Fabrication of LTCC-based Millinewton Force Sensor: Influence of Design & Materials Compatibility on Device Performance

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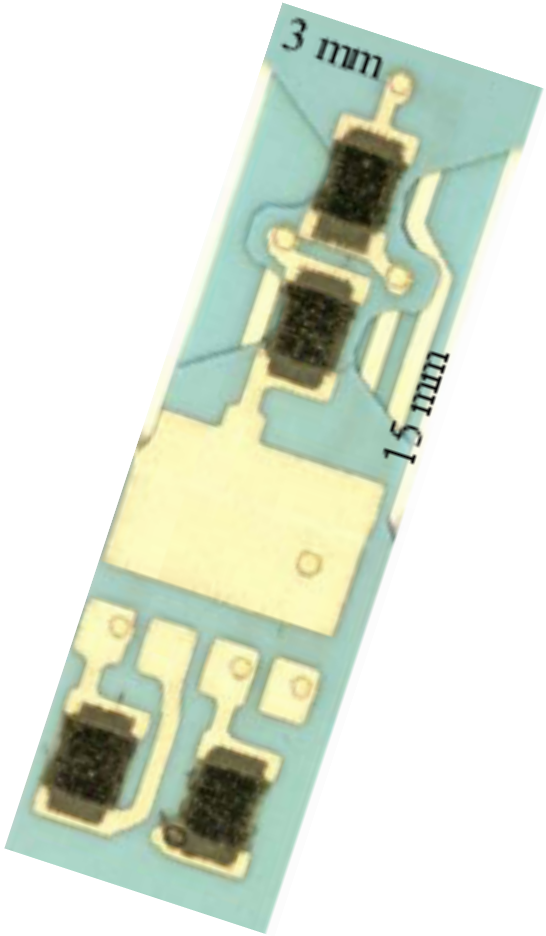
PURPOSE OF THE PRESENTATION

- Fabrication of the MFS using LTCC technology: design concept
- Measuring and comparing electrical performance with previously-fabricated MFS sensors
- Improving sensitivity by reducing LTCC materials incompatibility



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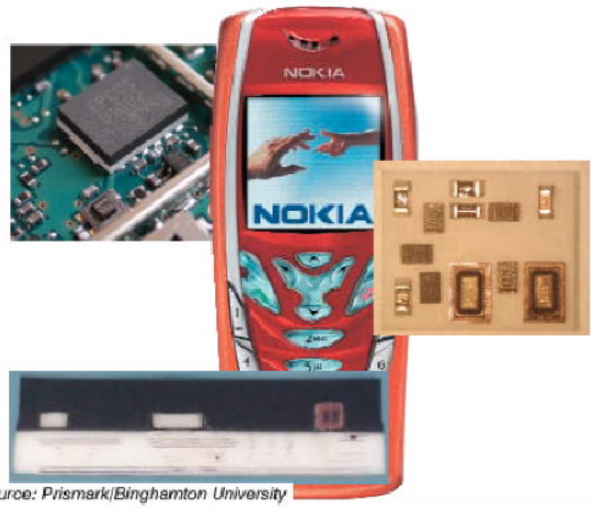
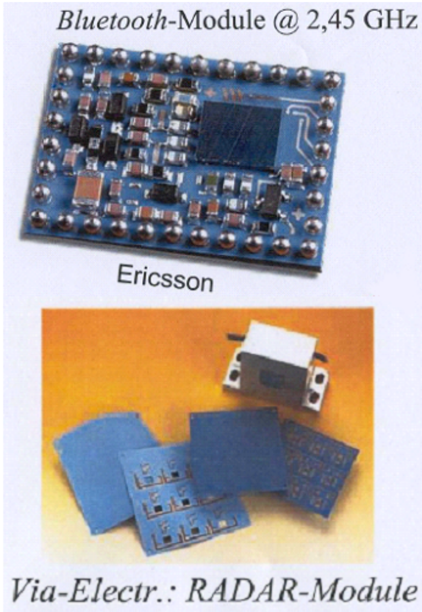
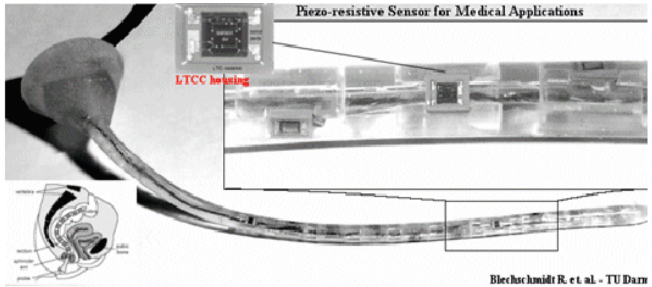
Application areas of LTCC technology have diversified

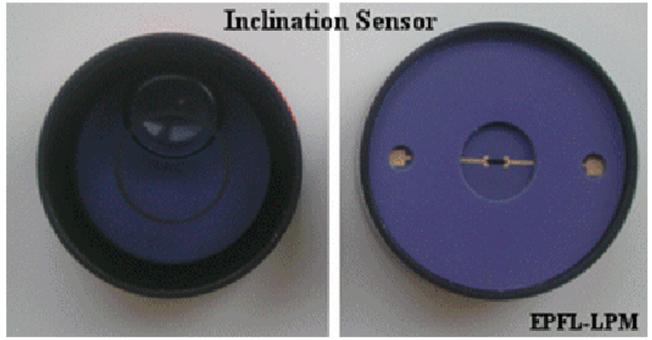


Source: Prismark/Binghamton University

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*







High – frequency applications (superior dielectric properties) → Sensors, micro – fluidics (ease of 3-D fabrication)

