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Concept of C/O monitor diagnostic for the stellarator W7-X

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The C/O monitor for W7-X is a spectrometer of special construction with high throughput and high time resolution, suitable for controlling the concentration of main plasma impurities. The spectrometer will be fixed in a nearly horizontal position and at wavelengths corresponding to Lyman-α lines of H-like ions of oxygen (at 1.9 nm), nitrogen (at 2.5 nm), carbon (at 3.4 nm) and boron (at 4.9 nm). Its purpose is fast monitoring of the spectral line intensities which are reflecting the content of impurities associated with the general wall condition (oxygen), plasma-wall interaction (carbon, boron, the latter being evaporated onto the plasma vessel wall in order to reduce the release of impurity ions from the vessel wall and plasma facing surfaces) or vacuum leakage (nitrogen from air).

As the main purpose of the system is fast detection of the impurities (and measuring its level with high time resolution) it will be constructed with a high throughput, but with not necessary high space and spectral resolution.

The proposed system will be mechanically divided into two subspectrometers. Each of them will contain two dispersive elements, enclosed in one (common) vacuum chamber. The line of sight of both spectrometers will cross at the main magnetic axis of the plasma.

Keywords: EUV/Soft X-ray spectroscopy, stellarator plasma, plasma impurities.

1. Introduction

Plasma impurities are one of the main factors influencing the efficiency of the plasma fusion device. Regardless of the the heavy, high-Z impurities, being the most severe ones due to strong radiation losses and their impact on the power balance due to strong radiation losses, low-Z impurities can affect the plasma start when the temperature is still quite low and decrease the plasma device efficiency (by plasma 'fuel' dilution). The most common light impurities are oxygen, nitrogen, carbon and boron or (beryllium).

Oxygen is always observed during every discharge. It is associated with the fact that during the venting of the machine the oxygen (mainly as water) is adsorbed at the walls of the inner plasma vessel. During the operation of the machine the oxygen is slowly released from the walls and penetrates into the plasma. Usually, the level of the oxygen in the plasma gradually (but quite slowly) decreases in time. Generally, in order to decrease the influx of impurities released from the walls the plasma vessel surface and plasma facing components can be covered (e.g. by glow discharge) with lower-Z elements such as boron or beryllium. This protective layer will be gradually destroyed during the plasma experiments and has to be renewed from time to time. By monitoring the level of this element (boron or berylium) in the plasma one can obtain information about the actual wall condition.

Inner walls of the majority of the currently working plasma devices are covered by carbon tiles (e.g. in form of CFC). The level of the carbon impurities can essentially increase as a result of unwanted plasma-wall interaction. In this case the intensity behavior of carbon radiation is an indicator of local overload of certain plasma facing tiles. Moreover, monitoring of the carbon impurity level will not only provide the status of contamination but can be also a tool for detection and study of plasma instabilities (e.g. ELMs).

Excluding very specific application of the nitrogen in some experiment scenarios (e.g. radiation cooling), one can assume that the presence of this element in the plasma is result of some kind of malfunction of the machine. Usually it can be mainly associated with leakage in the vacuum system.

For the purpose of monitoring the light impurities one can analyze the spectra registered by different optical, VUV or X-ray spectrometers. In some cases a special one spectrometer, assigned only for such purpose is constructed as e.g. paddle instrument of the JET KS6 spectrometer [1] or carbon and oxygen monitor for ASDEX-U tokamak [2].

Similarly, in order to study light impurities in the Wendelstein 7-X plasmas, a dedicated EUV/soft X-ray spectrometer has been designed. It will simultaneously measure the intensities of Lyman-α emission of the hydrogen-like ions of oxygen (O VIII at 1.9 nm), nitrogen (N VII at 2.5 nm), carbon (C VI at 3.4 nm) and boron (B

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V at 4.9 nm). Due to the historical facts, the spectrometer has been named C/O monitor but it will collect spectra of four elements.

During the first experimental campaign of W7-X (OP1.1) several spectroscopic diagnostics were in operation [3] but none of them is devoted to deliver simultaneously the information about impurities like C, O, N and B. That is one of the reason why C/O monitor is with a high priority system which is foreseen to be installed for OP1.2b.

2. General description of C/O monitor for W7-X

This spectrometer will work with high time resolution (1 ms or better) and will be fixed at its position and selected wavelengths. The fixed wavelength range and position will allow comparing the results obtained at different plasma configuration, in different experimental campaigns, before and after modifications of the machine. This device is designed only for measurement of the line intensities and the line shapes will not be studied by this spectrometer.

