High performance low-firing temperature thick-film pressure sensors on steel

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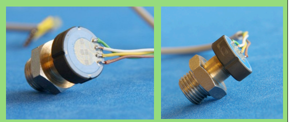
Aim of this project: Produce high-performance piezoresistive thick-film pressure sensors on steel substrates.

- Reduce the firing temperature to avoid degradation of the steel mechanical properties: a series of thick-film materials systems (dielectrics, resistors and conductors) firing at temperatures <700°C has been developed for ferritic / martensitic steels.
- Main issue in these systems:
  - Materials interactions between resistor, conductor and dielectric
  - Termination effects
  - Adherence & solderability

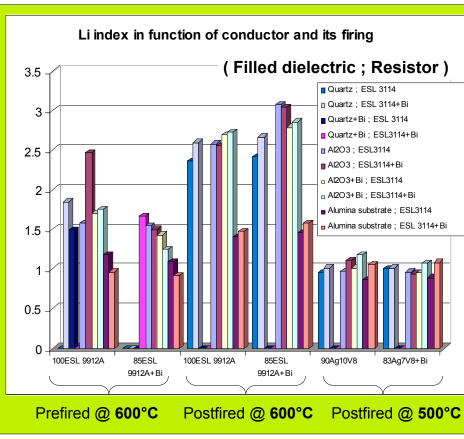


Termination effects: A serious problem with thick-film terminations is the increase of sheet resistance for the short resistors. In order to avoid this problem:

- Dope the thick-film materials (dielectric, conductive and resistive materials) with Bi_2O_3.
- Modify the standard screen-printed sequence in order to decrease the firing temperature of the conductor.

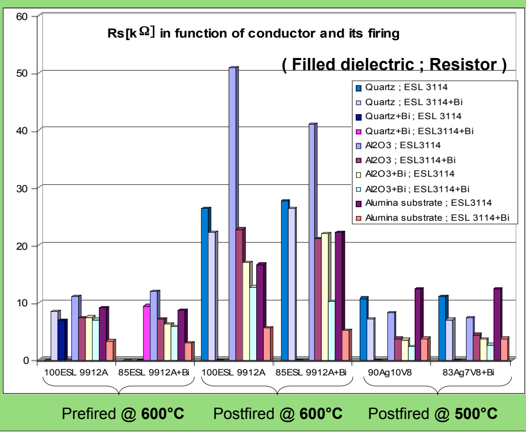
•Quick assessment of the termination effects: "length index" *LI*: $$LI = \frac{\text{Value of short resistors}}{\text{Value of standard resistors}}$$

- Dominant parameters : conductor and its firing temperature.
- Strong inverse size effects for conductors fired at 600°C (especially for post-fired ones).
- Very small size effect for conductors post-fired at 500°C.
  For this "good" group, smaller, secondary effect of the presence of Bi.
  Best LI values (1 or slightly lower) are obtained with Bi in conductor or in both conductor+resistor.



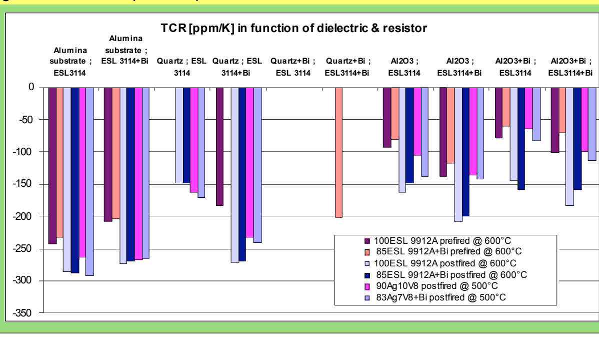
Sheet resistance (Rs) & Thermal coefficient of resistance (TCR)

- Addition of Bi_2O_3 in the dielectric strongly decreases the sheet resistance.
- The dielectric filled with Al_2O_3 and doped with Bi_2O_3 is favourable, because TCR is shifted towards 0.
- Doping ESL 3114 with Bi_2O_3 gives good results, but is not necessary to achieve good TCR and termination properties.



Best solution:

- Dielectric filled with alumina & doped with Bi_2O_3.
- Commercial ESL 3114 resistor composition (fired at 625°C).
- Fritted Ag conductive composition post-fired at 500°C.



Adherence and Solderabilty

- First dielectric layer filled with an adhesion promoter (Fe_2O_3 powder, 25% vol.)
- Tests on both oxidised and unoxidised substrates (oxidation 1 hour at 900°C in air).
- Solderability tested with different conductors.
- Bending tests on brass parts soldered with Sn-Ag (96.5%-3.5%) lead-free alloy.

- Fe_2O_3 – filled dielectric is an efficient adherence layer (no rupture in substrate-dielectric interface).
- No pre-oxidation required with this layer.
- ESL9912A conductor exhibits the best strength.
- The wettability of the solder is a little worse with low firing conductors, even when fired at 625°C, which explain the worse results.