VUV AND USX DIAGNOSTICS OF IMPURITIES IN CASTOR TOKAMAK

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1. Introduction

Carbon and Oxygen are the dominant low-Z impurities in the most of tokamaks. The highly charged ions of them radiate predominantly in the ultrasoft-X-ray (USX) spectral range and this radiation gives a good information on the impurity behaviour. In the small and medium sized tokamaks, the spectroscopic data of the lower ions radiating in the vacuum ultraviolet (VUV) range are desirable as well, that can contribute to a more complex figure.

In several last years, a set of diagnostic instruments was designed or modified in IPP Prague and arranged at the CASTOR tokamak that allow the impurity radiation to be measured in the USX and VUV ranges simultaneously with a spatial resolution.

2. Multilayer mirror based USX spectroscopy

The double-channel multilayer mirror based (MLM) [1] spectrometer for ultrasoft X-ray spectral range has been built in IPP Prague [2] and operated at CASTOR as an easy-to-use monitor since 1994. The spectrometer covers relatively wide wavelength range 14÷50 Å divided into two ranges corresponding to energy range 250-400eV (for Carbon lines) and 500-900eV (for Oxygen lines), depending on the dispersive element (multilayer mirror) and the band filter (submicron metalic film) that are used. The transmissivity of the filters as well as the reflectivity of the mirror are absolutely calibrated by X-ray grazing incidence monochromator in the considered spectral ranges.

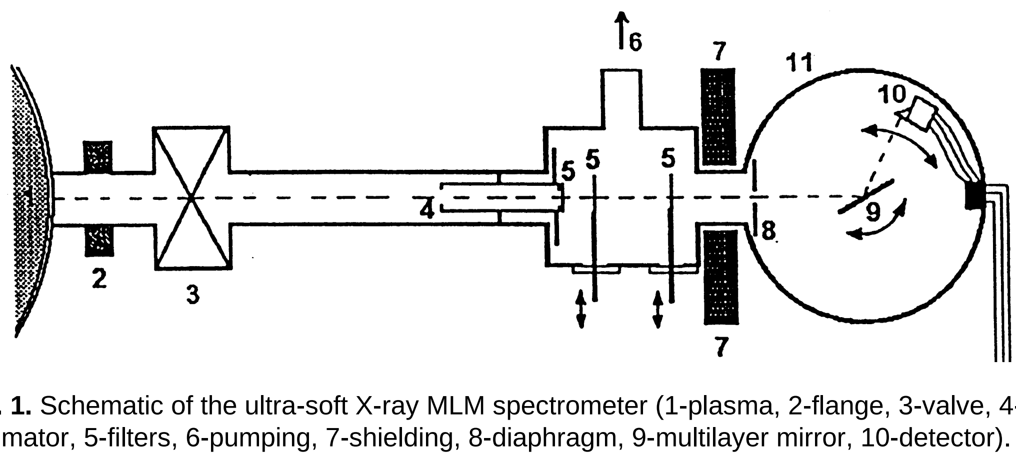

Fig. 1. Schematic of the ultra-soft X-ray MLM spectrometer (1-plasma, 2-flange, 3-valve, 4-collimator, 5-filters, 6-pumping, 7-shielding, 8-diaphragm, 9-multilayer mirror, 10-detector).

A channeltron supplied with photon-to-electrons convertor [2] was used as the detector in the first modification of the spectrometer. The use of the convertor has supressed a certain inhomogeneity of the sensitivity over the input cross-section of the channeltron and has allowed the detector unit to be absolute calibrated as well. On the other side, the output signal is reduced to appr. 10% of the original value using the convertor.

Later, microchannel plates in the Chevron set together with a collector were used as the detector of the USX spectrometer. A better dynamics of the measurement and only a weak sensitivity to the dispersive magnetic field of the tokamak are the main advantages of this solution.

If the channeltron with the photon-to-electrons converter is used as the detector, the output signal is a sequence of pulses with allowed rate of $5{\cdot}10^5$ count/sec as a maximum. The low intensity of the radiation (and partially an effect of the converter) give a statistic feature of the time distribution of the pulses. The time resolution of 0.1ms has been achieved in the measurement of spectral line emissivity in CASTOR.

