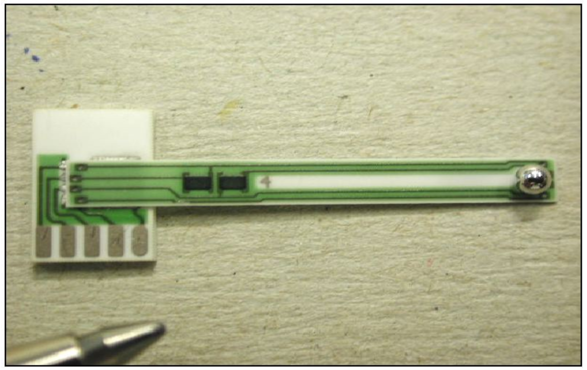
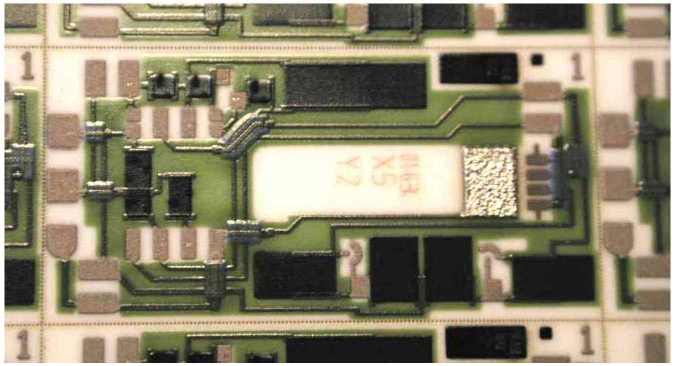
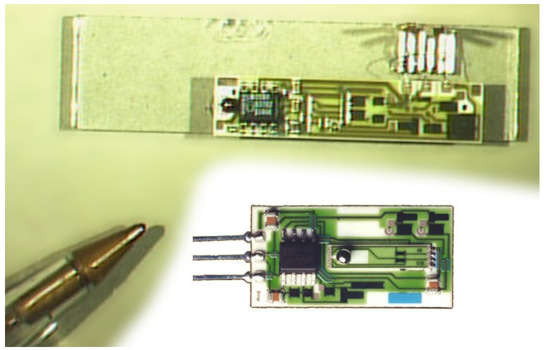
Assessment of thick-film resistors for manufacturing piezoresistive sensors

Thomas Maeder, Caroline Jacq and Peter Ryser

École Polytechnique Fédérale de Lausanne (EPFL), Switzerland







Outline

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1. Introduction – manufacturing & trimming issues
2. Resistor study
3. Overglazing, trimming, etc.
4. Conclusions & outlook

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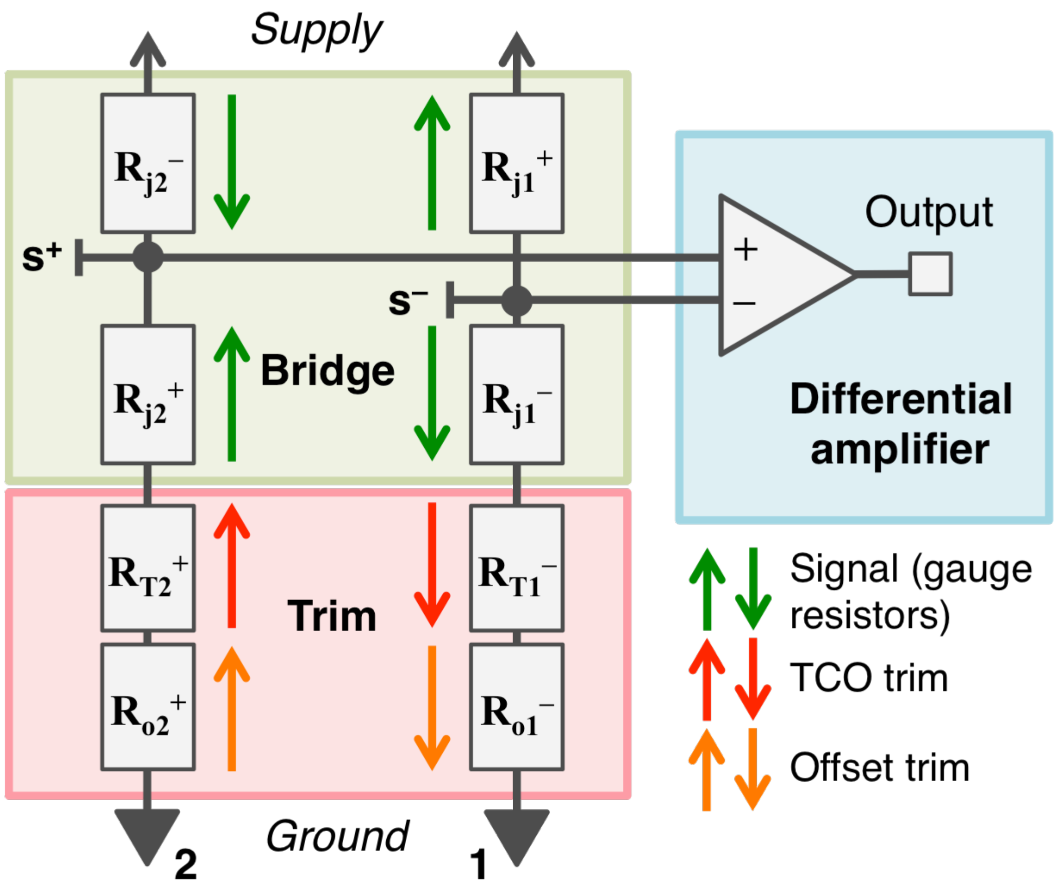
Typical thick-film piezoresistive sensor

- **Typical elements**
  - Sensing bridge
  - Offset trim
  - TCO trim
  - Differential amplifier
- **Typical values (±)**
  - **Offset ~30 mV/V**
  - **Response ~3 mV/V**
  - TCO ~1 μV/V/K
    (50 K : ~0.05 mV/V)
- **For 0.1% F.S.:**
  - Offset reduction ~10'000×
  - Stability (bridge) ~10 ppm



Why trim?

