Estimation of Effective Responsivity of AXUV Bolometer in ADITYA Tokamak by Spectrally Resolved Radiation Power Measurement*)

Kumudni TAHILIANI, Ratneshwar JHA, Prabhat KUMAR and ADITYA Team

Institute for Plasma Research, Bhat, Gandhinagar-382428, India

(Received 9 December 2012 / Accepted 22 July 2013)

The radiation emission from ADITYA Tokamak is routinely measured using AXUV bolometers [K. Tahiliani *et al.*, Plasma Phys. Control. Fusion **51**, 085004 (2009)] and the total radiation power loss is estimated from these measurements assuming constant responsivity. This assumption is valid for the current flattop phase of the discharge, where the contribution from long wavelength radiation (> 620 Å) is expected to be small and the AXUV responsivity is almost constant. It is likely that in disruptive discharges, with significant edge radiation, a part of the unaccounted power is in the long wavelength range. A better approach is to experimentally determine an effective responsivity by spectrally resolving the radiation power loss and assigning appropriate weights to spectral ranges [S.D. Gray *et al.*, Rev. Sci. Instrum. **75**, 376 (2004)]. For this purpose, we have installed a multichannel filtered bolometer camera in ADITYA Tokamak. The wide angle view camera houses three single channel AXUV bolometers, of which two view the plasma through different ultraviolet filters and one has an unfiltered view. All the bolometers have the same poloidal view and are located adjacently in the toroidal direction. The initial results of the spectrally resolved bolometer measurements show that the radiation in the spectral range > 1200 Å is significant fraction of the total radiation during the disruptive phase, but doesn't contribute much during the flattop region. An effective average responsivity has been estimated for AXUV bolometer for ADITYA.

Keywords: bolometer, AXUV, radiation, filter, ADITYA, responsivity

DOI: 10.1585/pfr.8.2402124

1. Introduction

Bolometer diagnostic is indispensable for any tokamak. It measures the radiation power loss from a tokamak, which is a significant fraction of the input heating power and determines the confinement properties of the plasma. Also it is essential for the characterization of various plasma regimes.

Three kinds of bolometers are being used in the present day tokamaks. The metal foil bolometers are most widely used for they are robust, radiation hard and can be calibrated in-situ. IR bolometers are another kind that has been implemented in stellarators and tokamaks in recent years. They are preferred as there is no need of in-vessel cables. The third kind is the AXUV bolometers, which are photodiodes, sensitive to radiation over a wide range from visible to soft x-ray region. AXUV bolometers have high time and signal response and are immune to low energy charge exchange neutrals. These bolometers are routinely used in ADITYA tokamak for radiation power loss measurement [1].

The medium size tokamak ADITYA [2] is regularly operated with the transformer-converter power system. Discharges of 60 - 100 kA with the central electron density of $1 - 2 \times 10^{19}\,\mathrm{m}^{-3}$ and electron temperature of 400 - 600 eV are produced in ADITYA. The radiation power loss in ADITYA tokamak varies from 20% - 40% during the discharge flattop and is much higher towards the discharge end. It is measured using AXUV bolometers that have constant responsivity in the plasma emission region, 620 Å - 2 Å. Hence the radiation power loss can be estimated accurately during the flattop region of the discharge. There is however a loss in the response for photon wavelengths above 620 Å and it is likely that there is a significant contribution from such photons during the disruptive phase. It is therefore essential to estimate the contribution of long wavelength photons to the total radiated power [3]. In this paper we report on the results of the spectrally resolved radiation power measurement on ADITYA tokamak and we attempt to obtain the effective responsivity.

2. Spectrally Resolved Radiation Power Loss

Figure 1 shows the responsivity (the photocurrent generated by unit photon power) curve of the AXUV bolometer [4]. The responsivity is fairly constant for photon wave-

author's e-mail: kumud@ipr.res.in

*) This article is based on the presentation at the 22nd International Toki Conference (ITC22).

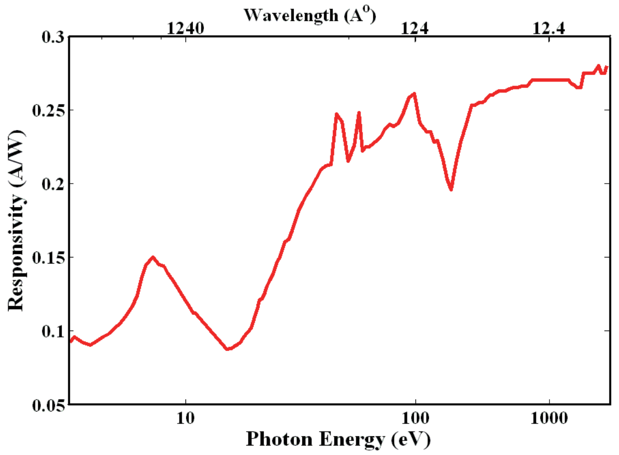

Fig. 1 Responsivity Curve for AXUV Bolometer.

