LTCC ultra high isostatic pressure sensors

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Outline

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

1. Introduction - LTCC & hydrostatic sensors
2. Sensor design & fabrication - LTCC process & package
3. Modelling - expected sensor performance
4. Results - sensor performance & limitations
5. Conclusions & outlook

1. Introduction

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1. Thick-film piezoresistive sensors

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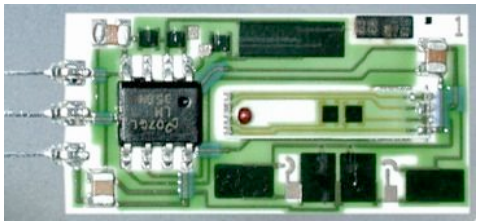
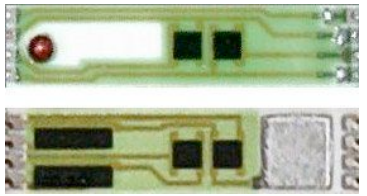
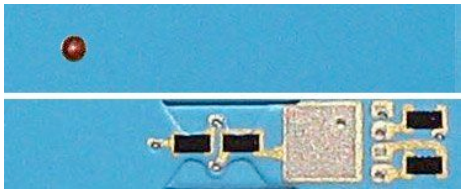
- Force sensor 100 … 2’000 mN
  - Alumina cantilever
  - LTCC cantilever
- Force sensor 4 … 200 N
- Pressure sensor (alumina)
- Pressure sensor (steel)

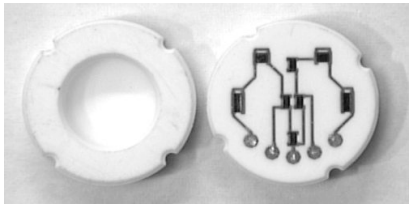


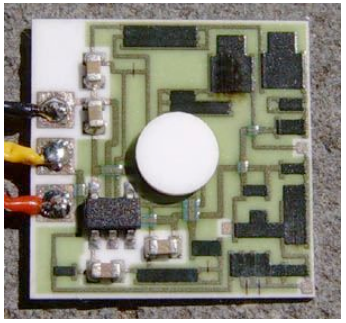
Top

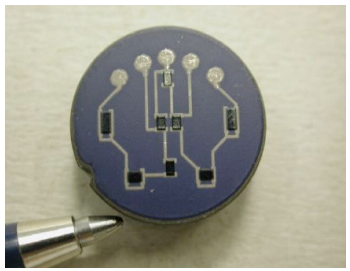
Bottom











→ **Principle: substrate bending**

1. Piezoresistive sensors: bending

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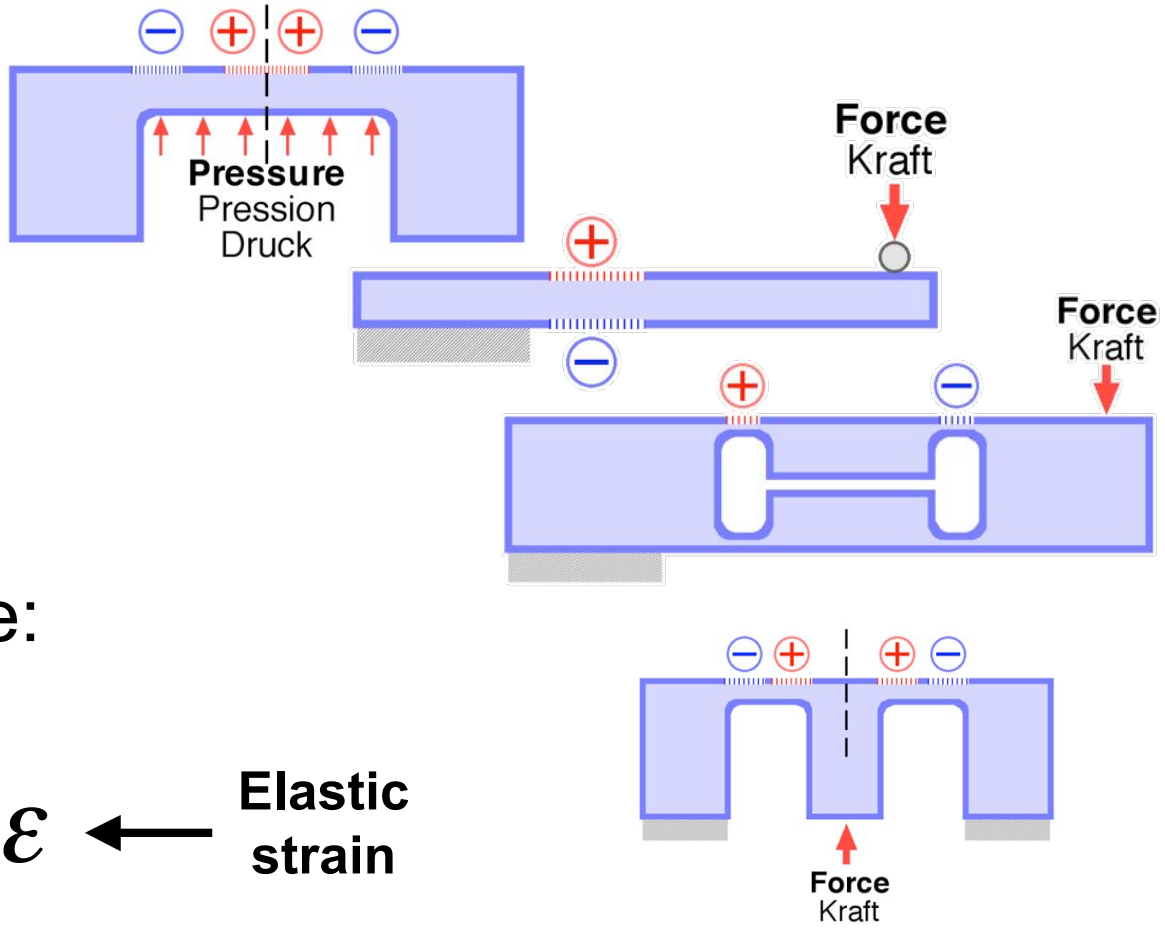
- Typical structures
  - Membrane
  - Cantilever
  - Parallellogram
  - Button / bridge