OUTLINE OF THIS PRESENTATION

LTCC Technology for sensor applications

- →Introduction
- →Advantages
- →Challenges

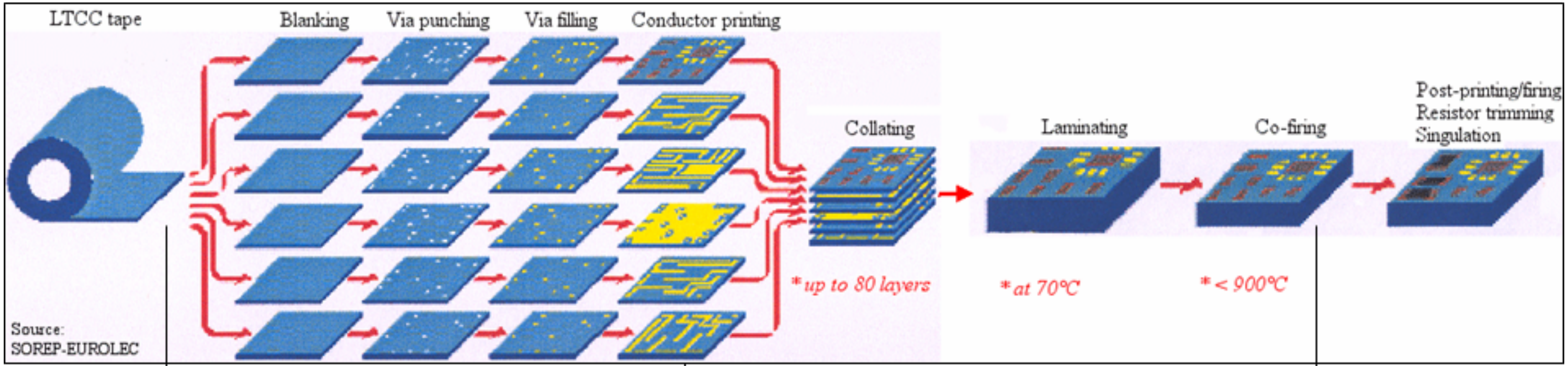
Design and fabrication of a novel MFS sensor

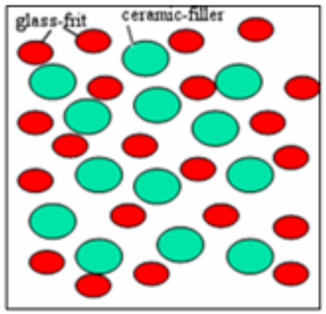
- →Theory
- →Design concept and fabrication of novel MFS
- →Materials compatibility