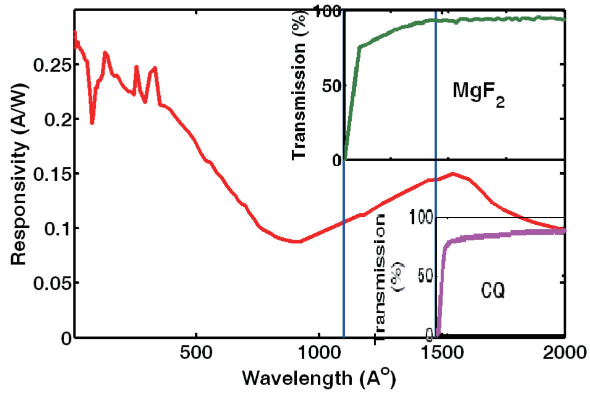

Fig. 2 Filtered AXUV Bolometer Response: Two filters viz. Magnesium Fluoride (MgF2) and Cultured Quartz (CQ) is used in front of the bolometers.

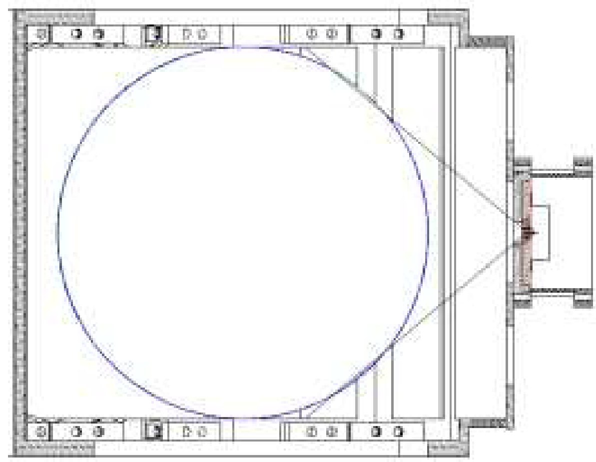

Fig. 3 Bolometer Field of view.

length below 620 Å but varies significantly above it. Using a constant value of 0.24 A/W for responsivity can lead to errors in the estimation of the radiation power loss if there is a significant contribution from the long wavelength region. This is due to the fact that the responsivity drops to as low as 0.1 A/W for such photons. And since the nature of the impurity and hence the spectrum of radiation is unique to each tokamak, spectral radiation power loss measurement is required for the determination of effective responsivity.

In order to determine the effective responsivity, we divided the radiation power loss in three spectral ranges: P_1 (< 1200 Å), P_2 (1200 Å - 1500 Å) and P_3 (> 1500 Å) based on the responsivity variation and on the availability of filters. The responsivity is assumed to be constant for region P_1. This is valid as a good comparison of the bolometer signal is observed with vacuum photodiode signal (VPD) [1] that are sensitive in the spectral range 100 Å - 1200 Å [5] and the responsivity is constant for lower wavelengths (< 100 Å). As mentioned earlier we used three single channel bolometers to measure the total radiation power loss. The first bolometer with no filter in the front gives the total radiation power loss, P. The second bolometer with a Magnesium Fluoride (MgF_2) filter measures the power above 1200 Å. And the third bolometer with a cultured quartz (CQ) filter measures the power above 1500 Å. The transmission curves for the two filters are shown in Fig. 2. We have assumed constant average transmission for the filters for analysis.

