STRENGTH OF CERAMIC SUBSTRATES FOR PIEZORESISTIVE THICK-FILM SENSOR APPLICATIONS

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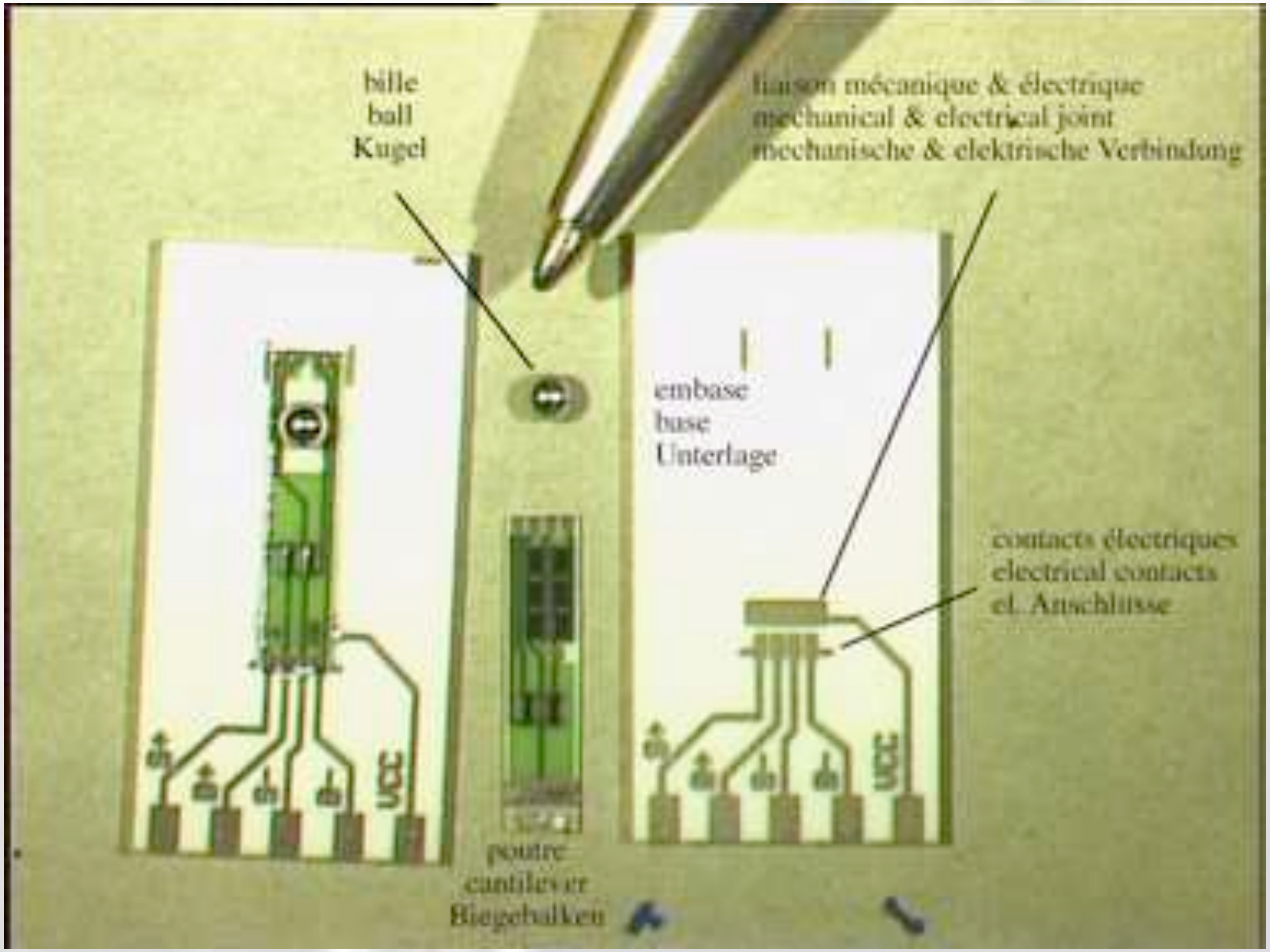
Principle: a simple force cell



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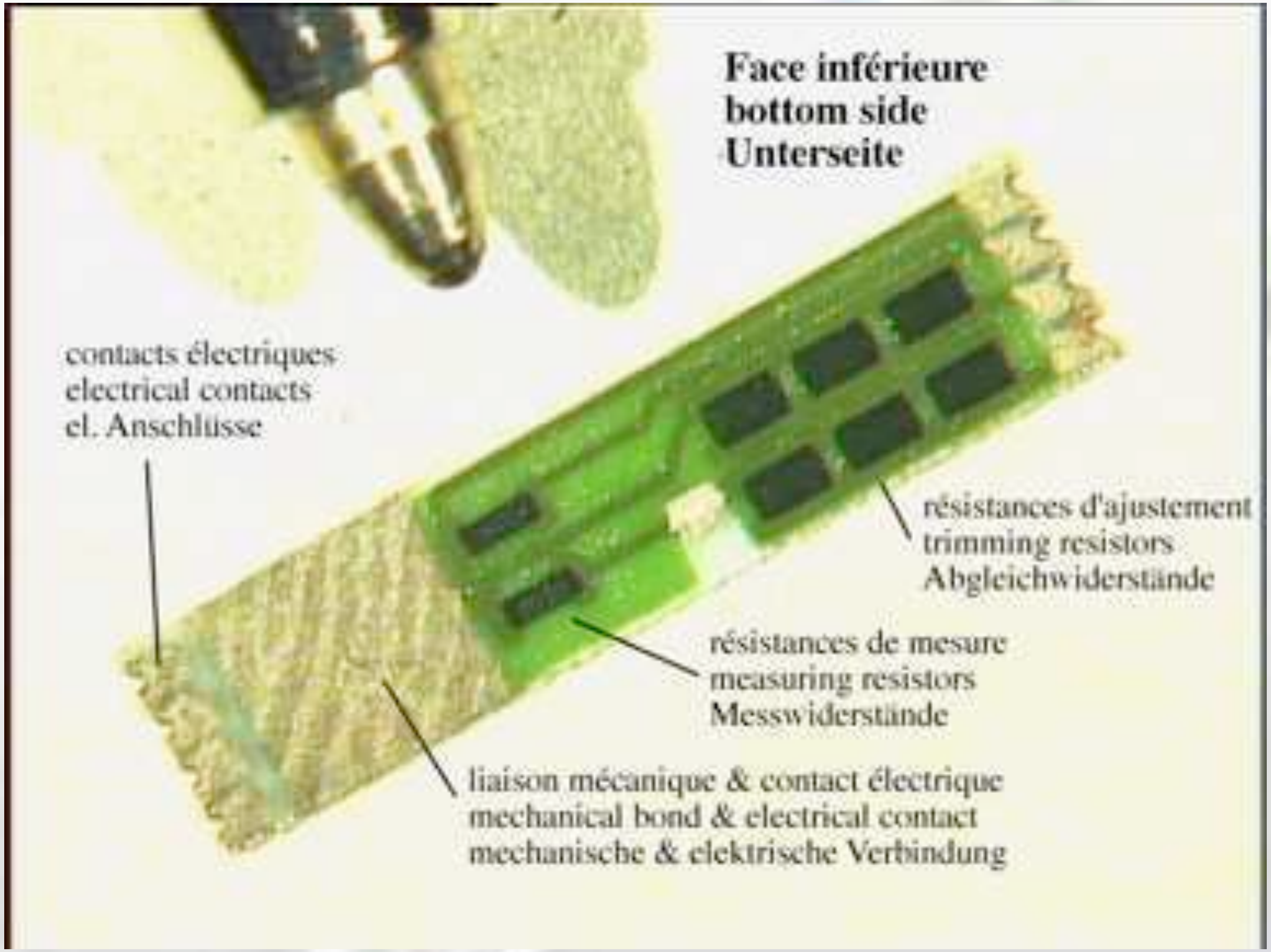
Alumina cantilever



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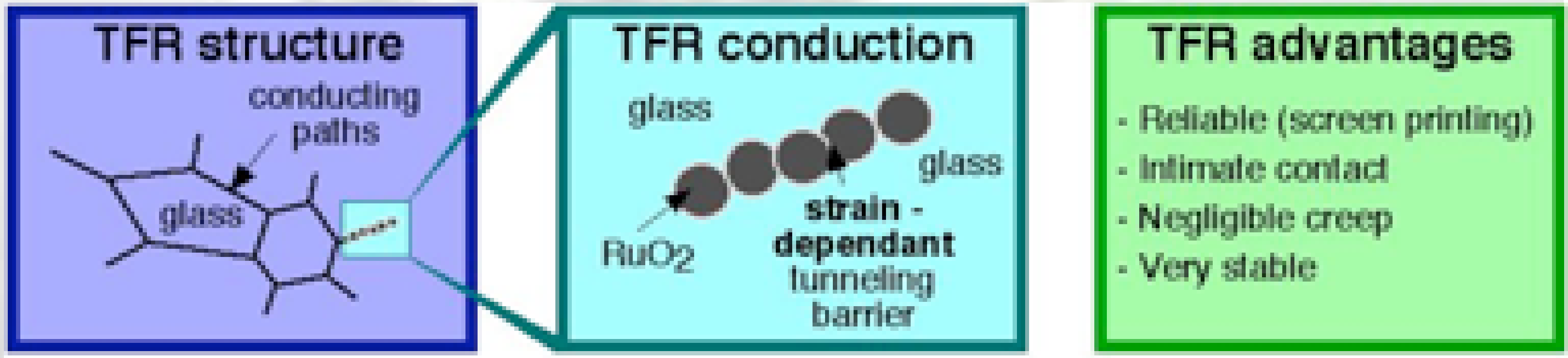
Piezoresistive thick-film sensors

Thick-film resistors posess a **piezoresistive effect**.

