

Recent developments for measuring high-temperature thermal diffusivity of advanced materials used for energy production



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BACKGROUND AND OBJECTIVES

- Energy industry develops high performance materials operating at high temperature to increase efficiency, reliability and safety of the thermal and nuclear power plants.
 - Ceramic coatings used up to 1000 °C for the thermal protection of gas turbine blades
 - Composite materials used in nuclear field for manufacturing accident tolerant fuel cladding
- Accurate thermal diffusivity measurement of advanced materials versus temperature is crucial for predicting their thermal behaviour in real conditions as well as in accident scenarios where materials can be exposed to temperatures higher than 3000 °C in nuclear reactors.
- Difficulties to ensure reliability and SI traceability of thermal diffusivity measurements at high temperature due to a lack of appropriate standard reference materials and reference facilities.

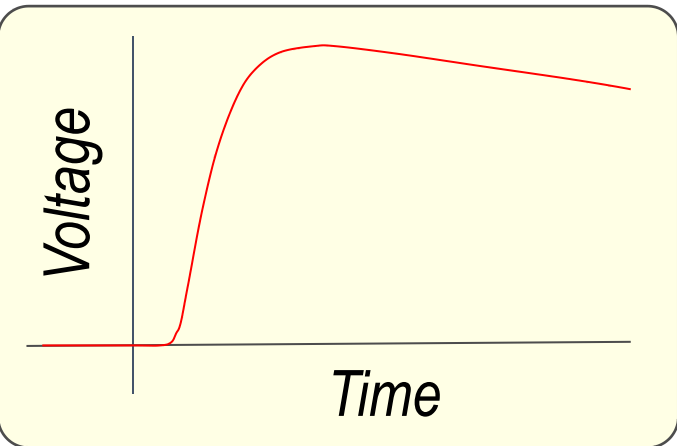
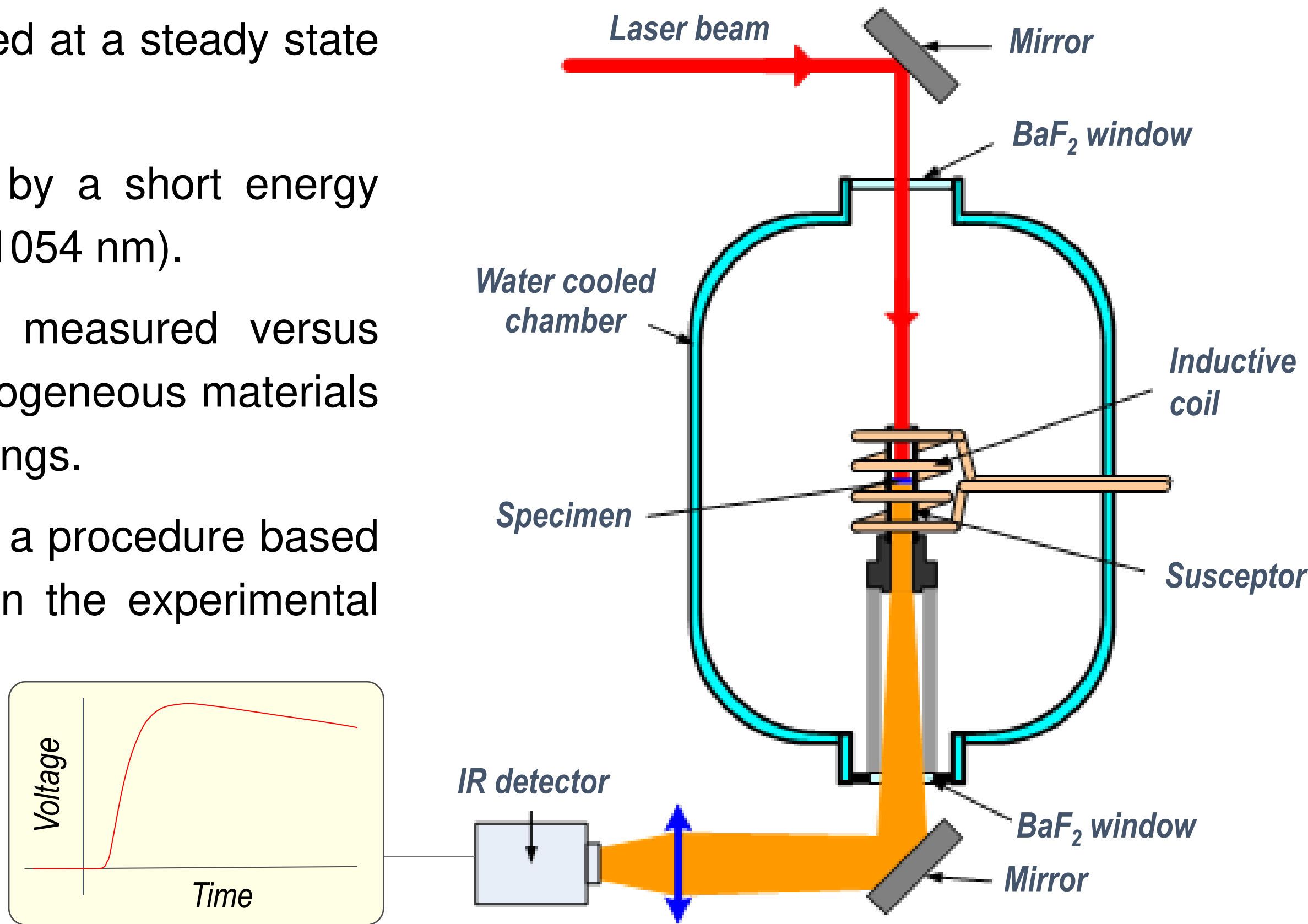