- **Modern digital chips**
  - Input stage usually PGA (programmable-gain amplifier)
  - Gain limited by signal
  - In raw state, offset dominates signal, >> response

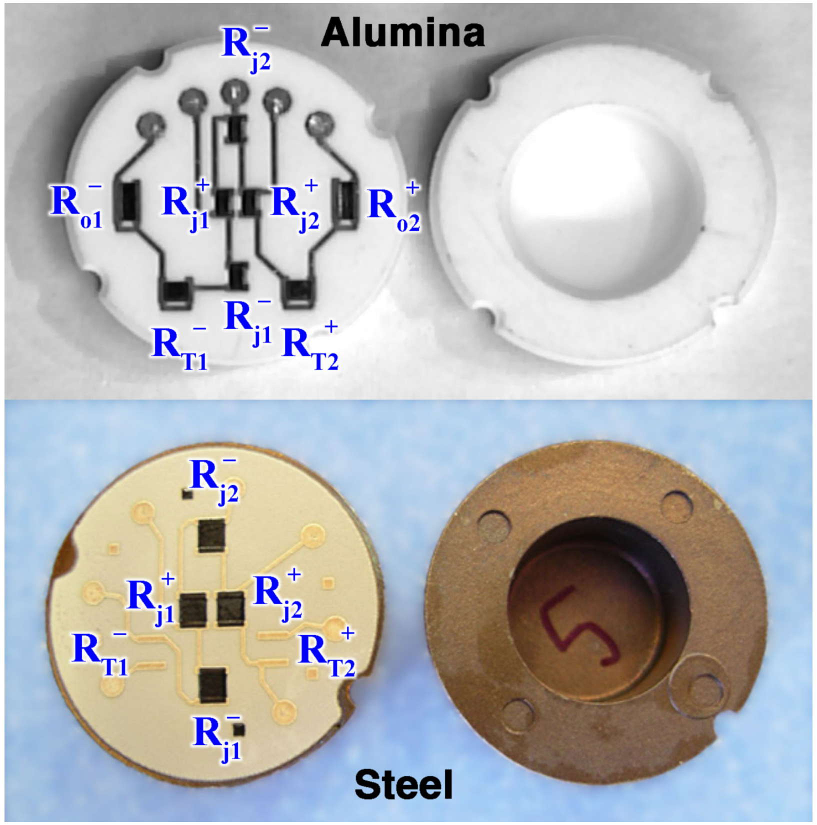
- **For optimal use, reduce offset to < response**
  - With typical raw offset ~30 mV/V, max. gain ~30×
  - With typical response ~3 mV/V, typ. gain required ~200×
  - **Reduce offset typically by ~10…30×**

- **Trimming of TCO usually not necessary with chips**
  - Typically, temperature error <10% of piezoresistive response
  - Can be done digitally
  - Laser trim: large-scale production; better temperature sensing

Examples – pressure cell

Ceramic: classical layout

- All-active bridge
- Coarse offset trim on cell
- Direct TCO trim
  - Need good amplifier – usually not accessible after mounting of electronics

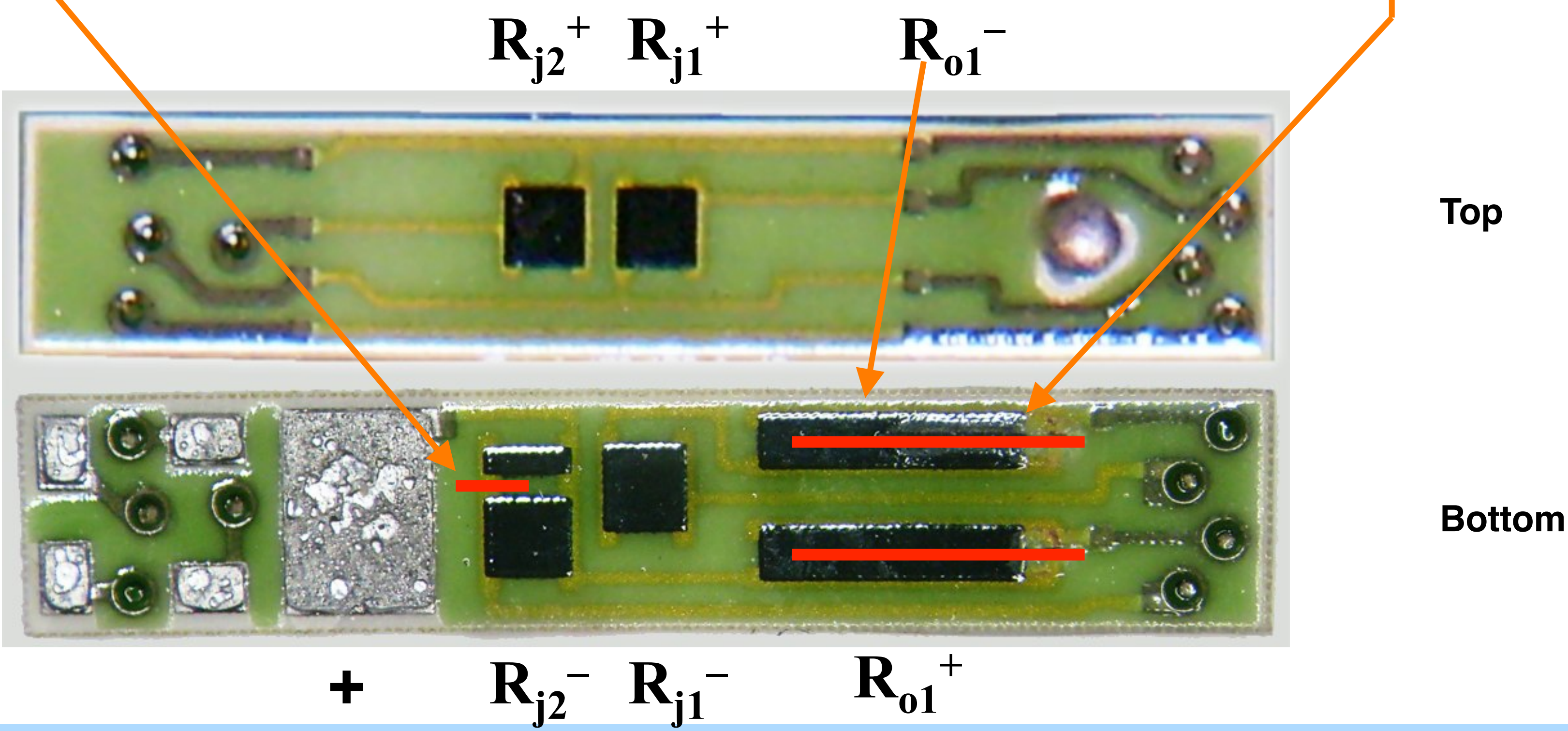


Steel: changes

- *Issue: trim on* dielectric
- Coarse offset trim off-cell
- Indirect TCO trim
  - PTC resistor on cell
  - Normal resistor in parallel