Gauge factor = rel. variation / strain = $(\Delta R/R) / \varepsilon$

The **gauge factor** is typ. 12.
(Si : 50)
(metal *DMS - Dehnmessstreifen* : 2)



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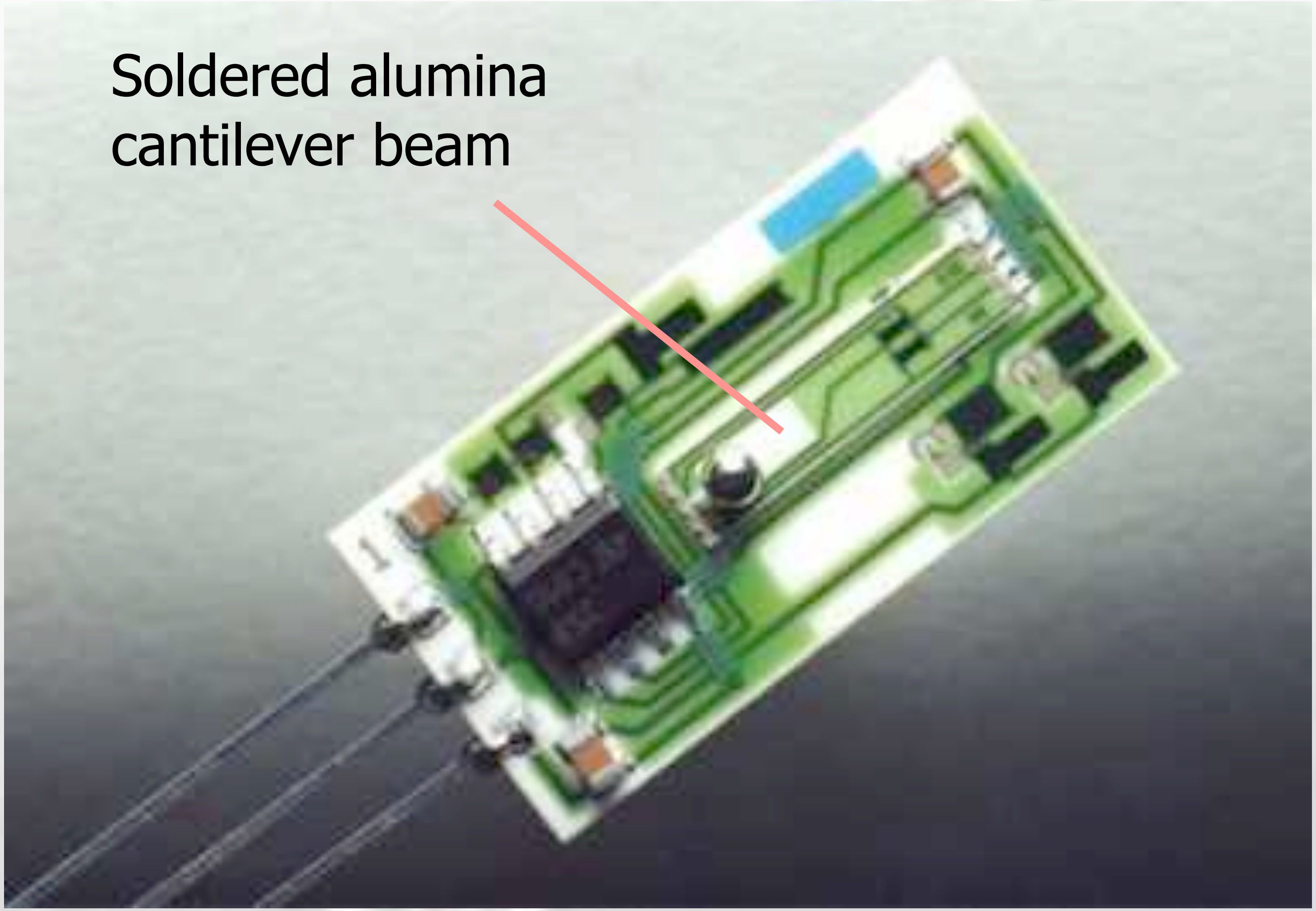
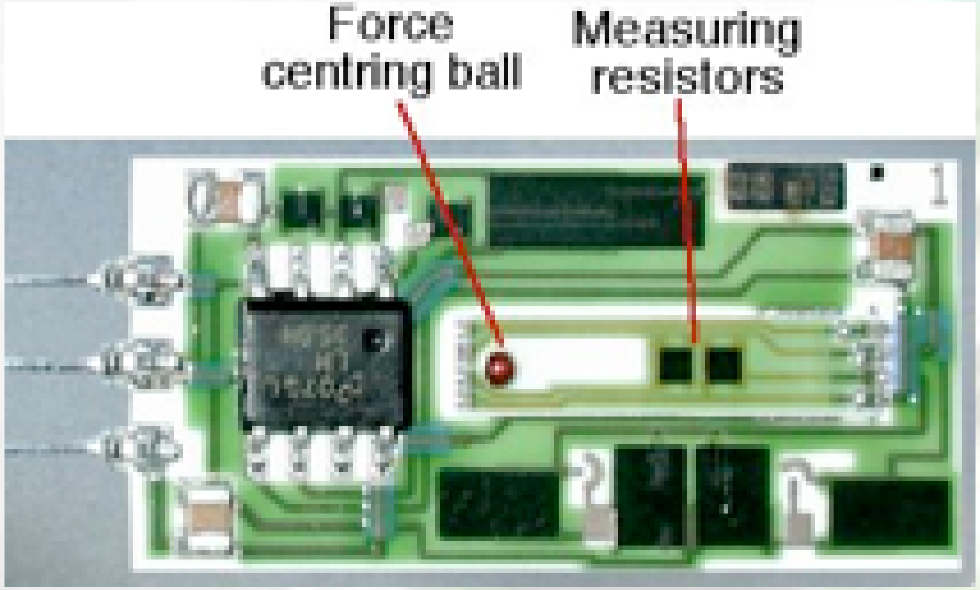
Product: force sensor



Product: force sensor



Stressed films

1. Terminations / conductor lines.
2. Measuring resistors.
3. Protective glass.

Improving sensor response?

1. **Resistive composition**. High gauge factor compositions have problems…
2. **Strain (substrate)**. Needs better material than alumina!
3. **Strain (films)**. May also need better materials!

Candidate ceramic materials

1. **High-purity alumina**: slight improvement.
2. **Zirconia**: potentially the best.
3. **ZTA**: $Al_2O_3 + ZrO_2$: strong & close to alumina.
4. **LTCC**? Not high strength, but other advantages (integration & shape).

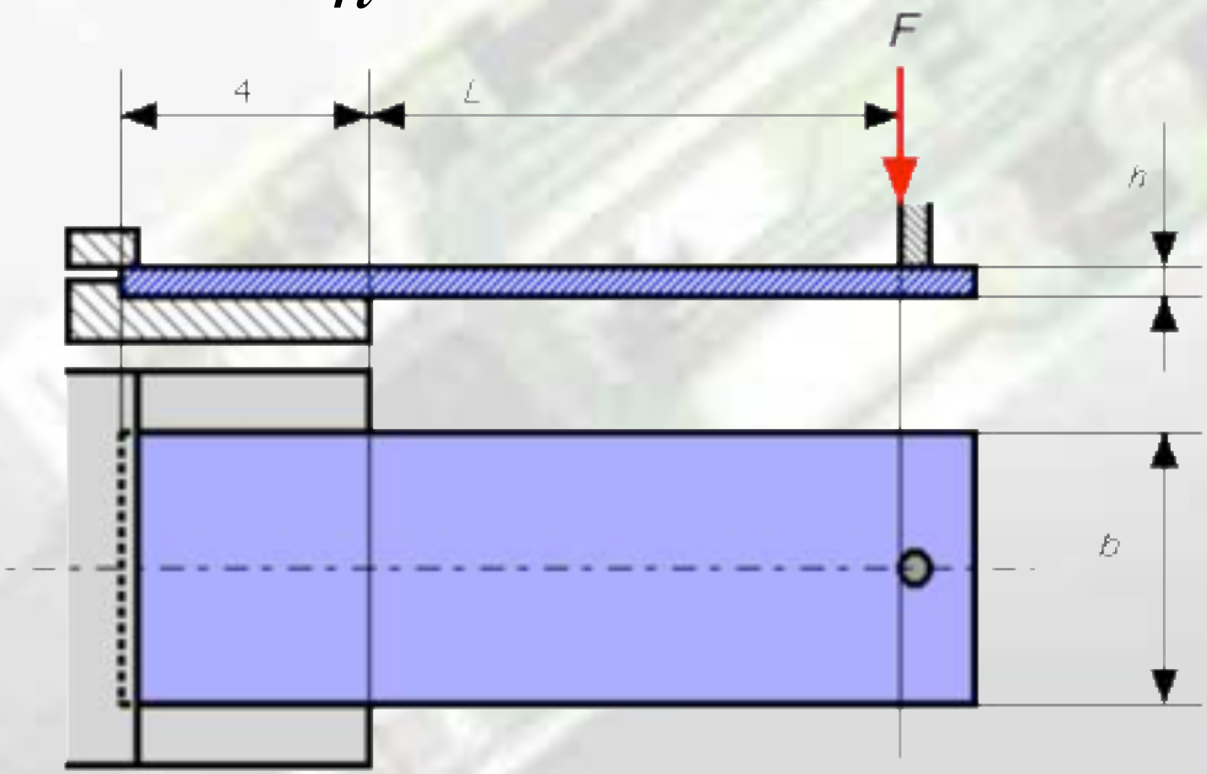
Issues with ceramics

- Chemical reactions with thick-film pastes?
- Strain limited by paste failure?
- Thermal expansion - stress and TCR.
- **Weakening of substrate by thick-films**: only tensile stresses really count…
- Weakening by firing schedule: metals, ZrO_2?

