Plasma radiation dynamics with the upgraded AXUV tomographical system in the TCV tokamak

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The specificity of Absolute eXtreme UltraViolet photodiodes resides in their structure: the n-type semiconductor layer is sandwiched between the extreme thin (approximately 8 nm) entrance window and the p-type waffer. Due to the arising electric field on the insulator - semiconductor junction this configuration is able to eliminate the surface dead layer, which is present in a commonly applied photodiode [1]. Although the remainder of the front glass layer reduces the response around 10 eV by a factor of 4 compared to the level in the soft X-ray range, the sensitivity covers the relevant radiation loss ranges of contemporary hot magnetized plasmas. Hence, the detector is often regarded as a bolometer in the fusion community. This concept is enhanced by the fact that it is fast (the rise time of the detected pulses can be less than a μs) compared to other bolometer types (having typically 100 Hz temporal response) and thus it has no alternative in measuring total energy losses during fast transients in fusion-grade plasmas. Additionally to the 'holed' spectral response, the other disadvantage of this kind of detectors is related to the stability of their sensitivity: UV or neutron induced radiation damage and layer deposition on their surfaces can significantly hamper their response. Considering the effect of eletromagnetic exposure UV-light around 10 eV is the most deleterious spectral range: it is absorbed in the entrance window breaking covalent bonds there. The strain in the glass, which is although mitigated by nitridization in the AXUV-G type diodes, attracts these defects to the junction where they act as interface traps decreasing the collection efficieny of the charge carriers [2].

The TCV tokamak was equipped with a diagnostic system that consisted of 140 detectors in 7 pinhole cameras covering a full poloidal cross section and thus allowing tomographical reconstruction of radiation profiles. Additionally, another array set with same poloidal line-of-sight arrangement but with a 20 mm toroidal shift was installed in the same cameras [3].

In order to study the aging effect of the detectors in tokamak environment we perform a significant upgrade on the camera system: protective shutters are installed and the twin camera structure is exploited to monitorize changes in detector response. The first one is responsible for detector protection against layer depostion during boronization and wall conditioning and against the light of glow and unconcerned plasma discharges. Due to the lack of neutral beam heating neutron damage is negligible in TCV. Identical detectors without any interference filters are installed, one poloidal array set, the *measurement* one, is used for experiments and the other one, called the *calibration* set, has been used only two times: during the first measurement with the refurbished system (#44505), and approximatelly 60 recorded discharges later (#44786). These two discharges are similar in terms of plasma parameters.

The ratio of *measurement* and *calibration* signals recorded in the aforementioned discharges are plotted in Fig. 1. (The channels where the signal levels are low or technical problems arise are simply omitted.) In discharge #44505 the ratios deviate from one by less than 5 percent in most of the channels, consistently with geometrical inaccuracies. Then, approximately 60 measured discharges later, the ratio is 20 - 40 percent lower. Neglecting radiation damage on the *calibration* detectors, this refers to an unexpectedly fast sensitivity degradation. In order to interpret this observation we compare the experienced degradation level to the degradation curve predicted by the manufacturer. As a first step the photocurrents are calculated, which are depicted in Fig. 1 (b). Then, as a conservative estimation, line radiation at 13.5 eV is assumed, since the entrance window absorbs the highest portion of the incident light causing maximal damage there. This way the photon fluence is calculated and compared to Fig. 4 of [2]. Based on the estimate, 20% degradation during 60 discharges is not controversal. Indeed, for some channels the degradation can even be over the considered range provided by the manufacturer. It must be noted, that our system does not operate with extremely high light yields, similar photocurrent levels are typical in AXUV systems on other tokamaks, too.

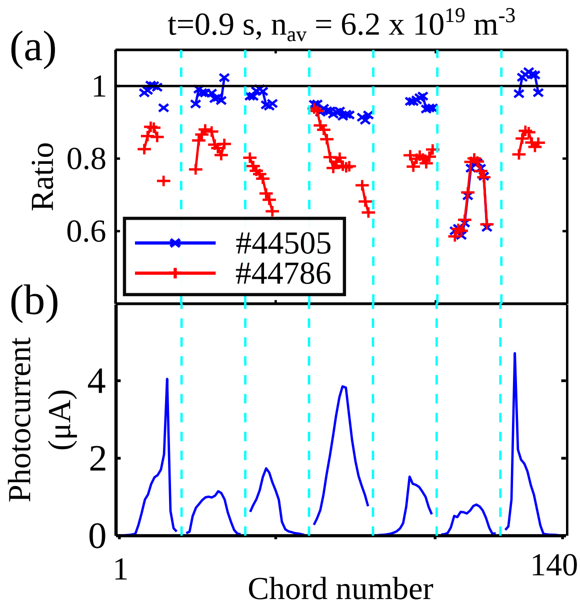

Figure 1: *(a) Ratio of signals recorded by the measurement and calibration arrays. (b) Measured AXUV photocurrents. Vertical dashed cyan lines indicate the different cameras.*

Nevertheless, the *measurement* detector array from camera 6, which has been exposed by accident for a week before discharge #44505, behaves differently: no remarkable further degradation is observed on its channels for the second calibration discharge #44786. This observation might be an indication of some dynamics in the degradation process [5]: a first short and efficient period of sensitivity degradation is followed by a slower one.