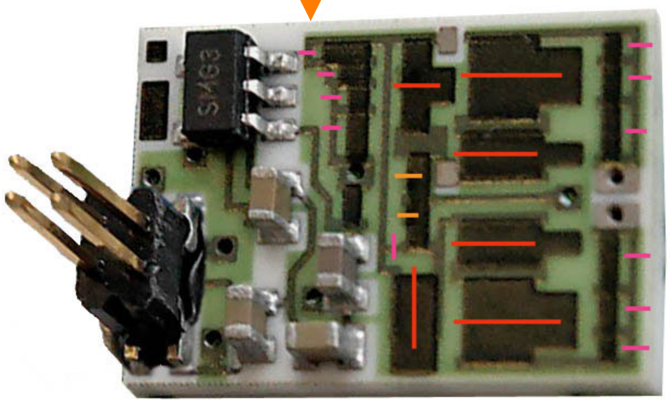
Examples – cantilever force cell

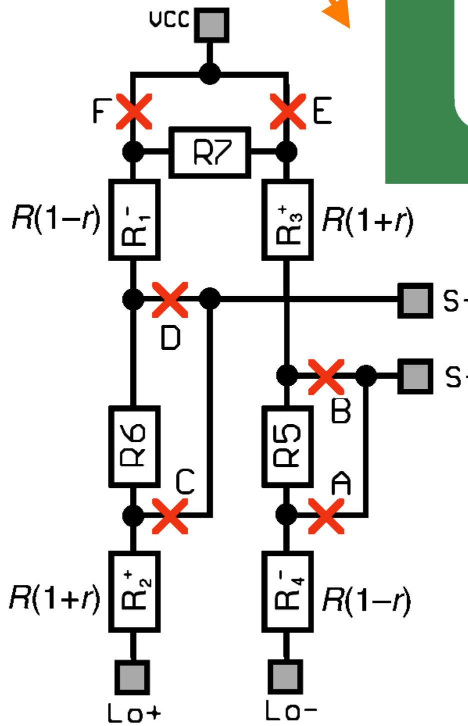
- All-active bridge
- Discrete offset trim (stable, active, ~no TCO change)
- Coarse classical trim (more precise)
- No TCO trim (on base, with fine trim)

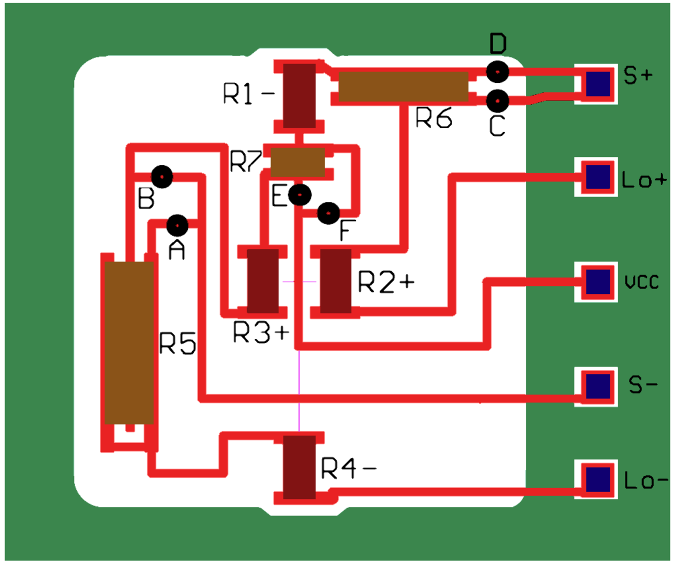


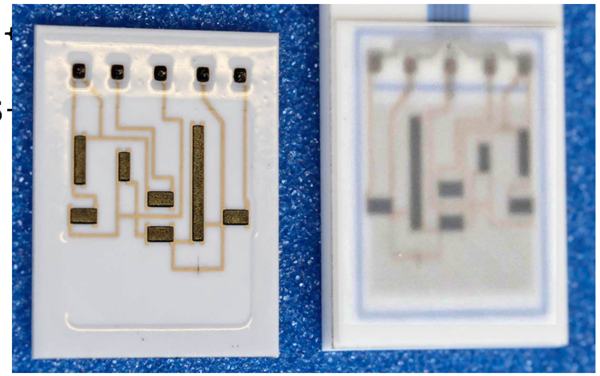
Examples – glass-sealed pressure cell

- All-active bridge
- Discrete offset trim cuts only on cell
- All other trims on separate module



