Infrared imaging bolometer on the HL-2A Tokamak

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1. Introduction

Plasma radiation plays an important role in the overall power balance of the plasma, and the precise accountability of power balance is always significant for the understanding of particle and heat transport[1-2]. As the progress of magnetic fusion studies beyond the relatively simple axisymmetric magnetic configurations of tokamaks to be the more complex, three-dimensional geometries calls for the development of two-dimensional diagnostics. This motivated the development of the infrared imaging bolometer, which absorbs the broadband radiation from nearly all spectral regions from the plasma[3-5]. It utilizes a gold thin foil to absorb the plasma radiation and an infrared camera to monitor the temperature evolution of this foil. Then with a numerical technique the distribution of plasma radiation on the foil can be deduced by solving two-dimensional heat diffusion equation[4].

HL-2A is a middle-size tokamak device with a closed divertor, its major radius $R = 1.65m$ and its minor radius $r = 0.4m$ [6]. In order to get the profiles of plasma radiation from the core and X-point region, which are needed to study in detail the radiative process, an infrared imaging bolometer have been developed on HL-2A recently. It covers the main plasma and throat region of divertor. And the preliminary results show that during ECRH the gradient of foil temperature increases suddenly and the deduced plasma radiation power is consistent with the incident radiated power measured by AXUV detector. The image taken from divertor discharge shows the structures of throat region of divertor clearly.

2. Infrared imaging bolometer and its first commissioning on HL-2A

The infrared imaging bolometer on HL-2A is designed to detect the plasma radiation tangentially, which is shown in a computer aided design (CAD) drawing in Fig.1. The infrared imaging bolometer consists of a $5 \times 5mm$ pinhole, foil detector, light shield tube, ZnSe window and IR camera. In the foil detector, a $100 \times 100 \times 0.001$ mm gold foil is sandwiched by two plates of $130 \times 110 \times 3.8$ mm stainless steel. After the foil and the frame assembled, the foil and frame are blackened on both side in order to promote thermal absorptivity on the plasma side and emissivity on the IR camera side. The ZnSe window is coated for a flat IR transmission of greater than 95% over the wavelength range of $6-14\mu m$. The IR camera is a FLIR SC3000 model with a Quantum Well Infrared Photodetector (QWIP). The wave-length range of the camera is $8-9\mu m$, and the frame rate is 60 Hz for 320×240 pixels, and the nominal sensitivity is 30mK at $30°C$. The camera is equipped with a telephoto lens with a field of view of $9\times 7°$.

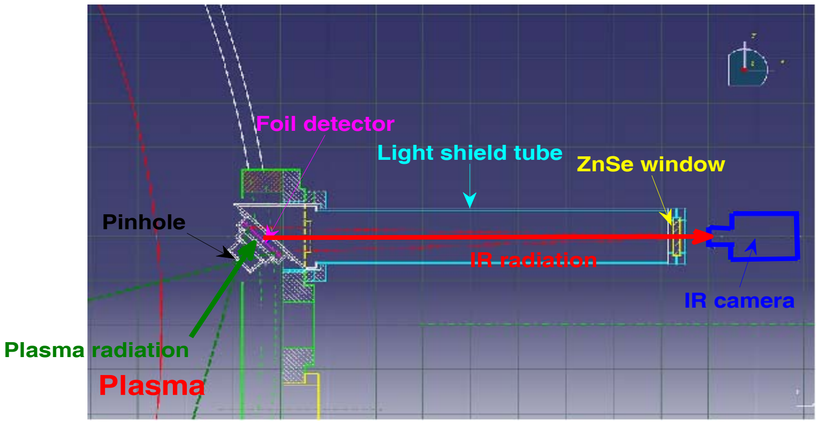

Fig.1. CAD drawing of side view of the infrared imaging bolometer on HL-2A

In order to determine the incident radiated power density distribution, the calibration technique described in Ref.7 is used to obtain local foil properties such as the thermal diffusivity κ and the product of thermal conductivity k and thickness t_f of the foil with graphite film. The foil detector is divided into 14×14 bolometer pixels and these parameters of each pixel are determined by comparing the measured temperature profiles(for kt_f) and their delays (for κ) with the corresponding results of a finite element model using the measured HeNe laser power profile as a known radiation source. Then a noise equivalent power density (NEPD)[5] is calculated of $1.65W/m^2$ for this diagnostic.