Electrical performance and comparison

- →Results
- →Comparing electrical performance
- →Conclusions and next steps

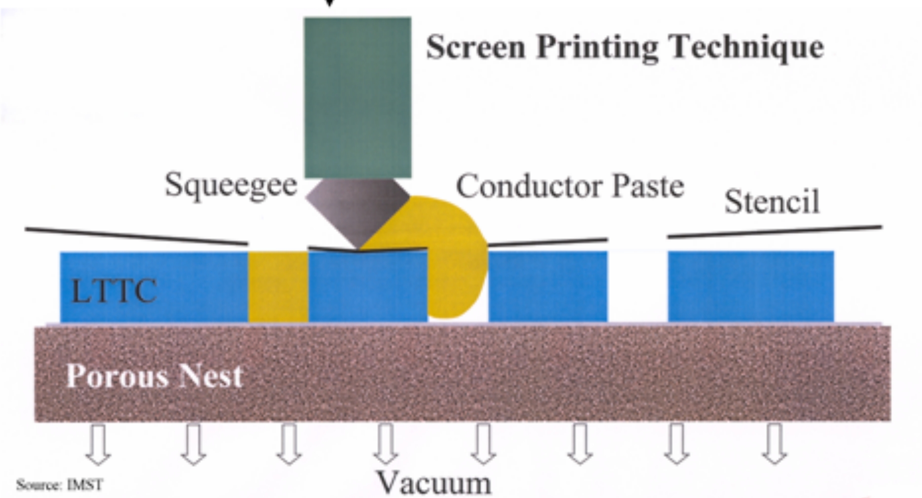
INTRODUCTION: LTCC MATERIALS SYSTEM

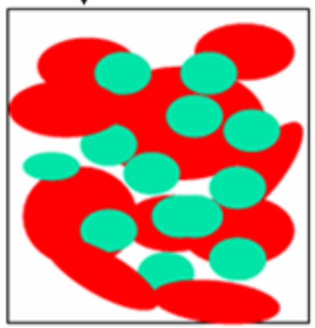




Glass-frit: low firing T
Filler: dimensional stability

... blended in organic-vehicle & cast on mylar sheets

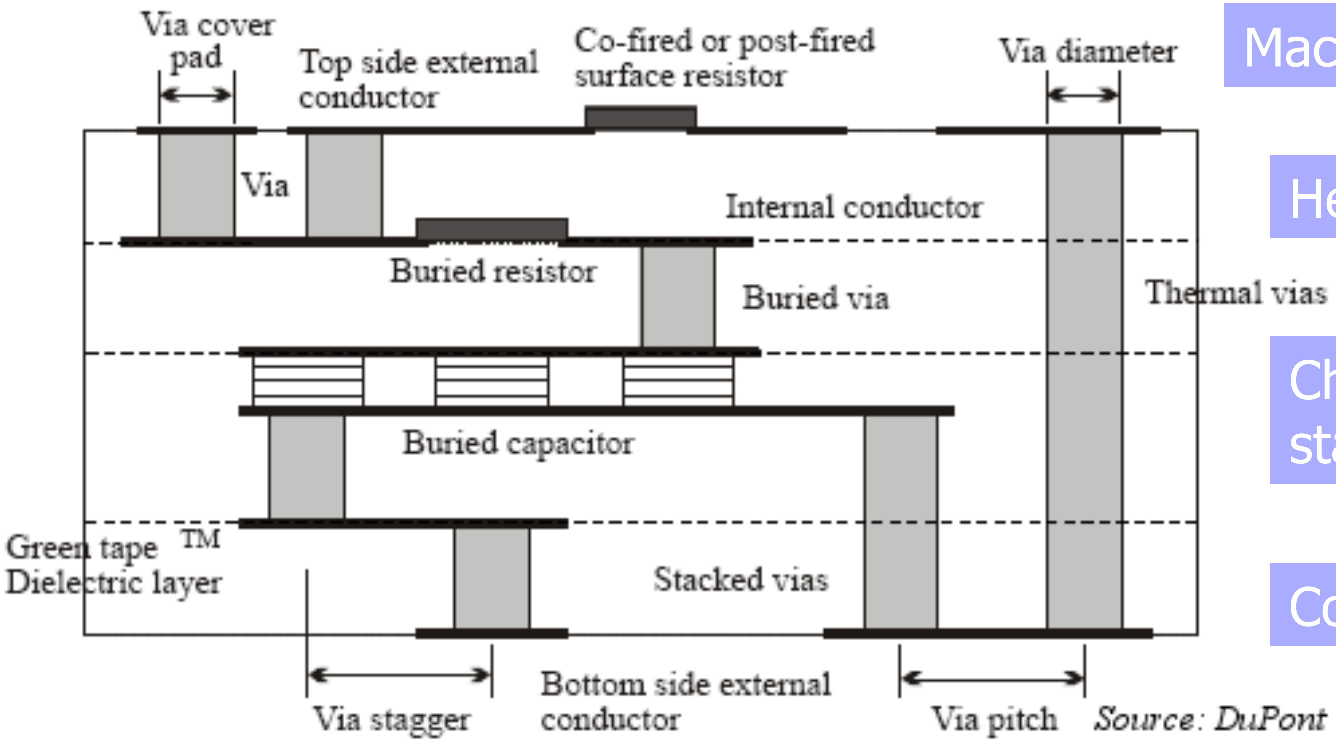




Glass wetting and ceramic rearrangement occur

ADVANTAGES OF LTCC FOR SENSOR APPLICATIONS

High density packaging



Machinability of tapes

Hermeticity

Chemical / thermal stability

Cost effective

Mechanical and electrical functions in one system

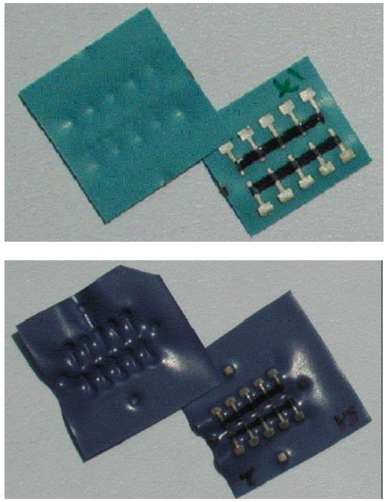
CHALLANGES

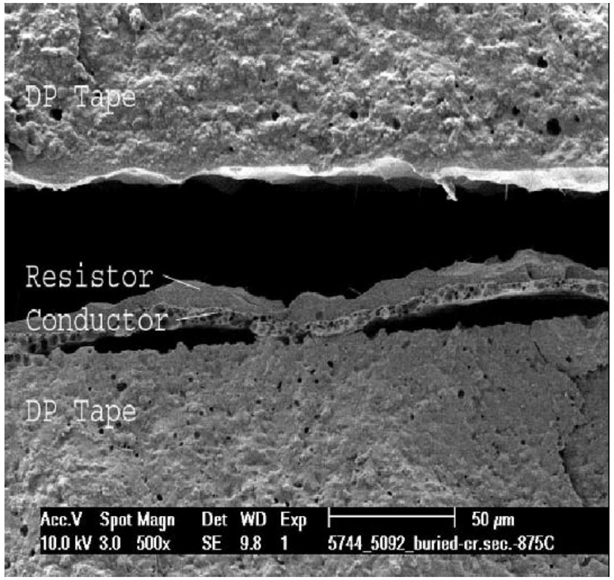
1. Physical Issues

→ differential shrinkage

→ degassing

→ delamination

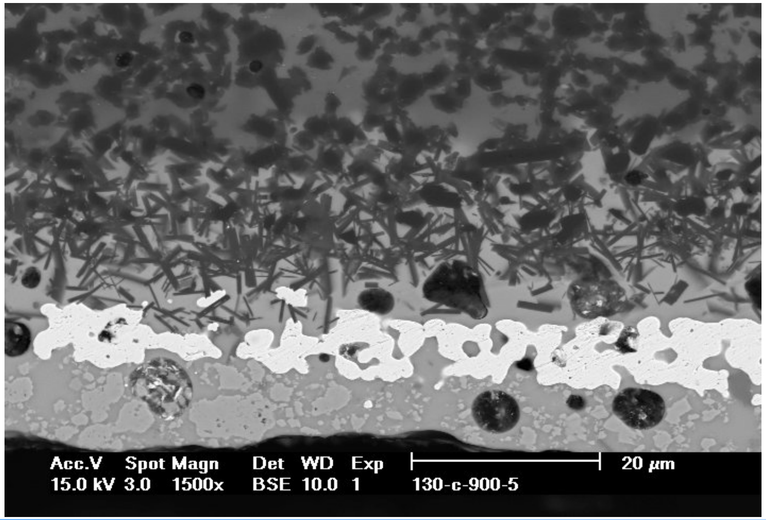




2. Chemical Issues

