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Measurement of the 2-dimensional Plasma Radiation Structure during Asymmetric Radiative Collapse by a Tangentially Viewing Infrared Imaging Video Bolometer on LHD

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Abstract

The infrared (IR) imaging video bolometer (IRVB) is a new type of plasma radiation measurement system, which uses an IR camera. For the 4th LHD campaign (2000), the IRVB type has been installed at a tangential port. Very clear helical plasma radiation structures were measured which agreed well with corresponding images of CIII radiation from a CCD camera. A change in the two-dimensional spatial distribution of the radiated power is observed during radiative collapse of the plasma which indicates that the asymmetric radiation is coming from the lower inboard side.

Keywords:

bolometric diagnostics, plasma radiation, 2-D structure, IR camera

1. Introduction

Bolometric measurements of total plasma radiation have long provided important information on the energy losses from plasma due to radiation by impurities [1]. Tomographic analysis of data from multiple one-dimensional bolometer arrays has provided two-dimensional information on the source of radiation in the plasma [2]. This information on plasma radiation structures is useful for the study of radiative phenomena.

The infrared (IR) imaging bolometer (IRIB) is a new type of plasma radiation measurement system, which uses an IR camera [3-5]. The IRIB uses a foil sandwiched between two identical masks to absorb the plasma radiation. The increase in the foil temperature due to the radiation is measured with an IR camera. The key feature of the IRIB is that using readily available IR imaging technology, a measurement of two-dimensional spatial radiation profiles is very easy. We have two mask patterns which are the Segmented Mask Imaging Bolometer (SIB) [6] and the Infrared Imaging Video Bolometer (IRVB) [5,7]. The SIB consists of a segmented array of foils formed by sandwiching a thin foil between two copper masks having identical hole patterns. The IRVB consists of one large thin foil held by the edges in a copper frame. In this paper we show images from the IRVB with a tangential view [7] taken during the 4th cycle which demonstrate its ability to provide two-dimensional measurements of three-dimensional radiative structures in LHD.

2. Experimental Setup

In this study we use the IRVB having a tangential view of the plasma shown in Figs. 1 and 2. The IRVB

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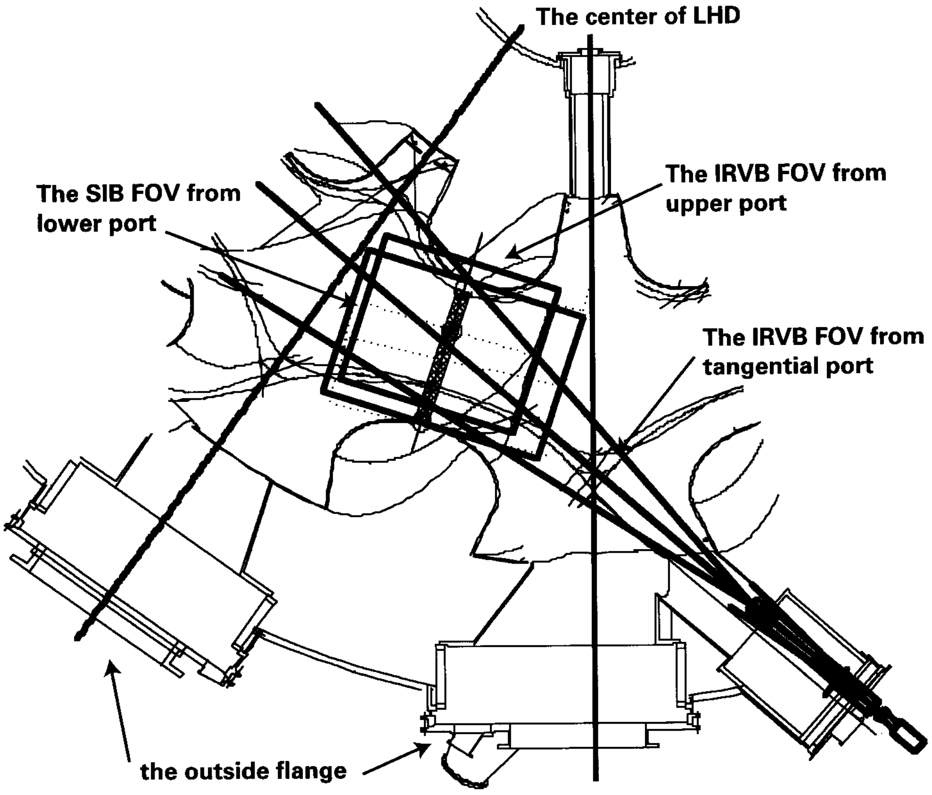

Fig. 1 Top view of LHD midplane, showing the field of view of each IR bolometer. The data discussed in this paper comes from the bolometer with the tangential view. The other two are for IR bolometers which have been installed at top and bottom ports for future use.

