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The emissivity of W coatings deposited on carbon materials for fusion applications

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HIGHLIGHTS

- The emissivity of tungsten coatings deposited on carbon substrates such as CFC and fine grain graphite was measured at the wavelengths of 1.064 μm, 1.75 μm, 3.75 μm and 4.0 μm in the temperature range of 400 °C–1200 °C.
- The emissivity of other materials of interest for nuclear fusion such as tungsten and beryllium was measured as well.
- The influence of substrate structure and of the viewing angle on the emissivity of W coatings was investigated in detail.

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ABSTRACT

Tungsten coatings deposited on carbon materials such as carbon fiber composite (CFC) or fine grain graphite are currently used in fusion devices as amour for plasma facing components (PFC). More than 4000 carbon tiles were W-coated by Combined Magnetron Sputtering and Ion Implantation technology for the ITER-like Wall at JET, ASDEX Upgrade and WEST tokamaks.

The emissivity of W coatings is a key parameter required by protection systems of the W-coated PFC and also by the diagnostic tools in order to get correct values of temperature and heat loading. The emissivity of tungsten is rather well known, but the literature data refer to bulk tungsten or tungsten foils and not to coatings deposited on carbon materials. The emissivity was measured at the wavelengths of 1.064 μm, 1.75 μm, 3.75 μm and 4.0 μm.

It was found that the structure of the substrate has a significant influence on the emissivity values. The temperature dependence of the emissivity in the range of 400 °C–1200 °C and the influence of the viewing angle were investigated as well. The results are given in a table for W coatings and for other materials of interest for fusion such as bulk W and bulk Be.

1. Introduction

Tungsten coatings deposited on carbon materials such as carbon fiber composite (CFC) or fine grain graphite (FGG) are currently used in fusion devices as amour for plasma facing components (PFC). More than 4000 carbon tiles were W-coated by Combined Magnetron Sputtering and Ion Implantation (CMSII) technology for JET, ASDEX Upgrade and WEST tokamaks [1]. The emissivity of W coatings is a key parameter required by protection systems of the W-coated PFC and also by diagnostic tools in order to get correct values of temperature and heat loading of PFC. The emissivity of tungsten is rather well known, but the literature data refer to bulk tungsten or tungsten foils [2,3]. Extensive research on the spectral emissivity and optical properties of tungsten was performed by L. D. Larrabee [4], but mainly at the wavelengths of 0.3-0.8 μm. More recently the emissivity of W material for ITER divertor was investigated at 4.0 μm at CEA, Cadarache [5].

To the best of our knowledge there is no literature data concerning the emissivity of W coatings deposited on carbon materials. The first investigations were carried out at the wavelength of 1.064 μm and the data are used for the protection system of the ITER-like Wall (ILW) at JET. Since the scientific cameras at JET work at 4.0 μm and

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[1] See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia.

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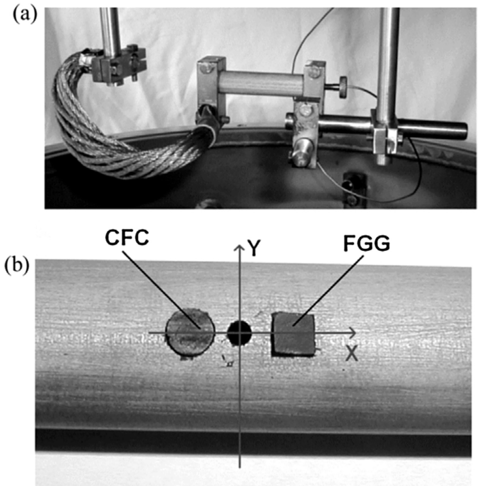

Fig. 1. The W-coated CFC tube with the supports and thermocouple (a) and the black body (central hole) and two CFC and FGG pins (b).

the wavelengths of 1.75 μm and 3.75 μm are of interest for WEST tokamak the research on emissivity of W coatings was extended for these wavelengths too. The results are presented in this paper.

2. Method and experimental setup for measuring the emissivity

The emissivity is defined as the ratio between the radiation intensity emitted by the surface of interest (I_{coat}) and the radiation intensity produced by a black body (I_{bb}) at the same temperature and wavelength after subtracting the background (I_0) that is measured near to the heated zone.

$$\varepsilon = (I_{coat} - I_0)/(I_{bb} - I_0) \quad (1)$$

The W coating with a thickness of 10 μm or 20 μm was applied on tubes (Φ16 × 0.8 × 85 mm) made of Dunlop DMS 780 CFC, N11 CFC or SGL fine grain graphite R6710 (FGG). A hole of Φ2.0 mm was drilled in the middle of the tube to play the role of black body. A K type thermocouple was introduced into the tube through an end and the welding was in contact with the wall (Fig. 1a). The W coated tube was heated by electric conduction using a high current power supply (I_{max} = 300 A, U_{max} = 6 V) up to 1200 °C. The tube temperature was monitored by an IR pyrometer as well.