- Piezoresistive response:

$$\frac{\Delta R}{R} = K \cdot \varepsilon$$

Relative resistance change

Gauge factor

Elastic strain

1. Sensors in bending: limitations

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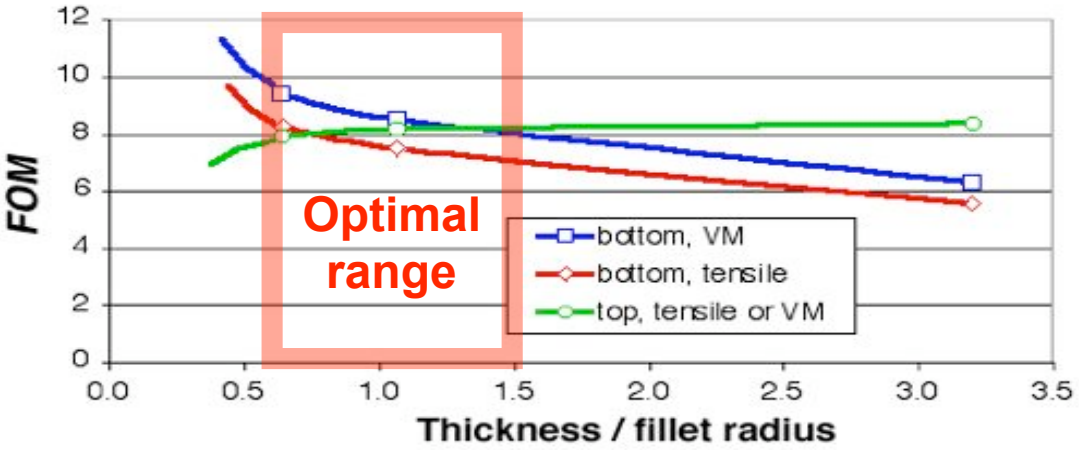
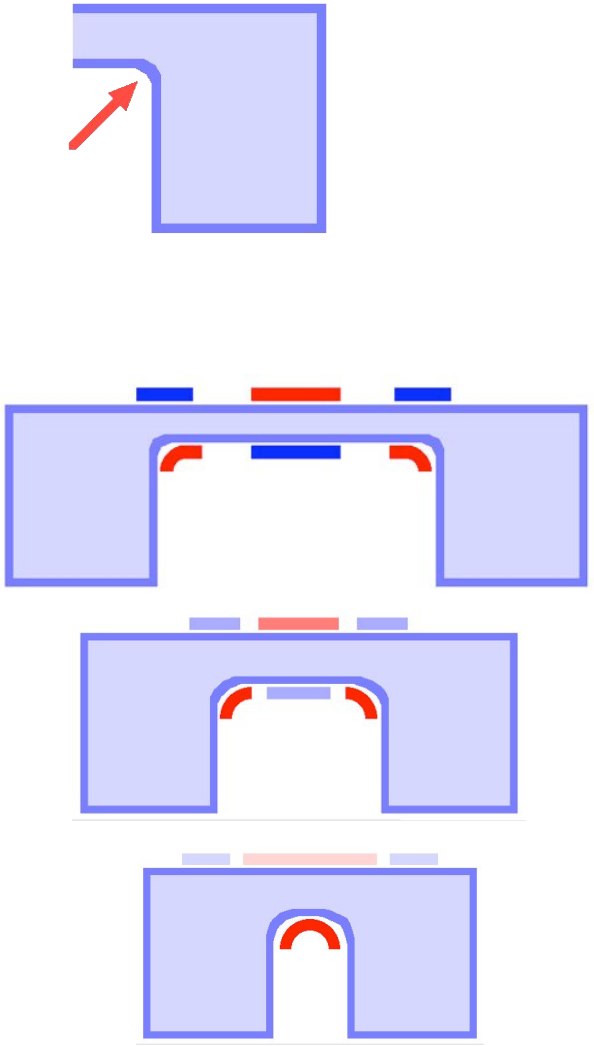
- Stress concentrations
  - Optimal: fillet radius ≅ membrane thickness





- Pressure range
  - Low to medium: ≅ membrane theory
  - High: lower signal
  - Very high: very low signal