→ Interaction of components

→ Oxidizing /reducing conditions



OUTLINE OF THIS PRESENTATION

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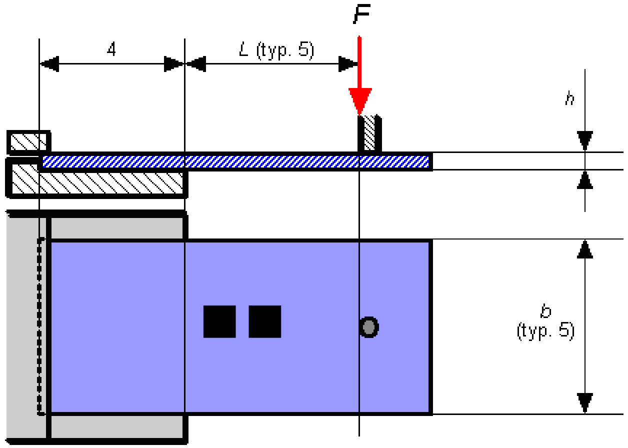
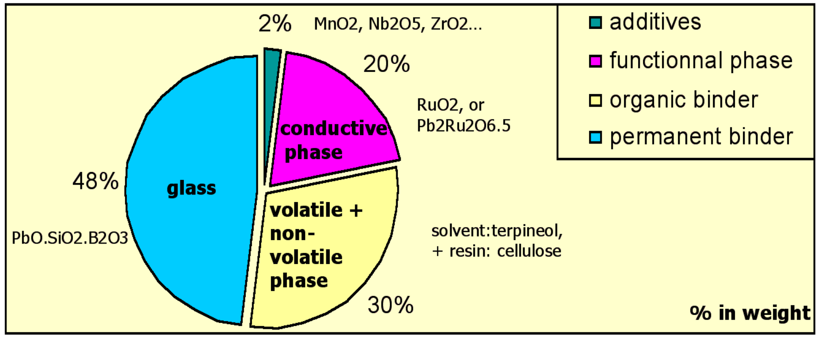
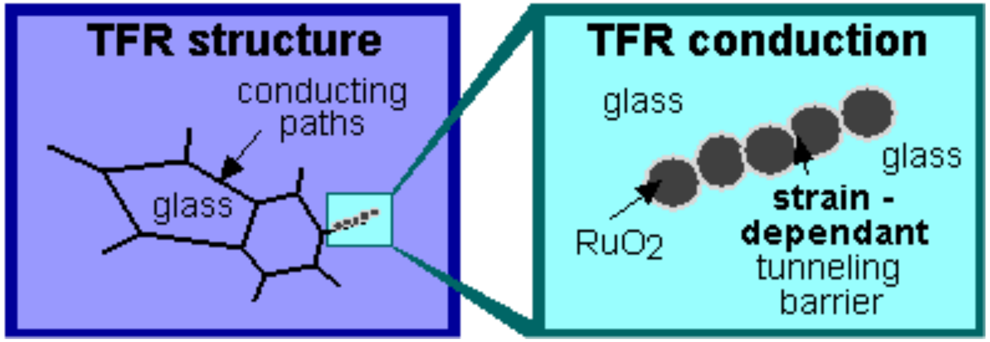
PRINCIPLE : Piezoresistivity ⟷ Force inducing resistance change

« Piezoresistor, a special-type thick-film resistor (TFR) paste, is screen-printed on the beam of the sensor »



μ-SCALE :





THEORY II
OBJECTIVE / SELECTION OF BEAM MATERIAL

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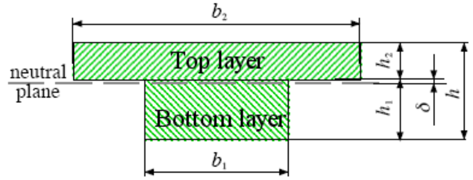


Maximum signal, (ΔR/R) ↔ $\text{Signal} = \varepsilon_{max} G_f$

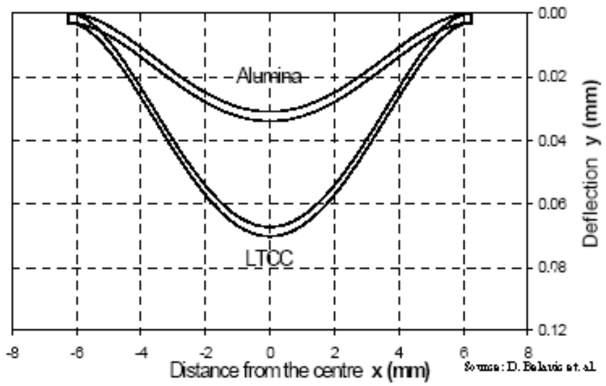
Maximum strain, ε (Δl/l) ↔ $E = \sigma / \varepsilon$

Maximum stress, σ_{max} ↔ $\sigma_{max} = (6FL) / (bh^2)$

$$\varepsilon = (6FL) / (bh^2)E$$

Alumina or LTCC ?