The effective responsivity is determined by using the filtered bolometer power measurements P_{MgF} and P_{CQ}, the unfiltered bolometer power and the responsivities R_1, R_2 and R_3 of the respective ranges as

$$R_{eff} = R_1 * P_1/P + R_2 * P_2/P + R_3 * P_3/P. \quad (1)$$

P_1, P_2 and P_3 are determined using the measured signals S′s (V), the preset gains G's (V/A) and the transmissions T's.

$$\begin{aligned} P_1 &= S/(G * T * R_1) - S_{MgF}/(G_{MgF} * R_{MgF} * T_{MgF}), \\ P_2 &= S_{MgF}/(G_{MgF} * R_{MgF} * T_{MgF}) \\ &\quad - S_{CQ}/(G_{CQ} * R_{CQ} * T_{CQ}), \\ P_3 &= S_{CQ}/(G_{CQ} * R_{CQ} * T_{CQ}). \end{aligned} \quad (2)$$

3. The Filtered Bolometer Camera

A filtered bolometer camera has been designed for the spectrally resolved radiation power measurement on ADITYA tokamak. The camera houses three single channel AXUV bolometers out of which two view the plasma through filters and one is without filter. All bolometers are located at similar poloidal locations and view the whole poloidal cross-section of the plasma (Fig. 3) and hence measure the total radiation from the plasma. There is a very small toroidal separation between the bolometers and since the camera is located far from the limiter hence the assumption of toroidal symmetry is valid. The current from the AXUV bolometers is amplified in two stages with the first stage having a fixed gain and the second stage having a variable gain. For the present experimental campaign the fixed gain for the three bolometers was set at 1000 V/A and the variable gain was set at 1 for P_B, 2 for P_{MgF} and 8 for P_{CQ}.

4. Results

We investigated the spectrally resolved bolometer measurements in two kinds of discharges, non-disruptive and disruptive. Figure 4 shows the discharge parameters for ADITYA discharge no. 25871 and Fig. 5 shows the signal from the three bolometers. We have compared the raw signals for the three bolometers since the geometric factor is same for each of them. These signals have been normalized by the corresponding variable gain factors. As seen, the total radiation power loss signal peaks at the start of the plasma and towards the end of the plasma discharge. Also it is clear that the signals P_{MgF} and P_{CQ} are significantly lower than P (< 0.1P) during the flattop and also during the startup phases. But towards the end of the discharge the P_{MgF} signal becomes comparable to the P signal. It is to be noted that we have not considered the varying responsivity and the filter transmission so far for the sake of comparison. Also we have seen that the factors are not significant. The average responsivity for the AXUV bolometer with CQ filter is 0.125 A/W. And the average transmission is 80 %. If this is taken into account the signal will slightly increase (factor of 2.4) but still the signal is low compared to the other contributions. For MgF_2 filtered bolometer with responsivity of 0.1 A/W and the average transmission of 0.75, the factor comes out to be 3.2.

Figure 6 shows the spectrally resolved radiation power signal calculated from Eq. (2). The major radiation power loss from the ADITYA tokamak during the flattop is in the range 2 Å - 1200 Å and around one tenth of this lies in the range 1500 Å - 2000 Å. There is not significant contribution from photon wavelengths 1200 Å - 1500 Å. Hence the effective value of responsivity can be taken as 0.24 A/W for the estimation of total radiation power loss during the flattop. Towards the end of the discharge the contribution from the radiation of wavelength 1200 Å - 1500 Å increases and so the effective responsivity will change from its flattop value.

We have compared the two signals P_{MgF} and P_{CQ} for a non-disruptive discharge (Fig. 7) and a disruptive discharge

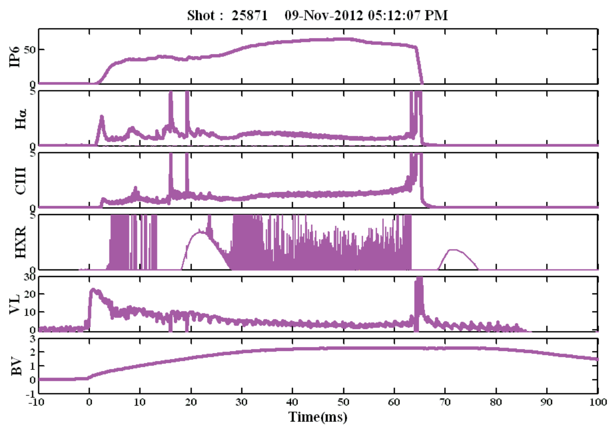

Fig. 4 The discharge parameter temporal profiles for ADITYA discharge #25871.

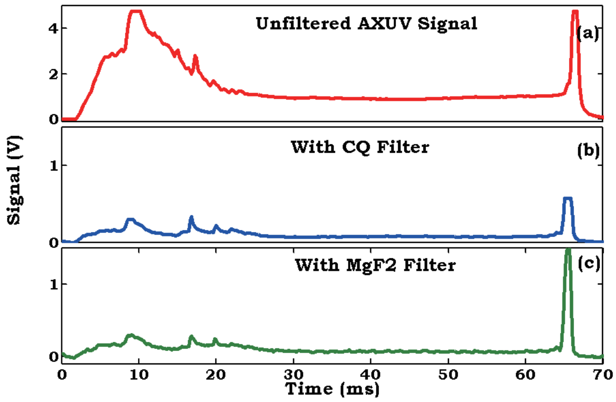

Fig. 5 Signal in the three bolometers: P_B (a), P_{MgF} (b) and P_{CQ} (c).