For measurements at 1.064 μm a Hitachi video camera type KP-M1AP, identical with those from the protection system of the ILW at JET, was used. Since an IR camera was not available for higher wavelengths a new technique was developed and applied. Instead of taking simultaneously the image of the entire W-coated component, a single pixel IR detector together with the IR optics (chopper, lens and filters) was moved in X and Y directions for distances of 20 × 20 mm using an X-Y motorized stage. The step was 0.125 mm.

For 1.75 μm an InGaAs IR detector type PDA20H (1.5–4.8 μm, 0.2 mm^2) was used. An IR TE-cooled detector type PDA10JT HgCdTe amplified with TEC, 2.0–5.4 μm, 1.0 × 1.0 mm, AC-Coupled Amplifier, with a detectivity of 10^{10} cm $Hz^{1/2}$/W at −30 °C was used for measurements at 3.75 μm and 4 μm. The noise equivalent power was $2.0 \cdot 10^{-11}$ W $Hz^{1/2}$. Using an aperture of 0.2 mm just below the detector the space resolution of the system was about 0.2 mm. Both detectors were supplied by Thorlabs. The IR measuring system and the diagnostics were installed on the top lid of the vacuum chamber. A sapphire window ensured the vacuum sealing below the IR optics. The FWHM of the bandpass filters were 50 nm for 1.064 μm and 250 nm for the other wavelengths.

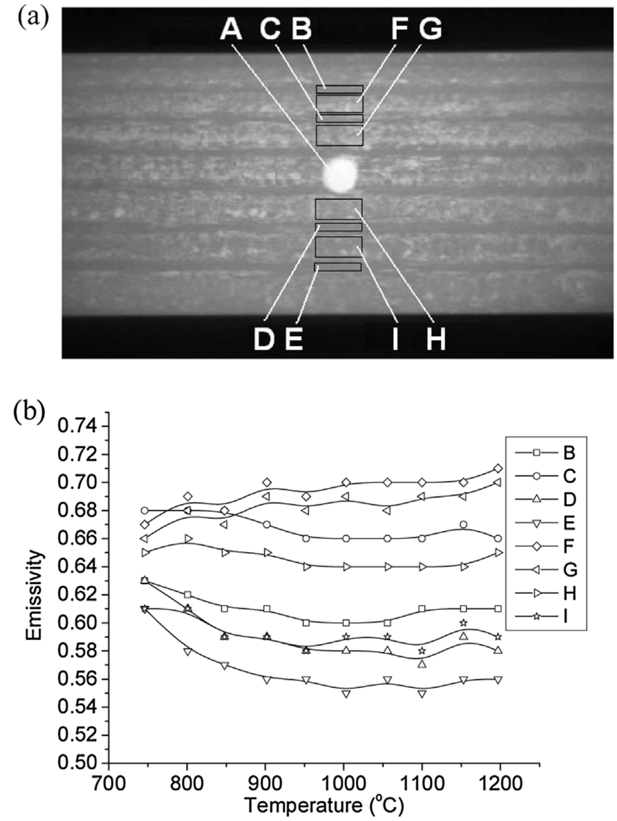

Fig. 2. IR image at 1.064 μm (T = 1172 °C) (a) and the emissivities for the regions of interest (b).

3. Experimental results and discussion

3.1. Measurement of emissivity at 1.064 μm

A typical IR image of the W-coated tube taken at the temperature of 1172 °C, (λ = 1.064 μm) and the temperature dependence of the emissivities for a few regions of interest (A, B, C, etc.) are shown in Fig. 2.

A strong influence of the CFC structure particularly of the porosity can be seen. The pores have the tendency to act as black bodies. This leads to a relatively large spread of the emissivity values (0.63 ± 0.07).

The influence of the viewing angle on the emissivity of 10 μm W coating deposited on FGG measured at 800 °C is shown in Fig. 3.

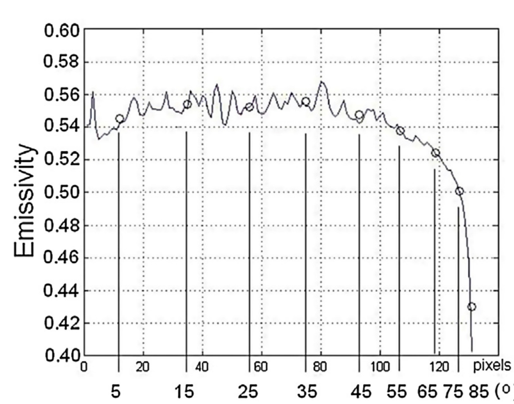

Fig. 3. Influence of the viewing angle on the emissivity of 10 μm W coating on FGG.