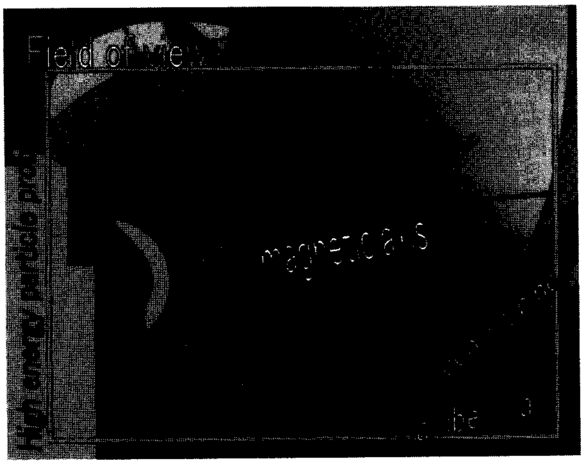

Fig. 2 CAD drawing of the field of view of the IRVB at the tangential port on LHD.

uses a 90 mm (horizontal) × 66 mm (vertical) × 1 mm gold foil. The Large Helical Device (LHD) is a large-scale superconducting heliotron system with a set of l/m=2/10 helical coils. Since the 1998 experimental campaign it has been operated with R/a=3.6~3.9/0.6 m, B_t=1.5~2.75 T, n_e=0.6~7.0×10^{19} /m^3, T_e=0.5~2 keV and T_i=0.5~2 keV [8]. For the diagnosis of the total plasma radiation, several resistive metal film bolometry systems were installed in different ports [9]. For the year 2000 LHD campaign IR bolometers have been installed in tangential, lower and upper ports on LHD as shown in the top view of LHD in Fig. 1. The presently used IR camera is an Agema Thermovision 900LW. The spectral response of the Mercury Cadmium Telluride (MCT) detector is 8–12 μm and it uses a stirling cycle cooler. The total numbers of pixels are 272 by 136, at a 15 Hz frame rate. To avoid a strong magnetic field effect, an iron magnetic shield covers this camera. The foil area is divided up numerically into 14 (horizontal) × 10 (vertical) bolometer channels. That means that one IR bolometer pixel consists of the average of 100 IR camera pixels. The sensitivity determined in part by the number of spatial channels used for this study has a noise equivalent power density of approximately 0.6

mW/cm^2. More details about the calculation of the sensitivity and the IRVB diagnostic are given elsewhere [5,7].

3. Experimental Results

Figure 3 shows the discharge summary for LHD shot #20740. This shot has three fueling pellet injections. Immediately after injection of the final pellet the plasma was prematurely terminated by radiative collapse as the plasma stored energy was rapidly reduced from its peak to zero, while the NBI continued according to plan. In Fig. 4 the brightness profiles during the final portion of the NBI discharge are shown from a resistive bolometer array set at a vertically elongated cross-section in the field of view of the IRVB. This contour plot shows the brightness profile changing from a symmetric profile prior to 1.04 s, to one that is asymmetric on the inboard side during the collapse from 1.09 to 1.14 s, to a symmetric peaked brightness profile during the NBI shine through phase after 1.14 s. This type of asymmetric radiation structure is commonly observed when the plasma reaches the density limit in LHD and has many features similar to the multifaceted asymmetric radiation from the edge (MARFE) in tokamaks [10]. Previous observations of this phenomenon using various diagnostics at different toroidal locations have indicated that it may be axisymmetric as in a tokamak even though LHD has a non-axisymmetric magnetic field and vacuum vessel [11]. At the vertically elongated cross-section we have observed an inboard asymmetry in density and radiated power [10]. At the horizontally elongated cross-section we have observed a symmetric up/down radiation profile [10] and an asymmetric temperature profile with lower temperature on the inboard side [11] indicating stronger radiation on the inboard side. However these data leave some unanswered questions about the three-dimensional structure of this asymmetric radiative phenomenon. Therefore it is very interesting to look at this asymmetric radiative collapse with the tangentially viewing IRVB.

The IRVB images from the three time frames corresponding to each of these phases are shown in Fig. 5. The IRVB image from the period approximately corresponding to the phase with a symmetric brightness profile prior to t = 1.04 s is shown in Fig. 5(a). In this image the IR bolometer observes a very clear helical radiation structure. The line drawn from "A" to "D"