Test setup: long & short-term

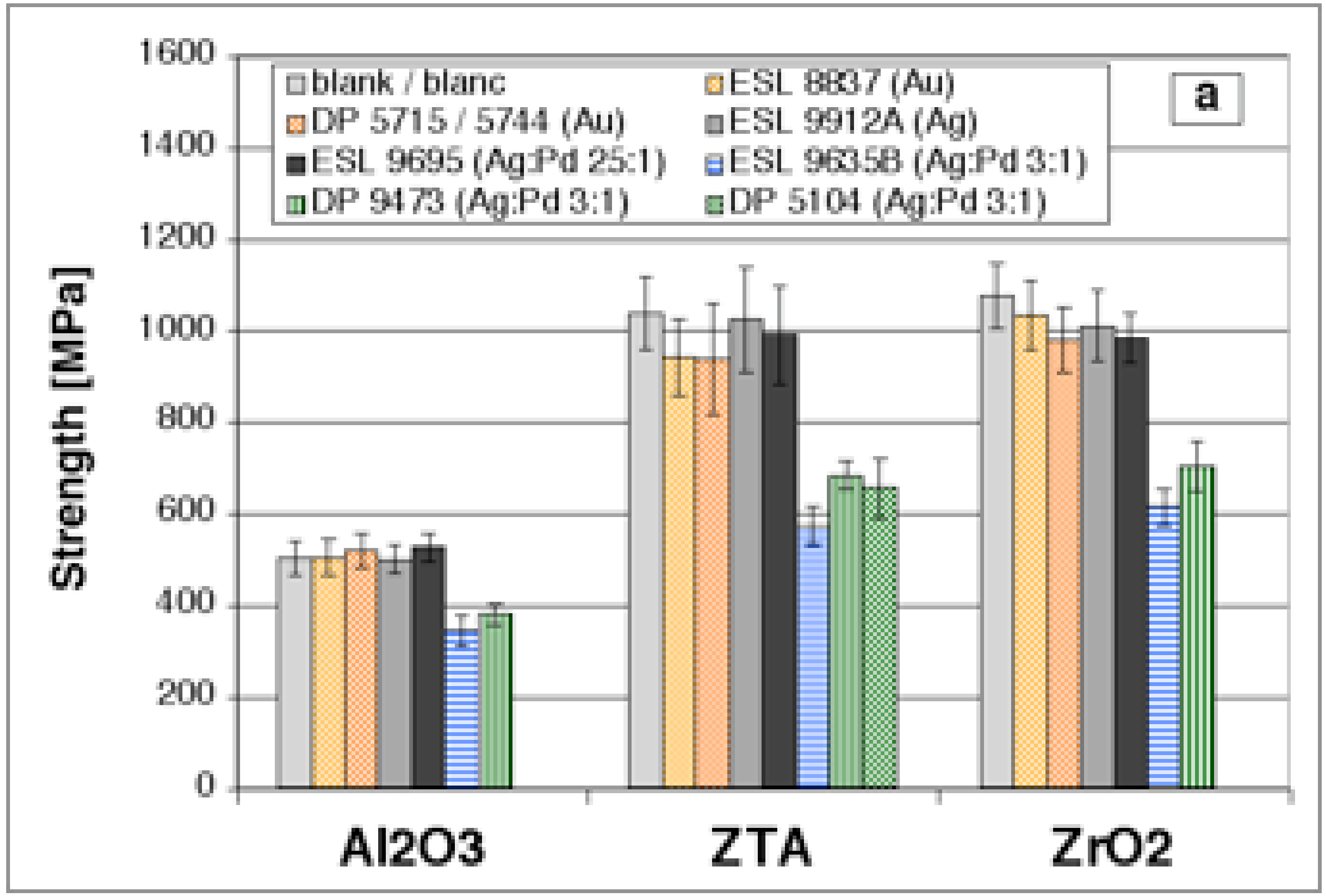
$$\sigma_{nominal} = \frac{6F \cdot L}{h^2}$$

$L \cong 8$; $b \cong 3$; $h \cong 0.25$ mm



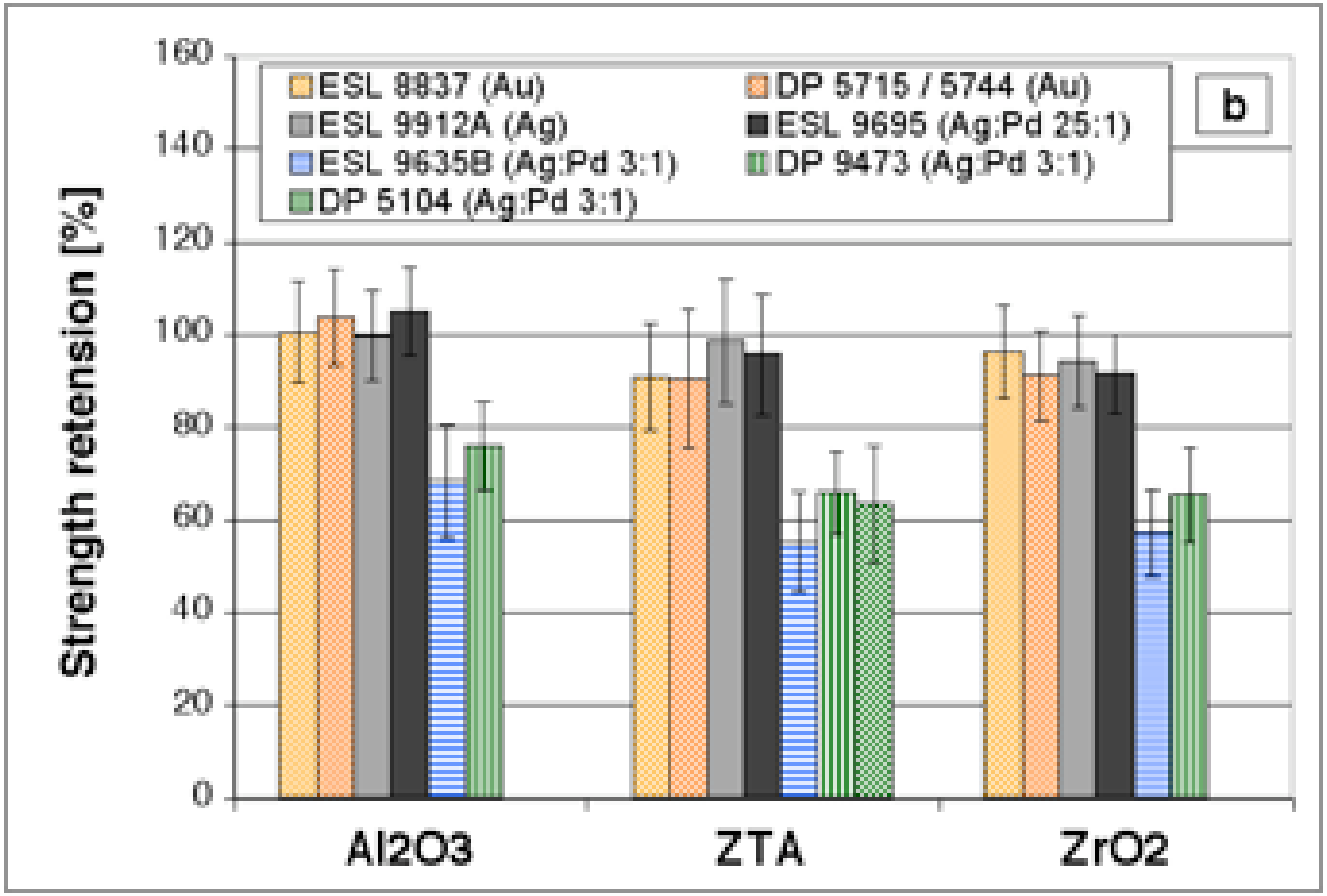
Effect of metals on strength

(Short-term, absolute)



Effect of metals on strength

(Short-term, relative)



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Effect of conductors

- Conductors with little or no glass frit: retention of original strength

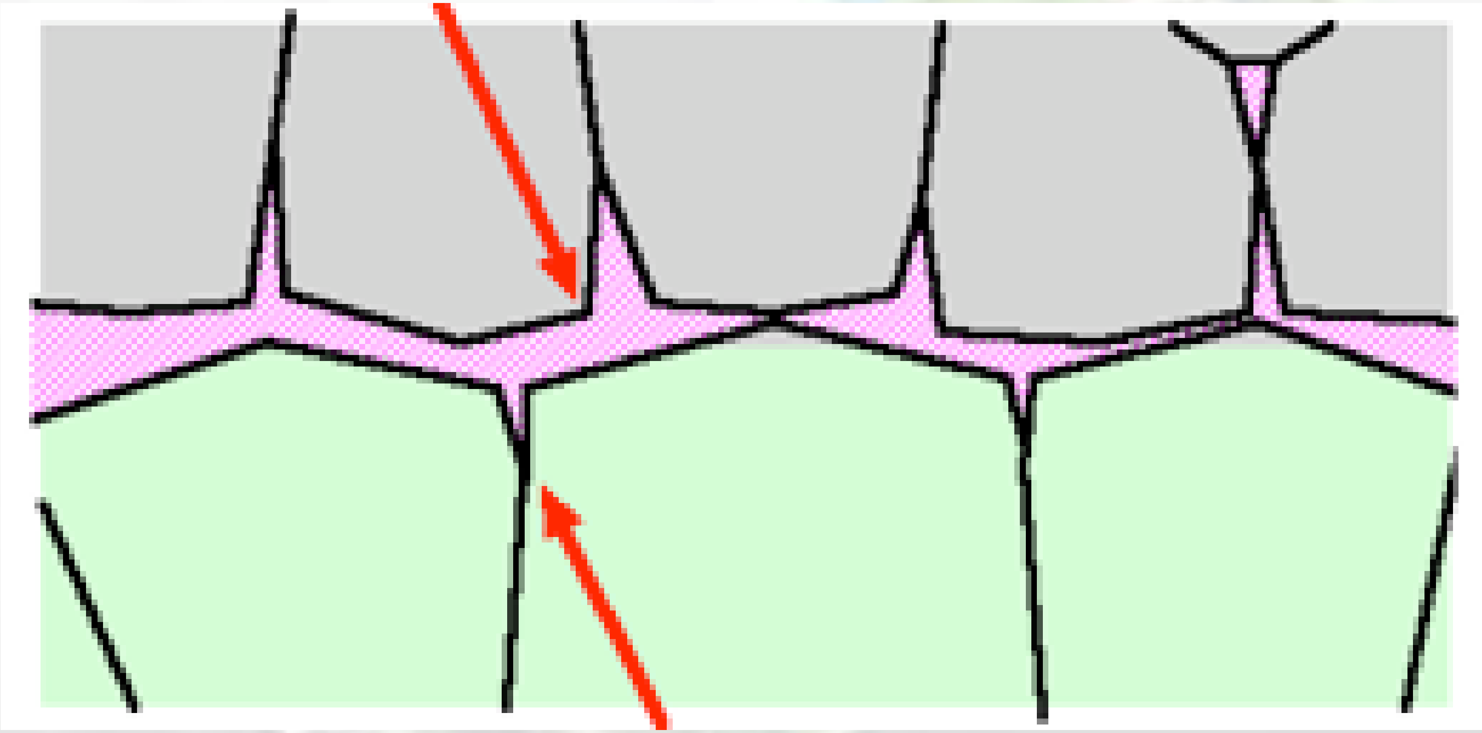
  Ag, Ag:(Pd+Pt) 25:1, Au, thin Au

- Conductors with high glass frit: significant loss in strength (25…45%)