Because the main purpose of this system is high time resolution it is necessary to select a design with high throughput and with broad acceptance angle. If the construction provides sufficiently high number of quanta, associated with the spectral line under study, the time resolution of the system is determined only by the temporal resolution of the detector itself.

In the wavelength range of interest the reflectivity of the gratings as well as of the crystals is very poor. Because the gratings available for EUV are working at very low, grazing incidence angles the acceptance angle of such system is also very low. As the C/O monitor ought to have high throughput it was obvious that one has to resign of applying a grating as the dispersive element. The crystals suitable for this wavelength range are also characterized by quite low reflectivity. As the contemporary technology, allows to construct the multilayer mirrors also for such short wavelengths it was decided to apply multilayer mirrors (MLMs) as a dispersive elements. The producer of MLMs declared the reflectivity to be at least two orders of magnitude higher than for crystals. Only for the oxygen line at 1.9 nm, which is the shortest wavelength of interest, the TlAP crystal will be applied.

Due to the fact that for the determination of the spectral line intensity it is necessary to register the intensity in line core as well as the intensity of the continuum (far wings of the line) the system has been designed as a polychromator, with the Johann geometry.

Because of the irregular shape of the plasma and simple function of the spectrometer it was decided that the curvature of the mirrors ought to be cylindrical (instead of spherical, enabling imaging of the plasma). As detectors a commercially available CCDs designed for high energy detection will be applied. As an alternative detectors, a proportional counter of special construction – a multistrip gaseous chamber (MSGC) is considered. [2].

3. Design of the C/O monitor for W7-X

The spectrometer is composed of four independent channels, with individual dispersive elements and separate detectors. It is designed according to the Johann geometry with Rowland circles radii adapted to the respective wavelength ranges of interest. As a dispersive element for the oxygen channel the TlAP crystal has been chosen. For the other three spectral ranges multilayer mirrors (MLMs) are foreseen, because of their high reflectivity and the fact, that their poor spectral resolution is still sufficient in this spectral range to resolve the specific spectral lines. The multilayer for observation of the nitrogen spectral line will consist of 150 layers of W/Si, for the carbon line 90 Cr/Sc layers and for boron 100 Cr/C layers.

The spectrometer will be divided into two subspectrometers located one over another, installed at the AEK30 port (see Fig.1): one for C and O channels, the second one for B and N channels. Each of the subspectrometers will contain a set of two dispersive elements and two separate detectors. Each of the dispersive elements will be mounted on a piezodrive rotational stage allowing fine-tune of the crystal/MLM angle (Fig.2). The line of sight of those subspectormeters will be tilted in such a way that it will cross the main magnetic axis at approximately the same location (see Fig.1). The observed plasma volume is determined in vertical/poloidal (perpendicular to the main magnetic axis) direction by a collimator, resulting in the height of the observed plasma close to 9 cm at the center of the plasma. In horizontal/toroidal direction the dimension of observed plasma is defined by the curvature of the dispersive element and varies for the different spectrometer channels. At the center of the plasma the length of the observed plasma, along the main magnetic axis is equal approximately 0.3 m to 0.5 m.

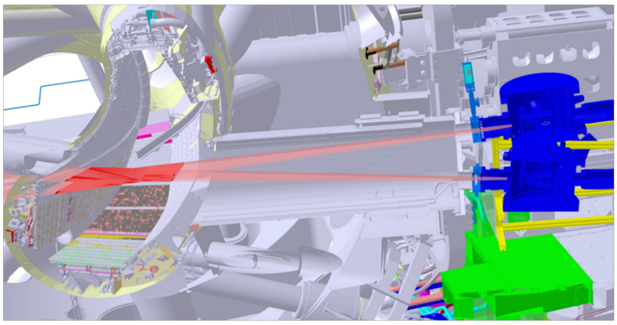

Fig. 1. Line of sight of the C/O monitor channels

The curvature of the dispersive elements was chosen such way that the detector length is sufficient to cover the range of the spectral line and its far wings (see Tab.1) i.e. continuum radiation. The detector orientation is not tangential to the Rowland circle but perpendicular to the incident radiation reflected by the dispersive element. The

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advantage of this solution is freedom to apply different types of detectors including proportional counter types as e.g. the MSGC or GEM detectors which are characterized by a deeper active/detecting volume inside the detector and mechanical elements (window foil support) which can shadow for radiation impinging at low angle.

Table 1. Channels of the C/O monitor.

Channel	O VIII	N VII	C VI	B V
Line wavelength (nm)	1.89	2.48	3.37	4.86
Wavelength range (nm)	1.86 – 2.00	2.25 – 2.66	3.08 – 3.50	4.65 – 5.19
Dispersive element	TlAP	MLM	MLM	MLM

The vertical acceptance angle is reduced by a grid collimator, constructed as a set of horizontal slits and defining the angle equal 1.43°. The line of sight of the subspectrometers are presented in Fig.1.