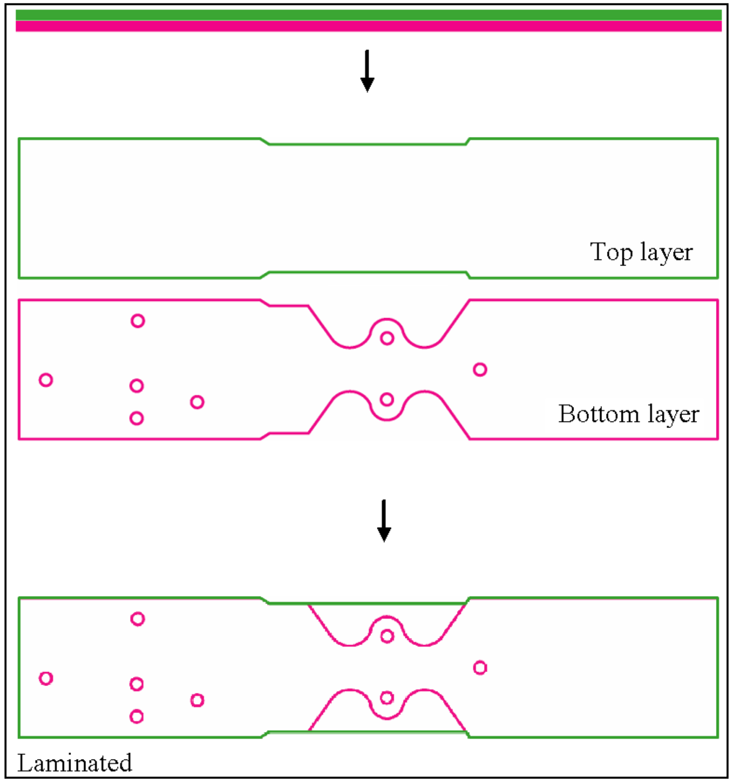
Properties	Kyocera A-476 Al_2O_3 (96%)	DuPont LTCC 951 (fired)
Elastic modulus (GPa)	330	152
Flexural strength (MPa)	310	320
Available thickness (mm)	0.25-1.00	0.04-0.21



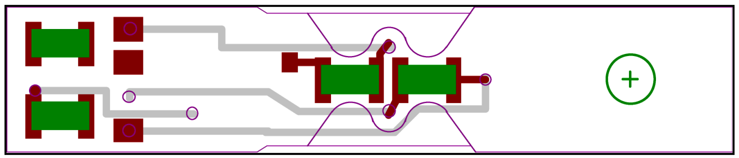
$$\varepsilon_{LTCC} / \varepsilon_{Al2O3} = (h^2{}_{Al2O3} E_{Al2O3}) / (h^2{}_{LTCC} E_{LTCC})$$

$\varepsilon_{LTCC} / \varepsilon_{Al2O3}$ → up to ~70 times theoretically

EXPERIMENTAL I DESIGN and PROCESSING



Layout



PROCESSING

1. Cutting green LTCC sheets,
2. Screen-printing inner conductors,
3. Attaching layers by gluing,
4. Screen-printing surface conductors, TFR
5. Lamination and co-firing the structure at 875°C

REMARKS

1. Top layer: under tension
   Bottom layer: under compression

2. Bottom layer is:

   - ideally selected thicker than top
   - narrows forming a neck

to *maximize the compressive / tensile forces* on the resistors (layout)

SELECTION OF LTCC SHEETS ←→ MAXIMIZING COMP. / TENS. STRESS

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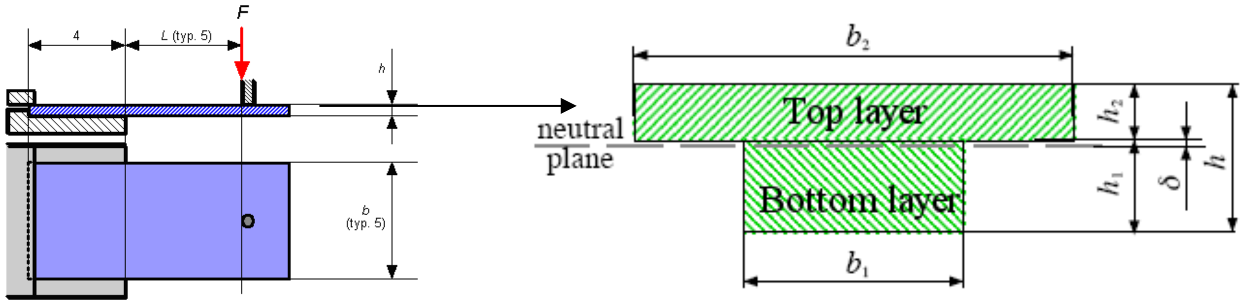
CROSS SECTION :



FROM MATERIALS POINT :

LTCC is ceramic → tensile forces are detrimental!
(crack-growth and propagation)

So, minimize tensile forces

FROM MECHANICS POINT :

$$r = \frac{-\varepsilon_{bottom}}{+\varepsilon_{top}} = \frac{-\sigma_{bottom}}{+\sigma_{top}} = \frac{h_1 - \delta}{h_2 + \delta}$$

Ratio between the compressive stress in the bottom and the tensile stress in the top;

So, maximize « r » or (h_1 / h_2)

