UT-VIV/PFC-Pyro

Task Title: APPLICATION OF A TRICOLOUR PYROREFLECTOMETER TO PLASMA FACING COMPONENTS IN-SITU INFRARED MONITORING

INTRODUCTION

The plasma-facing components in tokamaks are observed by infrared thermography to provide security against overheating.

The results depend on the emissivity of the surface which is not known a priori and may be a function of temperature, viewing direction, wavelength and physical state of the surface.

The latter changes in the course of the interaction with the plasma. Particularly important is this question for low emissivity metallic surfaces as tungsten and beryllium, which are presently foreseen for ITER alongside with carbon, that causes less problems due to its high emisivity.

The main aim of this collaboration is to develop a tri color pyroreflectometer technique [1] capable of measuring in-situ and in real-time the emissivity of the monitored materials. The main steps are:

A) For 2004 : use the multi colour pyroreflectrometry method on materials samples typical of fusion devices (Carbon Fiber Composite CFC or Tungsten W, new and used) to determine unambiguously their temperature and deduce the emissivity in the near infrared range (0.84 – 1.5 µm) and by additional luminance measurements at 5 µm and 8-12 µm to investigate the possibility to measure temperatures lower than 500°C.

B) For 2005 : evaluate the possibility to implement the pyroreflectrometer in the FE200 high heat flux station of CEA situated in Le Creusot and implement it for a testing campaign.

C) For 2006 : evaluate the possibility to implement the pyroreflectrometer in Tore Supra or another tokamak and eventually commission and implement it; and prepare a study of feasibility for ITER application.

2004 ACTIVITIES

EXPERIMENTAL SETUP

The experimental set up used for the first experiments (figure 1) is MEDIASE, one of the solar extreme test facilities of the laboratory [2].

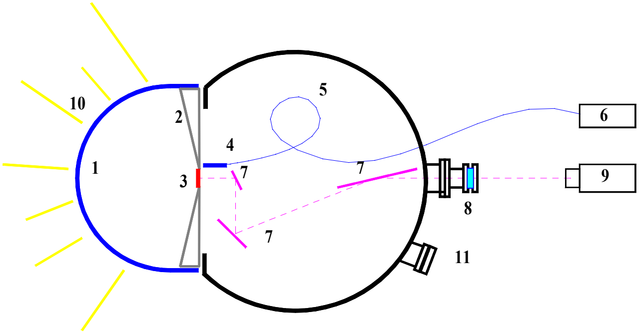

Figure 1 : MEDIASE test facility

The setup comprises:

1) hemispherical silica window
2) water-cooled front shield
3) sample
4) moving probe equipped with an hemispherical probe
5) optical fibers
6) bicolor pyroreflectometer
7) 3-mirrors goniometer
8) viewport
9) radiometer equipped with specific filter
10) concentrated sun radiation
11) connection to vacuum device

The sample (3) is heated by the concentrated solar flux (10) on its front face and instrumented on the rear face. The moving probe (4) can be located on the rear face of the sample or in its side. The probe is a reflecting hemisphere equipped with two optical fibers (5) linked to the bi-color pyroreflectometer (6) for normal normal reflectivity measurements.

Angular resolved reflectivity measurements are not possible with this set-up. The radiometer (9) can be equipped with filter at 5 and 8-12 µm to measure the directional radiance temperature Tr(λ,θ) of the sample through a window (8) and a 3-mirrors internal goniometer (7). During these experiments, MEDIASE was operated under residual pressure of 10^{-5}mbar (see vacuum device (11)).

Four cylindrical samples (diam. 25 mm, thick. 2 mm) were delivered by CEA to CNRS in may 2004 : two samples of pure W from Plansee Gmbh. One of the W samples was glass-blasted in Cadarache before sending to CNRS (sample 1), the other one was “clean” (sample 2), two samples of CFC N11 from manufacturing of Tore Supra LPT (samples 3 and 4).

METHOD

The bi [3] or tri [1] color pyroreflectomety is a new concept developed at the CNRS Odeillo to determine the true temperature for opaque material. The main principle is to measure simultaneously and for two or three working wavelengths the radiance temperature Tr(λ) and the bi-directional reflectivities on the normal position. The main hypothesis is to consider that the instrumented sample has the same B.R.D.F. (bi-directional reflectivity distribution function) at the working wavelengths. Taking into account these two points the true temperature is obtained solving a system of two or three equations based on a relation:

$$1/T=1/Tr(\lambda)+\lambda/C_2\ln(1-\eta(T)\rho^{0,0}(\lambda,T)) \qquad (1)$$

where η is the diffusivity factor which is the ratio of hemispherical reflectivity $\rho^{0,\cap}(\lambda,T)$ to normal normal reflectivity:

$$\eta(T)=\rho^{0,\cap}(\lambda,T)/\rho^{0,0}(\lambda,T) \qquad (2)$$

Consequently $\rho^{0,\cap}(\lambda,T)$ and $\varepsilon^{0}(\lambda,T)$ can also be determined.

