*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-2.082 (2008)*

Space-resolving flat-field EUV spectrograph for Large Helical Device

N. Yamaguchi[1], S. Morita[2], M.B. Chowdhuri[3], M. Goto[2] and H.Y. Zhou[3]

[1] *Physics Lab., Liberal Arts and Science, Graduate School of Medicine and Pharmaceutical Sciences, Univ. of Toyama, 2630 Sugitani, Toyama 930-0194, Japan*

[2]*National Institute for Fusion Science, Toki 509-0871, Gifu, Japan*

[3]*Department of Fusion Science, Graduate University for Advanced Studies, Toki 509-5292, Gifu, Japan*

1. Introduction

High temperature plasmas in magnetically confinement devices emit radiation mainly in extreme ultraviolet (EUV) region through soft X-ray region. Measurements of spatial distribution of these spectra are necessary for accurate determination of radiation losses, and for investigating impurity transport and its sources to understand plasma-wall interaction. It is required instruments which can provide data on radiation from plasmas with simultaneous spatial, temporal and spectral resolutions for these measurements.

A flat focal plane can be formed by using an aberration-corrected concave grating with varied spacing grooves [1], which has a best matching with flat, two-dimensional and multichannel detectors, comparing with a conventional concave grating having constant spacing grooves that forms a Rowland circle focal surface. Space-resolving VUV/EUV flat-field spectrographs have been developed for magnetic fusion plasma diagnostics [2, 3]. In these spectrographs, spatial imaging has been achieved by one-dimensional pinhole imaging through a rectangular opening of an entrance slit.

In this work, we have constructed a flat-field grazing-incidence EUV spectrograph which can provides spatially resolved spectra in the wavelength range of 50-500 Å with a large field of view. A newly developed laminar-type holographic grating [4] has been introduced in the spectrograph. The ray-tracing has been carried out to investigate basic characteristics of the spectrograph. The spectrograph was installed on an oblique-angle port in the large helical device (LHD). Descriptions on the design, basic performance of the spectrograph and preliminary results are given in this paper.

2. Spectrograph and Ray Tracing

Schematic drawings of the optical system are shown in Fig. 1. The holographic aberration-corrected laminer-type grating was fabricated by Shimadzu, which was designed to cover the wavelength range of 50-500 Å with an incident angle of 87°, a radius of curvature of 5606 mm, and effective area of $44^{W}x20^{H}$ mm^2. The parmeters of groove density variation [5] are as follows;

b_2 = -19.75, b_3=431.61, b_4 = -12954.51, b_5 = 541367.2, and b_6 = 25982434.37,

with the nominal groove density of 1200 g/mm at the center of the grating. A back-illuminated CCD (Andor DO420-BN) is used as a detector. The size of the CCD is 26.6x6.6 mm^2 with a pixel size of 26x26 μm^2. The detector can be moved along the axis of the wavelength dispersion, x_{out} in Fig. 1 (a), by using a pulse motor stage to change the measured wavelength range. The long side of the detector was settled to align to the z_{out} axis, shown in Fig. 1 (b), in order to ensure a large field of view at the plasma.

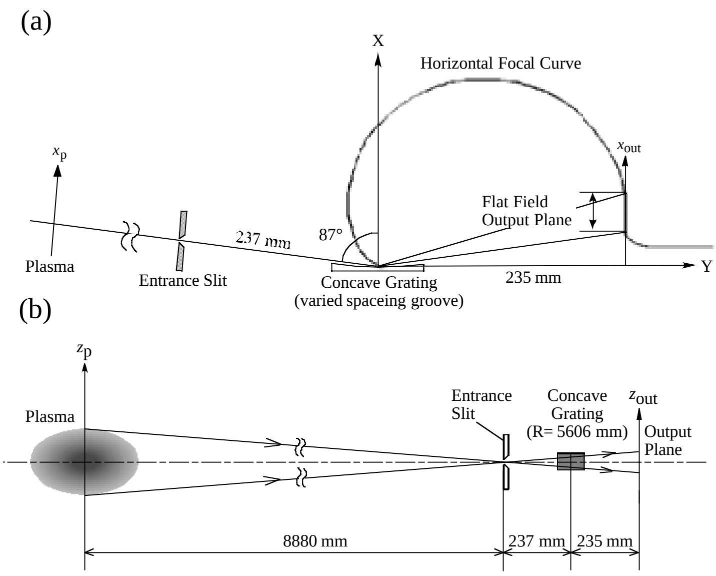

Fig. 1 Schematic drawings of optical system.
(a) plane view (b) elevational view

Ray tracing calculations have been performed by using the well-known method in which the light path function and Fermat's principle are used [6]. Point light sources are placed on a plane defined by axes x_p and z_p in Fig. 1 in the plasma, and emit rays uniformly irradiating an opening of the entrance slit. In the present study, the entrance slit with 30 μm width and 0.5 mm height is assumed. Spot diagram on the output plane for point sources at the plasma located on different position, z_p, is shown in Fig. 2. Because the spot diagram is symmetric with respect to the origin of z_{out} axis, that is placed on the principal plane of the optical system, the spatial coverage of our spectrograph is expected to be 50 cm. The demagnification factor of spatial image has been determined to be 18.8 - 18.7, which agrees well with that estimated from the geometrical condition shown in Fig. 1 (b). The FWHM of the calculated spectral profile is plotted as

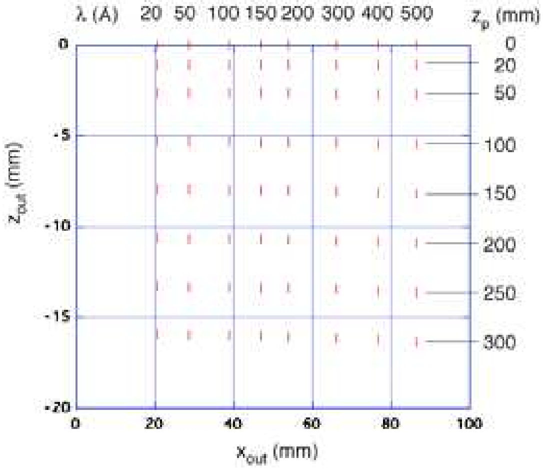

Fig. 2 Spot diagrams on the output plane for monochromatic point sources placed at different position, z_p, in LHD.