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*

→ **LTCC more sensitive, but less strong: overall ≅**

1. Hydrostatic sensors

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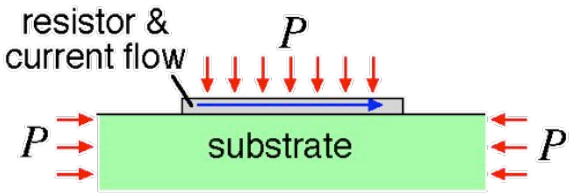
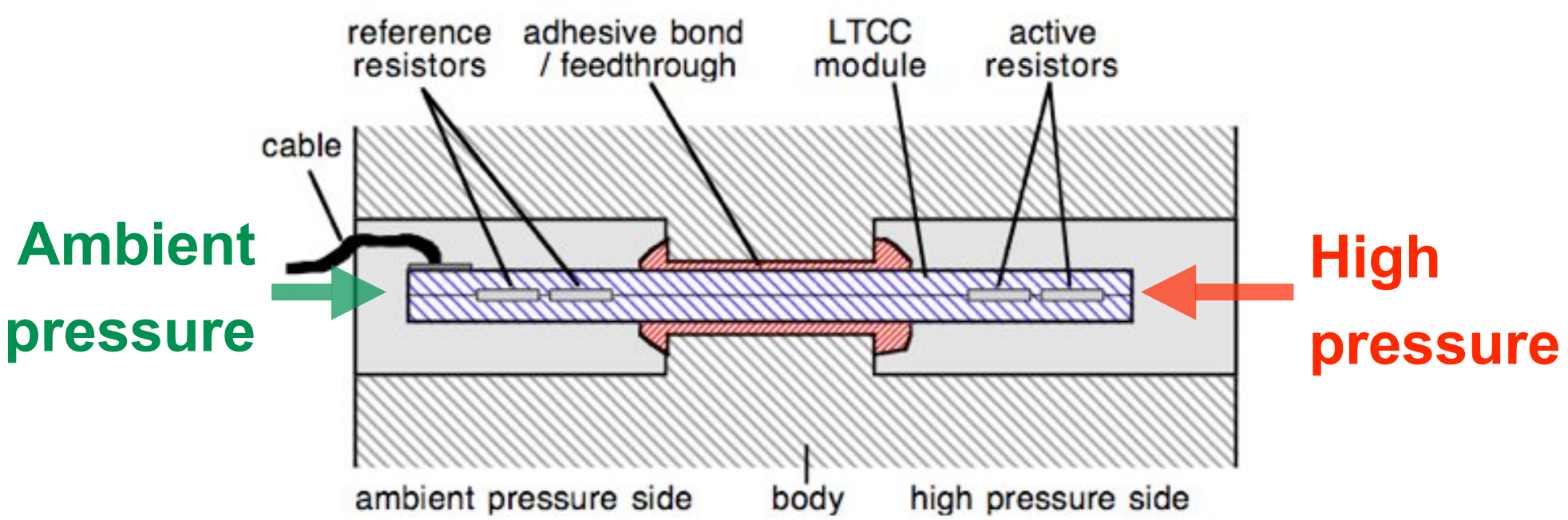
- Ceramics: limitations for tensile stresses
- In principle “unlimited” pressure allowed

→ **LTCC “hydrostatic” sensor concept:**





2. Sensor design & fabrication

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2. LTCC hydrostatic sensor module

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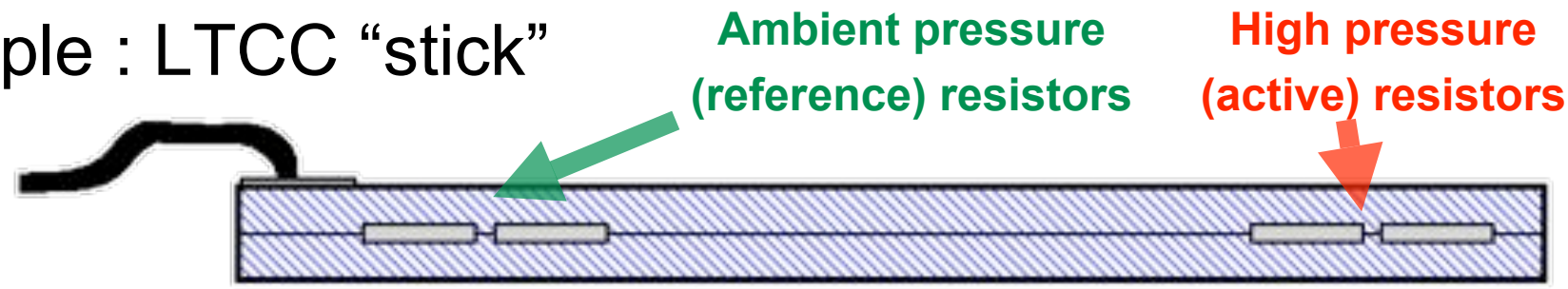
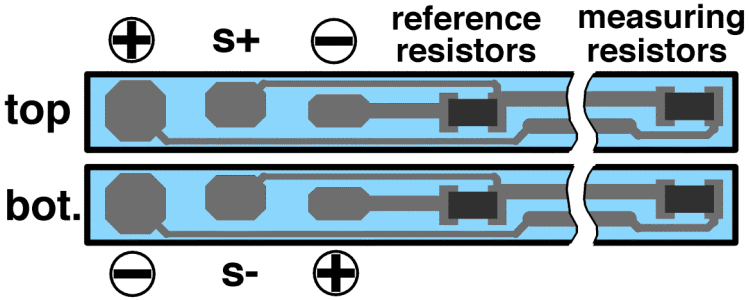
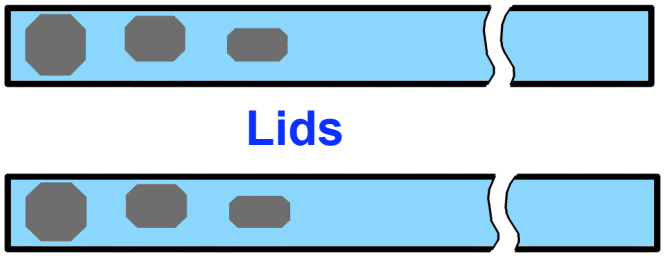
- Principle : LTCC “stick”



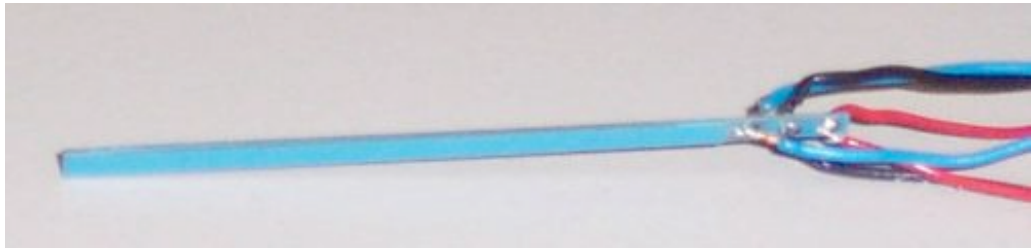
- Circuit: 4 LTCC layers (DP 951 & DP 2041)



