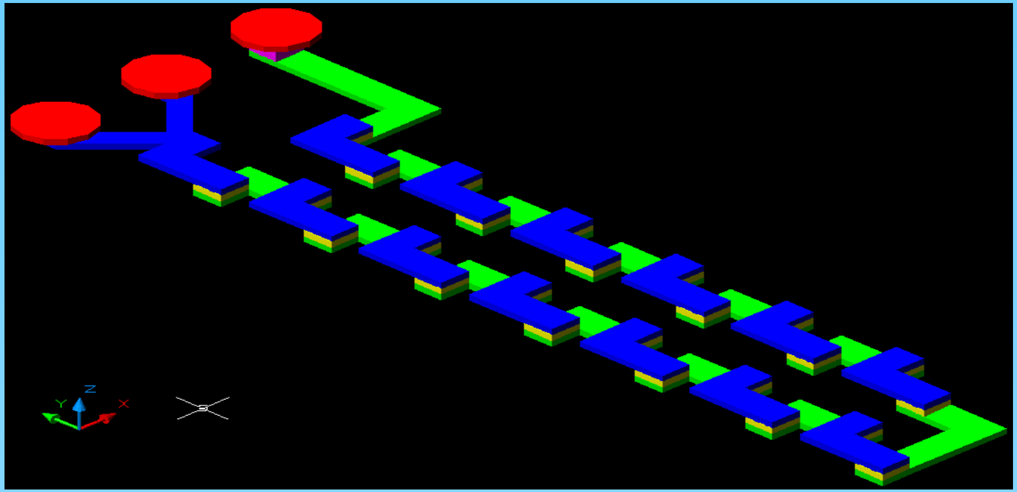
Spiral channel

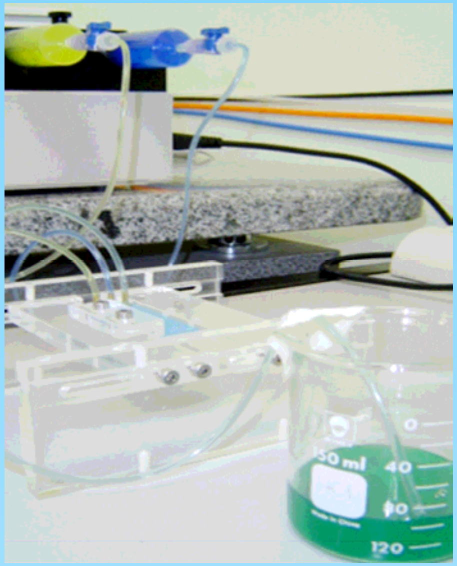
$$n_{edge}\uparrow \sim mixing\,rate\uparrow$$

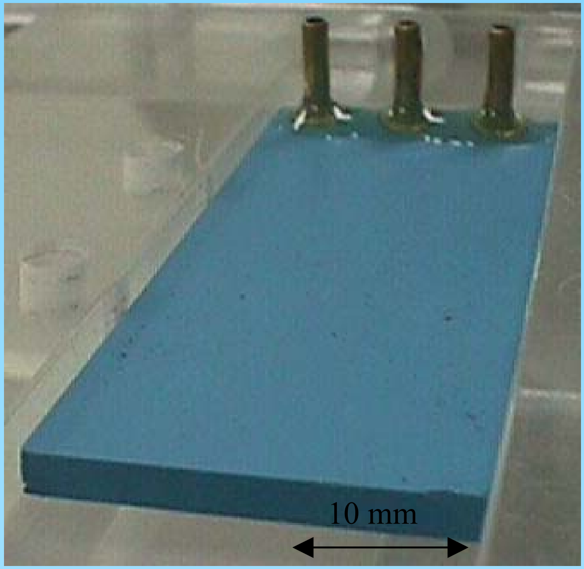
$$n_{edge}\uparrow \sim \Delta p\uparrow$$

3D MICRO MIXERS IN LTCC

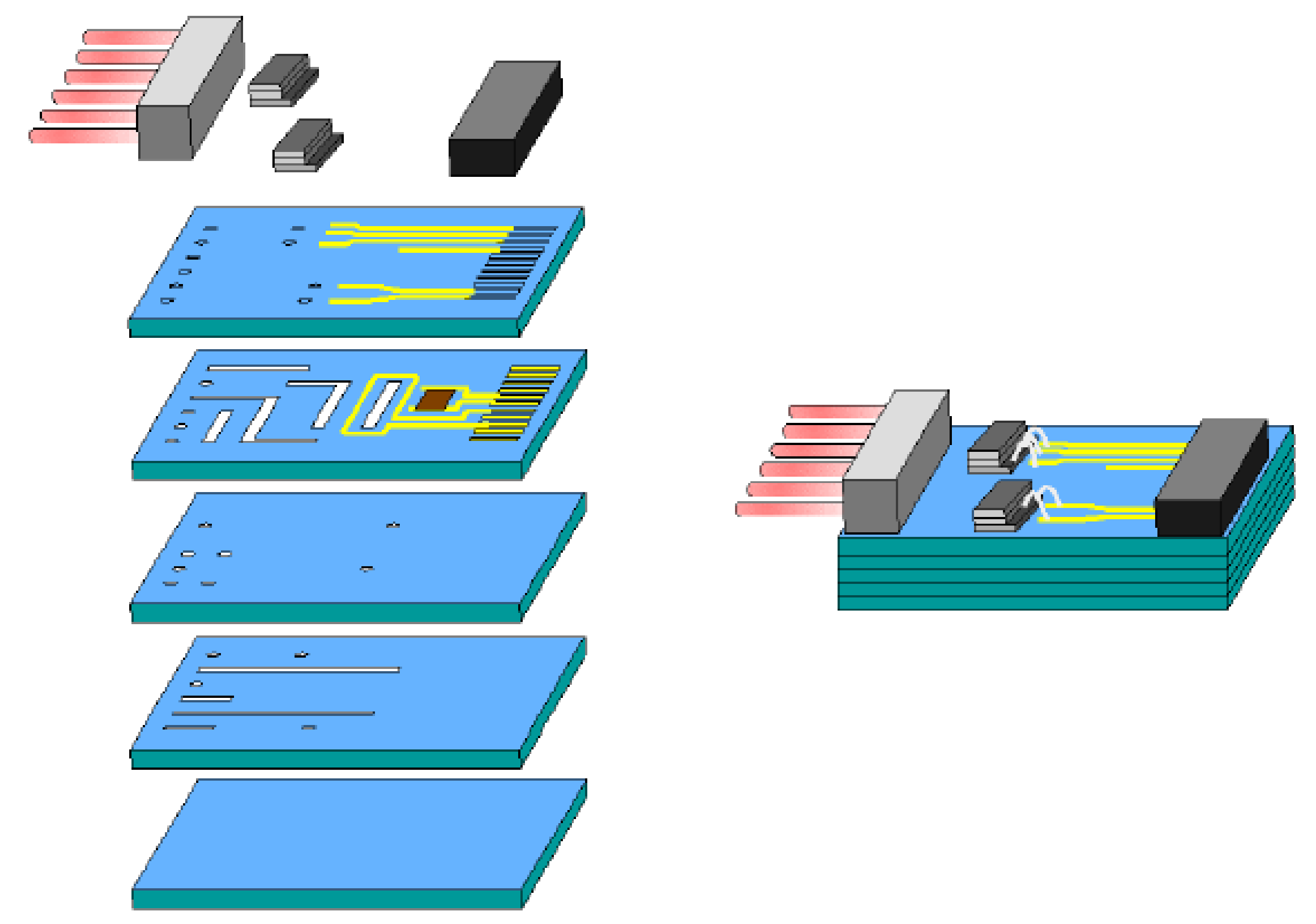
- 3D Serpentine Micromixers can be used for chemical Microreactors in order to fabricate emulsions, particle packaging and nanomaterial fabrication