  Ag:Pd 2:1…4:1

Effect of conductors: glass frit

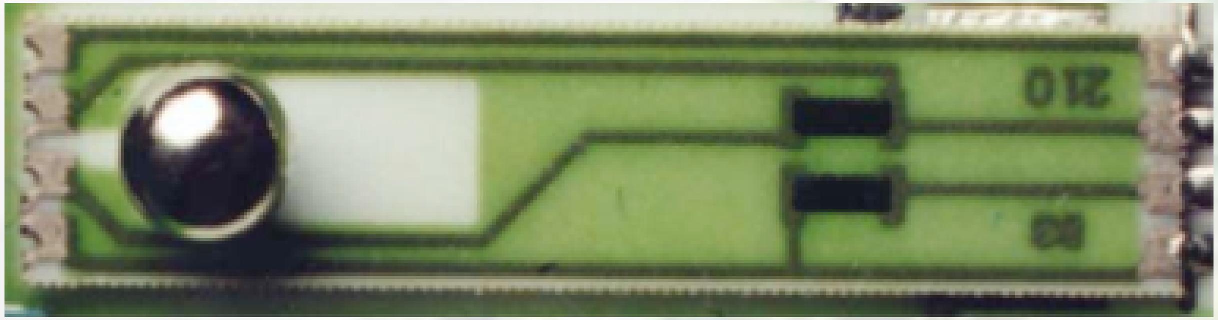
Local tensile stresses



Substrate grain boundaries

Design of load cell

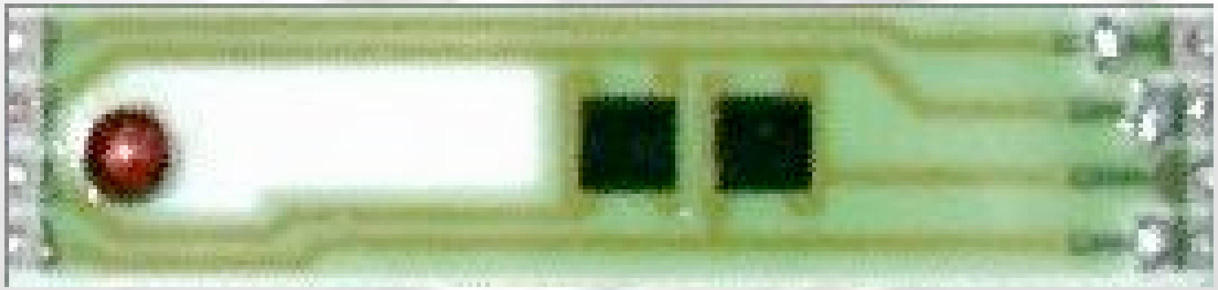
⇒ Replacement of Ag:Pd 3:1 by thin Au



Version 1

Ag:Pd 3:1

(& glass)



Version 2

Thin Au

(little glass)

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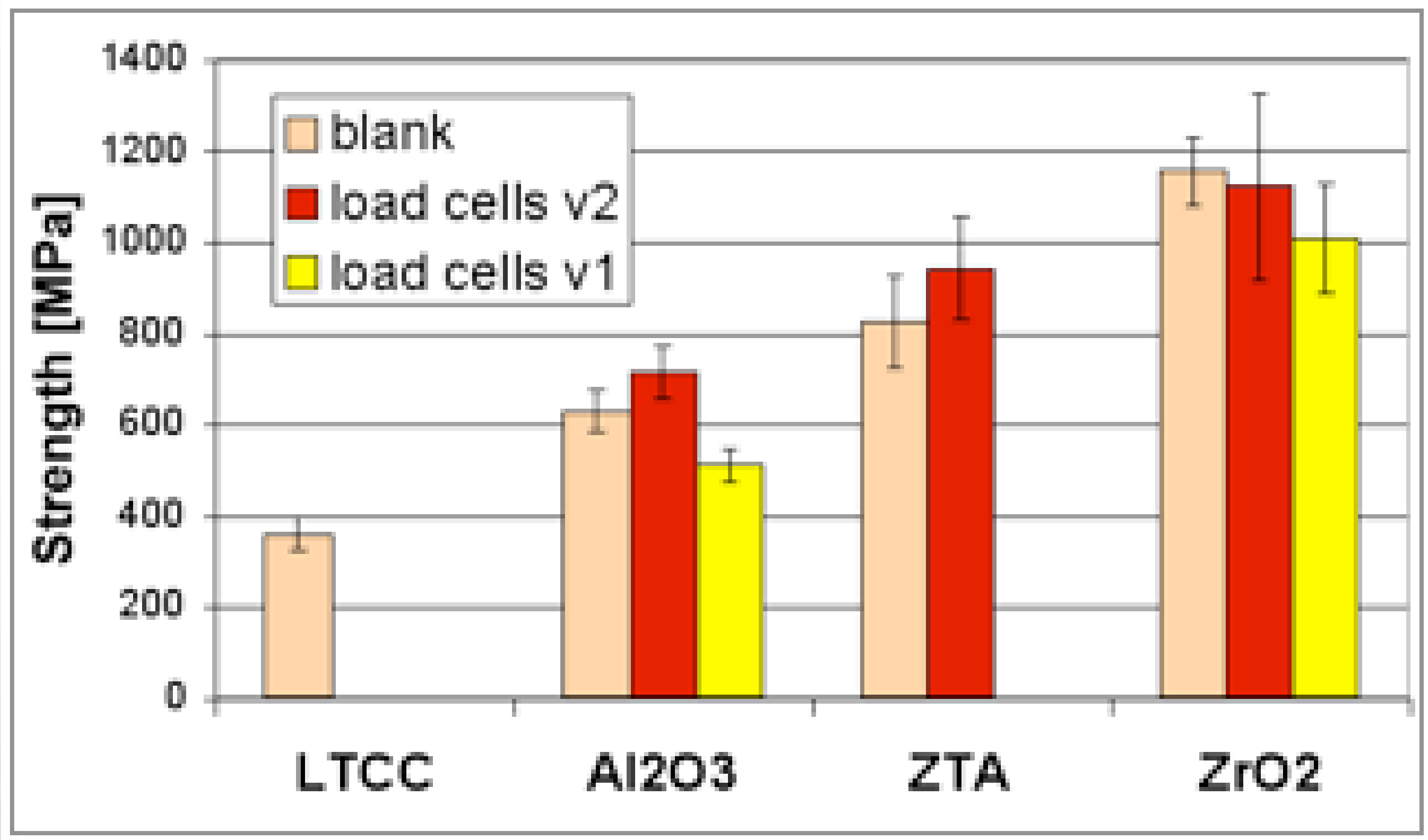
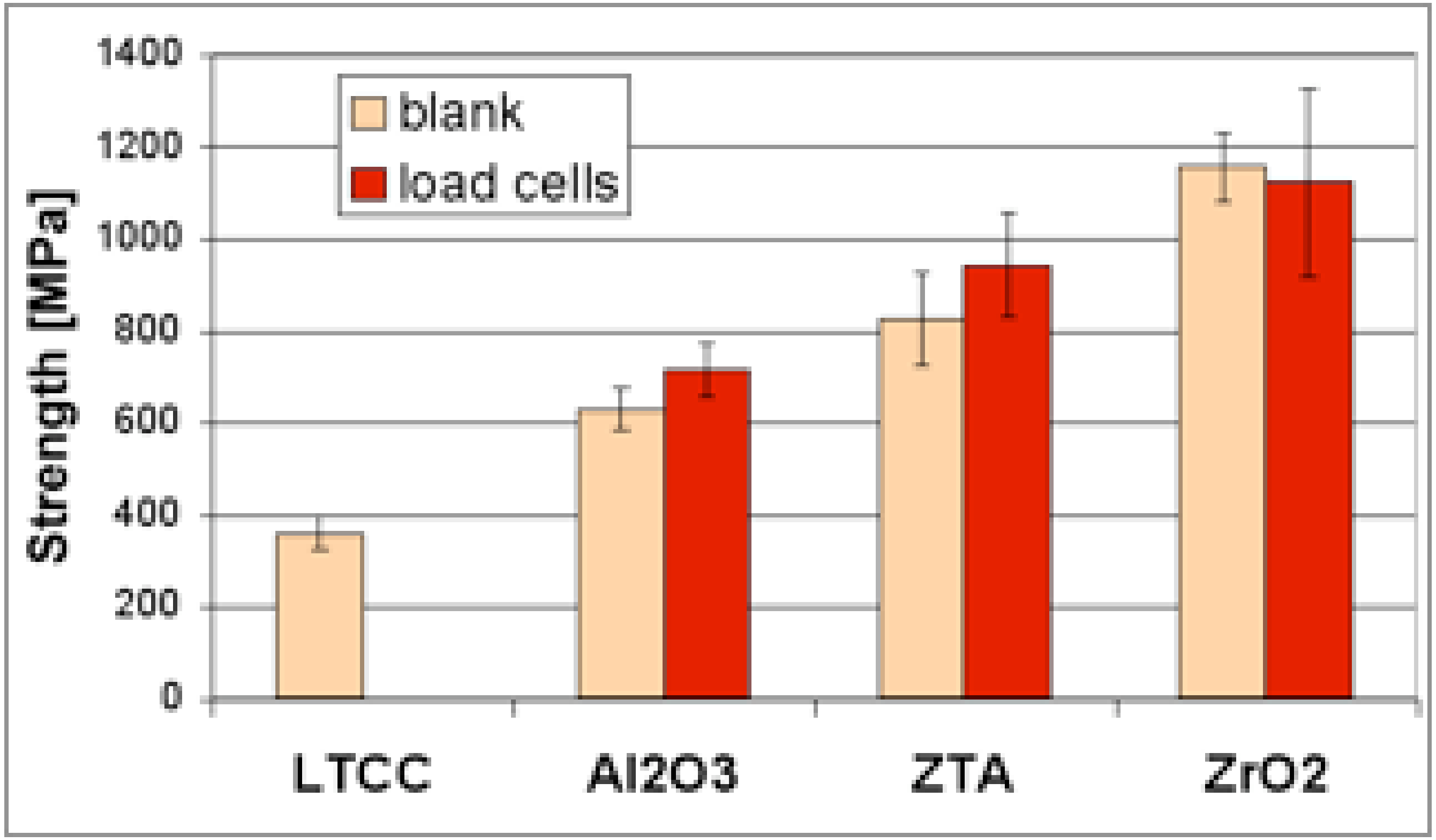
Blank and screen-printed