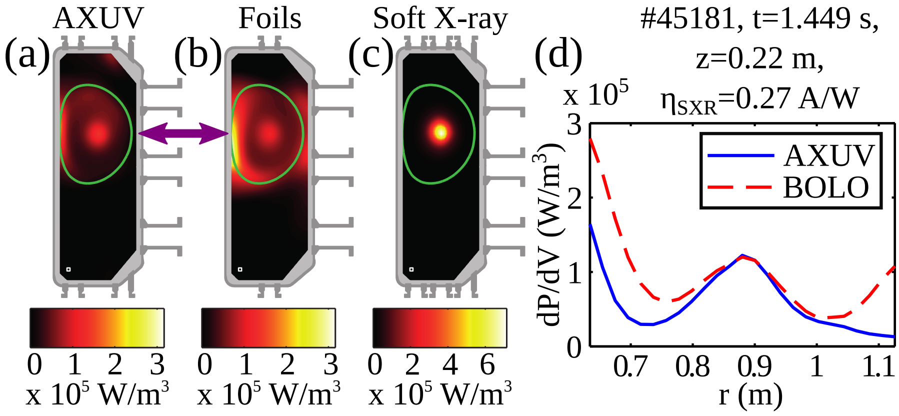

Figure 2: *Reconstructed radiation profiles of discharge #45181 at* $t = 1.449\,s$ *based on (a) AXUV, (b) foil bolometer and (c) soft X-ray signals. The green lines denote the LCFSs. (d): horizontal cut of the AXUV and the foil bolometer profiles at* $z = 0.22\,m$ *(marked by the purple arrow between (a) and (b)).*

Despite the problems related to sensitivity degradation the system provides radiation profiles which are consistent to the distributions obtained from other diagnostics. As an example profiles in a limited plasma discharge (#45181) are depicted in Fig. 2. In the selected time instance the plasma is not too far but below the density limit $\left(n_{av} = 7.5 \times 10^{19}\,m^{-3}\right)$, it is slightly shaped and Ohmically heated only with plasma current $I_p = 190\,kA$. Fig. 2 (a) demonstrates that the most intense radiation comes from the limiter wall - plasma contact zone and from the magnetic axis. The other, low-intensity radiation patterns are not reliable. Similar radiation profile is measured with the foil bolometer system shown in Fig. 2 (b). However, in this case the radiation is more intense near high field side wall and nonnegligible near the outer side of the torus. The latter pattern may be artificial since the signals of this diagnostic are significantly polluted by low-energy (some eV) neutrals. The profiles obtained from the soft X-ray cameras are peaked on the magnetic axis, as expected (Fig. 2 (c)). A quantitative comparison between the reconstructed AXUV and foil bolometer profiles are shown in Fig. 2 (d). These curves are the horizontal cuts of the contours in Fig. 2 (a) and (b) at $z = 0.22\,m$ height marked by a purple arrow. Here the $\eta_{\mathrm{SXR}} = 0.27\,A/W$ sensitivity constant, which is proper for most of the semiconductor detectors in the soft X-ray range, is applied. Quantitative agreement is experienced on the magnetic axis, which may refer to the dominant soft X-ray contribution there. Additionally, this spectral domain should not be affected by sensitivity degradation. Near the walls, where radiation is dominated by the UV range, AXUV provides much lower intensities than the foil bolometer system does. This may be explained by the spectral 'hole' in the AXUV sensitivity, radiation damage, and the effect of neutrals on foil bolometers. Similar observations have been done in C-Mod [6].

The unique capability of the AXUV system is exploited in the investigation of an m/n=1/1 MHD mode shown in Fig 3. The saturated mode activity is observed during a density limit disruption. The first row of the figure depicts profiles recorded by the soft X-ray cameras during one oscillation period. The rotating mode manifests here in the apparent poloidal gyration of the radiation peak around the stationary magnetic axis marked by a white 'x'. The same but less pronounced rotation is observed in the AXUV profiles. The opposite phase is caused by the odd toroidal mode number and the corresponding location of the two systems: they are installed on the opposite sides of the torus. Additionally to the central peak gyration, AXUV shows edge modulations, which are synchronized but not rigidly connected to the MHD mode. Based on this observation, which is also confirmed by inspecting the raw signals, we assume that large MHD modes can have significant influence on plasma-wall interaction.

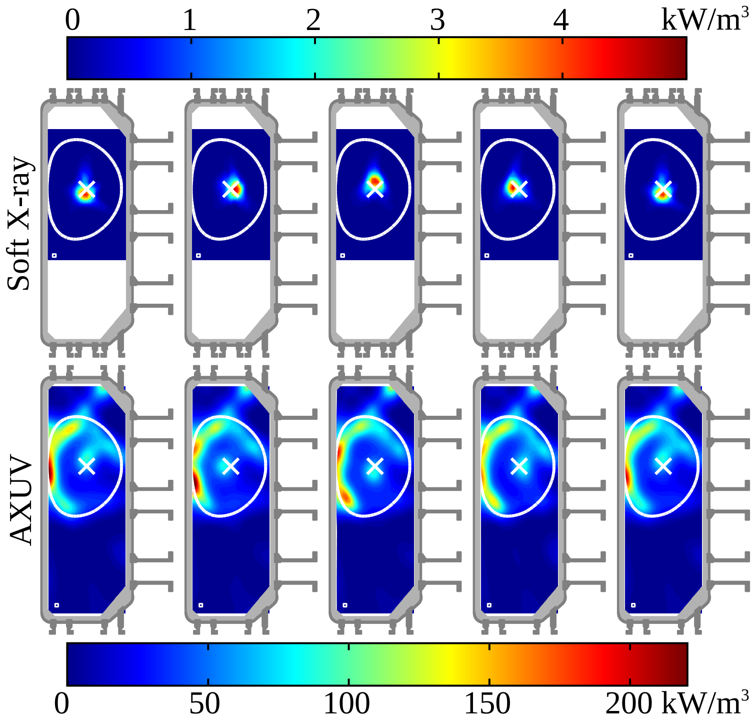

Figure 3: *Radiation profiles during significant m/n=1/1 MHD mode activity in the disruptive phase of discharge #45186. Top row: from soft X-ray cameras, bottom row: from AXUV.*

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