Radiated power measurement with AXUV photodiodes in EAST tokamak

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Abstract: The fast bolometer diagnostic system for absolute radiated power measurement on EAST tokamak is introduced, which is based on the absolute extreme ultraviolet (AXUV) photodiodes. The relative calibration of AXUV detectors is carried out using X-ray tube and standard luminance source in order to evaluate the sensitivity degradation caused by cumulative radiation damage during experiments. The calibration result shows a 23% sensitivity decrease in the X-ray range for the detector suffering ~27000 discharges, but the sensitivity for the visible light changes little. The radiated power measured by AXUV photodiodes is compared with that measured by resistive bolometer. The total radiated power in main plasma deduced from AXUV detector is lower a factor of 1~4 than that deduced from resistive bolometer. Some typical measurement results are also shown in this article.

Keywords: Radiated power, AXUV photodiodes, relative calibration, ELMy H-mode

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1. Introduction

In fusion plasma, part of the input power can be dissipated by radiation [1]. Bolometer diagnostic has been used to determine the total radiated power and the radiation profile in magnetically confined plasma for the study of power balance, particle transport, transient radiative activities, and so on. At present, two types of detectors, metal foil resistive bolometer and absolute extreme ultraviolet (AXUV) photodiodes, are widely utilized for radiated power measurement in many fusion devices [2-5]. The resistive bolometer is a common tool on most tokamaks as it has a fairly linear response to radiation power up to 200nm. But, its low temporal resolution of ~ms is the most restriction. Additionally, it is also sensitive to neutral particles. The AXUV photodiodes based on silicon *p-n* junctions are developed in last decade, which are characterized by a flat spectral sensitivity from vacuum ultraviolet to x-ray energies and a fast response of ~μs .Its compact structure and high time resolution allow them to be used to study fast processes as they are used on DIII-D and Alcator C-Mod for disruption analysis and on TCV for fast radiation dynamics studies [6-8]. The deficiency of the use of AXUV photodiodes as absolute bolometer is that its spectral sensitivity is dependent on photon energy, as shown in Fig.1.The very low sensitivity for photo energy below 30eV will lead to an underestimate of the radiation loss due to the strong line emission of low-charge impurities at plasma edge. Research on Alcator C-mode and LHD have shown that in some operation condition the total radiated power deduced from AXUV photodiodes is about half of that from the resistive bolometer after excluding the contribution of neutral particles [3,6].

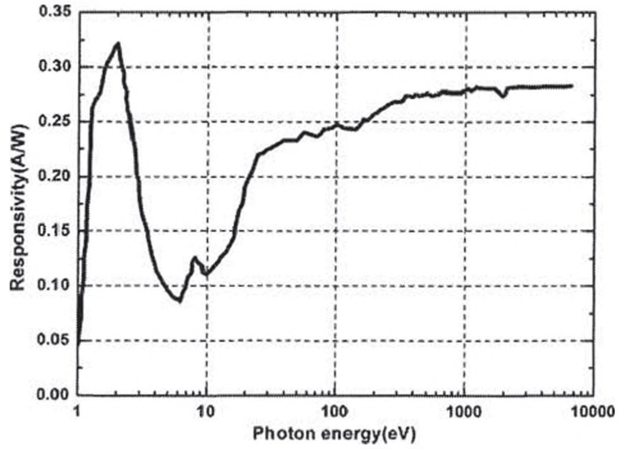

Fig. 1 The responsivity of AXUV photodiodes.

Both the AXUV photodiodes and metal foil resistive bolometer are used for absolute radiated power measurement in EAST (Experimental Advanced Superconducting Tokamak) device [9]. The AXUV photodiodes measurement system and the relative calibration are introduced in the section 2. Some measurement results of AXUV photodiodes are presented and are compared with that of foil resistive bolometer in section 3. A brief summary and upgrade plan for next experimental campaign are given in the final section 4.