Core layers: measurement bridge



- Resulting module



2. Sensor packaging & test jig

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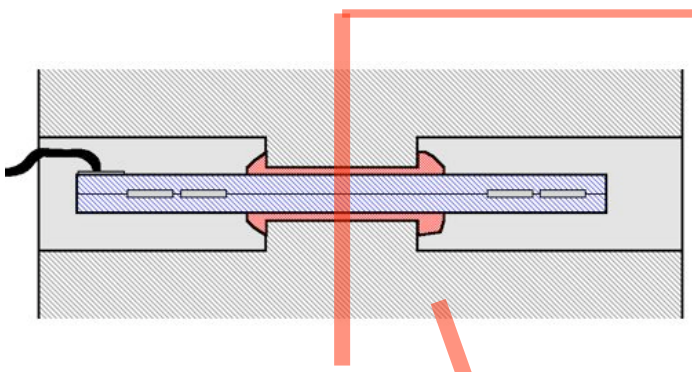
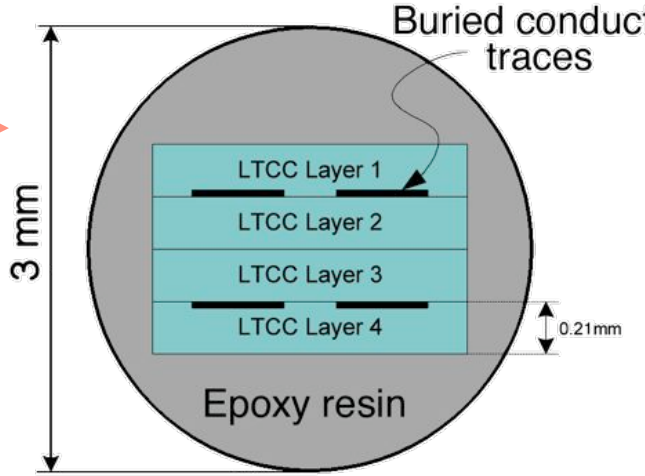
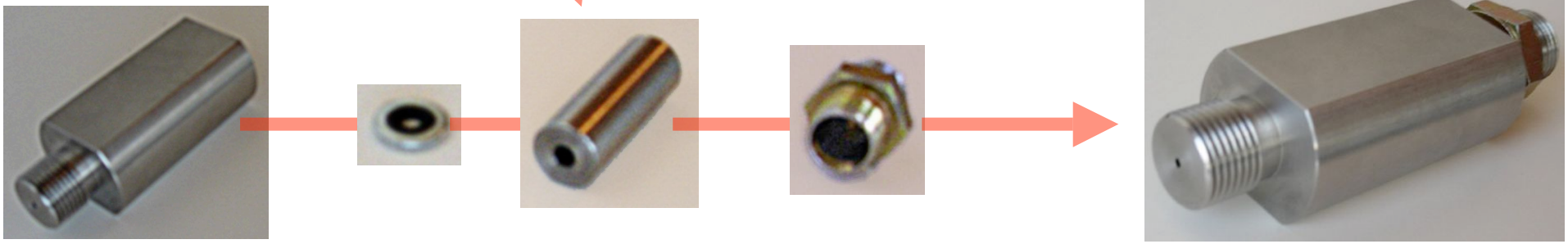
- Epoxy adhesive feed-through





- Sensor test jig:



Carrier | O-ring seal | Sensor | Tightening nut | Complete assembly

3. Modelling of sensor

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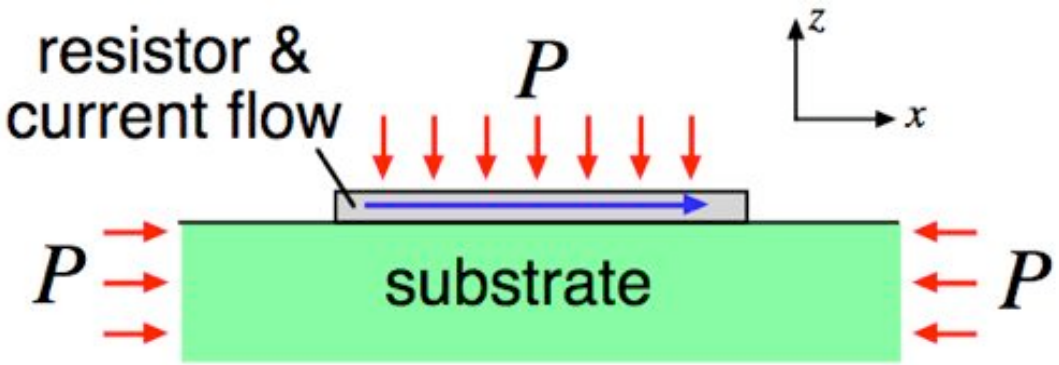
3. Resistor in hydrostatic pressure



Vertical:

- E(resistor) ≅ 70 GPa

Horizontal

- E(LTCC) ≅ 110 GPa
- E(Al_2O_3) ≅ 320 GPa

→ **LTCC advantages:**

- Higher signal
- More isostatic stress (smaller E difference)
- Easy hermetic sealing (buried resistors)