Development at LNE of a facility based on an absolute measurement method (laser flash method) for measuring thermal diffusivity of thermal barrier coatings up to 1000 °C and of homogeneous solid materials up to 3000 °C.

DEVELOPMENT OF A REFERENCE LASER FLASH APPARATUS

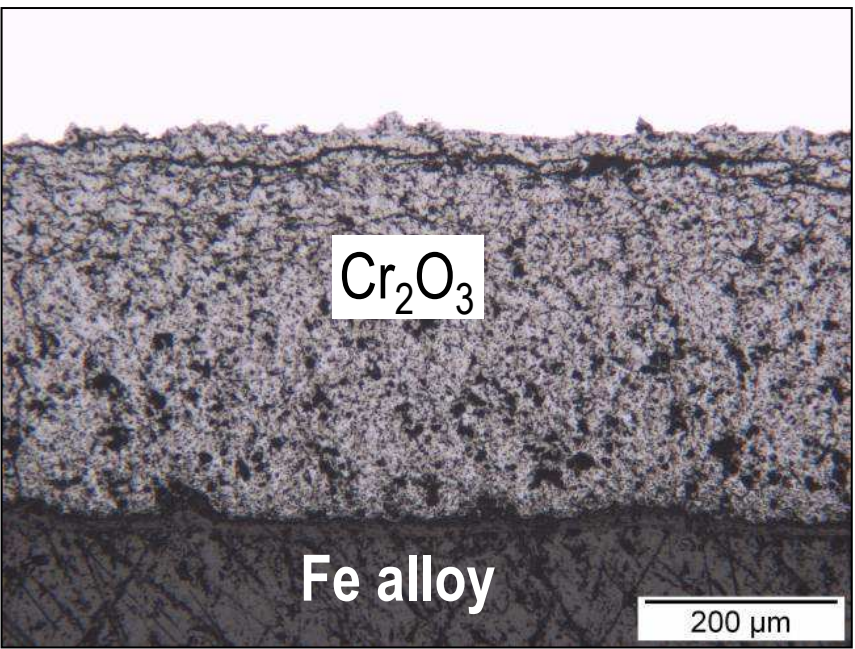
- Thin disk shaped specimen maintained at a steady state temperature in an inductive furnace.
- Front face of the specimen heated by a short energy pulse (450 μ s) generated by a laser (1054 nm).
- Induced transient temperature rise measured versus time on the back face in case of homogeneous materials or on the front face when testing coatings.
- Estimation of thermal diffusivity using a procedure based on minimizing the difference between the experimental curve and a theoretical curve.