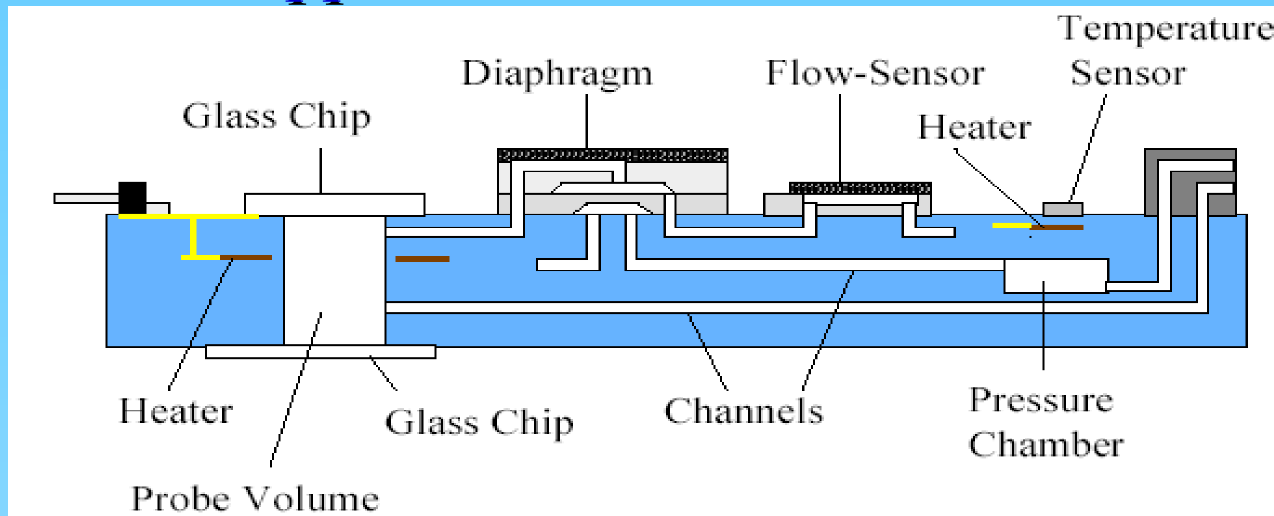


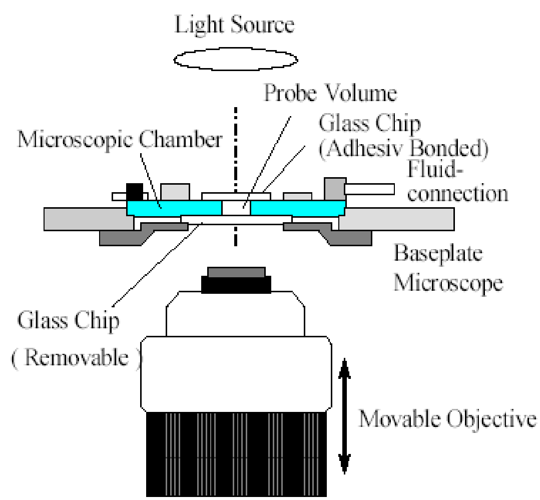


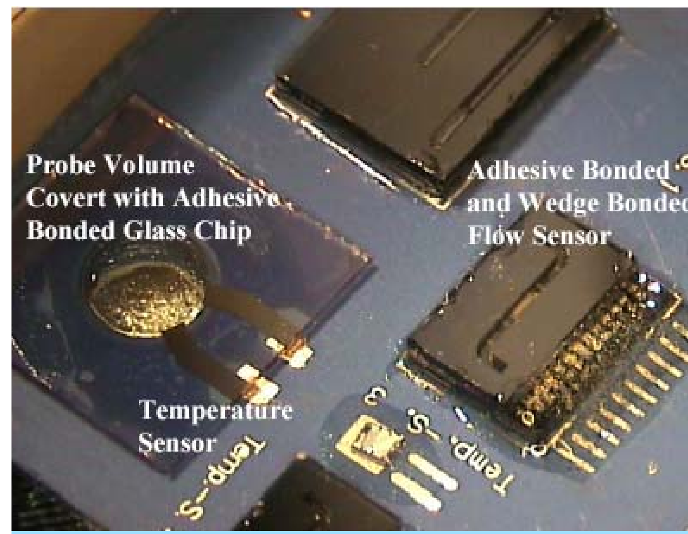
LTCC MANIFOLDS FOR MICROFLUIDICS



LTCC Applications on MICROFLUIDICS



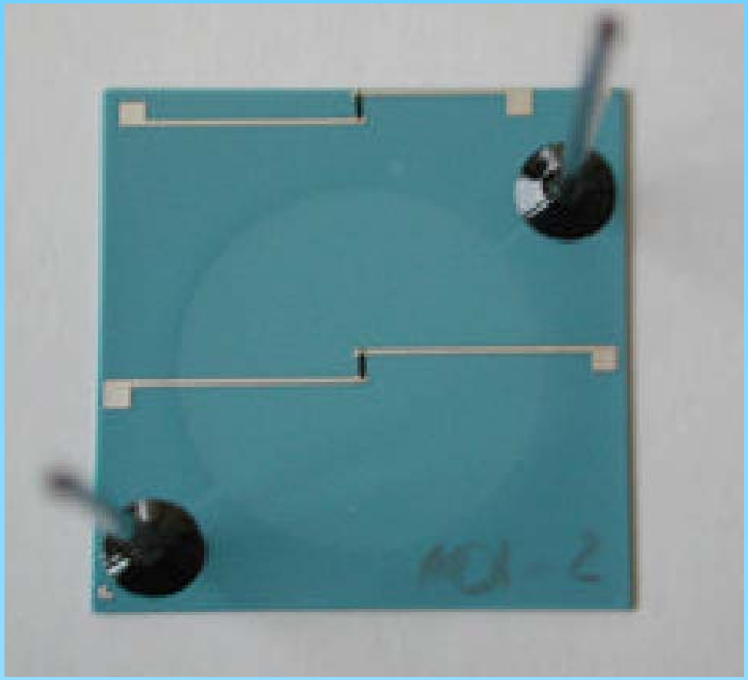




Technical University of Dresden

Heat Conductivity

- Detection of heat conductivity, fluid flow resistance,
- Membrane with 40μ-thickness, 16mm diameter and 15μ-thickness.

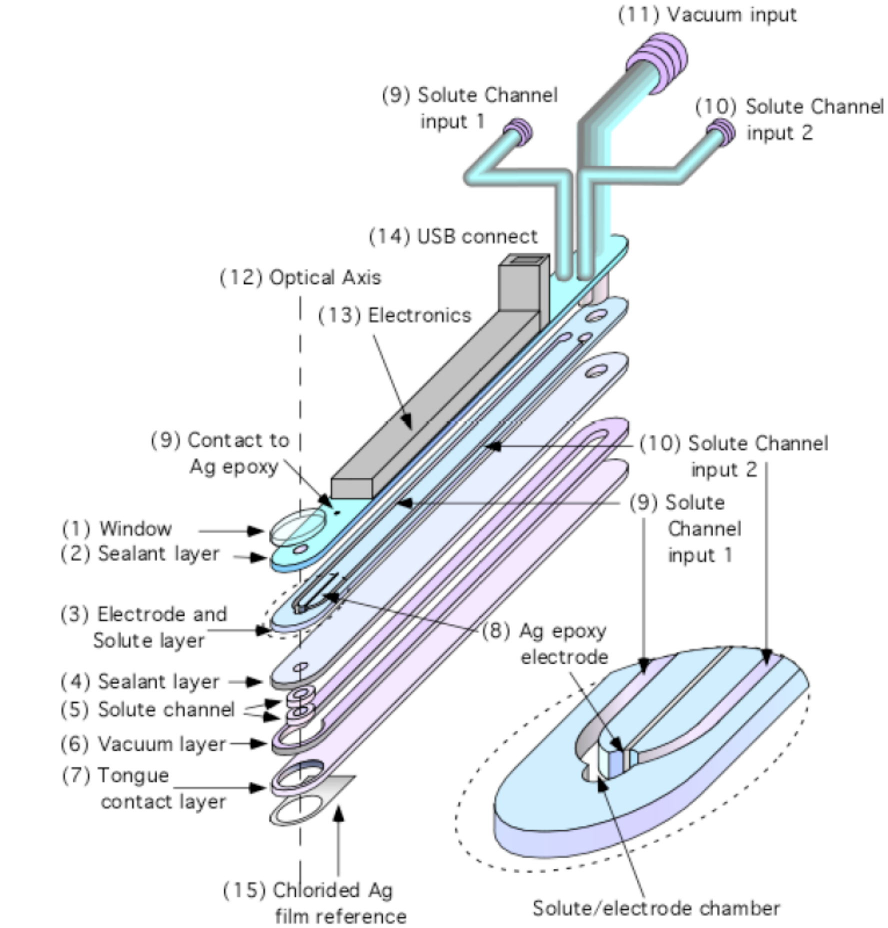


Swiss Federal Institute of Technology, Lausanne)

5. MESO SYSTEMS APPLICATIONS

MST APPLICATIONS: GUSTATORY PROBE

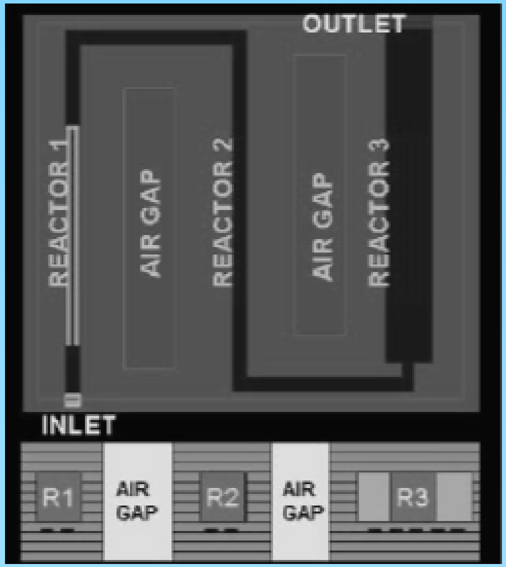
- This is an application in the field of Physiological Psychology.
- The proposed system is designed to extract as much information about the chemical and neurological responses of the taste buds within a given papilla as possible.
- The system is to measure the physiological (electrochemical) response to a flavor stimulus in the tongue and to see how it correlates with the persons perceived sense of taste.