EXPERIMENTAL II
LIMITATIONS / MATERIALS COMPATIBILITY

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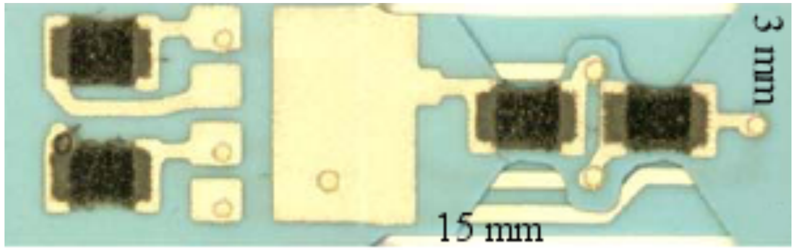
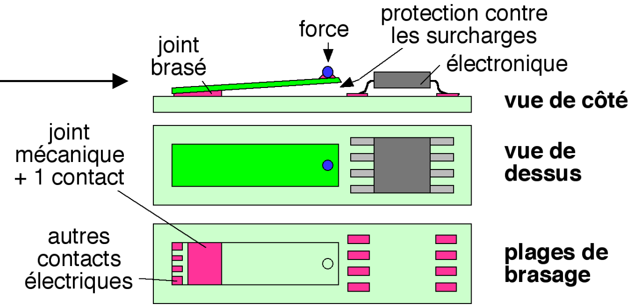
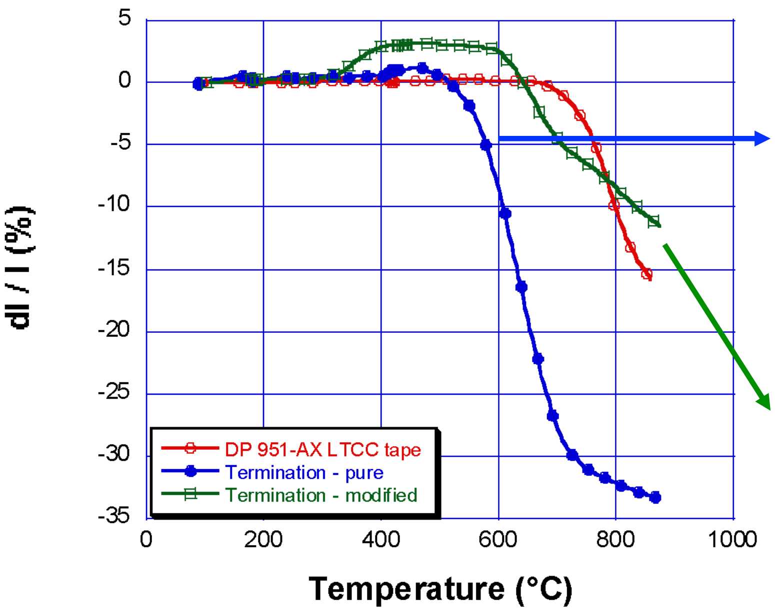
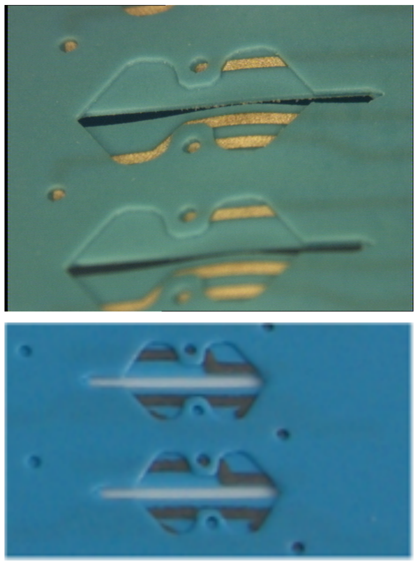




MAJOR PROBLEM: Differential Shrinkage (LTCC / Conductors)





Shrinkage-match achieved by

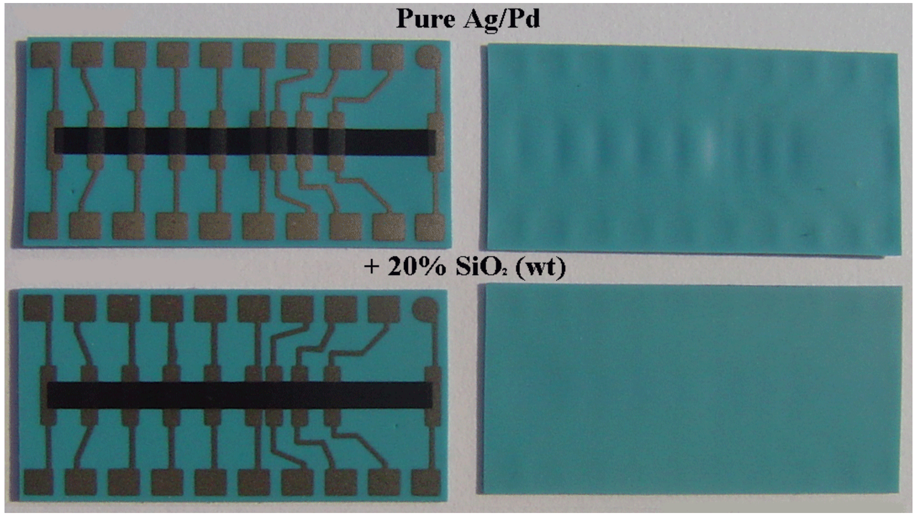
1. modifying commercial pastes using selected additives