(Short-term, stress)



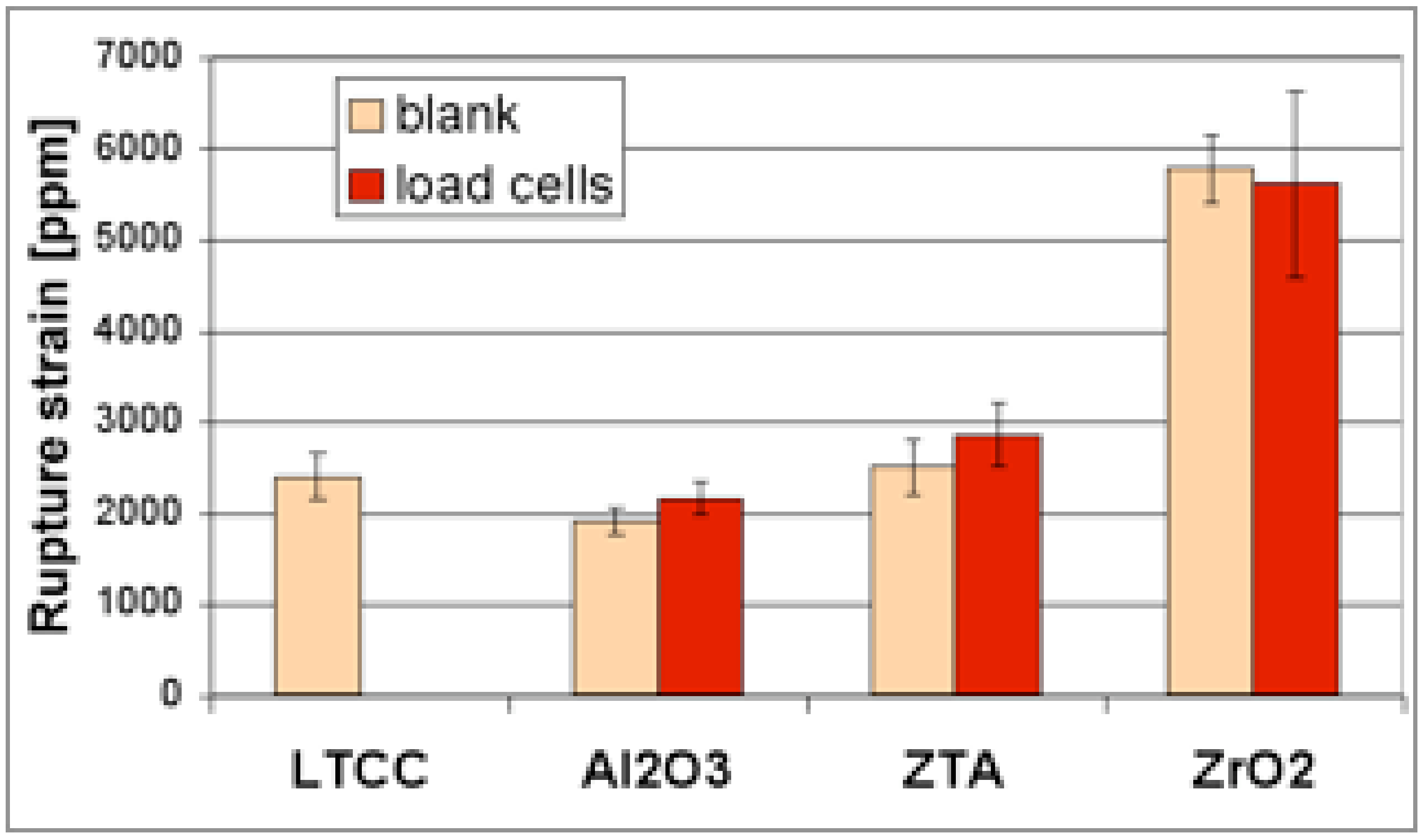
Blank and screen-printed

(Short-term, stress)



Blank and screen-printed

(Short-term, strain)



Summary: short-term results

- ZrO_2 gives potentially the highest signal, but also some problems: TCR shift, low thermal conductivity, and cost.
- ZTA is a « drop-in » improvement over Al_2O_3.
- LTCC (Du Pont 951) compares favourably with Al_2O_3.

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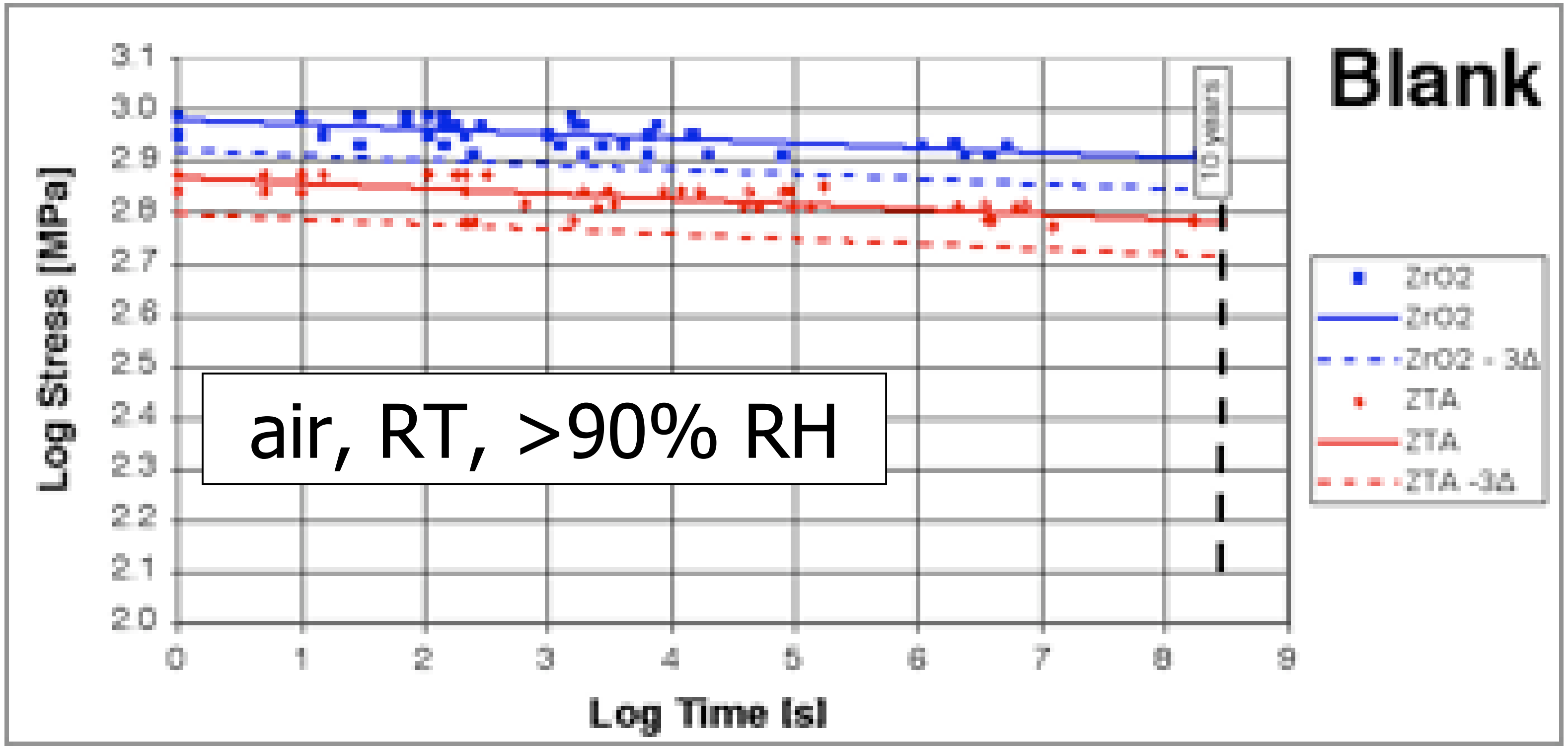
Long-term strength

- Subcritical crack growth occurs until rupture (static fatigue).
- Stress - time to rupture : Paris' law.

$$\sigma = \sigma_0 \cdot \left(\frac{t}{t_0} \right)^{-1/n} \qquad \log \sigma = \log \sigma_0 - \frac{1}{n} \log \left(\frac{t}{t_0} \right)$$