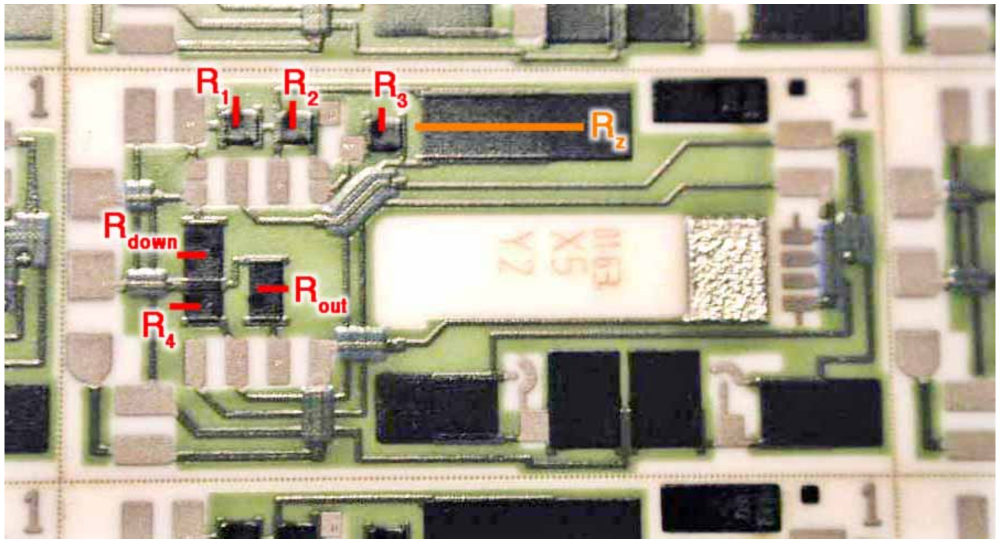


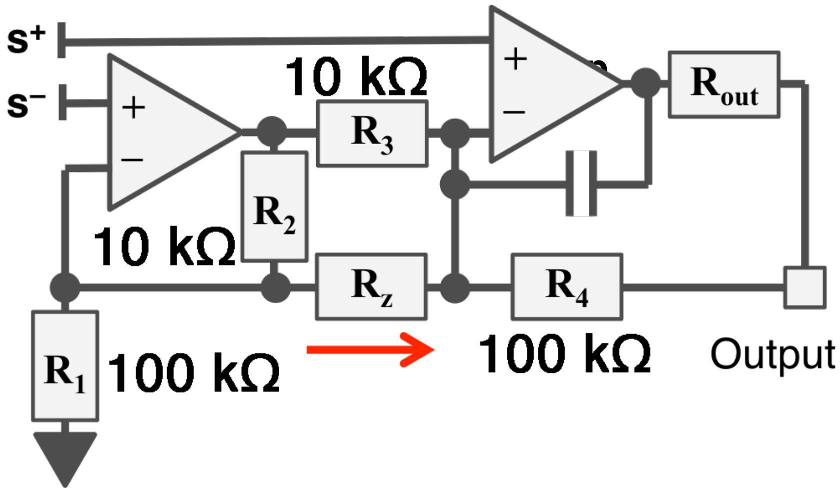




Trimming of sensor electronics

- Normally passive & active part
- High resistor values often problematic
- Harsh post-processing (breaking, soldering, ultrasound, …)





Factors for offset, TCO & stability

- **Resistor interactions**
  - Substrate (Al_2O_3, dielectric, LTCC…)
  - Terminations
  - Overglaze
  - ***TCO ≠ TCR; TCO determined by TCR tracking***

- **Trimming**
  - Discrete (stable) or classical (precise)
  - Trimming resistor used (coarse: use same as bridge)
  - Terminations (material near terminations ≠ away)
  - Parameters & resistor material

- **Post-processing**

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Resistor study

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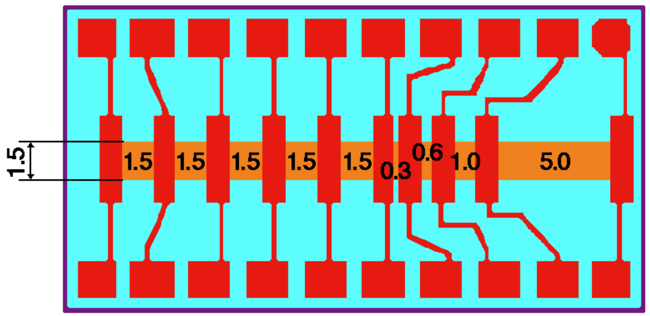
No	Film (Sheet res.) Screen[§]	Composition
1	**Conductor** 325 / 40	A) ESL 9635G[†] B) ESL 9635B[†] (Pb) C) DP 5104[†] (Pb) D) ESL 8837[*] (Pb, Cd) E) ESL 9695[#] (Pb) F) ESL 9562G[#] G) ESL 9912K[##]
2	**Resistor** (100 Ω PTC) 325 / 40	K) ESL 2612I (Pb)
	Resistor (100 Ω) 325 / 40	M) DP 2021 (Pb) N) ESL R312P (Pb) O) ESL 3912 (Pb, Cd)
	Resistor (10 kΩ) 325 / 40	Q) DP 2041 (Pb) S) ESL R314P (Pb) T) ESL 3984 (Pb, Cd) U) ESL 3914 (Pb, Cd)
3	**Overglaze** 325 / 20	V) ESL G-485-1[a] W) ESL G-481[a] (Pb) X) ESL 4771P[b] Z) DP QQ600[a] (Pb)

ESL = Electroscience Laboratories
DP = DuPont

- (Substrate = alumina)
- Termination material
- Resistor material & length
- Overglaze material



iMAPS

Processing parameters

- Resistor under…overfired
  - See whether this changes its interactions with overglaze
- Overglaze under…overfired
  - Extent of effect on resistor

Code	Conductor	Resistor	Overglaze
- -	850°C (n)	825°C (n-25°C)	VWZ : 575°C (n-25°C) X : 525°C (n-25°C)
n -	850°C (n)	850°C (n)	VWZ : 575°C (n-25°C) X : 525°C (n-25°C)
n n	850°C (n)	850°C (n)	VWZ : 600°C (n) X : 550°C (n)
n +	850°C (n)	850°C (n)	VWZ : 625°C (n+25°C) X : 575°C (n+25°C)
+ +	850°C (n)	875°C (n+25°C)	VWZ : 625°C (n+25°C) X : 575°C (n+25°C)