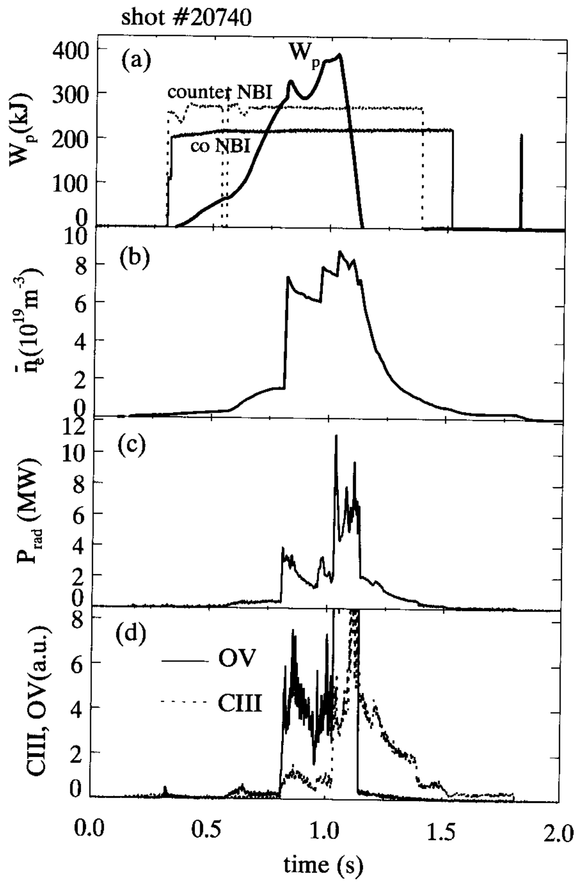

Fig. 3 Discharge summary for LHD shot #20740 with (a) stored energy from diamagnetic measurements and NBI timing, (b) line-averaged electron density, total plasma radiated power from resistive bolometers and (d) spectroscopic signals from CIII and OV.

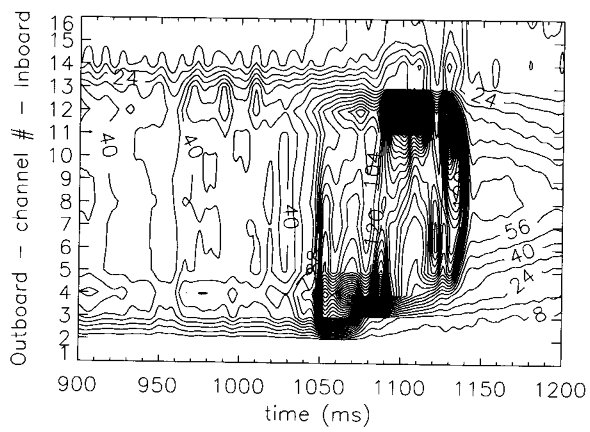

Fig. 4 Contour plot of radiation brightness from the resistive bolometer array at a bottom port viewing a vertically elongated cross-section.

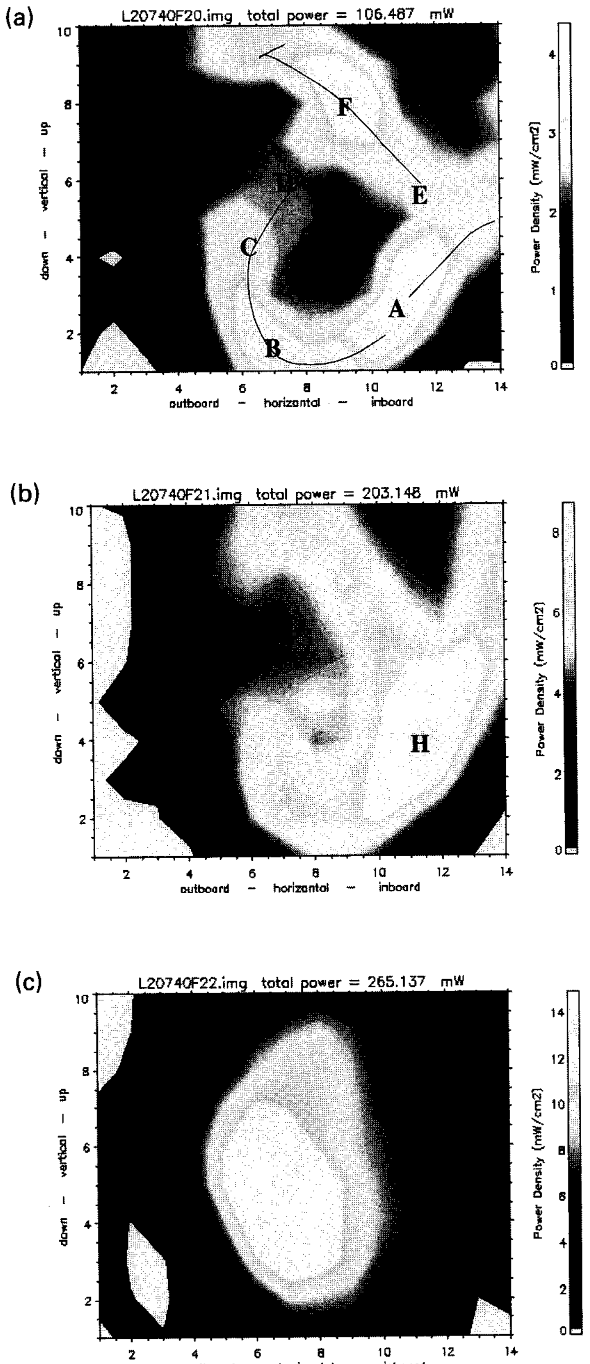

Fig. 5 Image of two-dimensional radiation from tangentially viewing IRVB at (a) t = 1.02 s, (b) t = 1.09 s and (c) t = 1.16 s, for LHD shot #20740.