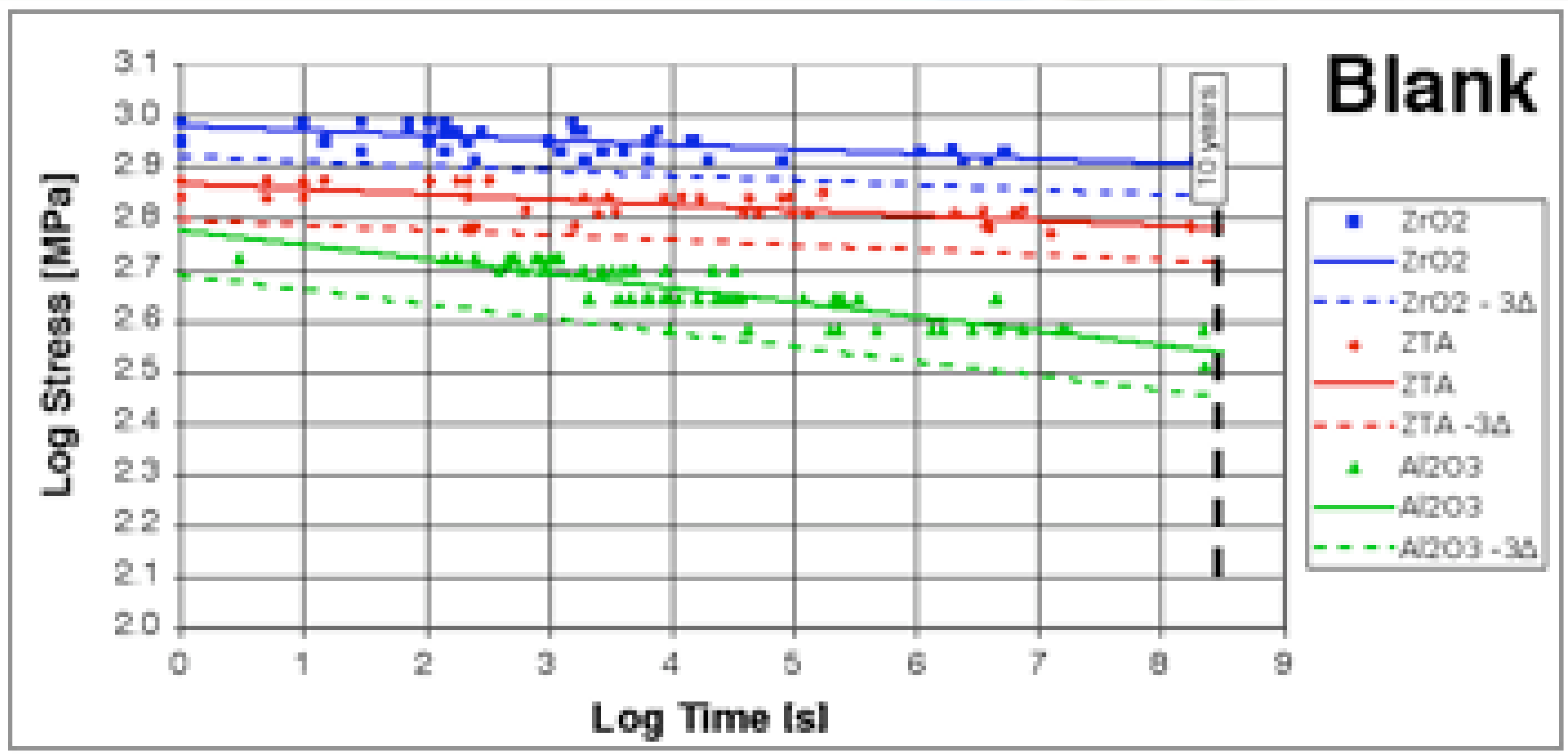
- The value of *n* is a quality indicator.

Long-term strength - blank



⇒ ZrO_2 & ZTA exhibit very small static fatigue

Long-term strength - blank



⇒ 96% Al_2O_3 : glassy grain boundary phase

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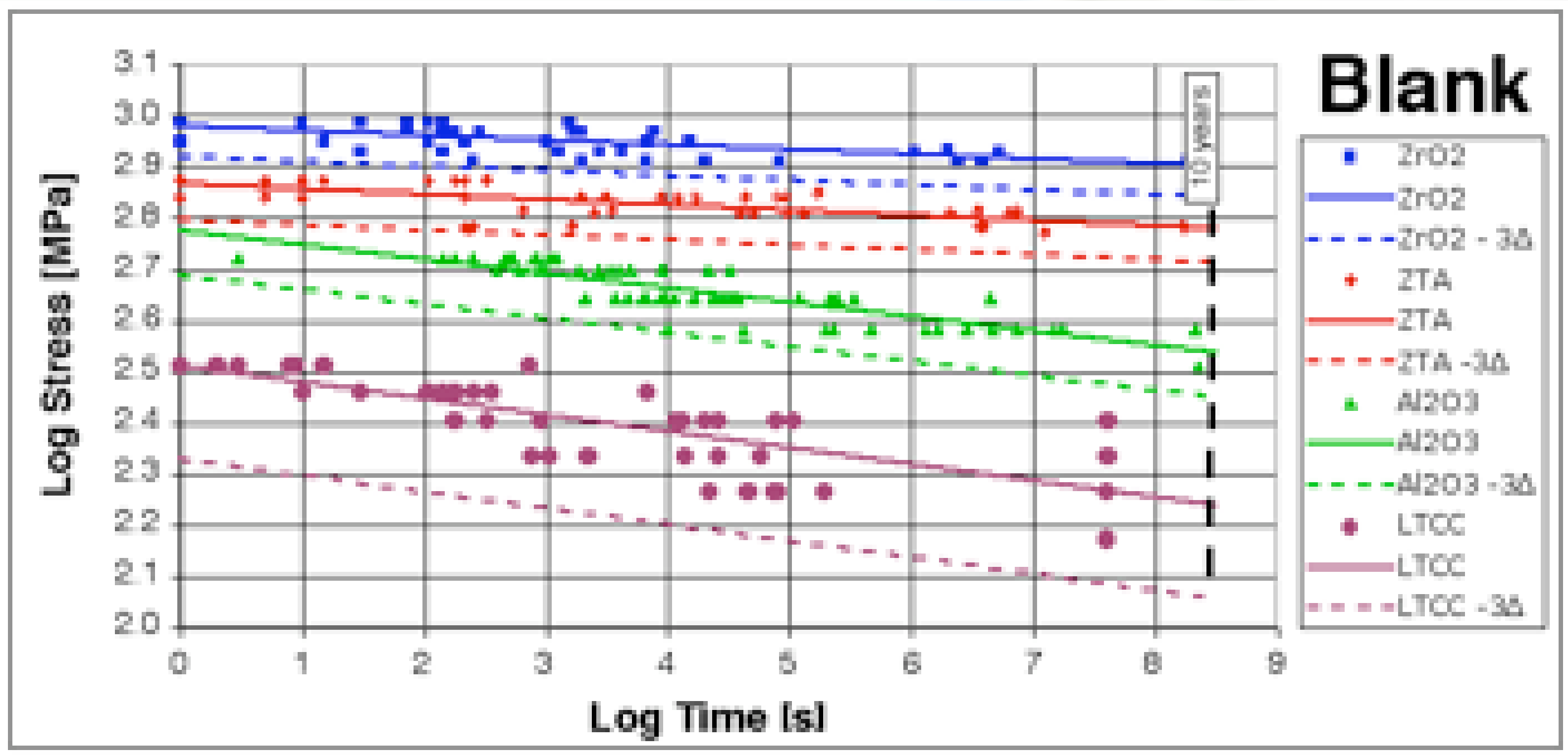
Long-term strength - blank



⇒ LTCC behaviour similar to Al_2O_3 : glassy

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Long-term : *n* values - blank

LTCC & 96% Al_2O_3 vs. ZrO_2 & ZTA

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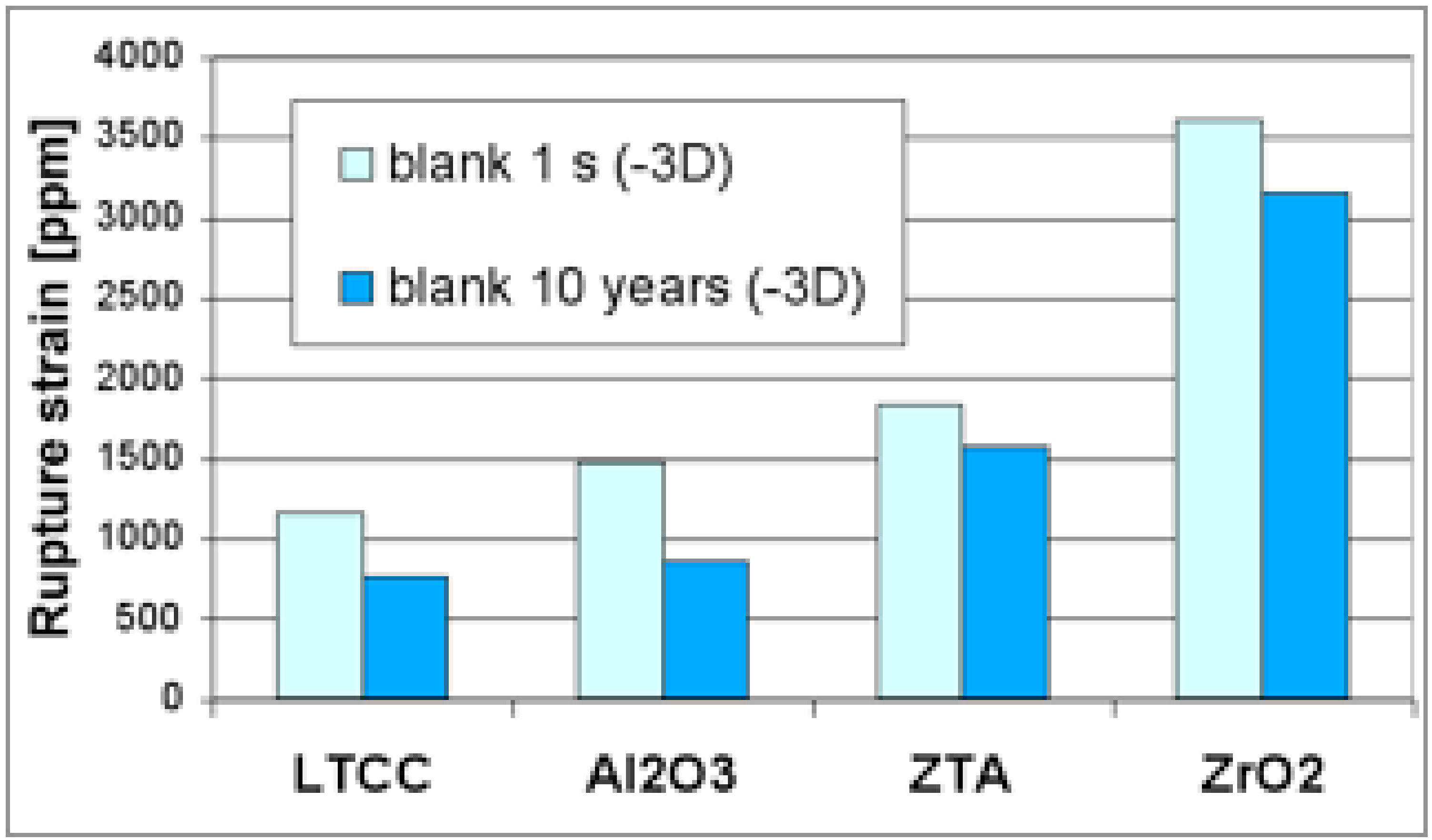
Long-term strain (blank, -3D)



