Solutions for thermally mismatched brazing operations for ceramic tokamak magnetic sensor

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Magnetic Sensor for Tokamak Nuclear Fusion

NUCLEAR FUSION

Thermonuclear reactor

Tokamak

Magnetic Sensor Goal & Environment

To control the plasma

Measure the fluctuations of the magnetic fields in 3D

Magnetic Sensor Specifications:

3D axis measurement (X Y Z)

Resistant to neutron flux

Functional up to 300°C

External dimensions (76 X 76 X 12 mm)

Magnetic sensor placed behind the protection tiles

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Tokamak schematic

Magnetic Sensor Placement

Cross-section of the
external walls

Tokamak

First generation of 3D magnetic sensor

- 20 LTCC windings for X and Y axis (10 each)
- Thick-film winding for Z axis (integrated in base)
- 6 alumina beams assembled to thermally decouple the end of the beams
- Cables are brazed @ 620°C
- Implies thick silver metallisation to avoid leaching by braze

Issue

- Thermally decoupling the brazing area
- Mechanically robust
- Ease of fabrication

Three solutions investigated

- Replacing the alumina beams with a porous dielectric
- Simply shortening the alumina beams
- Replacing the alumina beams by silver wire

Porous dielectric

	ESL 4913 : ESL 4917 weight ratio	KS5-44 (% vol. vs dielectric)
000Pb	1:0	50
033Pb	2:1	50
067Pb	1:2	50
100Pb	0:1	50

- The most compact solution
- Vertical thermal decoupling
- Four porous dielectric formulations based on two commercial dense dielectrics mixed with fugitive graphite powder

Porous dielectric – Thermal resistance

near increase of thermal resistance with thickness

thermal conductivity essentially constant

Porous dielectric – Shear test

Shear Stress [MPa]

With porous dielectric

10.2 ± 2.6

Without porous dielectric

42

Porous dielectric
without carbon residue

Shear testing machine

Destruction in the porous dielectric layer

Shorter beam and silver wire

- Heating source: SMD high power chip resistor
- Temperatures probes: Pt-1000 resistors placed along the beam / wire and on the substrate

Shorter beam solution

Silver wire solution

Shorter beam

- Measurements:
- At 3 power levels
- At 3 relatively low temperatures in a narrow range to avoid convective and radiative losses around the heating resistor

Silver wire

Strong decrease of temperature with distance from the heating source

Losses by natural convection along the wire

Critical length is ~ 20 mm at 500°C

- Critical length: convection on surface $>$ conduction along the wire

Brazing test

- Brazing of coaxial cables
- Carried out with sensor on a hotplate (decrease thermal stress)
- Porous dielectric broken by thermal stress from braze drop + wire

Coaxial cables brazed on beam, silver wire and porous dielectric supports

	Long beam	Short beam	Silver wire	Porous diele
Tmax thermal decoupling (°C)	97	139	98	179
Substrate Tmax (°C)	85	94	94	92
Heating plate Temperature (°C)	81	90	90	89
Thermal stress (Mpa)	31	111	10	204

Brazing test – porous dielectric

Brazing test – short alumina beams

Brazing test – silver wire

Conclusion

- Three solutions to thermally decouple the braze area from the magnetic sensor
 - Robustness and ease of operation
- Porous dielectric: most compact solution but the worst decoupling – **not usable**
- Shorter beam, more robust than long beam presents good decoupling properties
- Silver wire: best decoupling + soft and malleable

Outlook

- Connect silver wires to coaxial cables via HV/ neutron-compatible connector, e.g. screw terminal block
- Allows separate installation of cabling and sensor

Thank you for your kind attention