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Properties and Stability of Low-Firing Thick-Film Resistors
Effect of Composition and Processing Parameters

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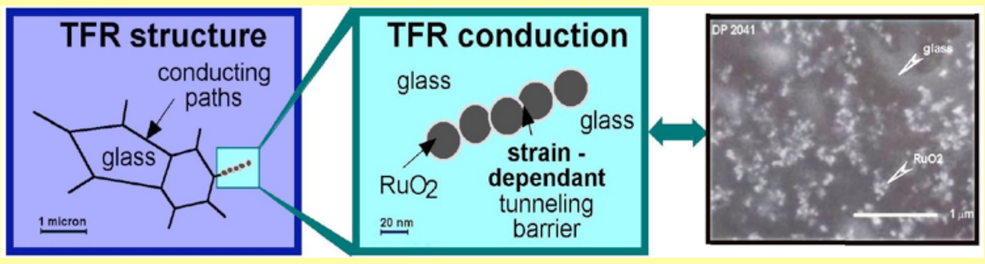
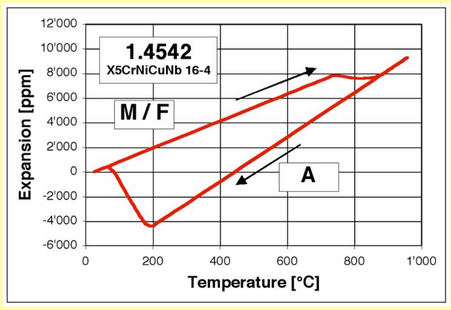
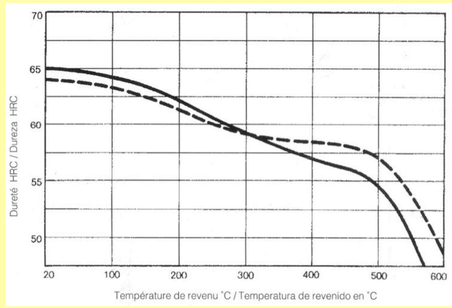
Low-firing thick-film resistors (TFRs) are useful for:
- Piezoresistive sensing with metallic (steel, Al, …) substrates
- High-power electronics on Al or Al-Si
- Thick-films on glass for displays

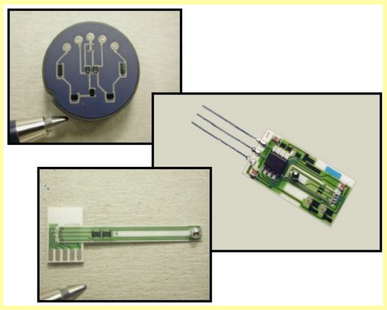


Resistor (TFR) microstructure

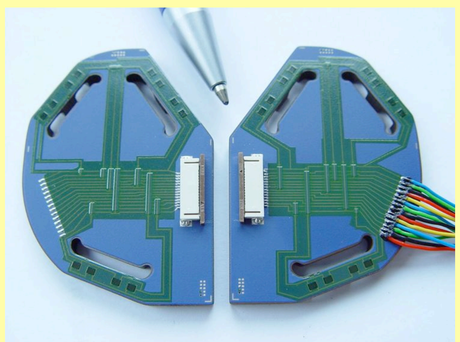




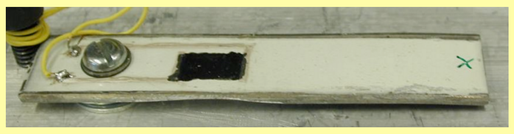
*High firing temperatures are incompatible with high-strength steel substrates, due to disruptive **phase transformations** (austenite - martensite, left), excessive **softening** (right), or **melting** (Al).*
→ Firing temperature ideally in 500…600°C range



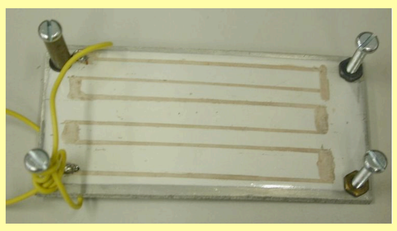
Thick-film piezoresistive force & pressure sensors @ EPFL



*Steel + thick-film force sensor for **total knee arthroplasty** ligament balancing*



Prototype force sensor on Al



Hot plate on Al

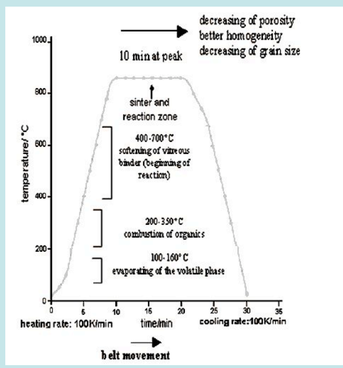
Glass frits

Ref.	PbO	B_2O_3	SiO_2	T_g
V2	63	25	12	500°C
V6	75	10	15	450°C
V8	85	10	5	370°C

Studied glass frit compositions (% mass)
+2% Al_2O_3 to suppress crystallisation

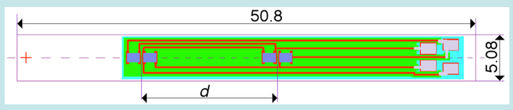
+ RuO_2 powder (40 & 400 nm) **+ binder**