LTCC & 96% Al_2O_3 vs. ZrO_2 & ZTA

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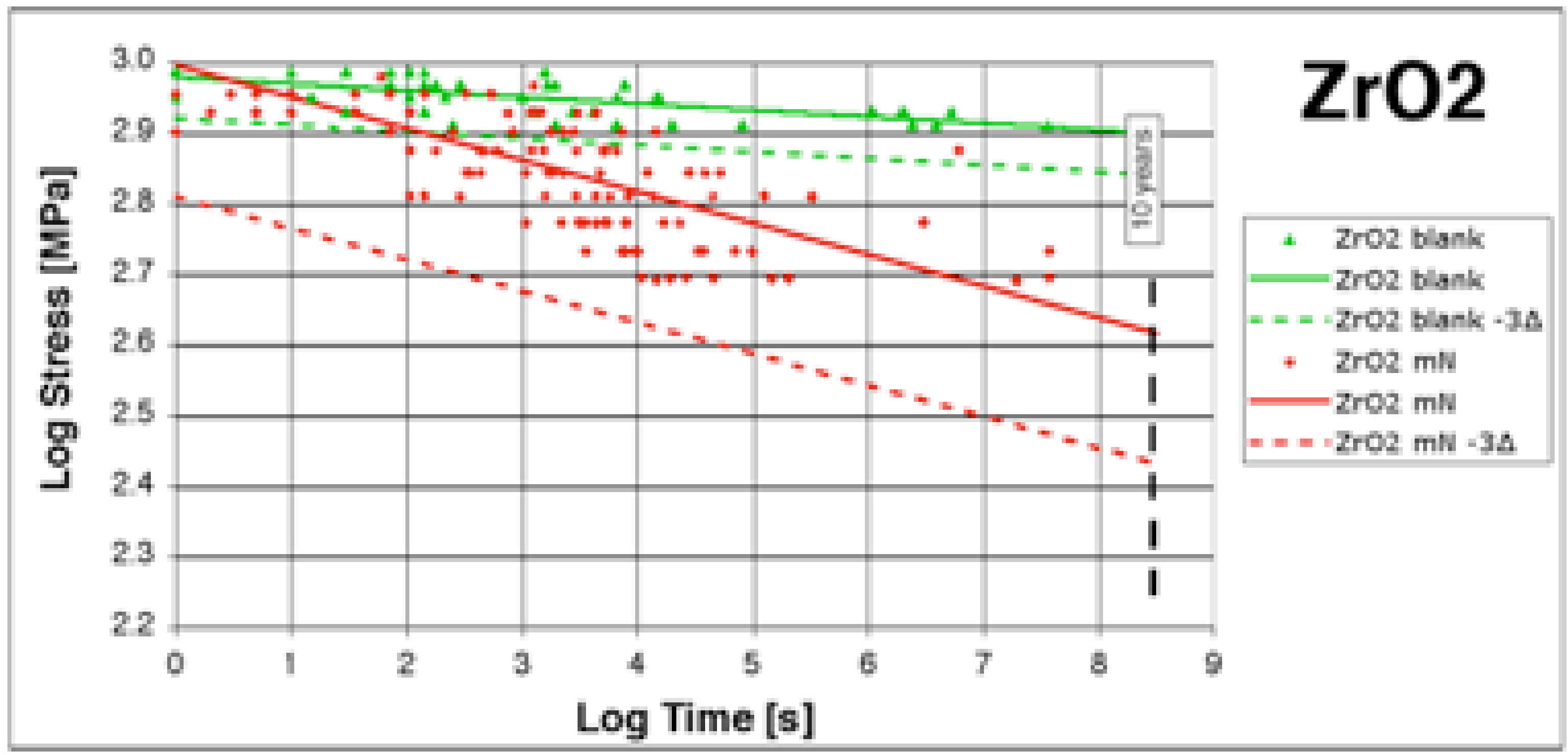
Long-term strength : load cells



⇒ **Strong** degradation by thick films

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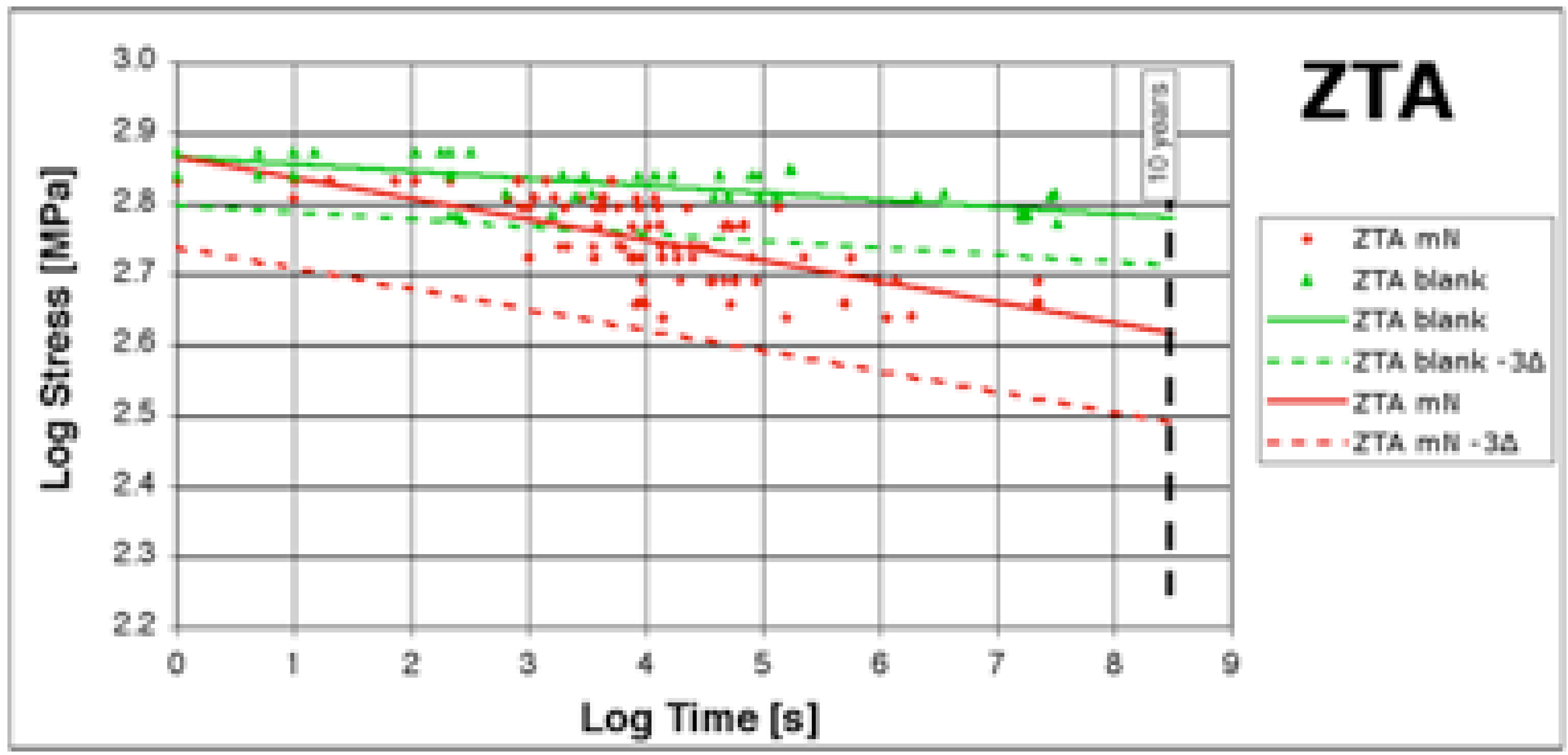
Long-term strength : load cells