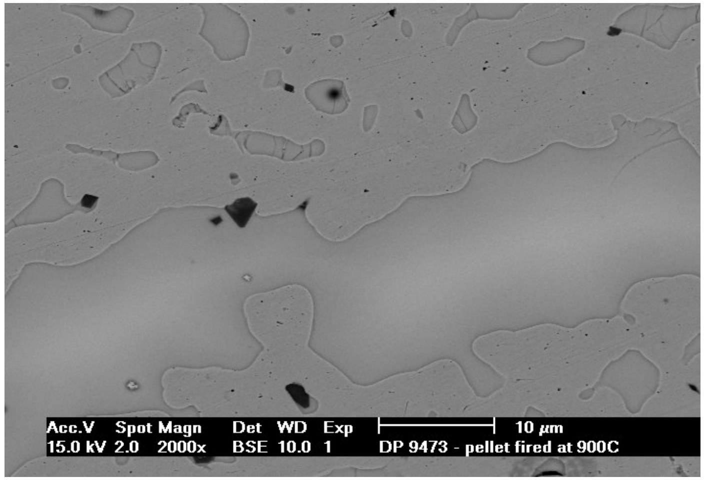
2. Hiding termination between layers

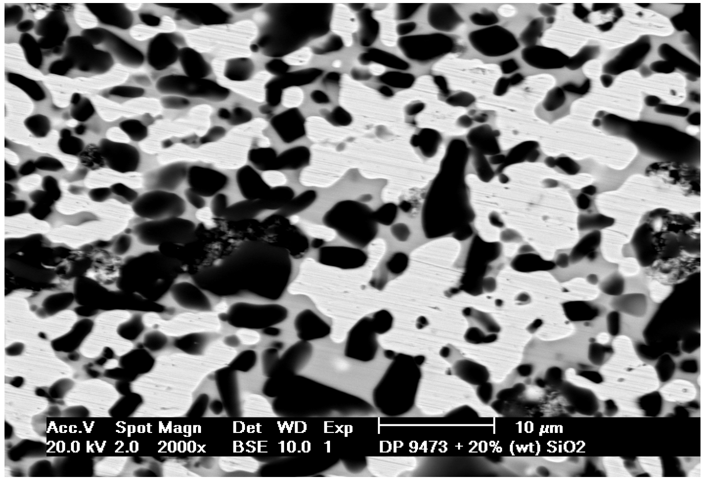
MODIFYING COMMERCIAL PASTES

Paste (ratio of doping)	$T_{shr.}^{+}$ (°C)	%Shrinkage^{++} (-)
DP 9473	516	23
DP 9473 + 10%	618	7.7
DP 9473 + 20%	644	2.3
ESL 9562	430	5.5
ESL 9562 + 10%	615	3
ESL 9562 + 20%	646	0.7

$T_{shr.}^{+}$:Onset temperature of shrinkage of the paste ($\Delta l/l<0$)
%Shrinkage^{++}: Amount of paste shrinkage at the onset temperature of the tape shrinkage (670°C).







→ Mobility of glass phase is supressed by SiO_2 addition

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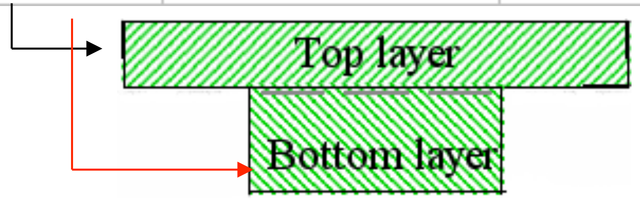
RESULTS I
MEASUREMENTS

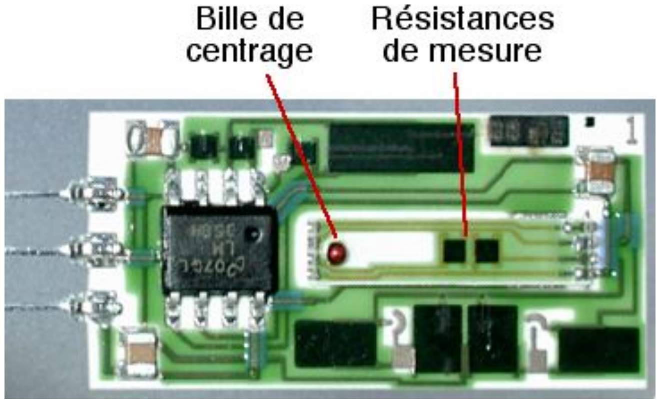
Prepared sensors

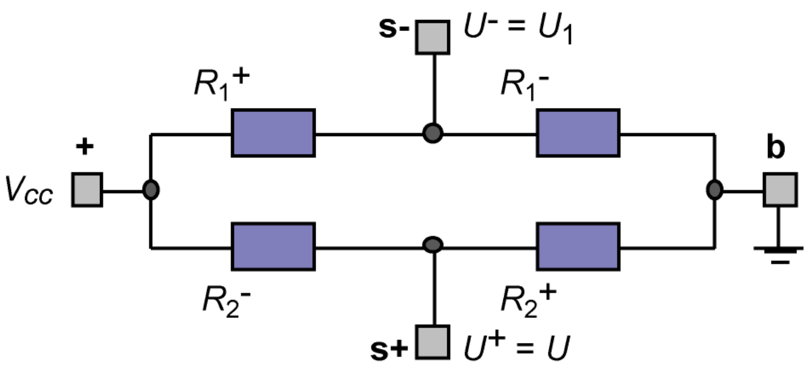
Material	Configuration	Fired thickness (mm)	Deformation	1/thickness (1/mm)	Signal (mV)
Alumina	250	0.25	-	4.00	7.5
LTCC	250 / 110	0.29	-	3.45	12
LTCC	110 / 250	0.29	-	3.45	15
LTCC	110 / 110	0.18	+	5.56	15
LTCC	110 / 50	0.13	-	7.69	40