As-fired 10 kΩ – spread of values

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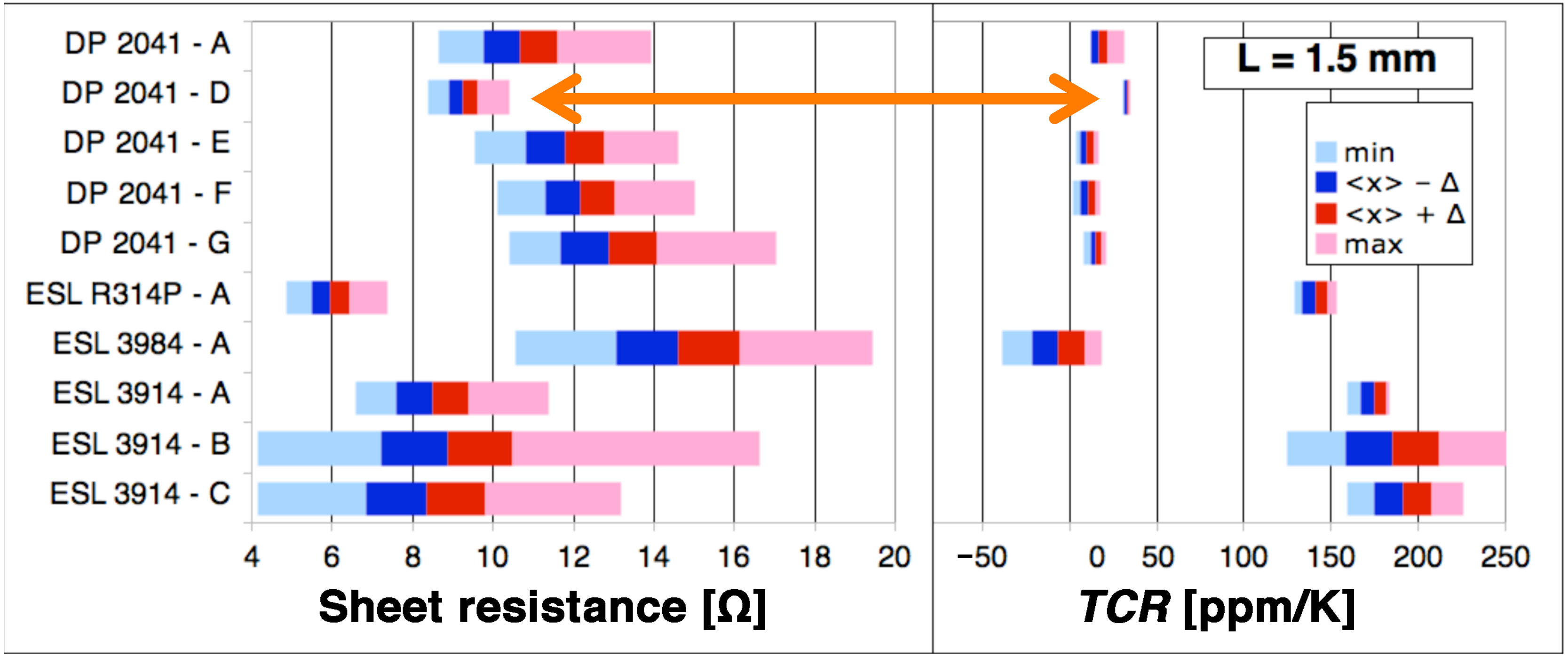
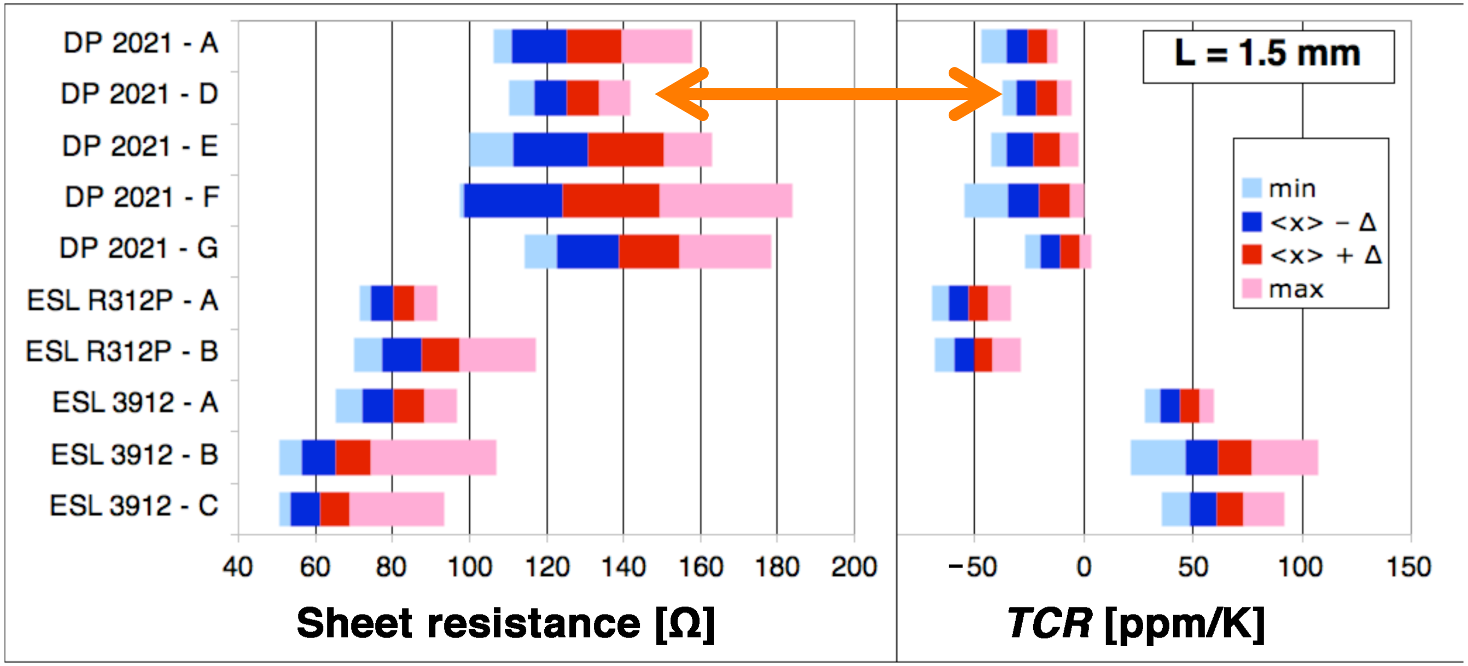


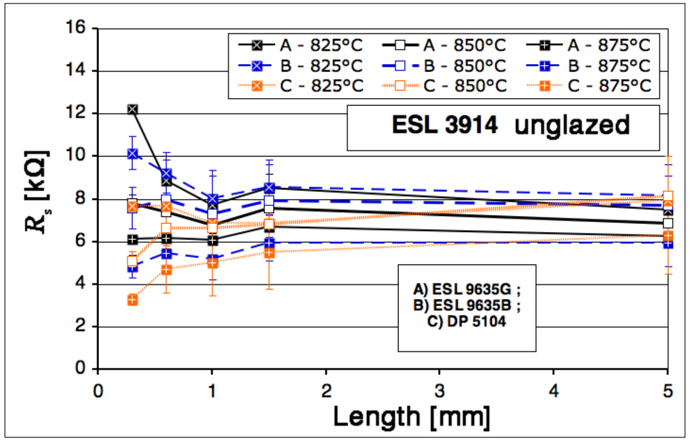
- Newer resistor compositions (DP 2041 / R314P) better
- Thin Au (D) terminations = lowest spread
  - Low geometric disturbance of screen printing
  - Low diffusion with terminations