The figure 2 presents an example of a graphical determination of solution the true temperature for a W sample heated at the solar furnace. Tc_a, Trr_a, Trb_a are the measured apparent (colour and radiance) temperatures and ρr_a and ρb_a the measured apparent normal normal reflectivities (r indicate 1.55µm et b 1.3µm).

The resulting convergence temperature T* is assumed to be equal to the true temperature T at a corresponding apparent value η^*_a and the apparent emissivities εr_a and εb_a. This method worked well for the tungsten targets. For the carbon targets the reflectivity was too low. Hence we assumed identical emissivity at the two wavelengths (1.3 and 1.55 µm) and determined the ‘true’ temperature via bi color pyrometry. After the true temperature of the samples had been determined further passive measurement were performed to determine the directional emissivity ε(T,λ,θ) at 5 and 8-12µm. In this case the method is a direct method:

$$\varepsilon(T,\lambda,\theta) = L°(Tr(\lambda,\theta))/\ L°(T,\lambda) \qquad (3)$$

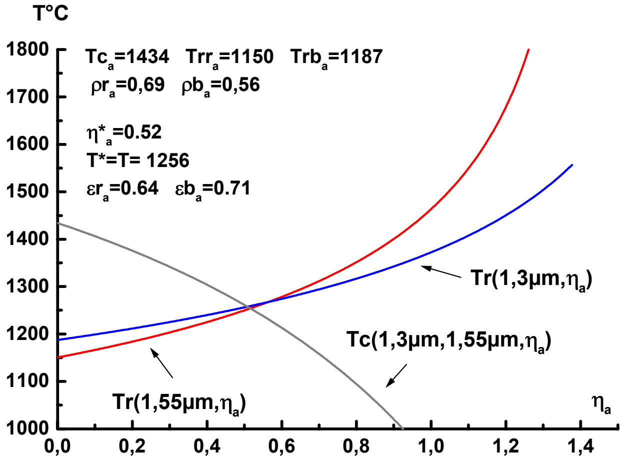

Figure 2 : Example of analysis of bi-color pyro reflectometry measurements

RESULTS

Figures 3 and 4 show the results obtained with the pyro-reflectometry method on the tungsten samples. In the case of the glass-blasted tungsten (figure 3) εr_a , εb_a , η^*_α values were different during the first and the following heating cycles. Such differences may be attributed to a modification of the state of the surface (outgassing of impurities, cleaning of surface) during the first temperature rise. The values for clean tungsten did not change from one cycle to another.

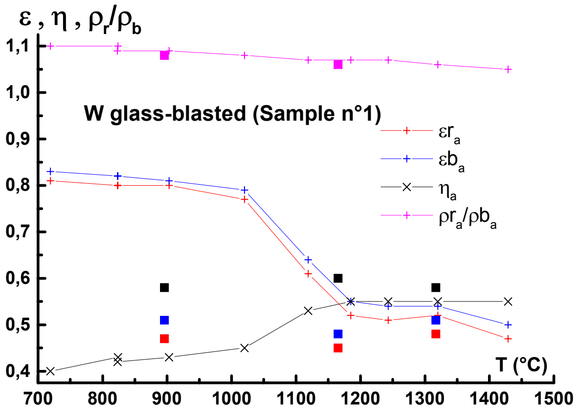

Figure 3 : Glass blasted tungsten: Curves and cross: first increasing cycle – Squares: a further increasing cycle

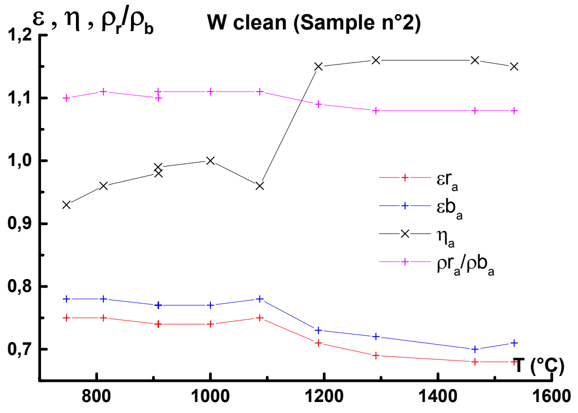

Figure 4 : Clean tungsten during a later increasing cycle

The angular resolved emissivity measurements at 5 and 8-12 µm are shown in the figures 5-12.