3. Expected response

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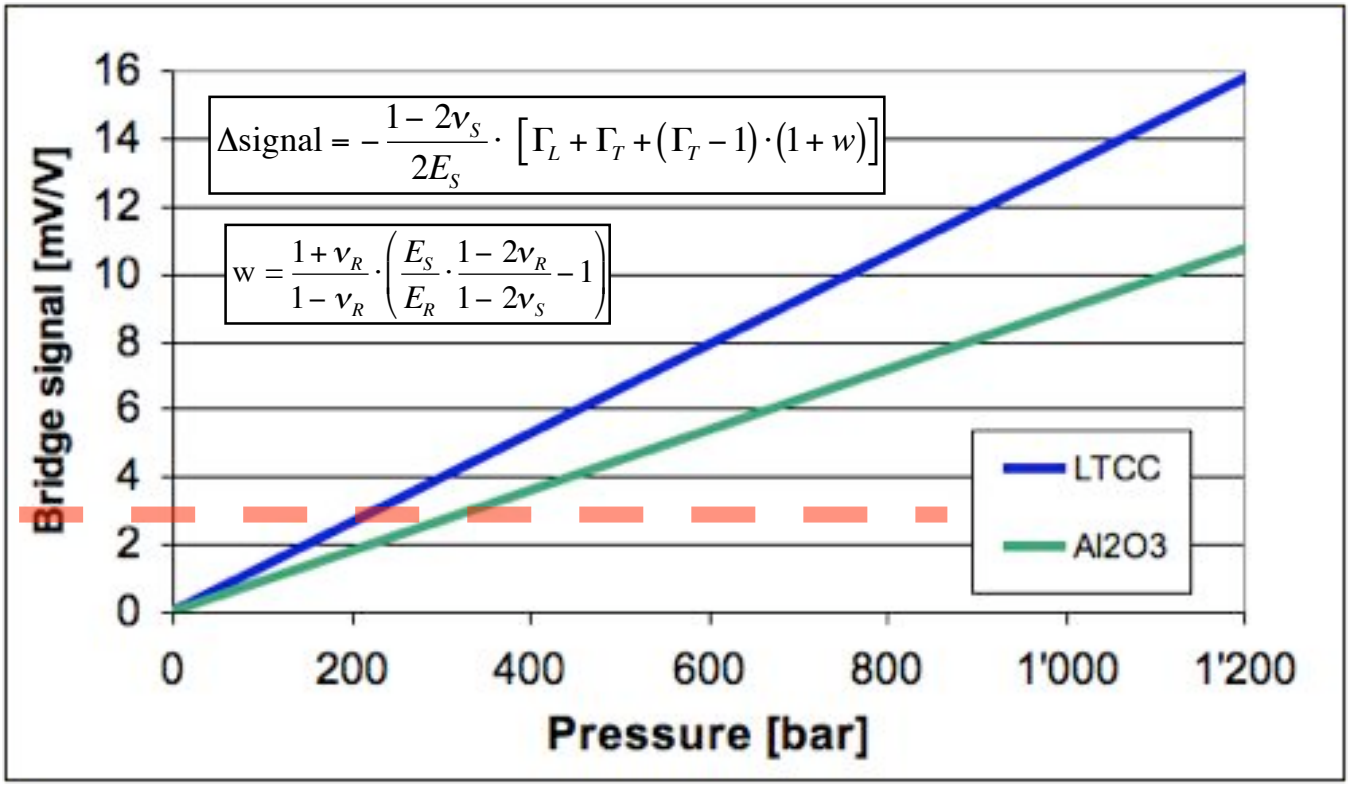
Includes 50% reduction due to half-bridge design

3 mV/V

LTCC : Al_2O_3 ≅ 3:2



- **Very high achievable signal**
- **In theory limited by packaging only (feed-through)**

4. Results

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4. Resistor & bridge offset values

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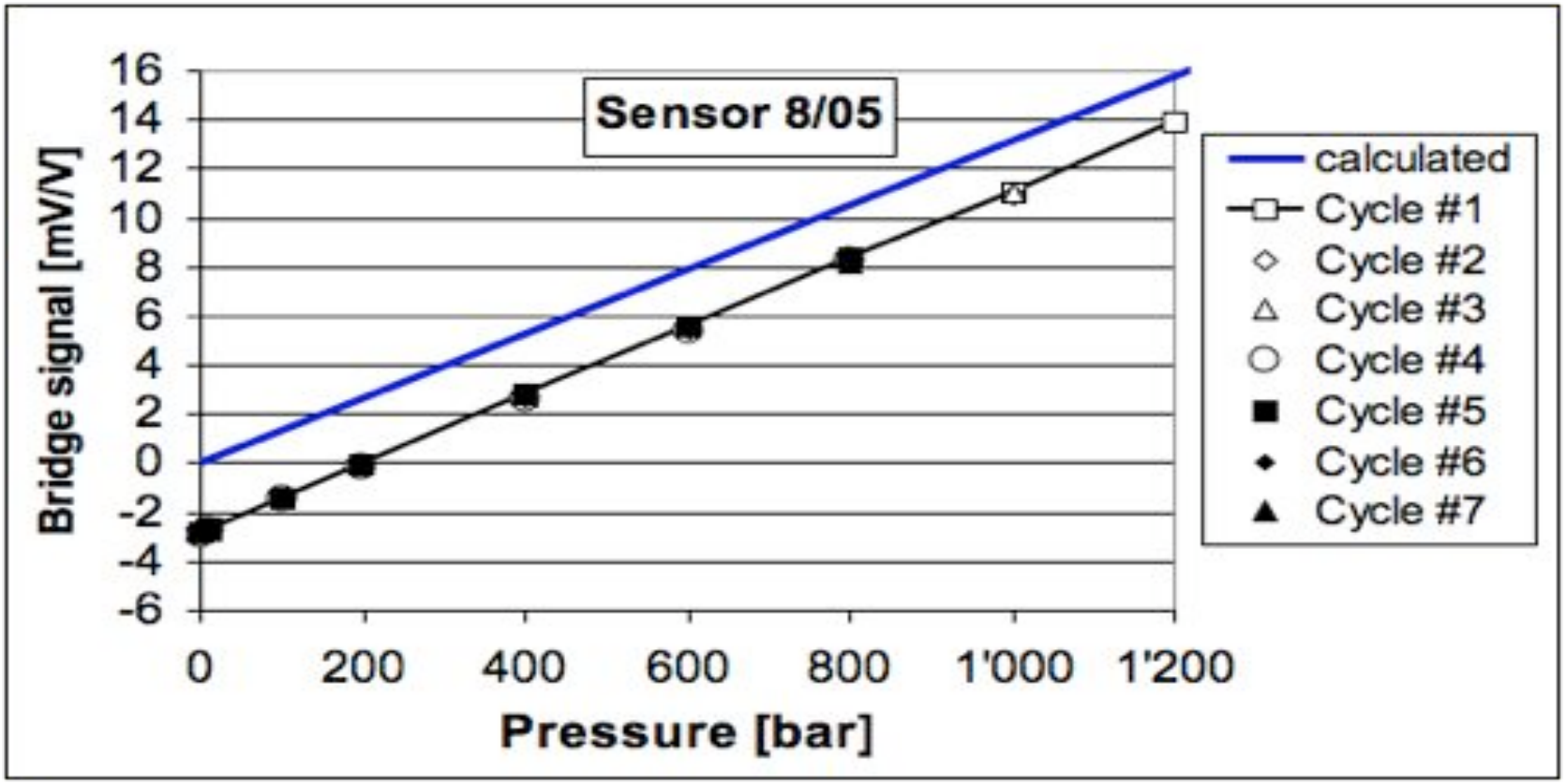
Type	Co-fired buried	Co-fired open	(nominal)
Resistance	24 kΩ ± 6%	3.6 kΩ ± 6%	(10 kΩ)
Offset	7 ± 21 mV/V	78 ± 33 mV/V	(0)

