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Development of the in-situ calibration method for ITER divertor IR thermography

ITERダイバータIRサーモグラフィーのためのその場較正手法の開発

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In ITER divertor IR thermography, the in-situ calibration of emissivity on the divertor targets is important because emissivity will change due to changes in surface properties. Therefore, the laboratory experiment for the development of the in-situ calibration method by using an IR laser was performed. The emissivity of tungsten samples heated up to 1000 degC were evaluated from the photons in the wavelength of 3-5 μm measured by an IR camera. The angle profiles of the scattered light of the IR laser with 3.22 μm were obtained. The relation between emissivity and scattered light is under investigation.

1. Introduction

In ITER, divertor IR thermography (IRTh) [1, 19PB-082 in this conference] for measurement of surface temperature on divertor targets with high resolutions in both time (2 ms - 20 μs) and space (3 mm) has been designed by Japan. In IRTh, the in-situ calibration of emissivity on the divertor targets is important because emissivity will change due to changes in surface properties (surface roughness) caused by depositions, erosions and re-crystallization. Moreover, emissivity has the dependence on the surface temperature, wavelength and emission angle. Though the calibrations in the phase of maintenance and baking can be utilized, in-situ calibration method in plasma operation phase has not yet developed. Therefore, laboratory experiments for development of the in-situ calibration method have been performed by using an IR laser since the last year [2].

2. Principle of the in-situ calibration method of emissivity by using an IR laser

We consider the situation that an IR laser is irradiated to the divertor target at the angle of θ_{IR} as shown in Fig. 1. The observed IR camera is also set in same angle. The IR laser is scattered and absorbed at the divertor target. The intensity of the IR laser is expressed as

$$I_{laser} = \int_{-\pi}^{\pi} I_{scat}(\theta_{scat}) d\theta_{scat} + I_{abs} \quad (1),$$

where I_{scat} is the intensity of the scattered light and I_{abs} is the intensity of the absorbed light. The angle of θ_{scat} is based on the direction of the specular reflection of the IR laser. From the Planck's radiation law, the emissivity of the divertor target is expressed as

$$\varepsilon(T_{div}, \lambda, \theta_{IR}, R_a) = I_{scat}(2\theta_{IR})(hc/\lambda)/[\frac{2\pi hc^2}{\lambda^5}\frac{1}{\exp(hc/\lambda kT_{div})}] \quad (2),$$

where T_{div} is the temperature of the divertor target, λ is the wavelength of the IR laser, R_a is the surface roughness of the divertor target, h is Planck constant, c is light speed and k is Boltzmann constant. If both λ and T_{div} are same and R_a is changed from the initial state to the calibration state, the emissivity of the divertor target in the angle of θ_{IR} at the calibration is expressed by the measuring the ratio of the scattered lights as

$$\varepsilon_1(T_{div}, \lambda, \theta_{IR}, R_{a1}) = \frac{I_{scat1}(2\theta_{IR})}{I_{scat0}(2\theta_{IR})}\varepsilon_0(T_{div}, \lambda, \theta_{IR}, R_{a0}) \quad (3),$$

where the subscripts of 0 and 1 mean the initial state and the calibration state, respectively.

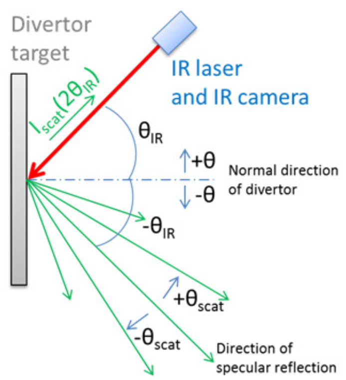

Fig. 1. The schematic of the irradiation of the IR laser to the divertor target.

Therefore, the relation of the scattered light and the emissivity needs to be investigated in the laboratory experiment.