The output signal is processed by two independent methods: 1) the output pulses are counted by a 400-channel counter in time windows following closely each to other. Typically, the time window is 0.1 msec in our case. This method was used for the absolute measurements; 2) the output pulses are converted by a passive RC integrated circuit (time constant 1 ms) to an analog signal and the latter is recorded by CAMAC acquisition system to the database together with other plasma parameters.

Using the microchannel plates as the USX detector, the output signal is typically processed by the passive RC integrator. In this case, the level of signal is similar as in case of the channeltron without photon-to-electron convertor.

Relatively high reflectivity of the MLM dispersive element together with high transmissivity of the metalic filters and the high gain of the channeltron have given a good chance that such a spectrometric arrangement will be suitable for the time (and possibly space) resolved measurement even at a low density plasmas.

3. Ultra-soft X-ray spectrum in the CASTOR tokamak

The USX spectral radiance of the H- and He-like ions of Carbon and Oxygen in CASTOR were first measured along the central line-of-sight using a two-channel multilayer-mirror (MLM) based spectrometer [2]. The first channel was fixed to a certain spectral line before the spectrometer vacuum vessel was closed. The second channel has allowed the mirror and the detector to be set separately at the angle θ and 2θ, respectively, by a vacuum-tight clock-like mechanism. The spectrum is possible to be constructed with a time resolution about 1 ms.

In Fig. 1, the spectra of the evidently observable lines in the wavelength range 15 Å to 45 Å are drawn for two different times of the tokamak discharges. The spectrum at the 7th msec (full line) is shown, when the plasma density reached a maximum. The spectrum at the 3rd msec (dotted) gives an information about the background radiation.

The OVIII (1s-2p, 19 Å, 653.6 eV) and the OVII ($1s^2$-1s 3p, 18.6 Å, 665 eV) as well as the doublet OVII($1s^2$-1s2p, 21.6 Å and 21.8 Å, 574 eV) lines, are dominating in Oxygen lines emission of CASTOR. The OVII doublet (18.6 and 19 Å) cannot be distinguished due to the rather low-resolution of the MLM spectrometer. Similar situation sets in the C V ($1s^2$-

1s2p, 40.3 Å, and 40.7 Å) lines. Fortunately, the line C VI (1s-2p, 33.7 Å, 368 eV) can be well distinguished from the C V ($1s^2$-1s 3p, 35 Å, 354.5 eV) line.

From the spectral line emission, the content of Carbon and Oxygen has been evaluated using a radiative model [3]. The estimated concentrations 3-5% of the Carbon and 0.5-1% of the Oxygen have served as a rough estimation of plasma purity in CASTOR as they were computed without an exact knowledge of the electron temperature and plasma density spatial profile.

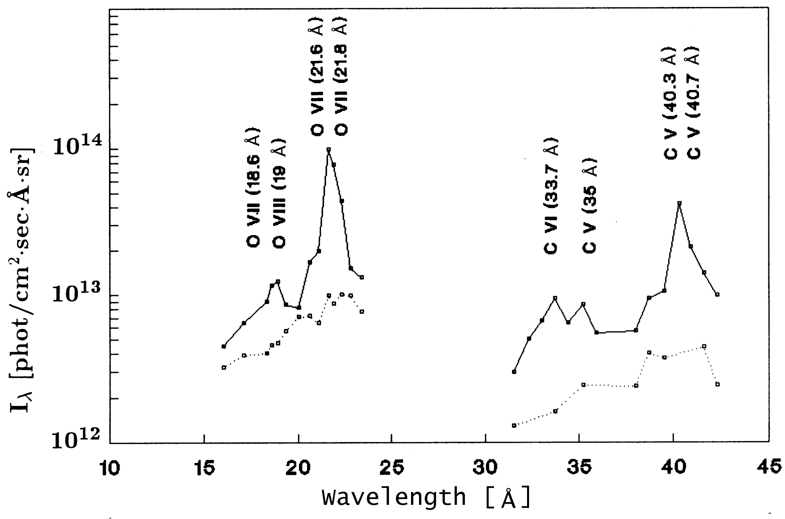

Fig. 2. USX spectrum at 7th ms (maximum plasma density-full line) and 3rd ms (background-dotted).