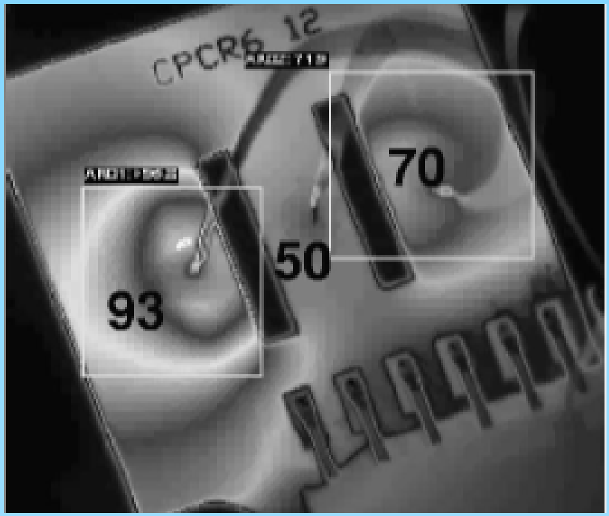


Penn Engineering

MST APPLICATIONS:
PCR IN CONTINUOUS FLOW

- Integrated microfluidic devices for PCR amplification and detection of biological samples that employ closed-loop temperature monitoring and control have been demonstrated within a multilayer low temperature co-fired ceramics (LTCC) platform.

