Development of low-firing lead-free thick-film materials on steel alloys for piezoresistive sensor applications

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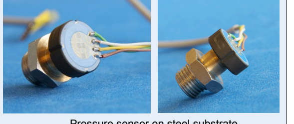
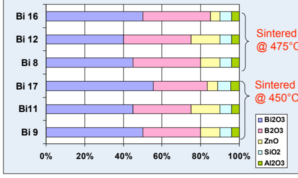
Aim of this project:

- Develop and characterise a range of low temperature firing TF materials (dielectric, conductor & resistor) based on lead-free glasses for piezoresistive sensors on steel alloys.
- Reduce the firing temperature to avoid the degradation of the steel mechanical properties to obtain better yield with steel sensor than ceramic sensor.
- TF material system: good TCE (Thermal Coefficient of Expansion) matching of dielectrics with steel substrates, conductor without termination effect and piezoresistive resistor.


Pressure sensor on steel substrate

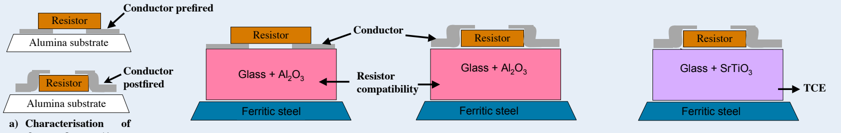
Glass Matrix:

- Thick-film materials are based on a glass matrix.
- To have a low firing temperature, Bismuth has replaced the Lead
- 6 vitreous glasses based on Bi_2O_3-B_2O_3-ZnO-SiO_2 system



Thick-film materials setup characterisation:

- Different configurations have been used to characterise the dielectrics, the conductor and the resistor (a) & (b)

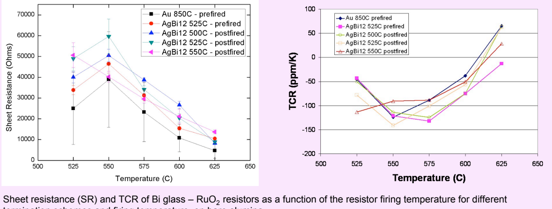


a) Characterisation of the conductor (Ag + Bi glass) and resistor on alumina substrate

b) Characterisation of the lead-free conductor (Ag + Bi glass) and resistor (RuO_2+ Bi glass) on steel substrate

Characterisation of TF resistor

Characterisation of the Bi glass – RuO_2 resistor on alumina substrate



Sheet resistance (SR) and TCR of Bi glass – RuO_2 resistors as a function of the resistor firing temperature for different termination schemes and firing temperature, on bare alumina

- Ag + glass conductor gives very promising sheet resistance (SR) in the range 10…100kW range and low TCR values without TCR drivers on alumina substrates.

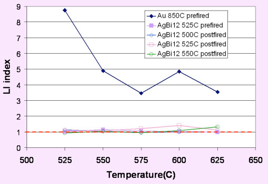
Characterisation of the termination effect on the resistance:

A serious problem with thick-film terminations is the increase of sheet resistance for the short resistors.

Dominant parameter: conductor and its firing process

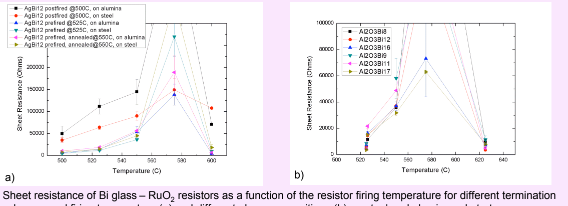
- **Quick assessment of the termination effects: "length index" LI:**

$$LI = \frac{\text{Value of short resistors}}{\text{Value of standard resistors}}$$



- Gold conductor is incompatible with the bismuth-glass.
- Ag + Bi glass conductor prefired and 500°C postfired are the preferable firing processes.

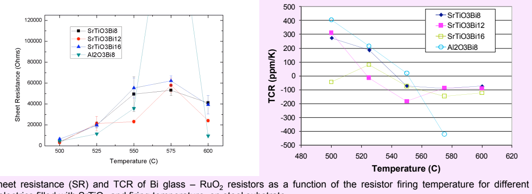
Characterisation of the Bi glass – RuO_2 resistor on dielectric filled with Al_2O_3



Sheet resistance of Bi glass – RuO_2 resistors as a function of the resistor firing temperature for different termination schemes and firing temperature (a) and different glass compositions (b) on steel and alumina substrates.

- SR on steel substrates are very reproducible.
- A peak of SR at 575°C, due to excess glass moving out of the dielectric into the resistor.
- All of 6 Bismuth glass dielectrics become too much glassy from 550°C.

Characterisation of the Bi glass – RuO_2 resistor on dielectric filled with $SrTiO_3$

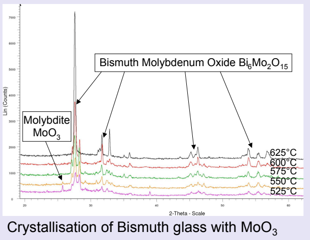


Sheet resistance (SR) and TCR of Bi glass – RuO_2 resistors as a function of the resistor firing temperature for different dielectrics filled with $SrTiO_3$ and firing temperature, on steel substrate.

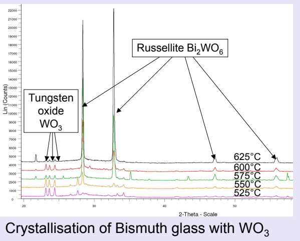
- Only 3 Bismuth glasses suited were compatible with $SrTiO_3$, the more the glasses are stable, the more they are compatible with $SrTiO_3$.
- Better TCE matching with steel substrate, similar results (SR & TCR) as on dielectrics filled with alumina.

Stabilisation of dielectrics by crystallisation

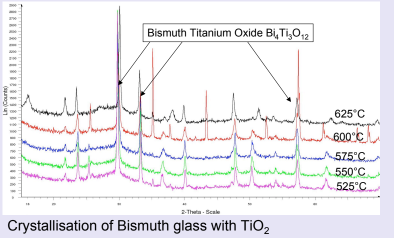
- To avoid problems with glassy dielectrics (breakages in the conductors track and increase of the SR)
- To stabilize the dielectric, 3 reagents was tested to crystallise the glass.
- MoO_3 is the most reactive



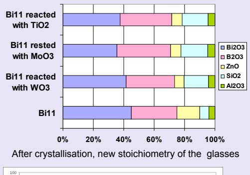
Crystallisation of Bismuth glass with MoO_3



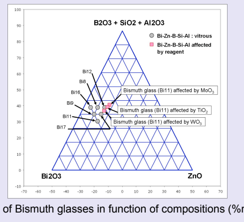
Crystallisation of Bismuth glass with WO_3



Crystallisation of Bismuth glass with TiO_2



After crystallisation, new stoichiometry of the glasses



Repartition of Bismuth glasses in function of compositions (%mol.)