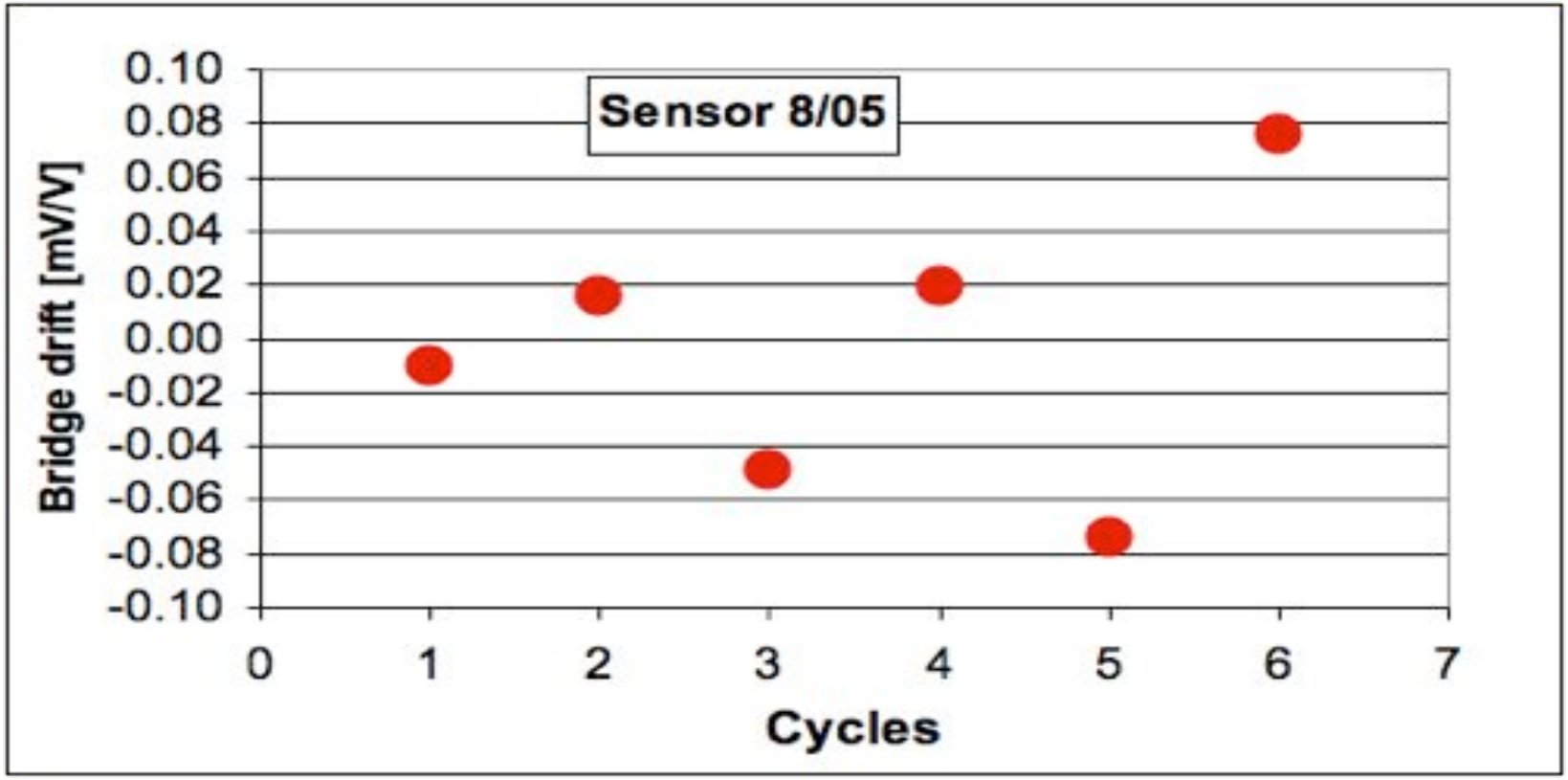
- **Values affected by interactions with LTCC**
- **Offsets OK**