2. Experimental setup

2.1 Arrangement of the AXUV arrays

The AXUV photodiodes are the type of AXUV-16ELG linear array produced by IRD Corp. [9]. Five pinhole cameras with total of 80 channels have been successfully developed presently, as shown in Fig.2. Each camera is one 16-channel array with a spatial resolution δr of ~ 3 cm. Four cameras are installed in the horizontal port to fully cover the poloidal cross section .The upper two cameras and the lower two cameras are symmetrical on the equatorial plane. Another vertical camera is installed in the upper port to view the lower divertor through bulk plasma. All the detectors are placed in the vacuum vessel. The current outputs of the detectors are directly led to the outside of the vacuum vessel through feedthrough and then to the amplifiers. The output voltages signals of amplifiers are transmitted to the data acquisition system (DAQ) through long twist cable. The sample frequency of DAQ is 100 kHz.

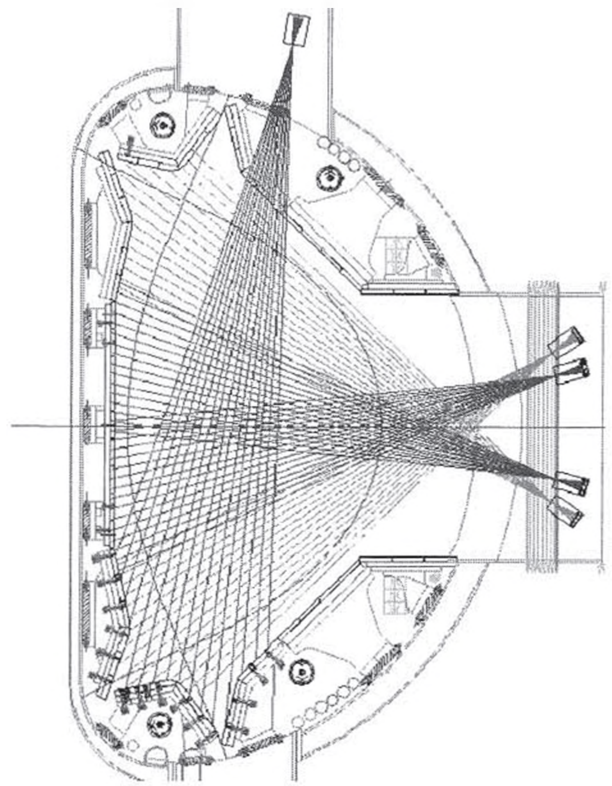

Fig. 2 Geometry of Viewing chords of AXUV arrays installed on EAST

2.2 The relative calibration of AXUV photodiodes

It is found that the sensitive of AXUV photodiodes have the trend of decrease caused by cumulative radiation exposure during plasmas discharges. Thus, four detectors which have ever been used on EAST and HT-7 are selected and are calibrated relatively. The relative calibrations are carried out by the Mini X-ray tube and standard luminance source separately. The photon energy of the X-ray tube is controlled in the range of 1-10keV. The output light of the standard luminance source is from 380(3.26eV) nm to 780 nm (1.59eV). Fig.3 shows the schematic of calibration. The light source is fixed and the detector can move by adjusting manually the support so that the light can aim at the detector unit one by one. The output current of the detector is amplified and then the output voltage is shown in the oscilloscope. A collimator with 2mm diameter is used for the X-ray tube while not for the standard luminance source. So, a new detector is also tested as reference. The output signals of each detector are normalized to the reference signals. Fig.4 gives the calibration results. It's found that the degree of the sensitive degradation depends on the plasma discharges number for photon energy in X-ray range. The sensitivity of the detector suffering ~27000 EAST discharges decreases about 23% for X-ray and changes little for visible light. However, sensitivity of the detector only suffering ~1000 HT-7 discharges increases on the contrary for visible light. The sensitive surfaces of this detector have a strong mark compared with the new detector which may be caused by bombing of glowing arc. The changes of the sensitivity are related with the front silicon dioxide window [10]. The passivating SiO_2 layer will create surface recombination after receiving large dose of radiation (>Grads) resulting in loss of quantum efficiency and damage of the thin oxide layer probably causes the sensitivity increase for low energy photon.

