§19. Improvement of Four Infrared Imaging Video Bolometer Systems in LHD

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The InfraRed imaging Video Bolometer (IRVB) is a powerful diagnostic to measure plasma radiation profiles especially for three-dimensional measurements. Currently four IRVBs are operating in LHD to investigate the radiation collapse and plasma detachment phenomena. The FoVs in the LHD equatorial plane are shown in Figure 1. IRVBs at 6-T and 10-O ports have a tangential view in the clockwise direction and a semi-tangential view in the counter clockwise direction, respectively, and the other IRVBs at 6.5-U and 6.5-L ports have vertical views for the three-dimensional tomography. These four FoVs can cover the whole region of the LHD plasma with the assumption of a helical periodicity[1].

These systems were improved from the 17th experimental cycle[2] : by (i) replacement of the IR cameras at the 6.5-L and 10-O ports, (ii) installation of a periscope system at the 6.5-U port. The IR cameras at the 6.5-L and 10-O ports were replaced from FLIR/Omega to FLIR/A655sc and FLIR/SC500 to FLIR/SC7600, respectively. The periscope system has been installed at the 6.5-U port to fit the field of view of the IR camera to the foil[3]. It consists of 3 camera lenses, a mirror and 3 relay lenses (including 2 in-vessel lenses). These lenses are made of ZnSe and Ge.

The sensitivities of the IRVBs at the 6.5-U, 6.5-L and 10-O ports were improved by the above upgrades. The sensitivity of the IRVB can be expressed as a noise equivalent power density (NEPD), S_{IRVB}, in Equation (1) [4].

$$S_{IRVB} = \frac{\sqrt{2}kt_f\sigma_{IR}}{\sqrt{f_{IR}N_{IR}}}\sqrt{\frac{5N_{bol}^3 f_{bol}}{A_f^2}+\frac{N_{bol}f_{bol}^3}{\kappa^2}}. \quad (1)$$

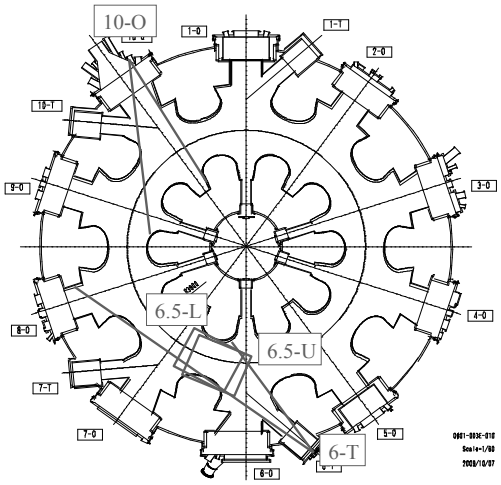

Fig.1 Location of IRVBs in LHD.

Here, k is the thermal diffusivity and 0.716 W/(cm·K) is used as the typical value of platinum. t_f is the foil thickness and 2.5 μm is assumed. σ_{IR} is the NETD of the IR camera including the effect of the F number of the optics and the maximum value of the specification of each camera divided by the square of the F number is applied. N_{bol} is the number of IRVB pixels and one IRVB pixel corresponds to 5×5 mm^2 on the foil. N_{IR} is the number of IR camera pixels utilized in the evaluation of the IR image in the LHD plasma experiment. A_f is the utilized area of the foil which corresponds to the foil size. f_{bol} is the frame rate of IRVB which is assumed to be the operating frame rate of the IR camera f_{IR}. The improvement of the IRVB parameters at the three ports are shown in Table 1.

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1) R. Sano *et al*., Plasma Fusion Res., **8**, 2402138 (2013).
2) K. Mukai *et al*., Plasma Fusion Res., **8**, 2402138 (2014).
3) S.N. Pandya *et al*., 40th EPS Conference on Plasma Physics (2012) P5.107.
4) B.J. Peterson *et al*., Rev. Sci. Instrum. **79**, 10E301 (2008).

Table 1 Improvement of IRVB parameters in LHD.

Port	6-T	6.5-U	6.5-L	10-O
Camera	FLIR/SC4000	FLIR/SC655	FLIR/OMEGA → FLIR/SC655	FLIR/SC500 → FLIR/SC7600
NETD [mK]	<25	<50	<100 → <50	<100 → <25
Pinhole size [mm×mm]	4×4	8×8	8×8	4×4
Foil size [cm×cm]	9×7	13×10	15×11	9×7
Foil thickness t_f [μm]	2.5 (typ.)	2.5 (typ.)	2.5 (typ.)	2.5 (typ.)
F number	1.35	1 → 1.35	2 → 1	1 → 1.15
N_{bol}	18×14	26×20	30×22	18×14
N_{IR}	307×237	180×149 → 528×408	80×63 → 171×126	227×171 → 586×458
A_f [cm^2]	9×7	13×10	15×11	9×7
f_{bol} [fps]	100	100 → 50	30 → 100	60 → 100
f_{IR} [fps]	100	100 → 50	30 → 100	60 → 100
S_{IRVB} [μW/cm^2]	395	687 → 226	4400 → 884	988 → 206