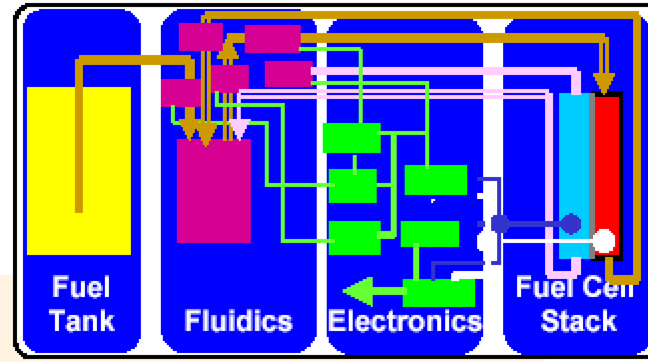


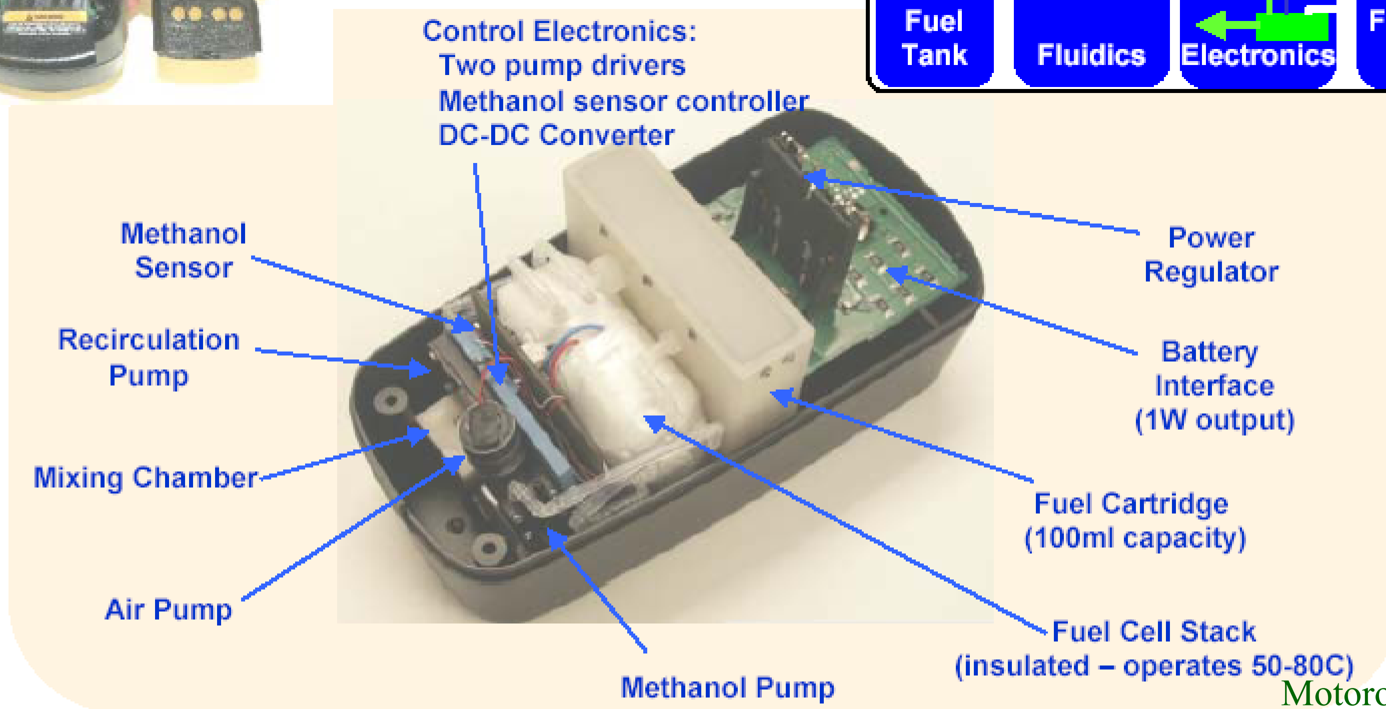


Motorola Labs

MST APPLICATIONS:
FUEL CELLS FOR PORTABLE ELECTRONICS

Everything Inside IMPRES™ Charger Package



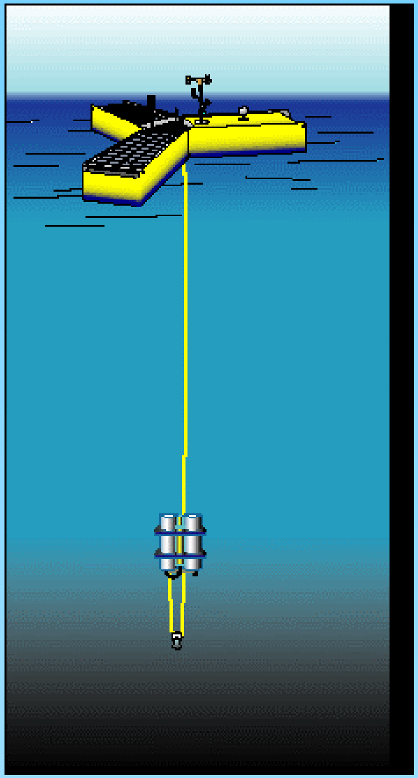


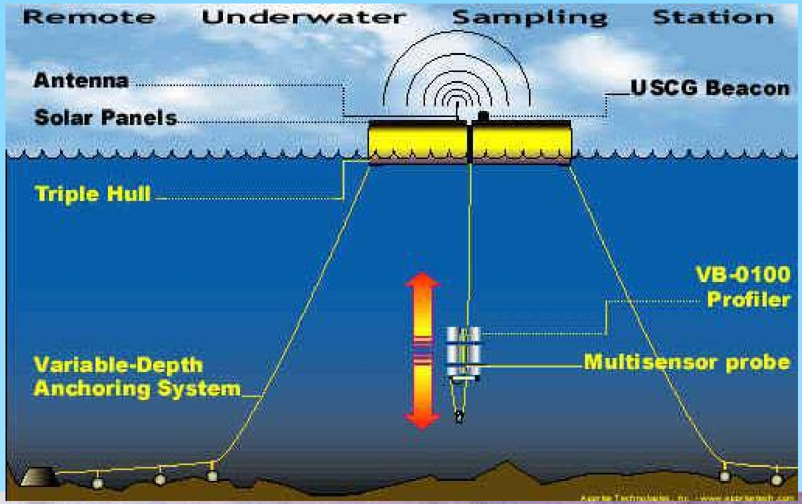
Motorola Labs

MST APPLICATIONS:
LAB ON A CREDIT CARD

POLLUTANTS CONTROL

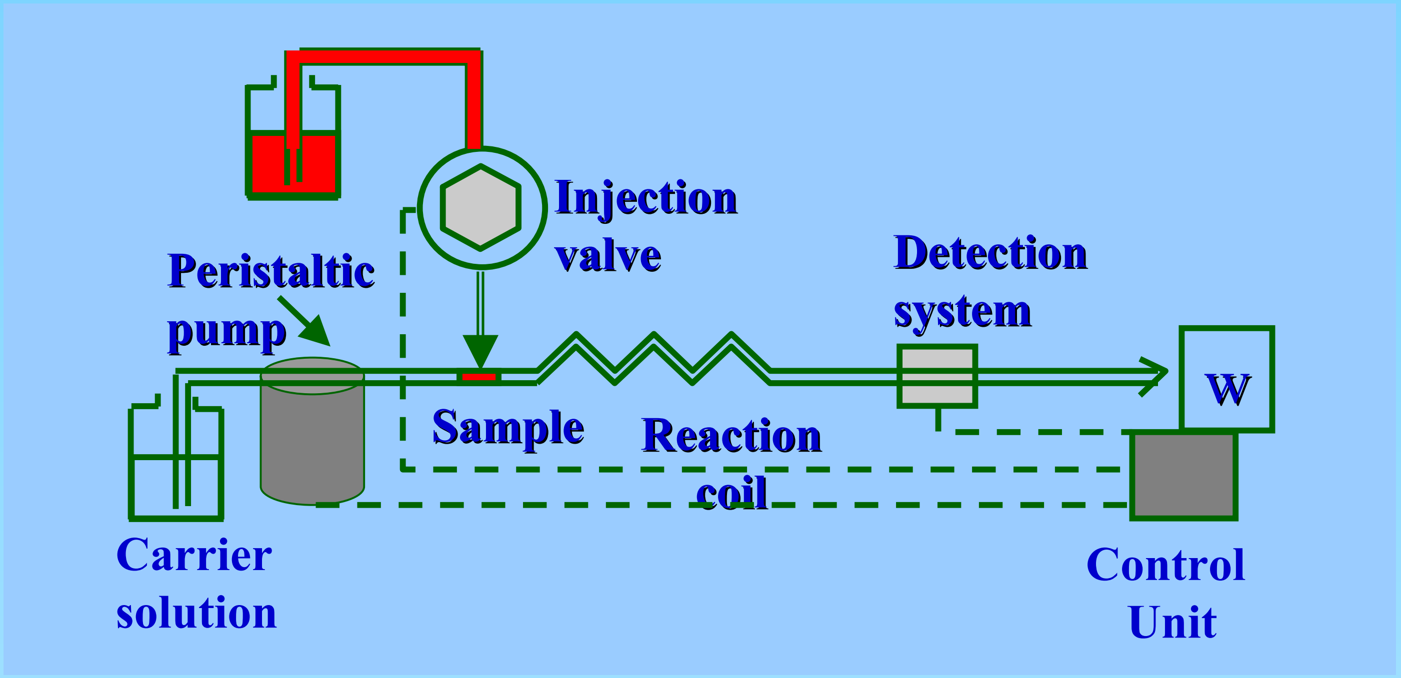