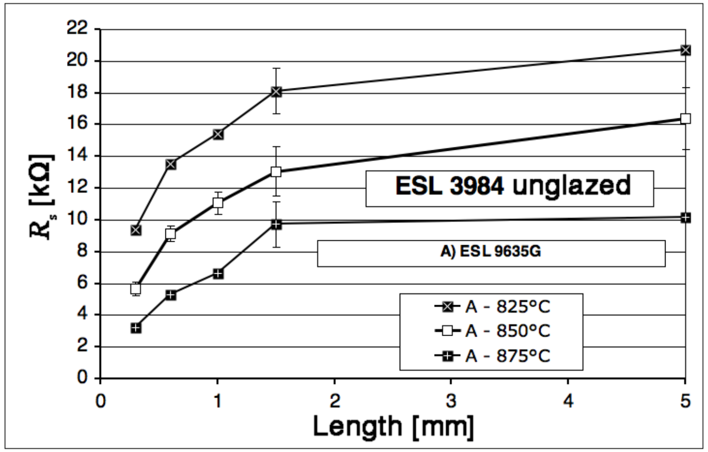
As-fired 100 Ω – spread of values

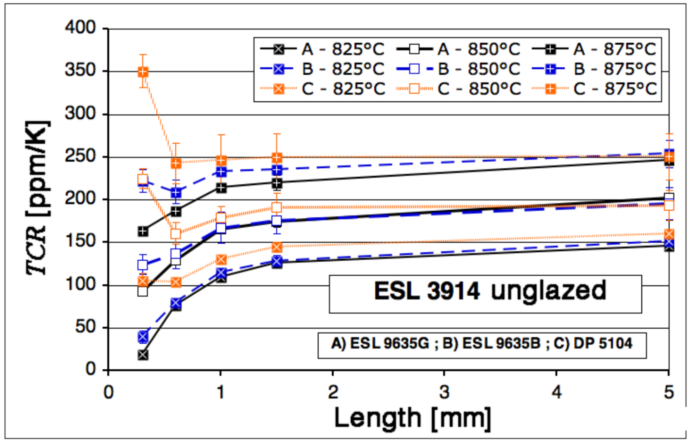


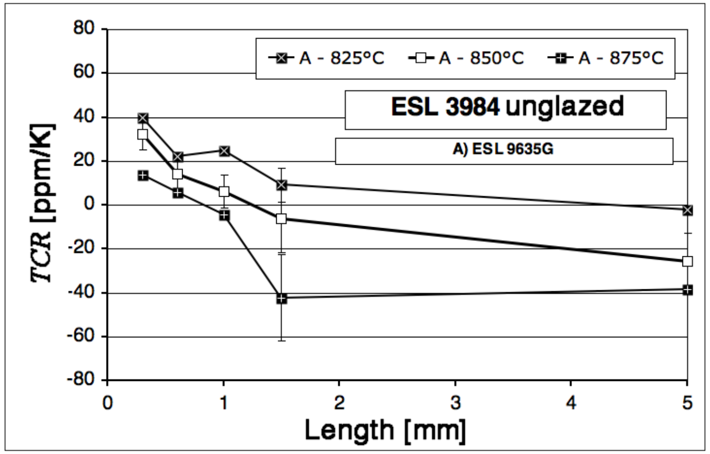
- Less difference seen in 100 Ω compositions
- *Not dominant – used for fine trimming*

As-fired 10 kΩ – effect of process









- Process dependence of value & TCR different
- Strong length effects on TCR -> TCO for short resistors