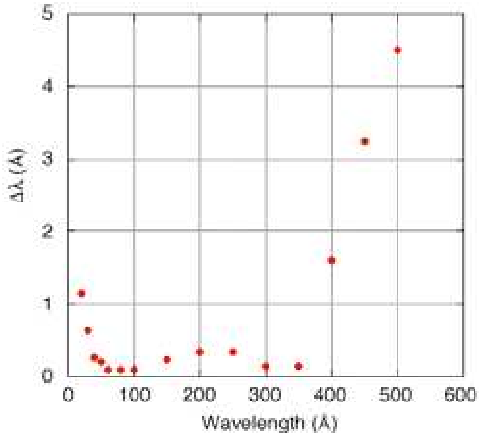

Fig. 3 Calculated spectral resolution as a function of wavelength.

a function of wavelength in Fig. 3. A wide coverage of spectral image with good spectral resolution, less than 0.3 Å, is realized for the wavelength range from 40 Å to 370 Å, whereas spectral resolution becomes worse in the outer region of the above range because of defocusing in spectral image due to the distortion of the horizontal focal curve as shown in Fig. 1 (a). These results have been confirmed with the measured data [7].

3. Spatially Resolved Spectra in LHD

The spectrograph was installed on a radial port in the LHD where the line-of-sight was slightly oblique to the normal direction to the toroidal axis. The LHD has a helical magnetic configuration. In this measurement, the radius of magnetic axis was set to be 3.85 m, the discharge with about 2 s duration was started with ECH and sustained by NBI. The CCD detector of the spectrograph was operated in the 10x5 pixels binning

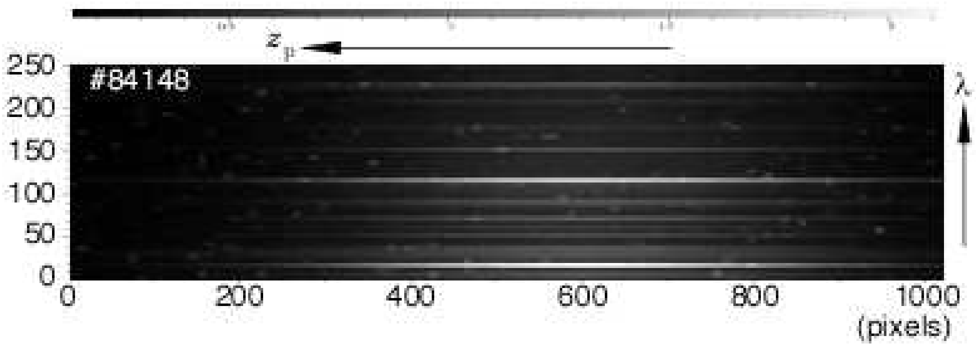

Fig. 4 Space-resolved EUV spectral image at around 150 Å. The numbers are channels on CCD. Fe XXII & Fe XX lines (149 & 132 Å) are observed with full radial coverage.

mode with resulting effective channel numbers of 102x50 and with accumulation time of 500 ms per frame. A space-resolved image of spectra around 150 Å is shown in Fig. 4, where the whole distribution in the plasma can be obtained. The two strong lines are assigned to be the Fe XXII ^2D-$^2D^0$ (149.8 Å) and Fe XX $^4S^0$-^4P (132.8 Å) transitions. It is found that iron impurities distribute with peaked profile at the plasma center having FWHM size of 22 cm in this particular shot, where the electron density is high, above 10^{14} cm^{-3}, and the temperature is relatively low, below 1 keV. On the other hand, it has been observed that low-Z impurities, such as C and O, distribute dominantly in the outer region of the plasma.

4. Summary

A flat-field grazing-incidence spectrograph which can provides spatially resolved spectra in the wavelength range of 50-500 Å has been developed. The ray-tracing calculations have been carried out and have clarified the basic spectrograph characteristics. The spatial coverage of 50 cm has been obtained in a single shot. And excellent space-resolved EUV spectra has been obtained with enough intensities and spectral resolution. Applications of the spectrograph would be carried out to investigate impurity distribution and transport in the LHD.

References

[1] T. Kita, T. Harada, N. Nakano, and H. Kuroda, Appl. Optics 22, 512 (1983).

[2] N. Yamaguchi, J. Katoh, et al., Rev. Sci. Instrum. 65, 3408 (1994).

[3] N. Yamaguchi, Y. Sato, J. Katoh, et al., J. Plasma Fusion Res. 71, 867 (1995).

[4] M. Koike, T. Yamazaki, and Y. Harada, J. Electron Spect. Rel. Phenom. 101-103, 913 (1999).

[5] T. Harada and T. Kita, Appl. Opt. 19, 3987 (1980).

[6] T. Namioka, J. Opt. Soc. Am. 49, 446 (1959).

[7] M. B. Chowdhuri, S. Morita, M. Goto, et al., Rev. Sci. Instrum. 78, 023501 (2007).