The two-dimensional heat diffusion equation is taken as following:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=\frac{1}{\kappa}\frac{\partial T}{\partial t}+\Omega_{bb}-\Omega_{rad} \tag{1}$$

Where the term on the left is the two-dimensional Laplacian term, $\Omega_{bb}=\varepsilon\sigma_{SB}(T^4-T_0^4)/kt_f$ is the blackbody radiation loss term, $\Omega_{rad} = S_{rad} / kt_f$ (S_{rad} is the incident radiation power density) is the radiation source term. With the parameters mentioned above, an image of radiated power density taken from limiter discharge 12352 at 600ms is shown in Fig. 2(a). The operational parameters for this discharge are $r = 38cm$, $I_P = 156kA$, $B_t = 1.39T$, $n_e = 1 \times 10^{19} / m^3$ and 0.8MW ECRH for on-axis heating. In order to demonstrate their accuracy, time evolution of the power density from a pixel is compared with that of an AXUV detector, which is obtained from the data of a AXUV array. With Abel inversion technique, the power density alone the same sight line of the pixel is calculated with the condition that plasma radiation is toroidal symmetric, as shown in Fig.2(b). In addition to this, the original data of the pixel (as shown in the Fig. 2(a)) are also given out. At the beginning of ECRH, the gradient of foil temperature increases suddenly, which should be responsible for the more intense radiation corresponding to the incident radiated power measured by AXUV detector.

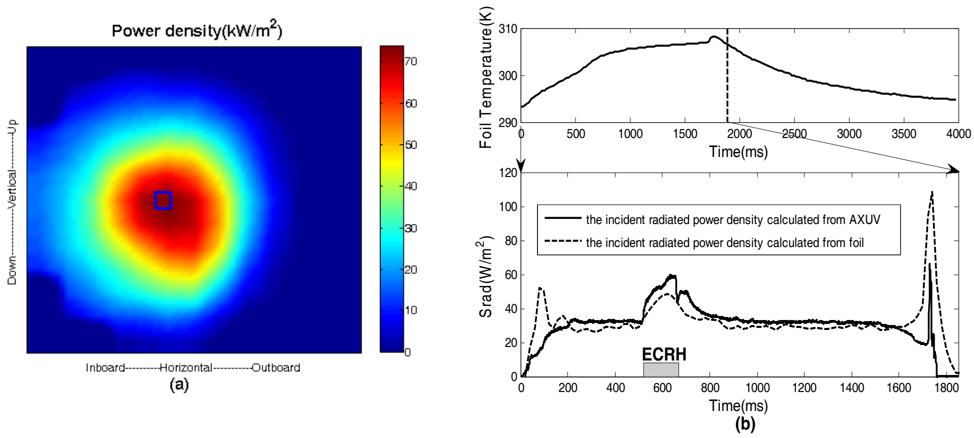

Fig.2. (a) Image of plasma radiation and a pixel used for comparison (the blue square). (b) Raw data from infrared imaging bolometer (top) and radiated power density compared with AXUV measurement (bottom).

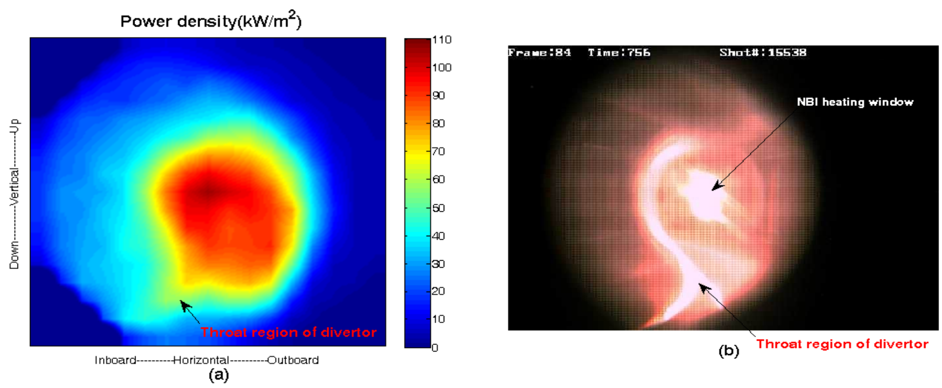

Fig.3. (a) Image of radiation from infrared imaging bolometer during a divertor discharge #15538 and (b) an corresponding image from CCD camera.

Fig.3(a) shows an image of plasma radiation during discharge #15538 with the lower single null divertor configuration. Because of high impurity density and high recycling around throat of divertor, high radiation is shown in this region comparing with Fig2.(a). And a simultaneous image from a CCD camera, which is used to grab plasma image tangentially, is also shown in Fig.3(b). Comparison of the two images show very similar features around throat of divertor.

3. Summary

An infrared imaging bolometer has been developed in HL-2A tokamak with 14×14 bolometer pixels and a NEPD of $1.65W/m^2$ for this diagnostic. And good qualitative agreement is observed by comparison of the bolometric result with conventional bolometric data and the comparison of the bolometric image with a corresponding image from a CCD camera for visible light. The next step in this research is to carefully calibrate to get more accurate data. And the data from the infrared imaging bolometer will then be used to attempt the two-dimensional tomography of plasma radiation including the core and X-point region with three-dimensional treatment of detector geometry.

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