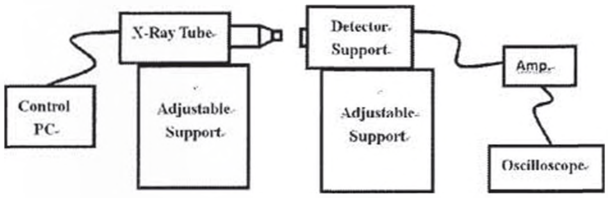

Fig. 3 The relative calibration schematic of AXUV photodiodes

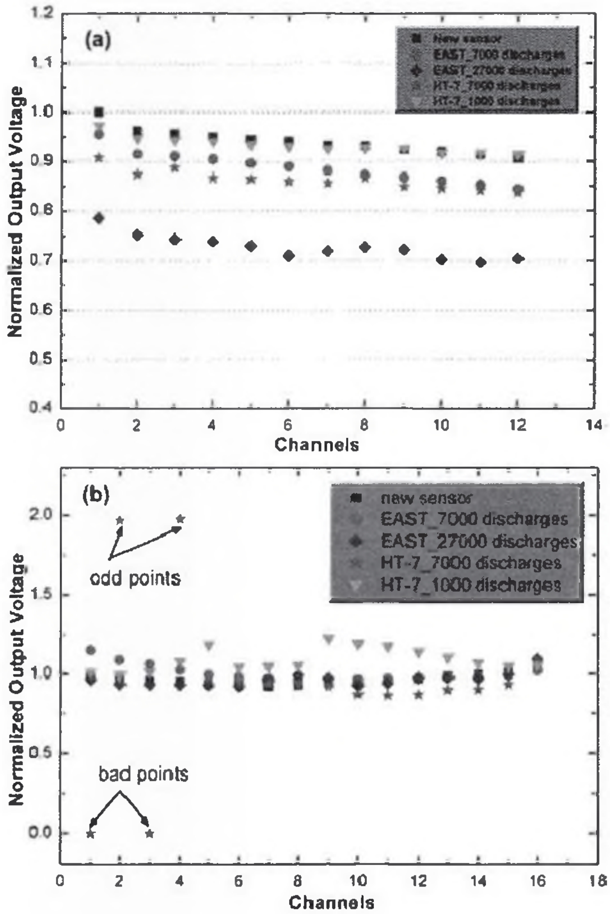

Fig.4 The relative calibration result (a) by Mini X-ray tube; (b) by standard luminance source

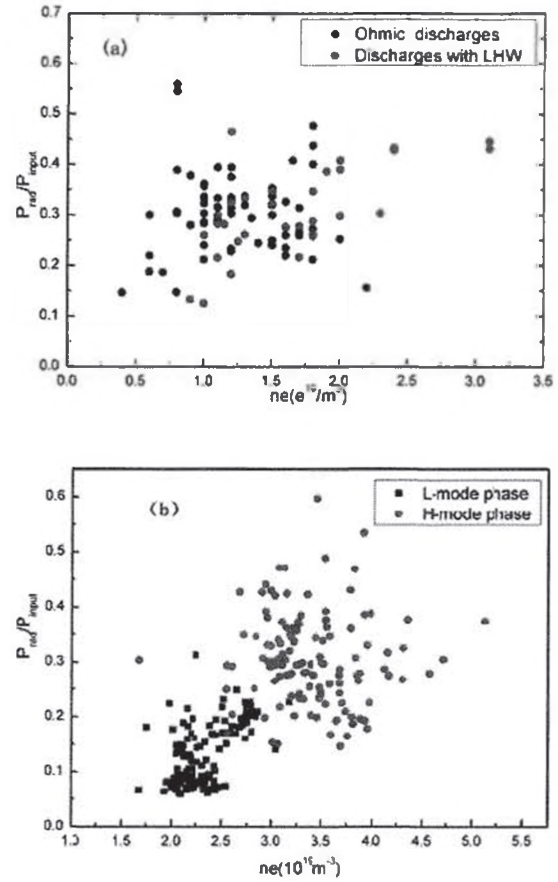

Fig.5 Dependence of the radiated power fraction (P_{rad} to P_{input}) on the line-averaged electron density (a) for L-mode discharges;(b) for H-mode discharges