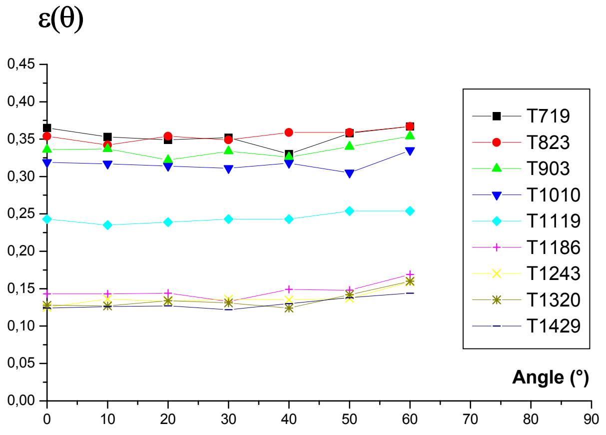

Figure 5 : Glass blasted tungsten at 5µm: first temperature rise

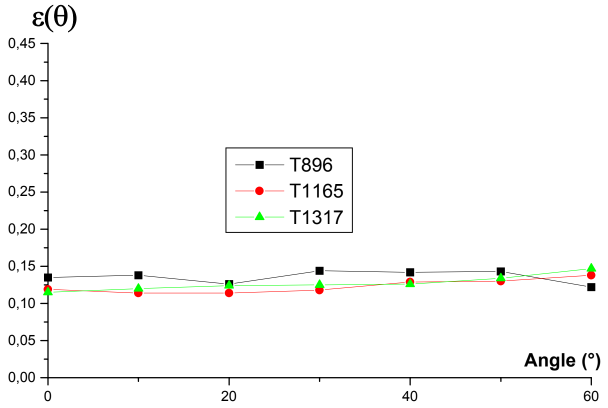

Figure 6 : Glass-blasted tungsten at 5 µm during later cycle

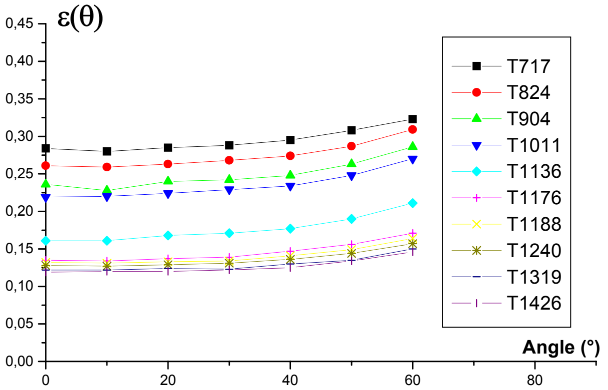

Figure 7 : Glass-blasted tungsten at 8-12 µm during first temperature rise

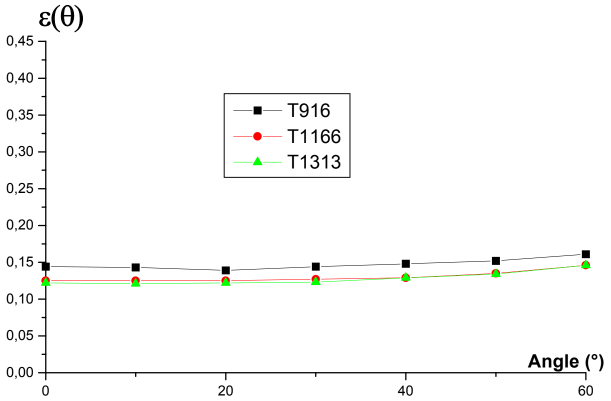

Figure 8 : Glass-blasted tungsten at 8-12 µm during later cycle

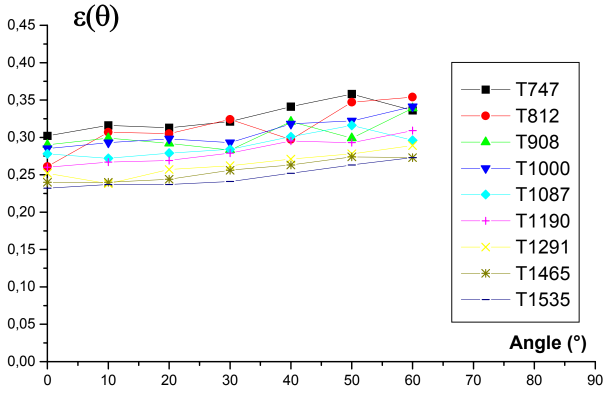

Figure 9 : Clean tungsten at 5 µm

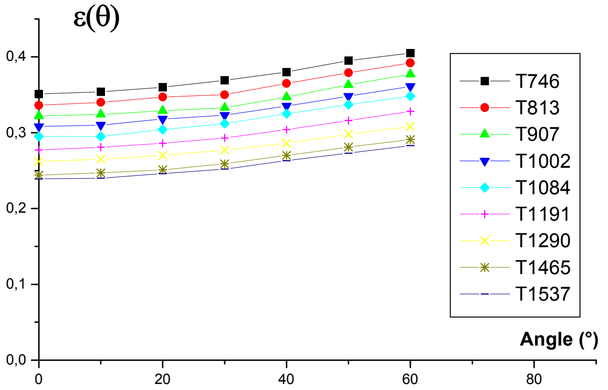

Figure 10 : Clean tungsten at 8-12 µm

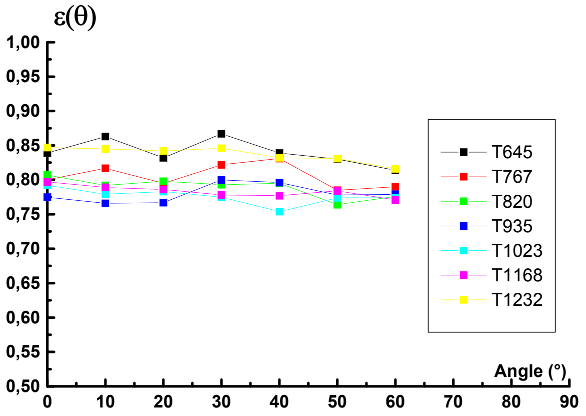

Figure 11 : CFC N11 at 5 µm

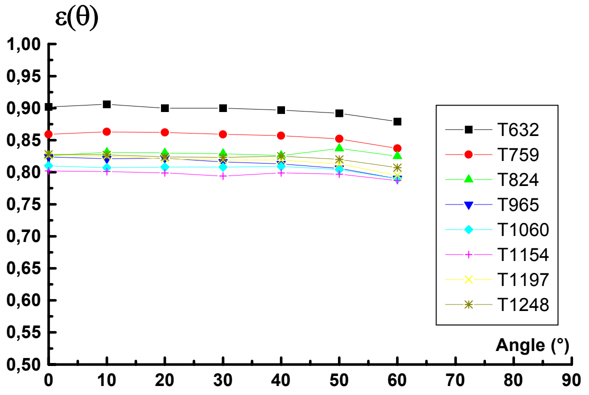

Figure 12 : CFC N11 at 8-12 µm

CONCLUSION

Tungsten and Carbon Fiber Composite CFC N11 samples from CEA Cadarache were tested at the MEDIASE facility. Bi-color pyroreflectometry could be used to measure both the true temperature and the emissivity on tungsten but not on CFC N11.

The use of a spherical probe prohibited emissivity measurements at 1.3 and 1.55 microns. These measurements are planned for 2005 using a dedicated experimental set-up called DISCO.

Emissivity of W and CFC N11 were measured at 5 and 8-12 microns. At 5 microns, the results obtained for W (emissivity as low as 0.10-0.40 for 750 < T(°C) < 1550) are consistent with results obtained at FE200 facility with an infrared device working in the range 3-5 microns.

The results for CFC N11 (emissivity as high as 0.75-0.90 for 600 < T(°C) < 1250) are consistent with results obtained at FE200 facility with an infrared device working in the range 3-5 microns and at SATIR facility with an infrared device working in the range 8-12 microns. The glass blasted tungsten yielded in the first heating cycle different values than later. The other samples did not sohow such variations.

REFERENCES

[1] D. Hernandez - A new concept to determine the true temperature of opaque materials using a tricolor pyroreflectometer - publication accepted in 2004 to be published in 2005 in Review of Scientific Instruments.

[2] M. Balat-Pichelin, D. Hernandez - Concentrated Solar Energy as a diagnostic tool to study materials under extreme conditions - Journal of Solar Energy Engineering Vol. 124 pp 215-222 august 2002.

[3] D. Hernandez, et al. - Bicolor pyroreflectometer using an optical fibre probe - Rev. Sci. Instr. 66 (1995), 5548.

REPORTS AND PUBLICATIONS

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