⇒ **Strong** degradation by thick films

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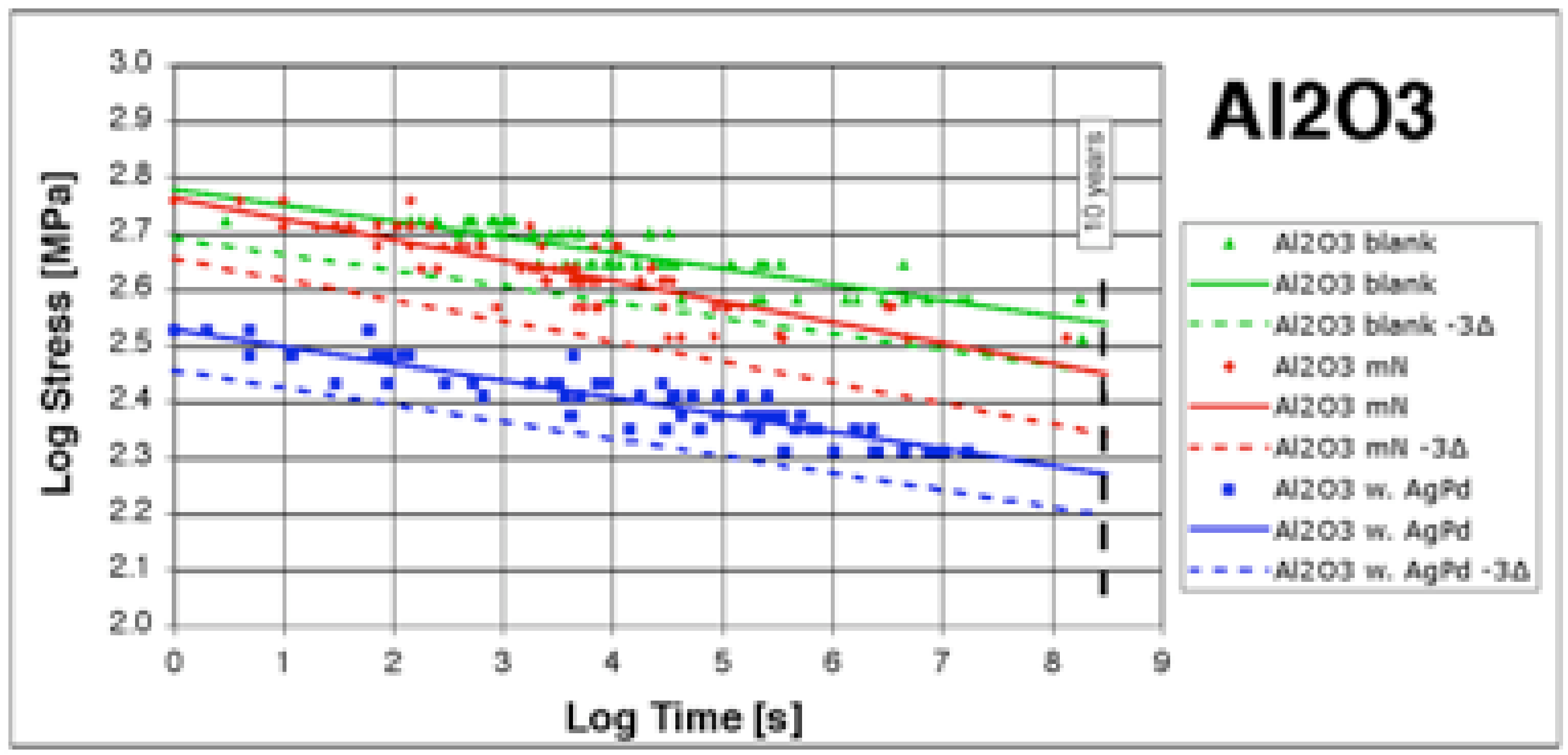
Long-term strength : load cells



⇒ **Little** degradation by « good » thick films

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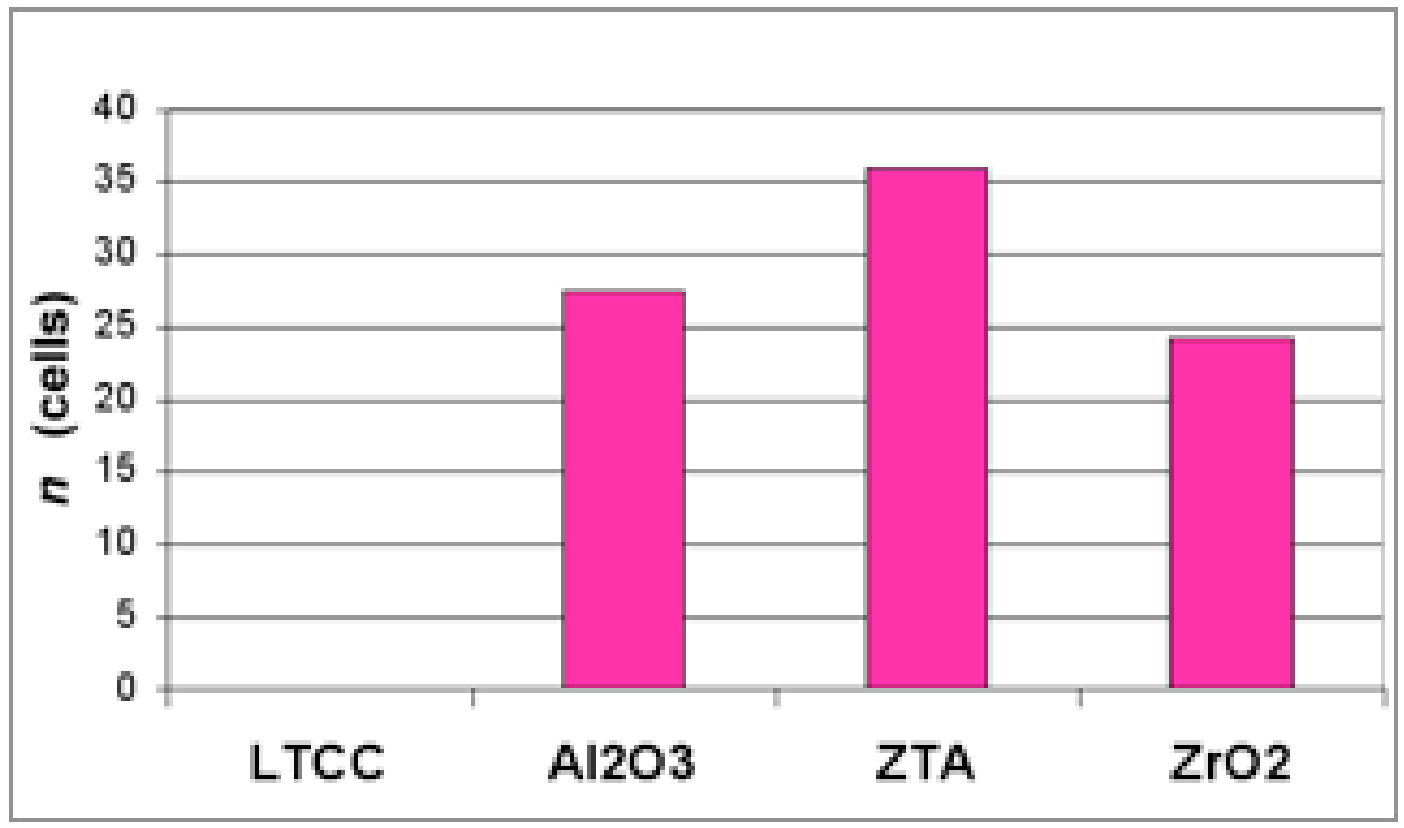
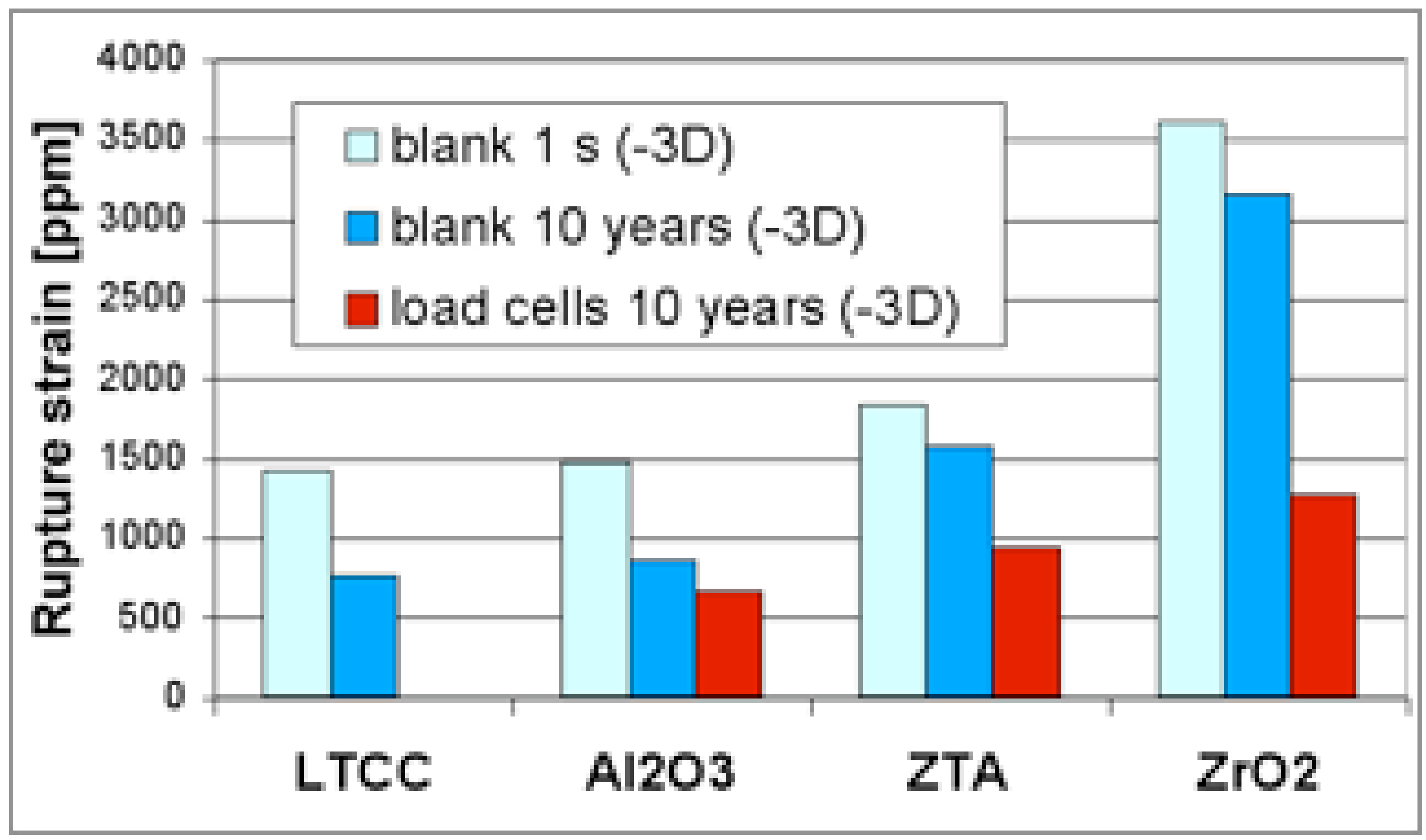
Long-term : *n* values - load cells



Values of *n* no longer very different!

Long-term strain (load cells, -3D)



High strength substrates degraded…

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Conclusions

- LTCC promising, ≈ Al_2O_3 96%
- No degradation of short-term strength with « good » thick-film system
- Long-term severely degraded on high-strength substrates
- Suitable thick film systems must be introduced!

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THANK YOU !

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