Obtained by modelling the transient heat conduction in the specimen



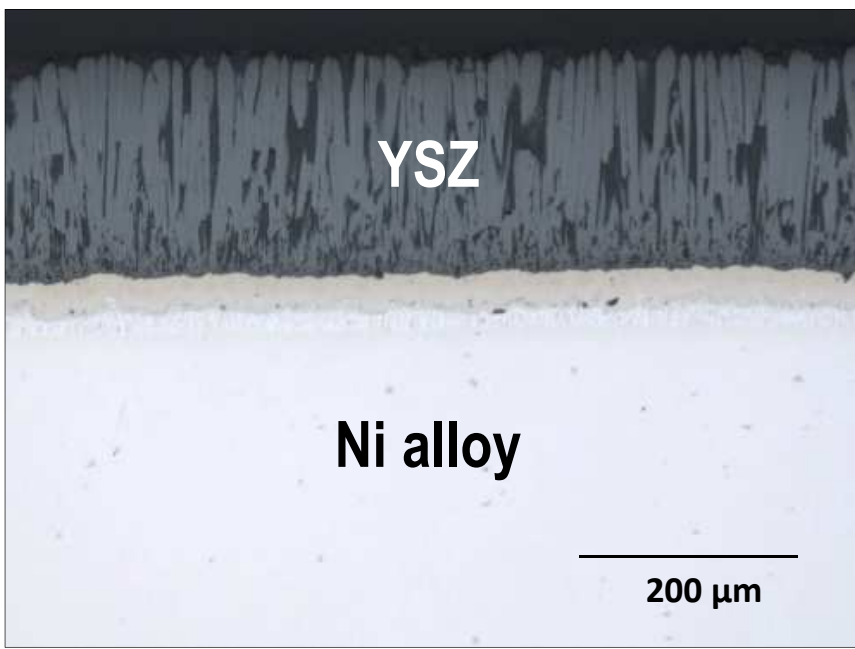
STUDY OF THERMAL DIFFUSIVITY α OF CERAMIC COATINGS DEPOSITED ON METALLIC SUBSTRATE

- Characterization of two multilayer systems (materials typically used for gas turbine blades).
 - Chromium oxide coating (0.405 mm) deposited by plasma spraying on an iron alloy substrate (6.000 mm)
 - Nickel alloy (2.920 mm) coated by e-beam physical vapour deposition with yttria-stabilised zirconia (0.190 mm)