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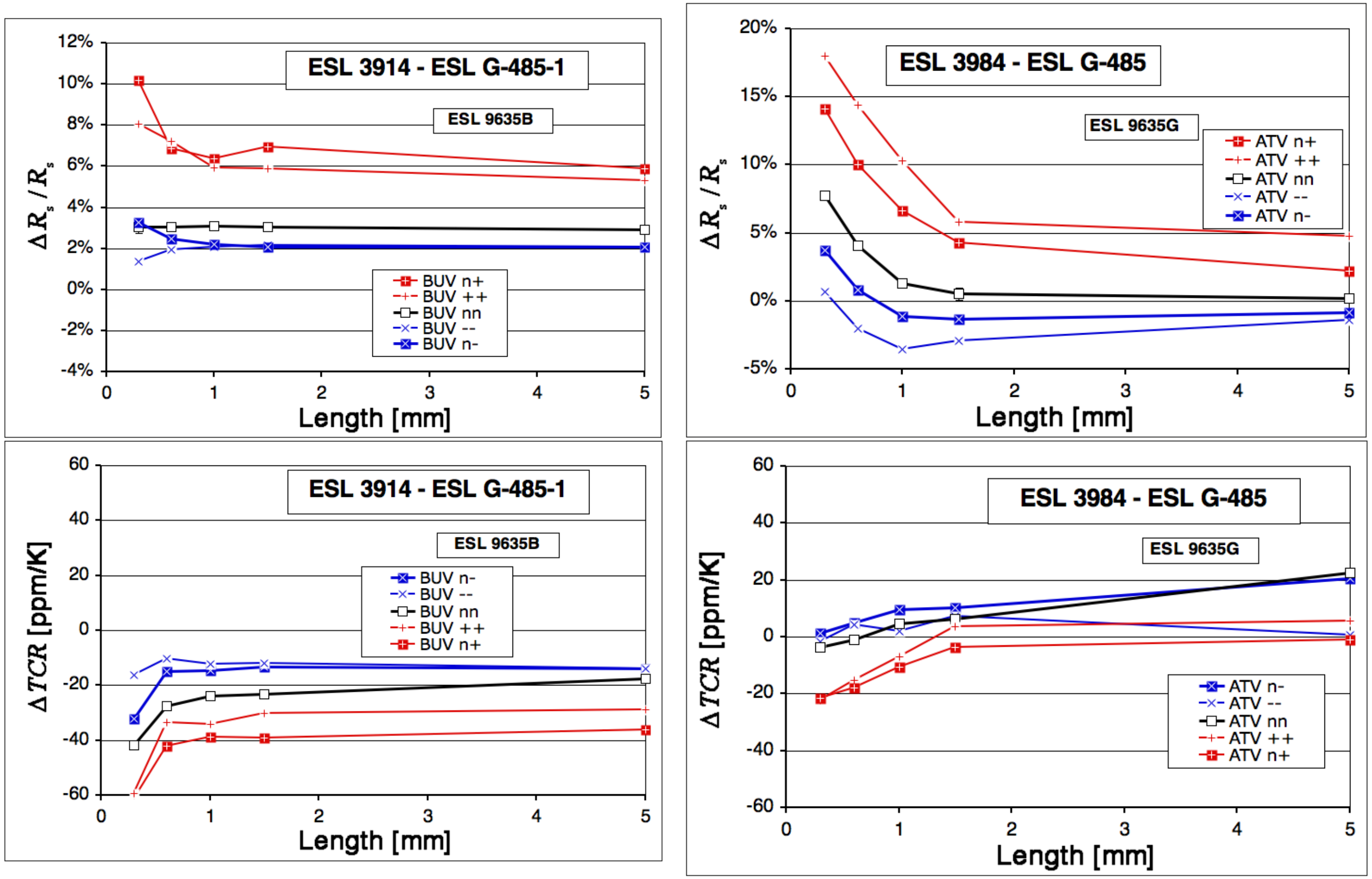
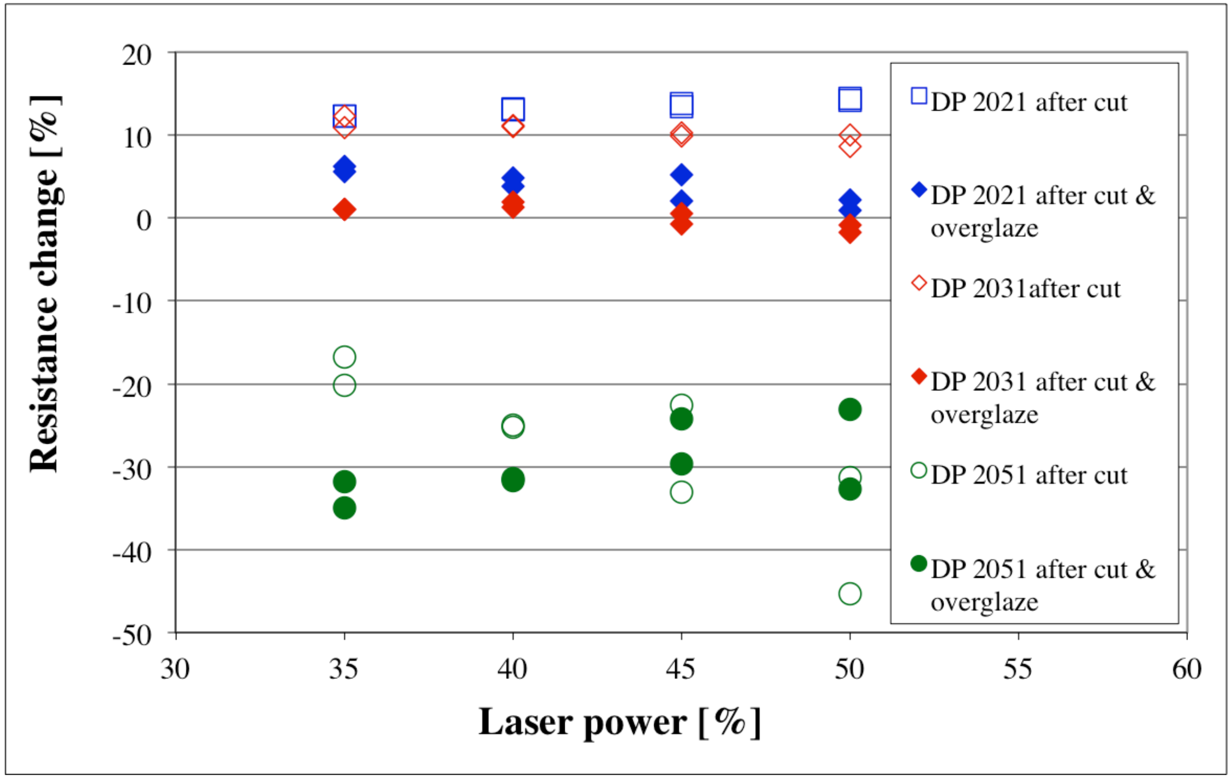
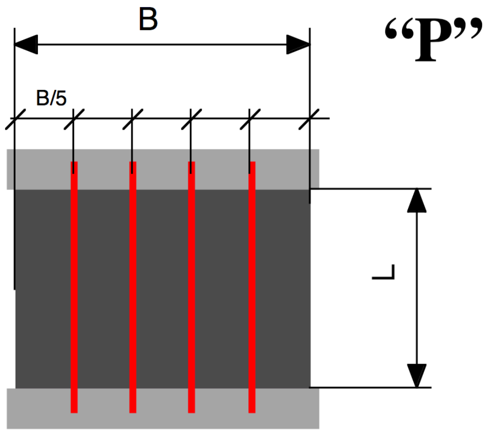
Overglazing resistors



- Overglazing above nominal temperature – : strong drift
- Length dependence on ΔTCR: leads to TCO

Trimming problems





- Behaviour mostly normal: slight value increase
- *Decrease* of value for 100 kΩ composition!

Trimming & stability of DP 2041 bridges

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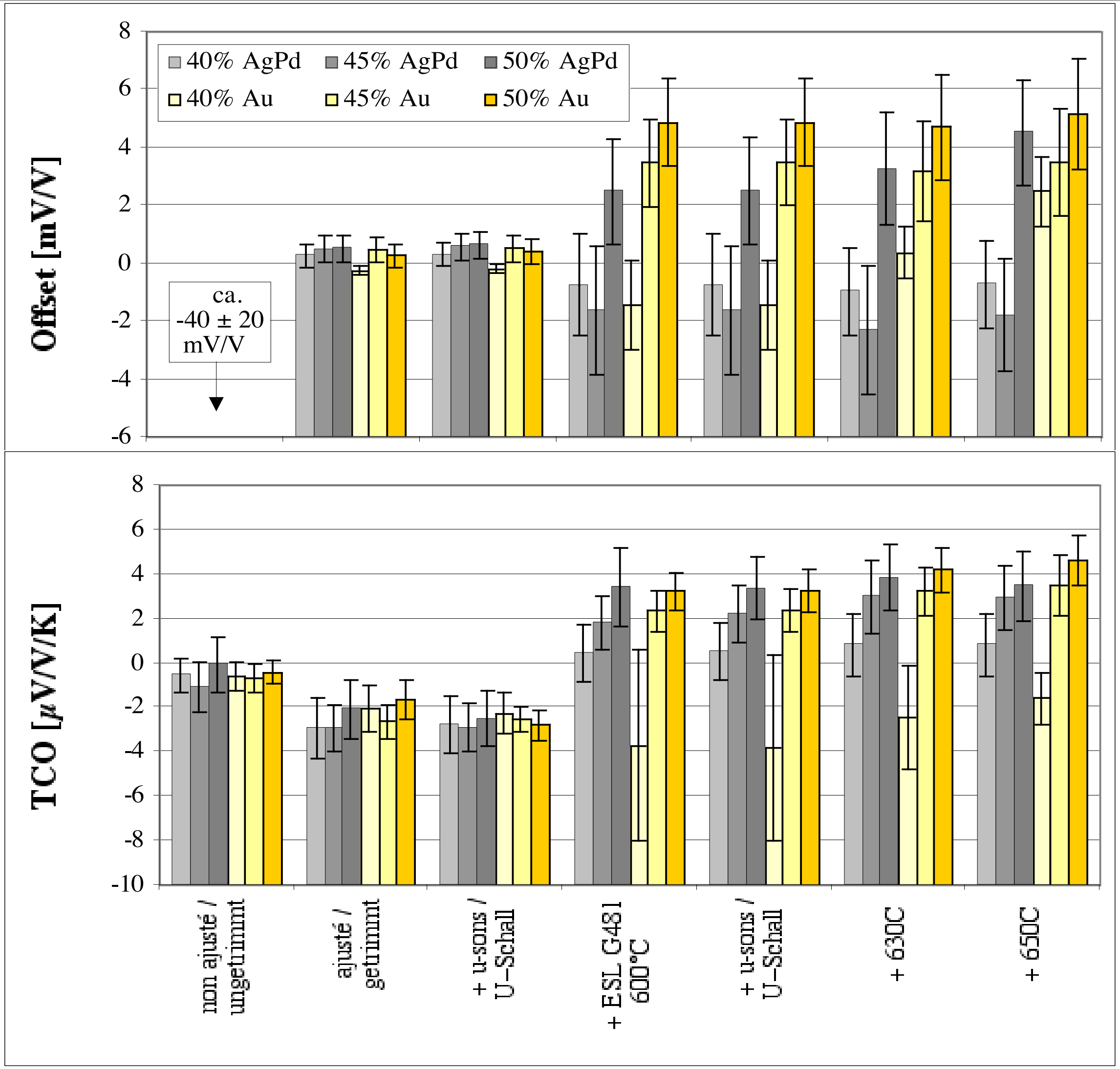