• Mobile devices for monitorazing the eutrophication process (nitrites, ammonium & phosphorous species), dissolved oxygen and heavy metal contamination in lakes.





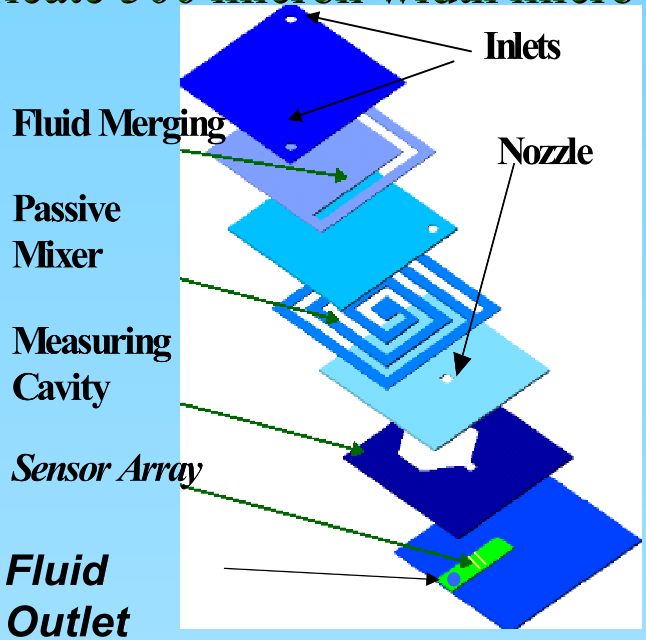
FLOW INJECTION ANALYSIS (FIA) FOR WATER CONTAMINATION STUDIES

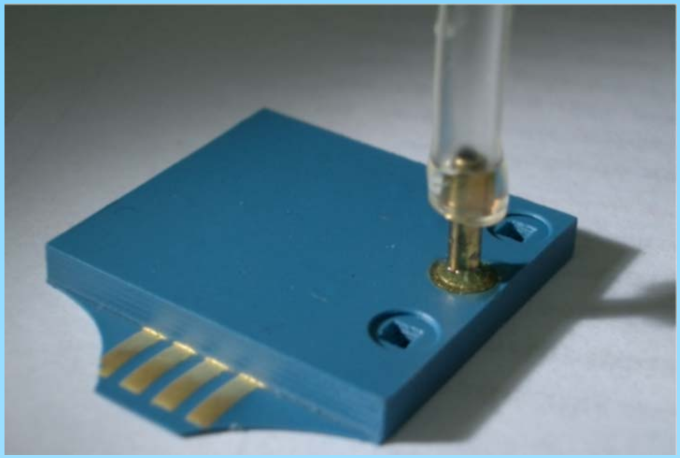
- Sensitivity and selectivity of the sensor can be optimized
- Time for analysis is minimized
- Waste and sample size are minimized