4. Measured sensor response



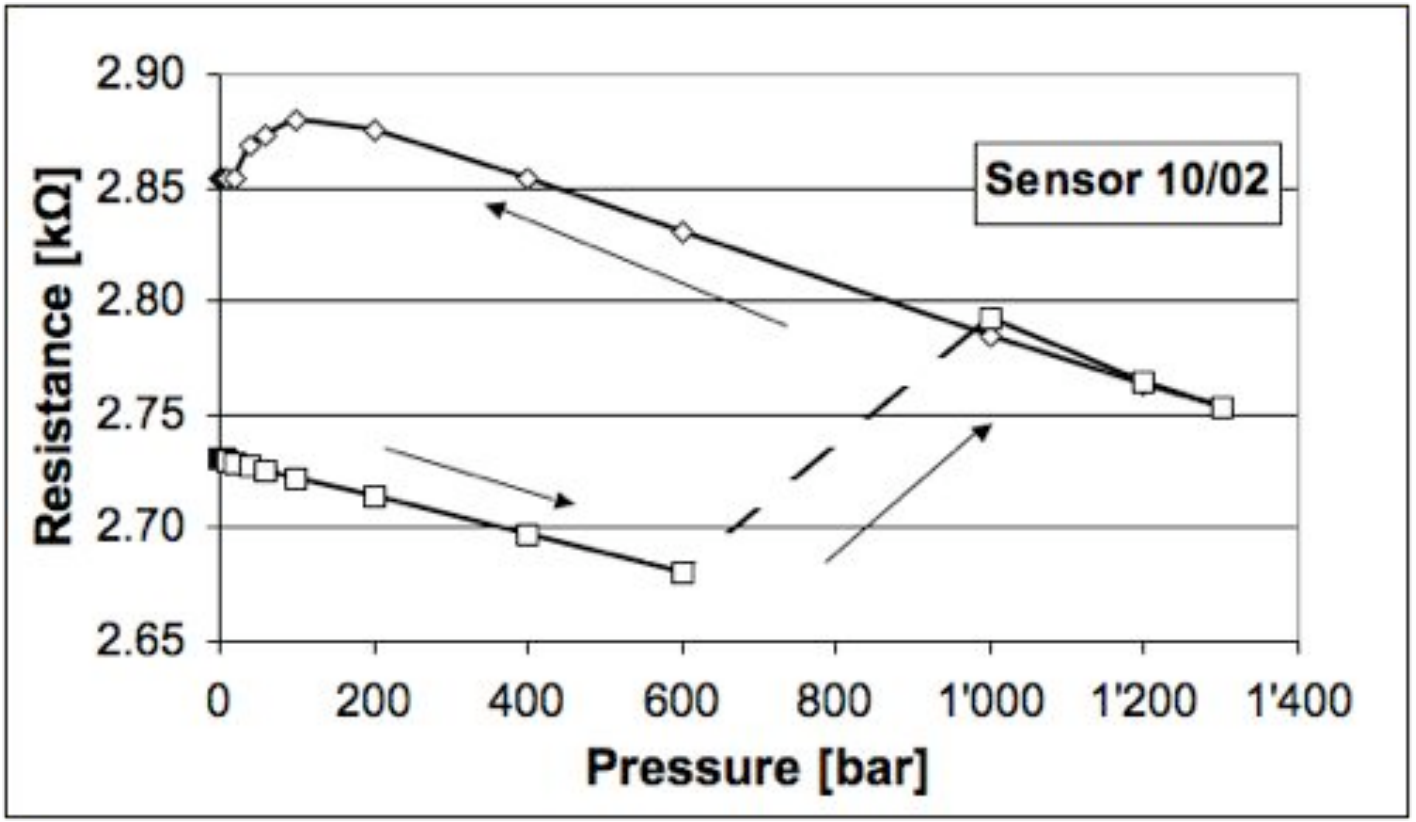
- Linear & hysteresis free behaviour up to 1’200 bar
- Response corresponds to expected value

4. Measured sensor drift



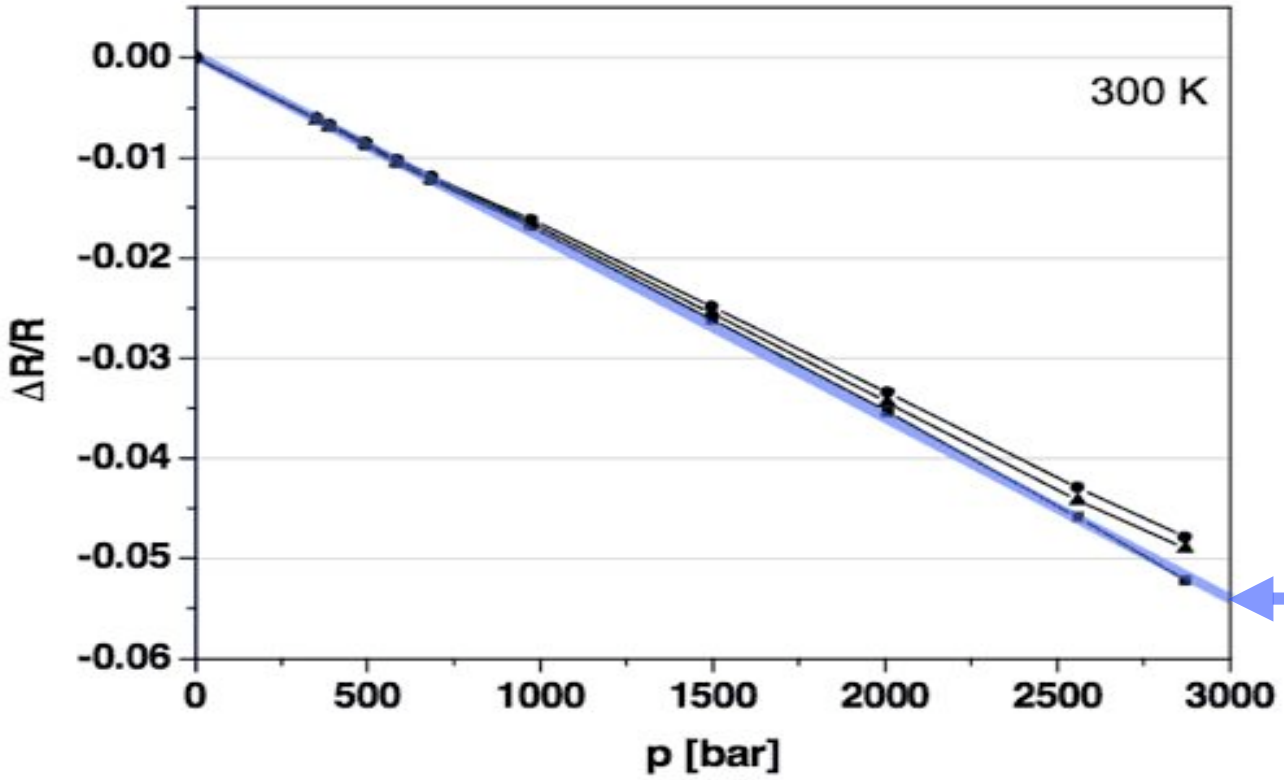
- Zero-pressure drift is low
- Drift probably thermal (sensor not compensated)

4. Limitations



- Problems with some sensors (sudden drift or death)
- Cause: voids or local stresses at feed-through ?