TFR paste

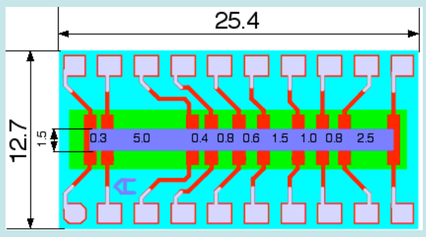


Screen printing & firing

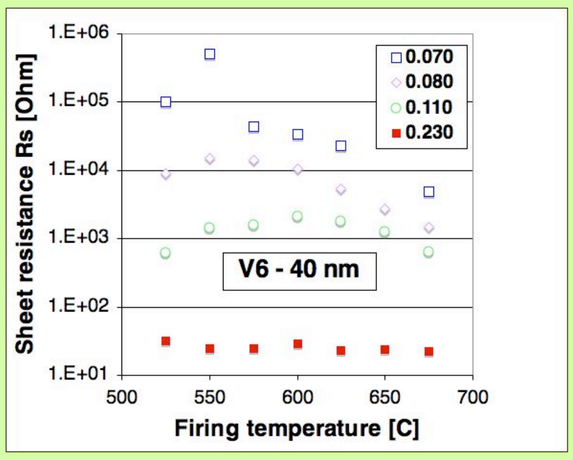
Gauge factor samples

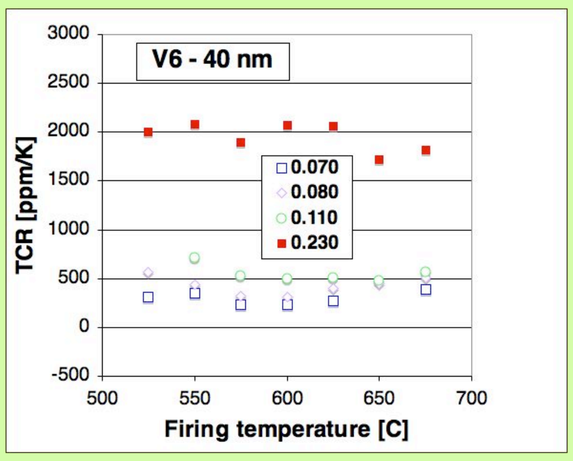


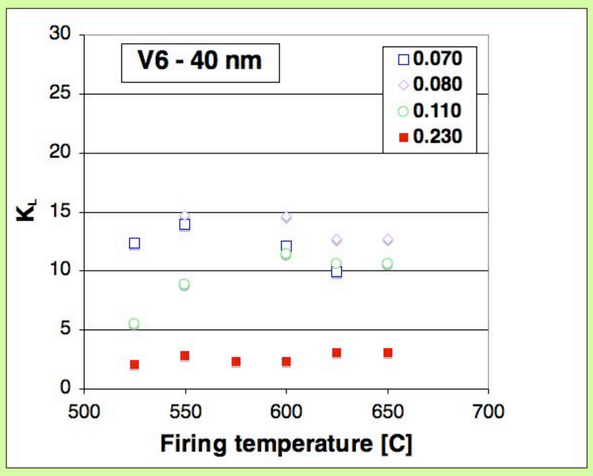
Resistive property samples



550-600°C system
V6 + 40 nm RuO_2



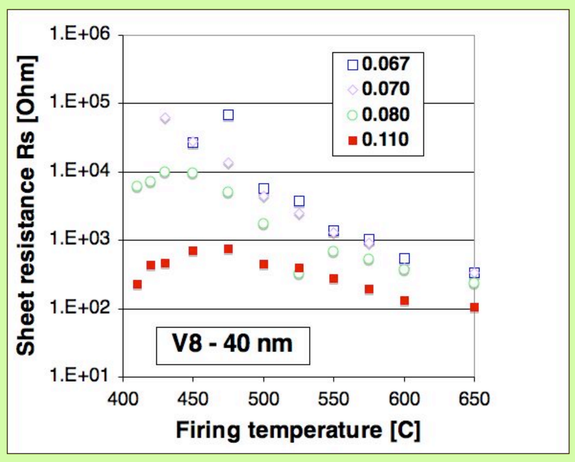




Stability of resistors at 250°C (1…10 kOhm/sq. samples)

Sheet resistance & its temperature coefficient TCR, and longitudinal gauge factor K_L vs. RuO_2 volume fraction & firing temperature

475-525°C system
V8 + 40 nm RuO_2



Sheet resistance vs. volume fraction & firing temperature

Low-firing 550…600°C resistors
- Excellent piezoresistive properties
- Compatible with high-strength steels
- Good stability at 250°C
- Additives needed for TCR adjustment

Ultra low-firing 475…525°C resistors
- Compatible with steel, glass, Al-Si, Al
- Reasonable gauge factor (ca. 6)
- Limited stability at 250°C