4. USX space resolved measurement

The two-channel USX spectrometer was supplied with an equipment allowing all the spectrometer to be mechanically tilted within a range of ±10° related to the horizontal plane (Fig. 2). The spectral radiance could be now measured shot-to-shot all over the plasma cross-section of the CASTOR tokamak. The spatial resolution about 1 cm is determined mainly by the collimators. The time resolution is about 1ms.

The radial profile of the spectral line was measured shot-to-shot by the tilting of the spectrometer that corresponded to the 0.5 cm shift of the line-of-sight in the center of the plasma column. The tokamak dischar-ge parameters were hold possibly the same during the set of measurements.

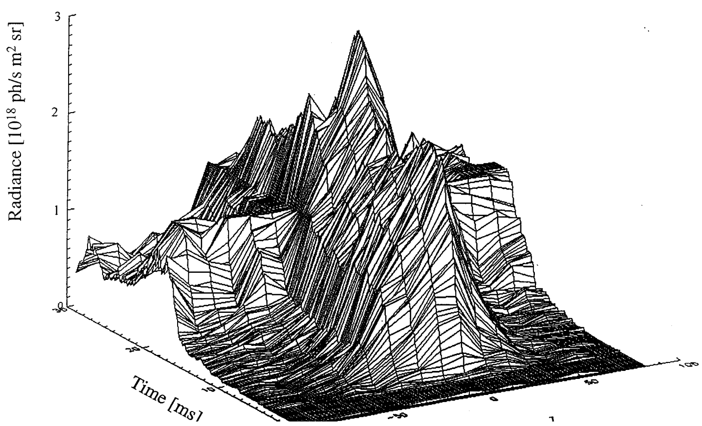

Fig. 3. Time evolution of the spatial distribution of OVII (574eV) line.

In the low current (8 kA) discharges, the experimentally measu-red maximum of the CV(308 eV) line intensity 1.5 10^{19} phot $m^{-3}s^{-1}sr^{-1}$ and the concave shape of the radial profile agree well with those predicted by model calculation for about 5% Carbon concentration and central electron temperature lower than 100 eV.

The maximum emission power 9.3 kW m^{-3} of the CV(308 eV) line has been found. The global radiation losses related to this single line calculated in the total plasma volume represent 1.3% of the input ohmic heating power. For comparison: ten times lower emission power has been evaluated for CVI(368 eV) line under the same experimental plasma conditions.

In the higher current (13,6 kA) discharges, the plasma density grows up to 1.1 $10^{19}m^{-3}$. The maximum radiation power losses of the CV(308 eV) line in the total plasma volume reach up the 10 kW and represent about 26% of ohmic heating power in this case.

The global radiation power losses of the dominating impurities, Carbon and Oxygen, measured in XUV spectral range reach almost of 35% of the total ohmic heating in higher current discharge regime in tokamak CASTOR.

5. VUV spectroscopy

The radiation of the impurity lower ions was measured by the Seya-Namioka type VUV monochromator equipped with double-curved (toroidal) grating that covers partially visible range. The spectral resolution was about 3 Å in the VUV range. The line radiance could be measured in absolute units as the calibration of the monochromator was done.

First, the radiance was measured only in the central line-of-sight. A photomultiplier with a VUV-to-visible convertor was used as the detector.

Later, the imaging ability of the toroidal grating was employed that together with multichannel detector allowed the radiance to be measured with a space resolution in vertical direction. A "Chevron set" of the multichannel plates (MCP) with eight strip-anodes was used as the multichannel detector.

6. Conclusion

Both the VUV and USX spectrometry are very useful implements to the learning of the impurities behaviour. The measurement in the VUV range is useful namely for investigation of impurities in the small- sized tokamaks, but also in the perifery of the larger devices. The USX diagnostics in the wavelength range of 10-100 Å represents a unique way how to learn the intrinsic impurities behaviour even in the middle/large sized tokamaks.

A high-throughput USX monochromator for time and possibly also space resolved measurements in the USX range, based on a spherical (or toroidal) multilayer mirror, should be the next step.

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References

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