4. Comparison with other results



Dziedzic et al., IMAPS-PL conference, 2003

DP 2041 on alumina

Calculated

→ Very good match with published results on same resistors

5. Conclusions & outlook

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5. Conclusions

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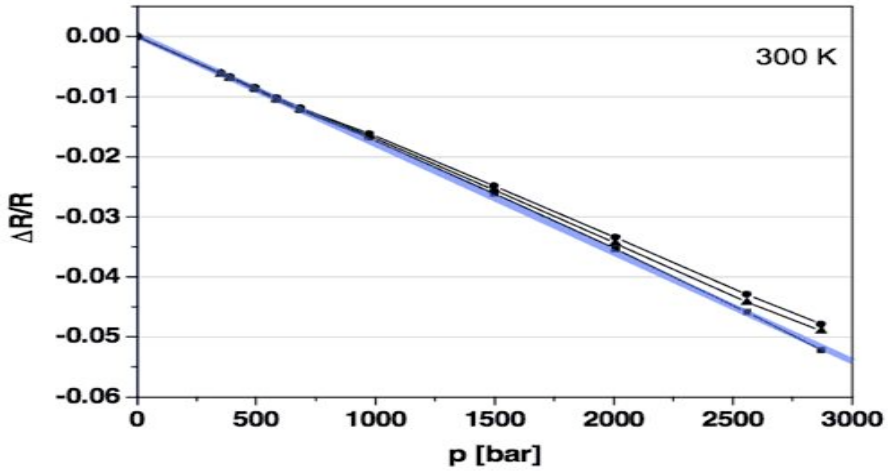
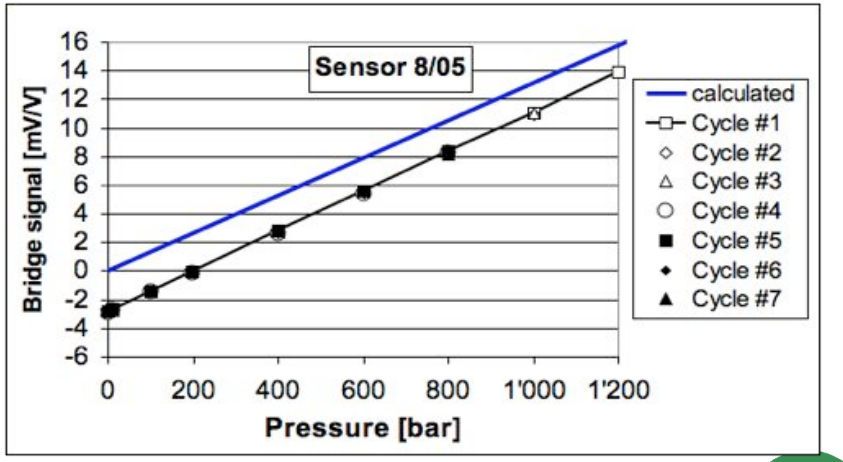
- Studied “hydrostatic” LTCC high pressure sensor
- Model for resistors under hydrostatic pressure
- Sensor successfully tested at > 1’000 bar
- Some quality issues
- High response agrees very well with predictions





5. Outlook

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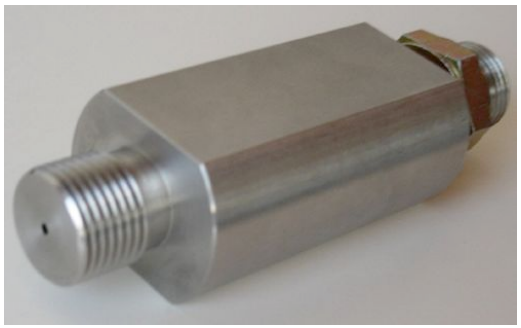
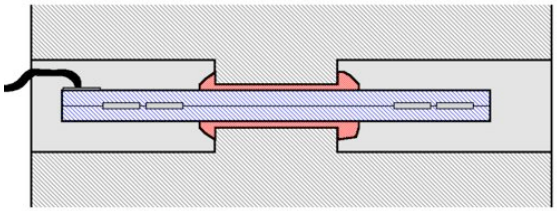
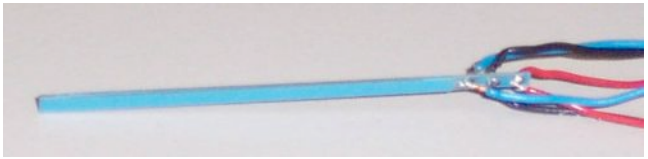
- Characterise sources of failures under pressure
  - Bubbles / voids in LTCC structure ?
  - Stress gradients in feed-through ?
- Improve feed-through (epoxy → glass ?)
- Hydrostatic studies on other resistors
- Better characterisation of resistor materials







Merci

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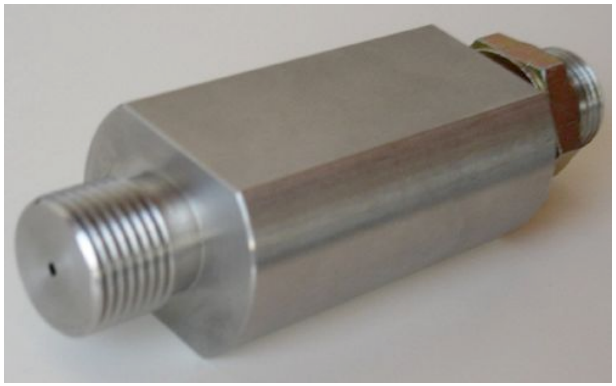

Thank you !