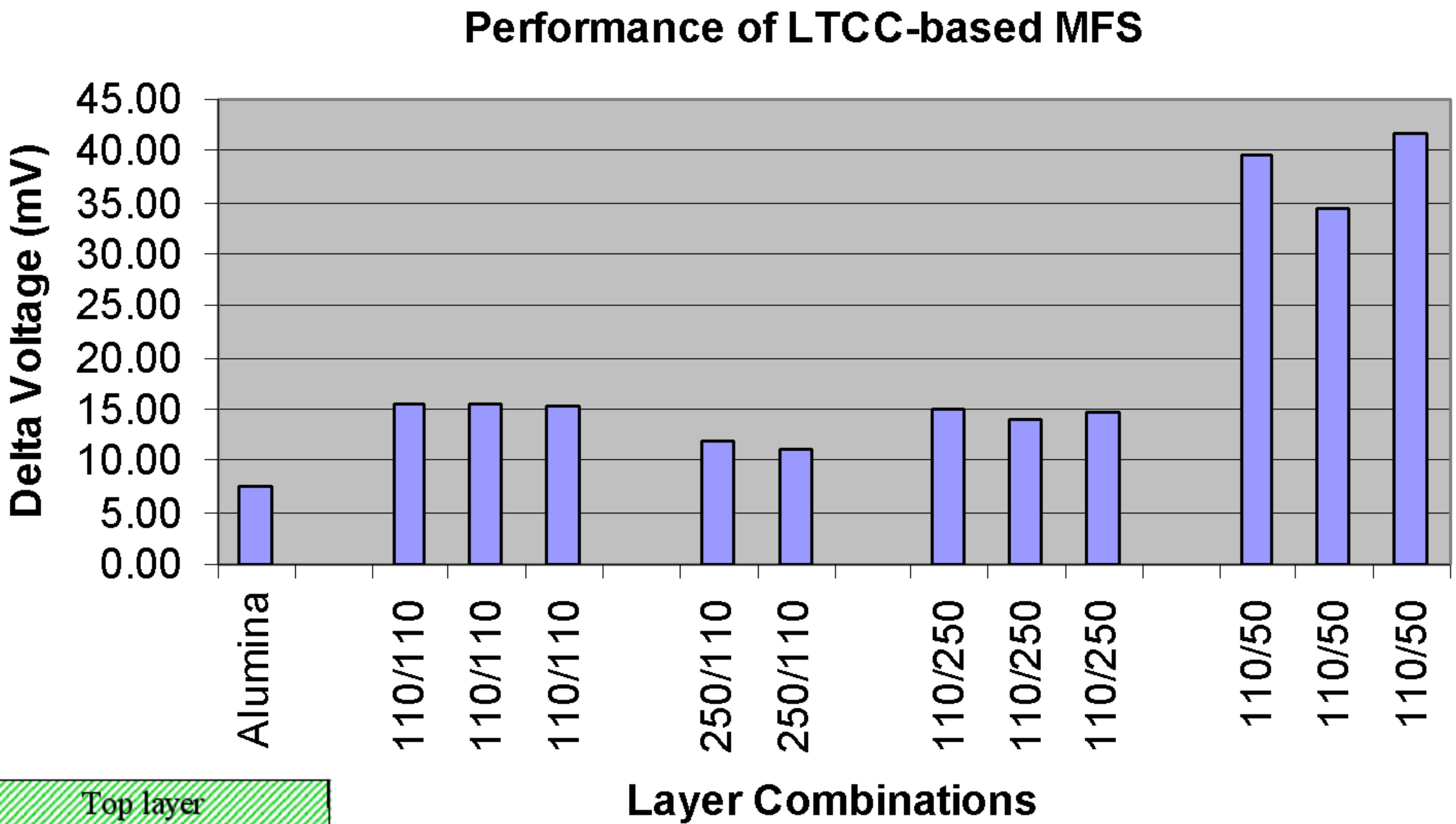
Beam soldered on the mechanical support, Which also carries electronic components

Measurements made by applying varying weights on MFS, with a wheatstone-bridge conf.





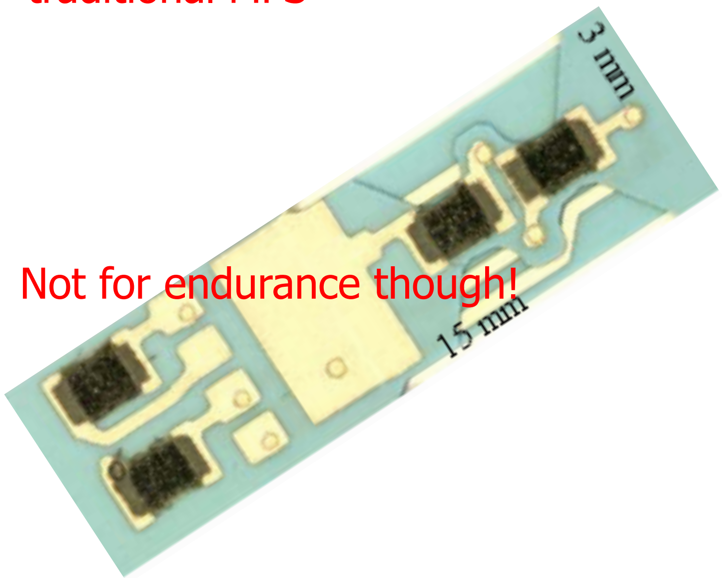
RESULTS II PERFORMANCE / COMPARISON



CONCLUSIONS

- LTCC-based MFS is fabricated, yielding a performance that is expected theoretically

→ ~ 6x better sensitivity than Al-based, traditional MFS



- The elastic modulus, thickness and design flexibility makes LTCC an interesting choice for force sensing

→ Not for endurance though!

- Materials compatibility improves sensitivity by reducing deformation on the beam

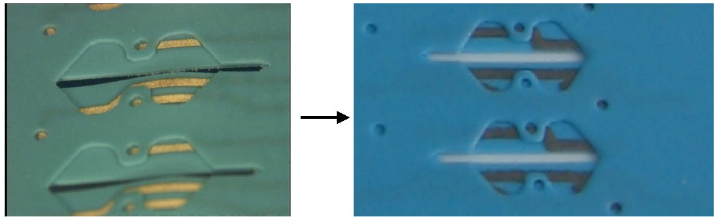
→ Reduced deformation on the beam means stress-free TFR

NEXT STEPS

- Further reducing MFS thickness is limited by the technology:

  - LTCC tapes available
  - Materials compatibility

  → Differential shrinkage



- Novel designs with improved comp. / tens. stress distribution on the TFR

- Improving line-definition of the printed thick-film material