LTCC MANIFOLD FOR HEAVY METAL DETECTION

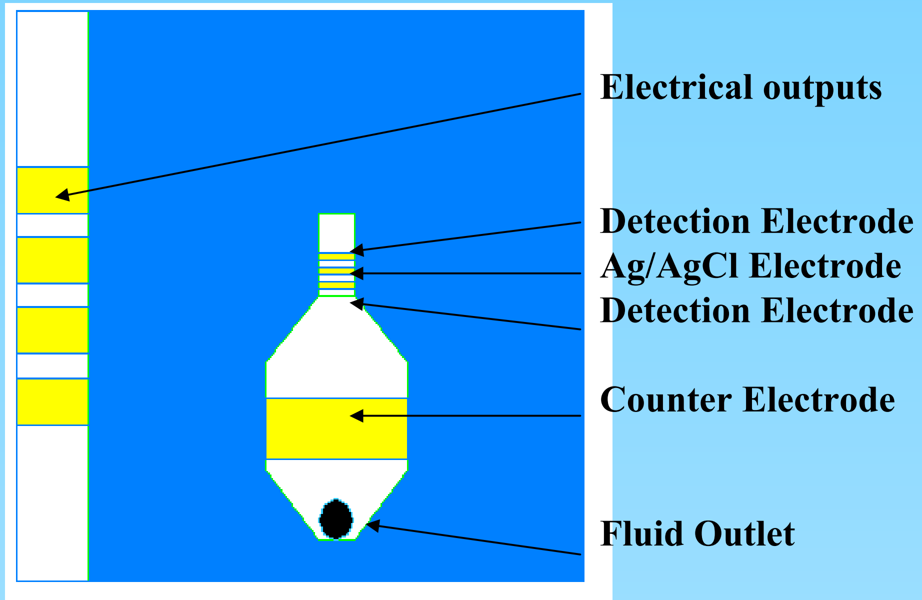
- Here one can see a laboratory the size of a credit card realized in LTCC. It is a system for the electrochemical detection of heavy metals in river waters.
- A manifold for various tasks was designed, we include the possibility of mixing two fluids (if a reagent is needed) and implement a spiral coil used as a mixing/reaction chamber.
- DuPont 951 LTCC tapes with layer thickness of 250 μm were used to fabricate 500 micron width micro channels.





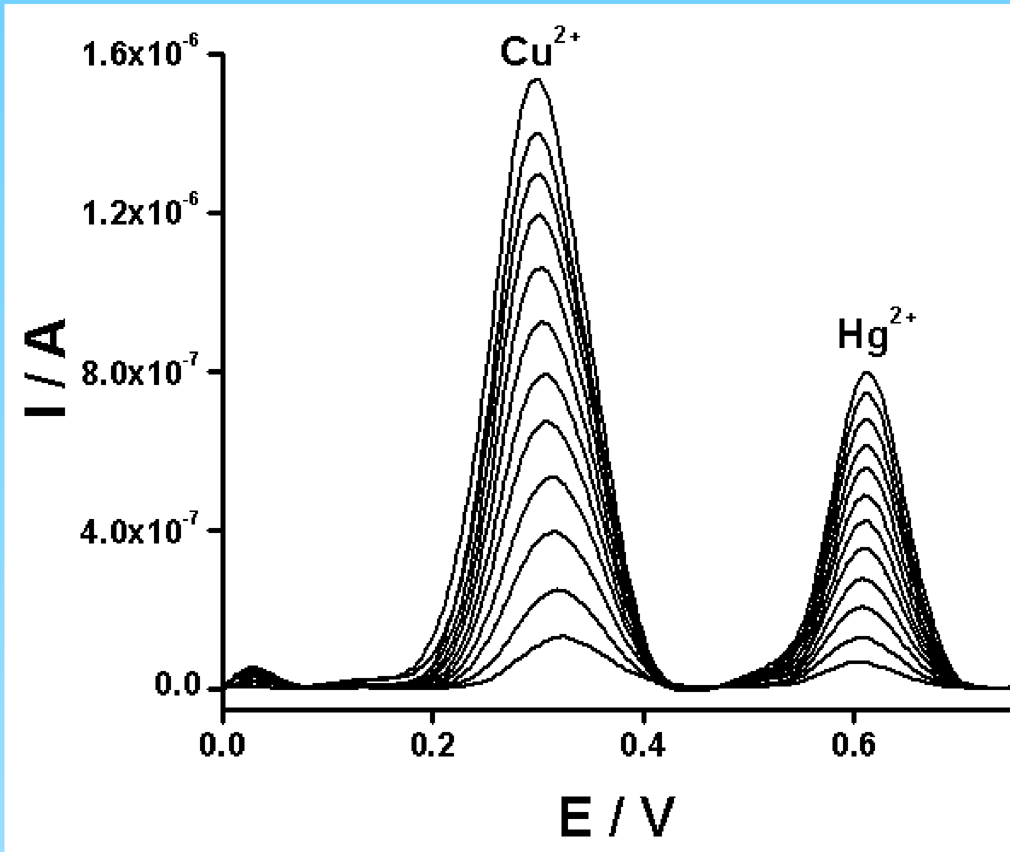
ELECTRODE DESIGN

- A multi-electrode sensor array for electro-chemical measurement was fabricated using thick film screen-printing deposition of gold paste.
- The sensor array is composed of a silver/silver chloride reference electrode, a gold counter electrode and two gold detection electrodes (L=300µm, W=2mm)



