Assessment of thick-film resistors for manufacturing piezoresistive sensors

Thomas Maeder, Caroline Jacq and Peter Ryser
École Polytechnique Fédérale de Lausanne (EPFL), Switzerland
Outline

1. Introduction – manufacturing & trimming issues
2. Resistor study
3. Overglazing, trimming, etc.
4. Conclusions & outlook
1. Introduction – manufacturing & trimming issues
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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 $\sim$30 mV/V, max. gain $\sim$30×
  - With typical response $\sim$3 mV/V, typ. gain required $\sim$200×
  - Reduce offset typically by $\sim$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 ($\text{Al}_2\text{O}_3$, dielectric, LTCC…)
  - Terminations
  - Overglaze
  - \( TCO \neq TCR; \ TCO \text{ determined by } TCR \text{ tracking} \)

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

- **Post-processing**
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# Resistor study

<table>
<thead>
<tr>
<th>No</th>
<th>Film (Sheet res.) Screen$</th>
<th>Composition</th>
</tr>
</thead>
</table>
| 1  | Conductor 325 / 40       | A) ESL 9635G$^\dagger$  
     |                           | B) ESL 9635B$^\ddagger$ (Pb)  
     |                           | C) DP 5104$^\ddagger$ (Pb)  
     |                           | D) ESL 8837$^*$ (Pb, Cd)  
     |                           | E) ESL 9695$^\#$ (Pb)  
     |                           | F) ESL 9562G$^\#$ (Pb)  
     |                           | 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)  
| 3  | 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$^a$ (Pb)  
     |                           | W) ESL G-481$^a$ (Pb)  
     |                           | X) ESL 4771P$^b$ (Pb)  
     |                           | Z) DP QQ600$^a$ (Pb)  

ESL = Electroscience Laboratories  
DP = DuPont  

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

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

<table>
<thead>
<tr>
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<th>Resistor</th>
<th>Overglaze</th>
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<tr>
<td>- -</td>
<td>850°C (n)</td>
<td>825°C (n-25°C)</td>
<td>VWZ : 575°C (n-25°C)</td>
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<td>X : 525°C (n-25°C)</td>
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<tr>
<td>n +</td>
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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

- Au initially \(~2\times\) 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

- Offset [mV/V]
- TCO [\mu V/V/K]
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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

- Alumina cantilever
- Effective signal ~independent of loading errors