3. Experimental setups

The IR laser with the wavelength of 3.22 μm was irradiated from the angle of $\theta_{IR\ laser}$ = 5.0 deg. against to the angle of the IR camera ($\theta_{IR\ camera}$ = 0 deg.) as shown in Fig. 2. The tungsten samples (R_a = 0.3, 1.0, 2.3 and 5.9 μm) can be heated up to ~1000 degC in the vacuum chamber by a graphite heater to clarify the dependence of emissivity on temperature. The angle of the tungsten can be changed to clarify the effect of the inclined divertor target and baffle against to the line of sight of the IR camera. The eight band-pass filters in the range of 3-5 μm were used to clarify the dependence of emissivity on the wavelength. In the IR laser irradiation, band-pass filter of 3.22 μm with narrow bandwidth (0.06 μm) was used.

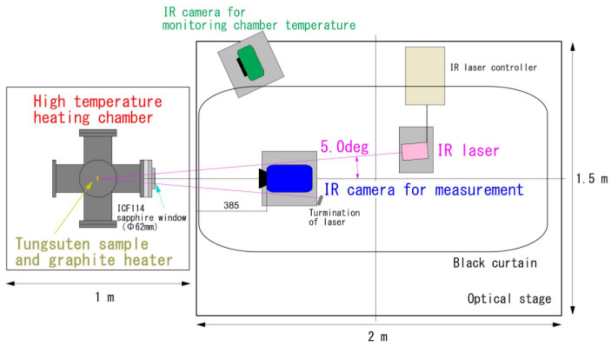

Fig. 2. Arrangement of experimental instruments for the development of in-situ calibration method.

4. Experimental results

In first, the detectivity of the IR camera with band-pass filters was calibrated by a blackbody. The detectivity was almost constant in the temperature range of 350-600 degC. Therefore, detectivity was averaged in the range and the value was used in other temperature range.

Next, the emissivity was evaluated from the photons measured by the IR camera. The emissivity does not have strong dependence on both the wavelength in 3-5 μm and the temperature in 400-1000 degC. As the surface roughness is larger, the emissivity showed the higher value from 0.2-0.6.

Figure 3 shows the IR camera images with the 3.22 μm band-pass filter in the irradiation of the IR laser to the tungsten sample of R_a = 1.0 μm heated to 400 degC. The surface temperature was measured by a thermocouple and the exposure time of the IR camera was 400 μs. The scattered light was averaged in the area which was irradiated the IR laser and evaluated by subtracting the data in laser off. By rotating the tungsten sample from the angle of θ_w = -55 to +75 deg., the angle profiles of the scattered light of the IR laser were obtained as shown in Fig. 4. As the surface roughness was smaller, the angle profile of the scattered light of IR laser became to be peaked at the tungsten angle of θ_w = 0 deg. The relation between emissivity and scattered light is investigating and will be discussed in the conference.

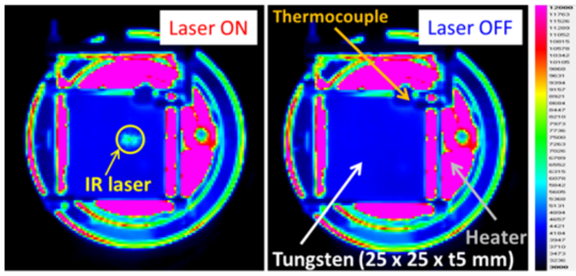

Fig. 3. The IR camera images in the irradiation of the IR laser to the tungsten sample.

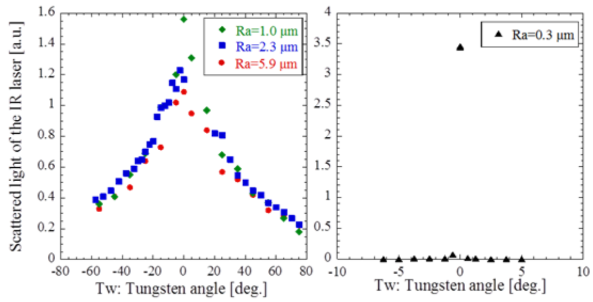

Fig. 4. The angle profiles of the scattered light of the IR laser in irradiation to the tungsten samples. The surface temperature of tungsten is 22 degC.

Acknowledgments

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The views and opinions expressed herein do not necessarily reflect those of the ITER organization.

References

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