In order to adjust and extend the dynamic range of the detector the input aperture will be equipped with a vertical shutter motorized by a high-vacuum compatible piezodrive.

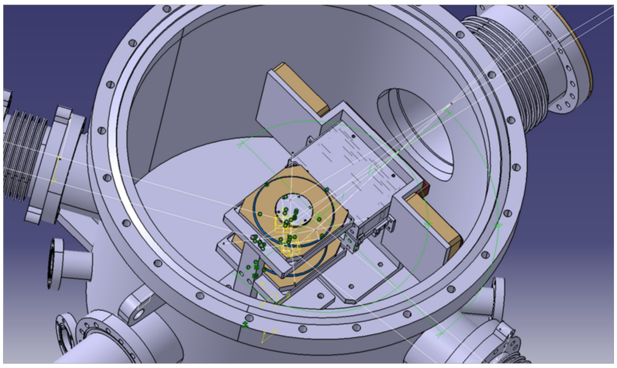

Fig. 2. A CAD model of the one subspectrometer interior.

The construction of the spectrometer allows to change the detector – the output arm is designed as a bellow equipped with a standard CF flange and its construction allows to modify its length, in order to adjust the position of the photosensitive area to the focal plane (fig. 3).

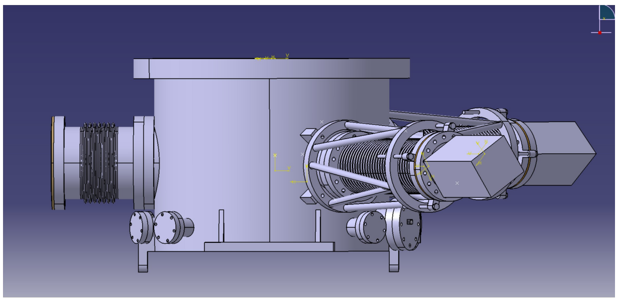

Fig. 3. Output arm of the spectrometer

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In many spectrometers working in magnetic-confinement plasma experiments (e.g. JET KT4 or KT7 spectrometers) the detector is constructed based on microchannel plate combined with the luminescent phosphor and a set of photodiodes (e.g. [4]). This solution appears to be unnecessary complicated and for our purpose we have decided to apply a simpler device. Several types of position sensitive detectors were considered. One of them is multiwire proportional counter with the electrodes evaporated on the surface of glass plate, called multistrip gaseous chamber. Such detector is applied in the spectrometer monitoring carbon and oxygen impurities, working at ASDEX-U experiment [2]. Another option is gas-electron multiplier detector. Technologies of such detectors are intensively developed in recent years and they were successfully applied for soft X-ray plasma spectrometry (e.g. spectrometer KX1 at JET [5]). There exist also, commercially available, back-illumineted CCD detectors designed for detection of EUV radiation.

For the initial phase of operation commercially available CCD detectors will be applied. The flexible design offers the possibility to change to multistrip- or GEM- like detectors in a later phase.

3. Summary

The paper presents the conceptual design of the light impurities spectrometer, called C/O monitor, for Wendelstein 7-X. The described diagnostic is based on the Johann geometry and will consists of 2 subspectrometers dedicated to Carbon, Oxygen and Nitrogen, Boron measurements, respectively. This system is planned to be installed at W7-X for OP1.2b experimental campaing.

Acknowlodgment

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References

[1] R. Barnsley, K.D.Evans, N.J.Peacock, N.C.Hawkes. et. al., Bragg-rotor spectrometer for tokamak diagnostics, Rev.Sci.Instrum. 57 (8) (1986) 2159

[2] R. Neu, K. Asmussen, G. Fussmann, P. Geltenbort, G. Janeschitz, K. Schoenmann, G. Schramm, U. Schumacher, and the ASDEX Upgrade team, Monitor for the carbon and oxygen impurities in the ASDEX Upgrade tokamak, Rev. Sci. Instrum. 67 (5) (1996) 1829-1833

[3] R. König et al., The Set of Diagnostics for the First Operation Campaign of the Wendelstein 7-X Stellarator, J.Instrum 10 (2015) doi:10.1088/1748-0221/10/10/P10002
[4] J.L.Schwob et. al., High-resolution duo-multichannel soft x-ray spectrometer for tokamak plasma diagnostics, Rev.Sci.Instrum. 58 (9) (1987) 1601
[5] J. Rzadkiewicz, et al., Design of T-GEM detectors for X-ray diagnostics on JET, Nucl. Instrum. Meth. A 720 (2013) 36

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