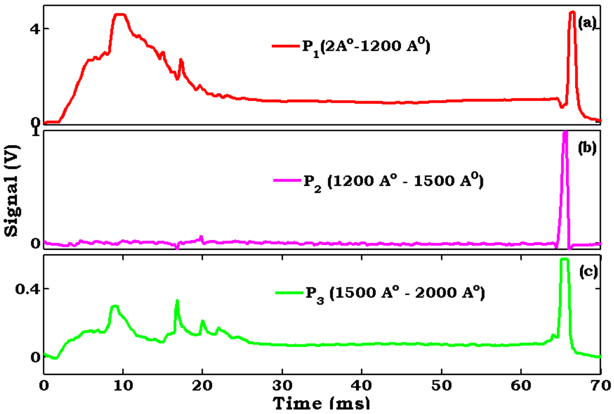

Fig. 6 Radiation signals P_1, P_2 and P_3 for a normal ADITYA discharge.

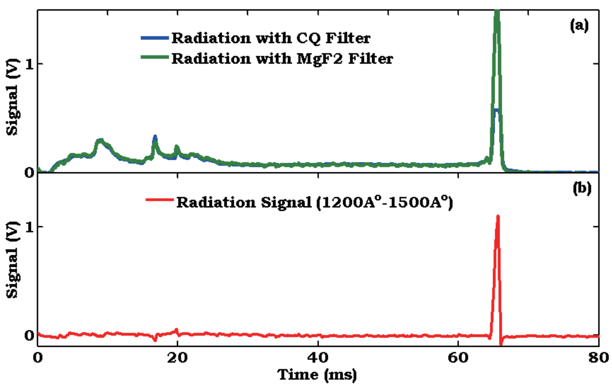

Fig. 7 Comparison of P_{MgF} and P_{CQ} their difference in a non-disruptive shot.

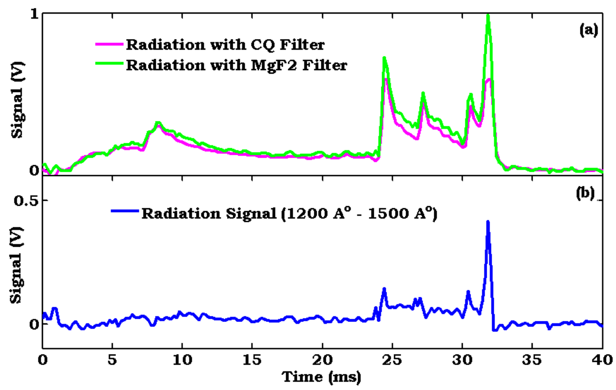

Fig. 8 P_{MgF} and P_{CQ} in a disruptive discharge.

(Fig. 8). In case of a non-disruptive discharge, a peak in radiation signal is observed at the end of the discharge and it is mostly dominated by 1200 Å - 1500 Å radiation. Similarly, in case of disruptive discharges, there is an increased contribution from the long wavelength radiation both in the current quench and thermal quench phases. So for estimating the radiation power loss during such events, a lower responsivity value (0.18 A/W) has to be used. These results need to be confirmed in various kinds of discharges.

5. Summary

The filtered bolometer camera is successfully installed on ADITYA tokamak and it is now possible to spectrally resolve the radiation power signal. The effective responsivity of the AXUV bolometer is 0.24 A/W for the flattop region. However there is an increased contribution from long wavelength (> 1200 Å) radiation during disruptive discharges and the effective responsivity value (0.18 A/W) is less compared to the non-disruptive discharges. But it requires more measurements to accurately determine the responsivity.

[1] K. Tahiliani, R. Jha *et al.*, Plasma Phys. Control. Fusion **51**, 085004 (2009).
[2] S.B. Bhatt *et al.*, Ind. J. Pure Appl. Phys. **27**, 710 (1989).
[3] S.D. Gray *et al.*, Rev. Sci. Instrum. **75**, 376 (2004).
[4] http://www.ird-inc.com/Data/axuv_responsivity.xls
[5] C.V.S. Rao *et al.*, Rev. Sci. Instrum. **68**, 1142 (1997).