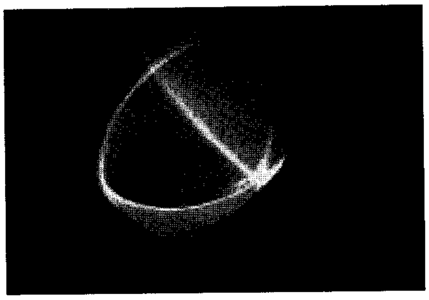

Fig. 6 Image of CIII radiation from a tangentially viewing CCD camera at t = 1.02 s for LHD shot #20740.

represents one edge field line of the plasma. The nearest point "A" to the mask of the IRVB shows a high radiation intensity. As it goes to the far point "D", the intensity is reduced. The line drawn from "E" to "F" corresponds to another edge field line. Where it crosses the other field line at point "F" we observe another bright spot. The point "G" near the center of the IRVB data measures radiation predominantly from the core plasma, and there plasma radiation intensity is lower than from the edge plasma regions as has been typically observed during the steady-state portion of plasmas in LHD [9]. This is a typical helical radiation structure of LHD plasma from a tangential view. The edge of the field of view as defined by the vacuum vessel walls and other structures is well reproduced by the dark edges of this image. A simultaneous image from a CCD camera using a CIII filter and having nearly the same view of the plasma is shown in Fig. 6. Both images show the helical structure of the radiation coming from the edge of the plasma.

In Fig. 5(b) the next time frame from the IRVB shows the radiation image during the asymmetric radiative collapse roughly corresponding to the time period from 1.09 to 1.14s. Compared to the previous IRVB image in Fig. 5(a), the radiation pattern is changed to a less helical structure and is more localized near the lower inboard edge that is point "H". One notes that the maximum radiation power density is different, for example the point "A" in Fig. 5(a) is about 4mW/cm^2 but the point "H" in Fig.5(b) is about 8mW/cm^2. This image confirms the observation from the resistive bolometers that the asymmetry occurs on the inboard side, and adds new information about the vertical position of the asymmetric structure of the radiation during the collapse of the plasma.

In Fig. 5(c) the image from the beam shine-through period of the discharge corresponding to the time after 1.14 s is shown. In the resistive bolometer brightness profile data shown in Fig. 4 a peaked symmetric profile at a lower level compared to the asymmetric period is seen during this period. This radiation is interpreted to be mostly due to carbon coming from the graphite beam dump as confirmed by the strong CIII signal seen in the shot summary in Fig. 3(d). In the IRVB image of Fig. 5(c) we see a signal coming from the core of the plasma which is devoid of any of the asymmetric or helical features of the previous two images. Also we see a much stronger signal than that of the previous image during the collapse which is in contrast to the weaker signal seen in the resistive bolometers. The source of this strong central signal in the IRVB image during the beam shine-through period is believed to be the shine-through neutrals which can be measured easily by the tangentially viewing IRVB compared to the perpendicularly viewing (from the bottom) resistive bolometer arrays.

4. Conclusions and Discussion

Results from an imaging bolometer with a tangential view have been presented. Two-dimensional images of the helical structure of radiation in LHD have been shown and compare well with CCD images of CIII light. Also, a change of the radiation structure during asymmetric radiative collapse of the plasma has been observed. In addition to confirming the results from the resistive bolometer arrays, which show an inboard asymmetry in the radiation, the IRVB adds information about the vertical position of the asymmetric radiation showing it to be coming from the lower inboard region of the plasma. This result demonstrates that IR bolometer spatial resolution is adequate to provide new information on the structure of radiative phenomena in LHD.

During the year 2000 campaign we hope to bring on-line an additional imaging bolometer with a top view of the plasma (as shown in Fig. 1). The ultimate goal of this imaging bolometer development program is to perform three-dimensional tomography of the LHD plasma. Using these imaging bolometers in conjunction with data from conventional resistive bolometer arrays and other plasma diagnostics we plan to study the three-dimensional structure of radiative phenomena in LHD including asymmetric radiative collapse, radiation from magnetic island structures and from plasma-limiter interaction.

Acknowledgements

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