- Au initially ~2× better than Ag:Pd
  - After trimming
  - Trim + ultrasound
- Advantage lost upon overglazing
  - Trim-overglaze interactions dominant
  - Temperature not so dominant (anneals)
  - Better: refire overglaze or glaze again

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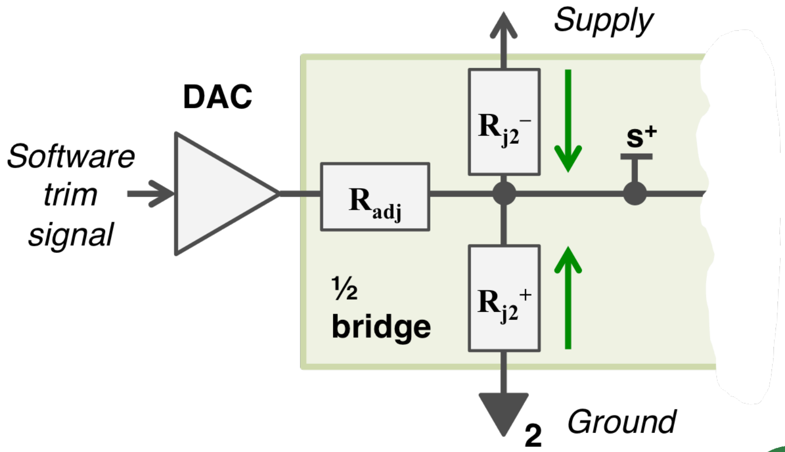
Conclusions & outlook

- **Thick-film piezoresistive sensors & laser trimming**
  - Relatively low signal + harsh environments: difficult
  - High process temperatures -> materials interactions critical
  - Few alternatives to laser trimming (voltage?) for large series (cost)
  - Best stability: start with discrete coarse trims
  - Parameter development can be tedious
  - Must ensure access of beam to resistor (not always practical!)

- **Software offset trimming**
  - R_{adj} = same paste as bridge, long meander (value ~10× bridge)
  - Little to no effect on TCO (if DAC reasonably good)



Questions?

THANK YOU!

Gauge factor measurement

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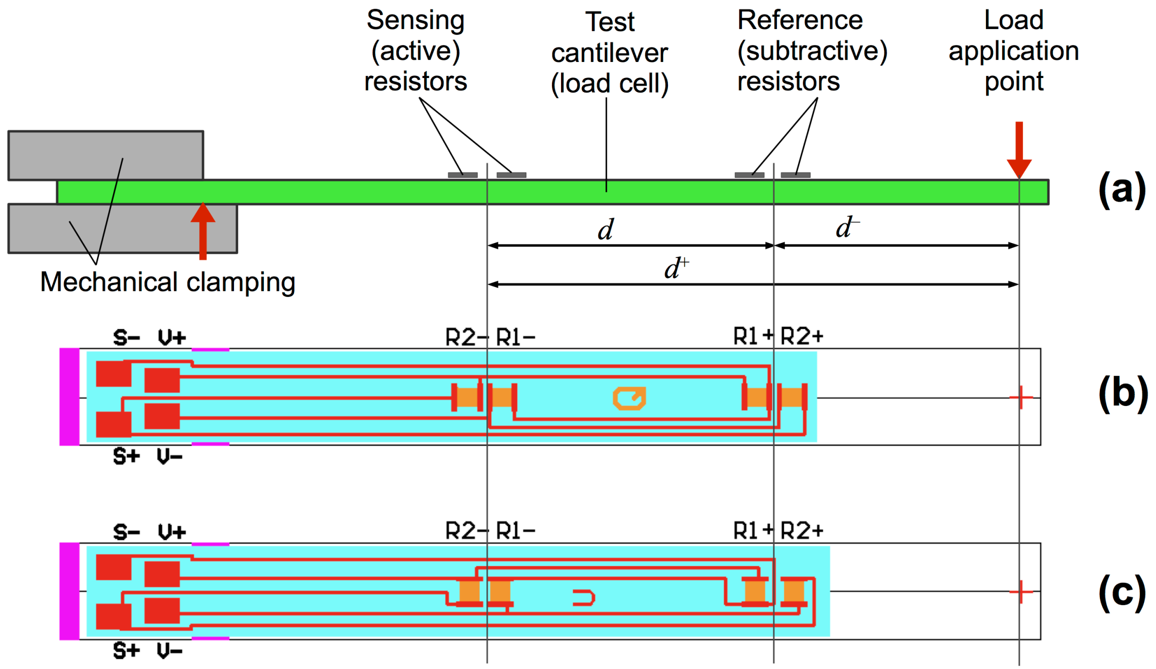

- Alumina cantilever
- Effective signal ~independent of loading errors