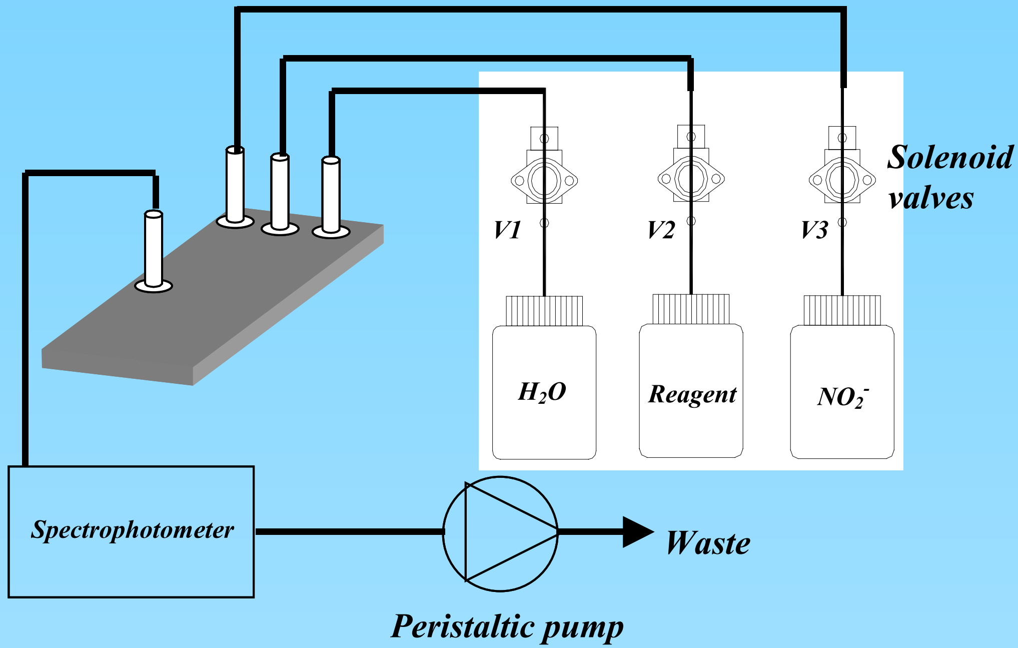
MANIFOLD RESPONSE

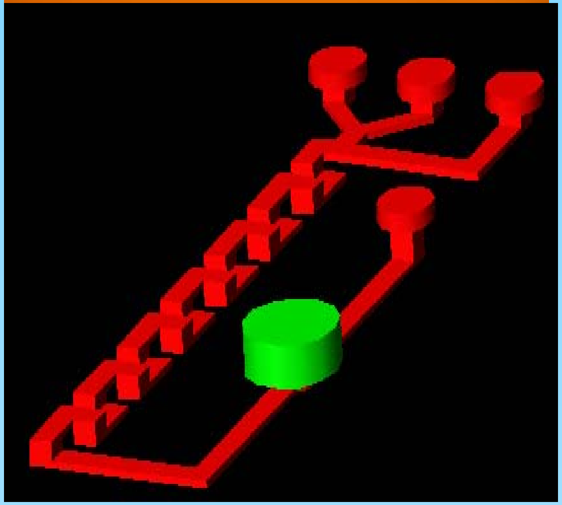
- Square-wave stripping responses for increasing concentrations of Copper and Mercury (10 a 115 µg L^{-1}).
- Pre-concentration time: 60 s



SPECTROPHOTOMETRICAL DETECTION OF NITRITES

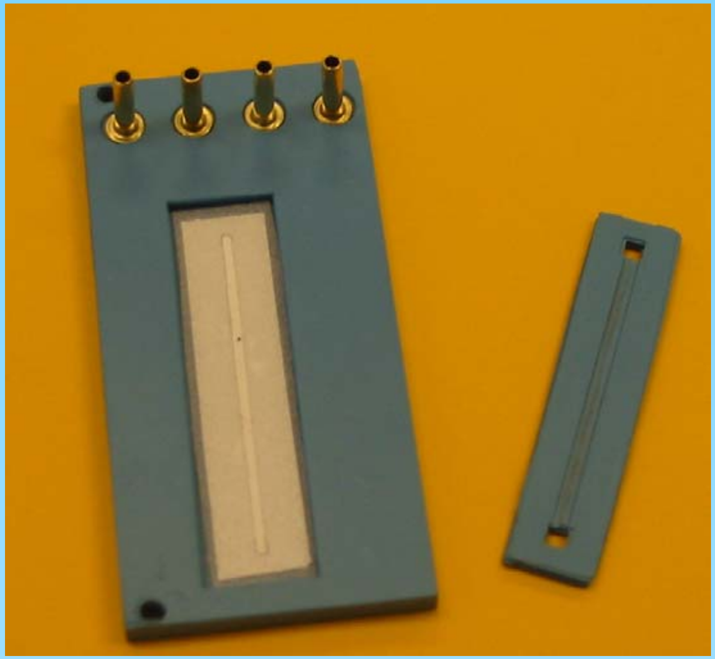
- Nitrite ion was determined by its reaction with sulphanilamide to form the diazonium salt which was coupled with N- (1-naphthyl) ethylene diamine to yield an azo dye whose absorbance was measured at 540nm