0.405 mm Cr₂O₃ / 6.000 mm Fe alloy

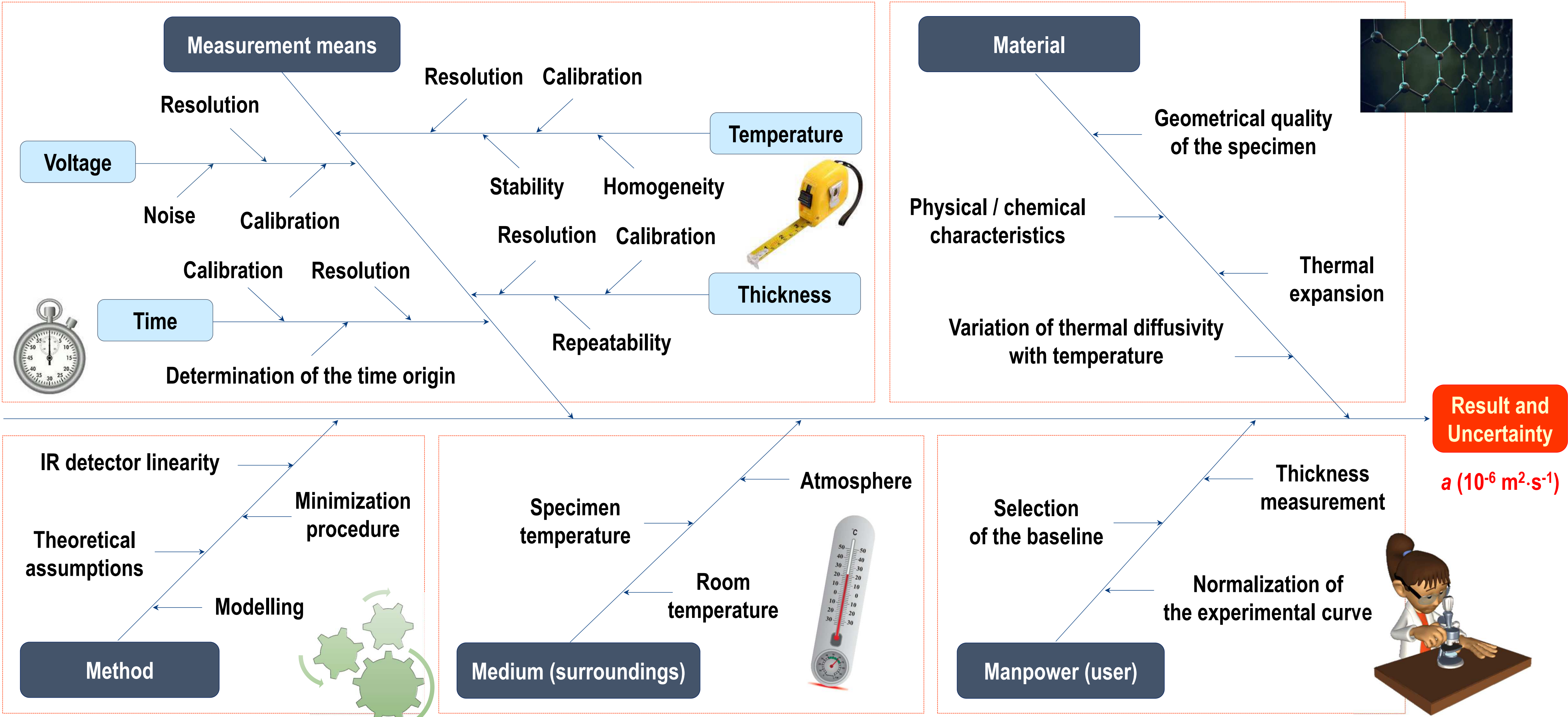
Temperature (°C)	α (Cr ₂ O ₃) (10 ⁻⁶ m ² .s ⁻¹)
23	1.263
200	0.954
400	0.779
600	0.783
800	0.809



0.190 mm YSZ / 2.920 mm Ni-base alloy

Temperature (°C)	α (YSZ) (10 ⁻⁶ m ² .s ⁻¹)
23	0.556
250	0.452
499	0.380
749	0.424
900	0.436
999	0.452

IDENTIFICATION OF THE UNCERTAINTY SOURCES



MEASUREMENT OF THERMAL DIFFUSIVITY α OF REFRACTORY MATERIALS VERSUS TEMPERATURE

- Thermal diffusivity with (corrected value) and without (raw data) correction of the specimen expansion during test.
- Expanded uncertainty ($k=2$) associated with thermal diffusivity measurement assessed for each temperature level.

Temperature (°C)	Isotropic graphite IG210			Tungsten			Molybdenum		
	α (10 ⁻⁶ m ² .s ⁻¹)	Raw data	Corrected value	α (10 ⁻⁶ m ² .s ⁻¹)	Raw data	Corrected value	α (10 ⁻⁶ m ² .s ⁻¹)	Raw data	Corrected value
23		87.91	87.91		68.61	68.61		55.22	55.22
400		30.05	30.16		49.12	49.30		42.89	43.07
800		18.27	18.42		40.63	40.94		36.97	37.30
1200		13.71	13.89		36.53	36.97		32.15	32.62
1600		11.18	11.39		32.70	33.25		26.65	27.21
2000		9.54	9.79		28.86	29.52		22.34	23.00
2200		8.98	9.24		26.87	27.55		20.12	20.78
2400		8.46	8.73		25.28	25.98			
3000		7.33	7.62						

CONCLUSION

- Relative expanded uncertainty $U(\alpha)$ estimated between 3 % and 5 % ($k=2$) in the temperature range [23 °C / 3000 °C].
- Error on thermal diffusivity values equals to 2.7 % for tungsten at 2400 °C, 3.2 % for molybdenum at 2200 °C and 3.8 % for graphite at 3000 °C, if the thermal expansion of the specimen between 23 °C and test temperature is neglected.

Unique worldwide measurement capabilities