3. Measurement results

The total radiated power in main plasma can be calculated by integrating the measured chord-integrated signals of the horizontal arrays [11]. Here, a flat spectral response 0.26 A/W is used for AXUV photodiodes when calculating the radiated power. The statistic results of radiated power loss fraction (the ratio of radiated power to input power) in different electron density conditions are shown separately in Fig.5a for L-mode discharges and Fig 5b for H-mode discharges. The radiated power loss fraction is in the range of 10%~60% and no strong dependence on the electron density is found due to data dispersion. The total radiated power deduced from AXUV photodiodes are compared with that deduced from resistive foil bolometer. Generally, the time evolution trend of the radiated power deduced from the two type detectors can agree well, but the absolute value given by AXUV photodiodes is lower a factor of 1~4 than that given by resistive bolometer.

The high temporal resolution of AXUV photodiodes enables it to observe fast plasma process, such as ELM radiation process. An example is given in Fig.6 showing a comparison of the AXUV signal with the foil resistive bolometer signal during ELM. The ELMs can produce modulation in the radiated power signals at the edge plasma. Thus, the radiated energy loss caused by one ELM can be obtained by time integrating the total radiated power. The background intensity need be subtracted during integration. The results show that the radiated energy loss caused by one type-III ELM is lower than 10% of the ELM-induced energy loss.

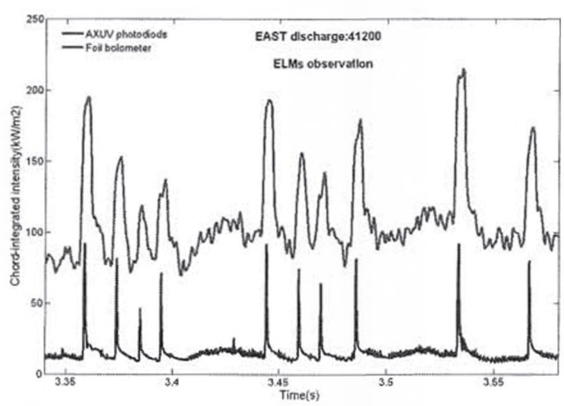

Fig.6 Comparison of the AXUV signal with the foil resistive bolometer signal during ELM

Fig.7 Tomographic reconstruction of radiated power density in the divertor region for EAST discharge #38300. (a) pre-ELM at 3.540 s; (b) during-ELM at 3.545 s; (c) after-ELM at 3.555 s.

The relative changes of radiation distribution during one ELM period can be analyzed by two dimensional tomography reconstructions techniques. The hybrid inversion algorithm is adopted due to the poor coverage of the vertical array at the present time. The whole rectangular poloidal cross section is divided into 20×40 pixels. The divertor region is separated from the main plasma by adopting the similar method used on JT-60U [12]. Analytic method based on Bessel expansion with the symmetrical hypothesis is used for bulk plasma and the finite element method is used for divertor region. Fig.7 presents the radiation patterns in the divertor region at three different time of one ELM cycle. It can be found that the radiation is focused on X point region between ELMs. The radiation region moves toward the targets and the radiation near outer target region shows clear increase during ELMs. The radiation from released particles due to the ELM-wall interaction, such as C impurity, would contribute partly to the increase of the radiated power near the outer target region.

4. Conclusion

The AXUV photodiodes are successfully applied on EAST as fast bolometer. The relative calibrations are carried out in order to evaluate the sensitive degradation of AXUV photodiodes after several experimental campaigns on EAST. About 23% sensitivity decrease is found for the detector exposed to 27000 discharges. The photon energy depended sensitivity of AXUV photodiodes will lead to an underestimate of the radiation loss as absolute bolometer. Compared with resistive bolometer, the total radiated power in main plasma deduced from AXUV detector is lower a factor of 1~4. The fast response time (~ μs) make it possible to study radiated pattern in one ELM cycle. So, the viewing region of vertical array need to be expanded to improve the precision of the tomography reconstructions and one tangential array will be added for next experimental campaign.

Acknowledgments

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