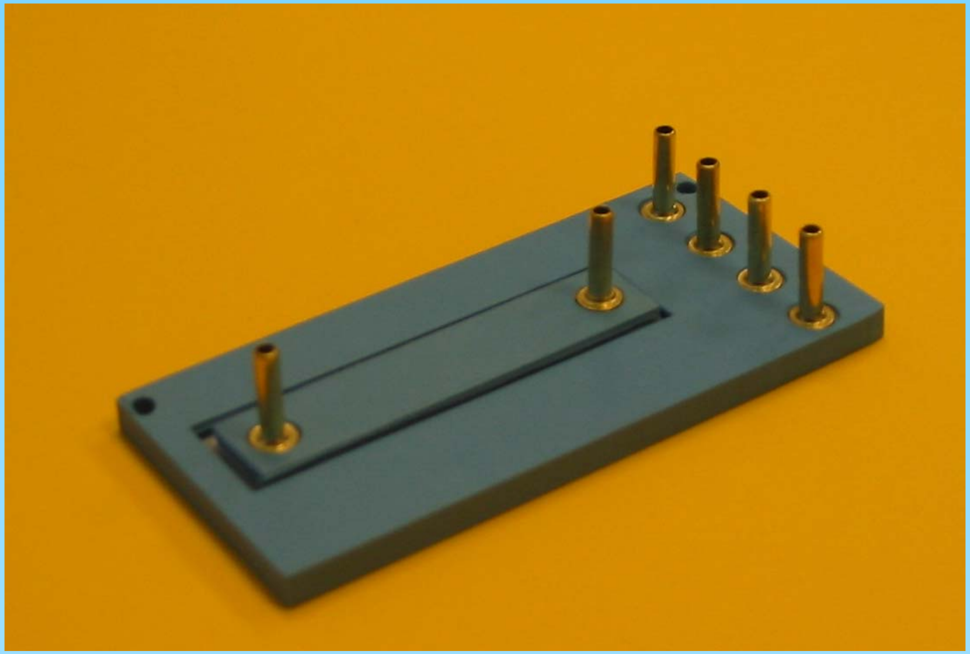




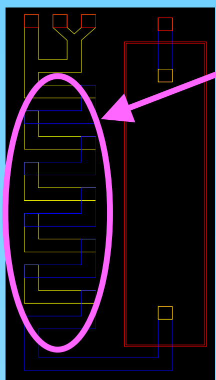
AMMONIA ION DETECTION

- Involved in the eutrophication process
- Found as NH_4^+
- Related to the presence of other ions, such as NO_3^- and NO_2^- (nitrogen cycle)
- Potentiometric detection: Ion Selective Electrode (ESI)

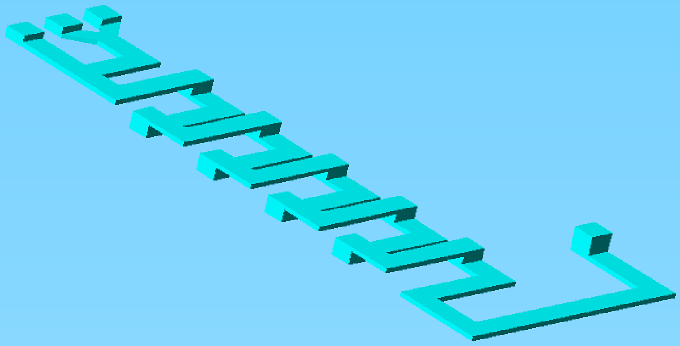


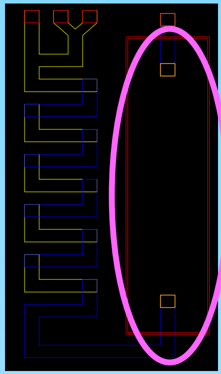


DEVICES WITH PVDF MEMBRANE

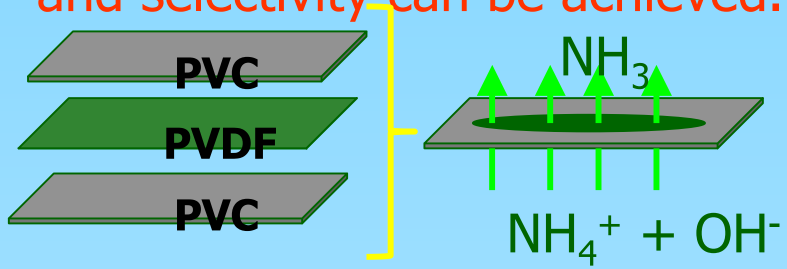


✓Spiral mixer provides a good interaction between reagents.



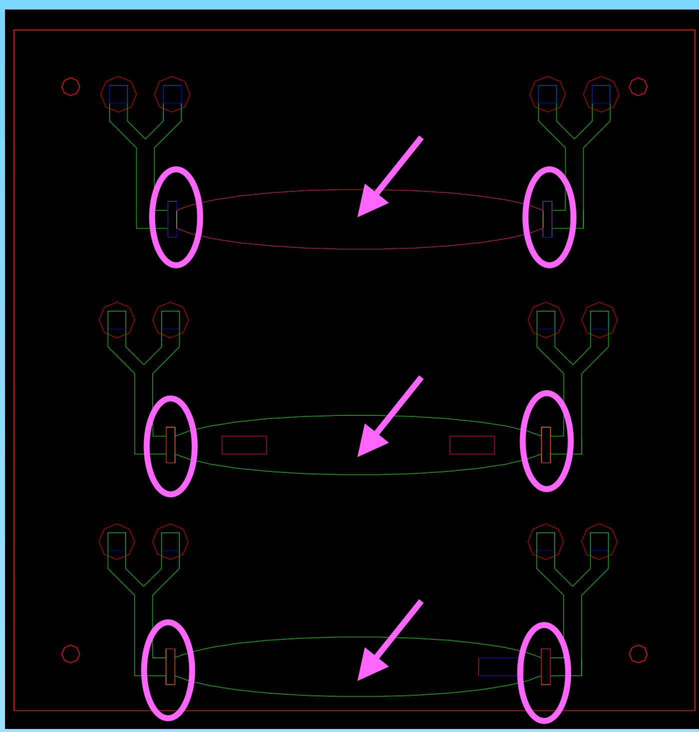


✓A Gas-diffusion membrane is used so that a better sensibility and selectivity can be achieved.



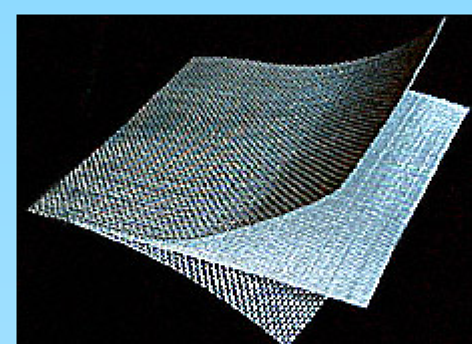
PHOSPHATES DETECTION

- Involved in the eutrophication process
- Mainly found as HPO_4^{2-} and H_2PO^{4-}
- Potentiometric detection:
  - –Ion Selective Electrode (ESI)



✓ Anion exchanger needed to preconcentrate analyte in order to increase detection limits.

✓ Metallic meshes are needed to keep the resin inside the cavity.



6. CONCLUSIONS

- The brief description given here demonstrates how LTCC technology is a suitable material for the fabrication of Meso systems.

Thanks for your attention !