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§18. Characterization of Space-Resolving EUV Spectrograph in LHD

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A flat-field extreme ultraviolet (EUV) or soft x-ray spectrograph with a varied spacing groove grating, aberration corrected grating, has been developed to study emission spectra from highly ionized medium Z impurities in LHD.[1) In this work, we report on the basic characteristics of space-resolving spectrograph, where a limited height entrance slit is employed. Second, the efficiency of a newly developed laminar-type holographic concave grating has been estimated by theoretical calculations based on a unified classical field theory.[2)]

Main parameters of the concave grating and the spectrograph mounting are listed in Table 1. In this spectrograph, spatial imaging has been achieved by one-dimensional pinhole imaging through a rectangular opening of an entrance slit. Basic characteristics of spatially-resolved spectral images has been investigated by ray-trace calculations based on the method of optical path function and Fermat's principle.[3)] It has been found that the size of the view-area is 50 cm when a CCD detector of 26.6 mm is used, the spatial resolution is 9.4 mm for slit height of 0.5 mm, and the wavelength range with a reasonable spectral resolution is expected from 4 nm to 37 nm.

The spectrograph was installed on a radial port in 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 power and sustained by NBI. The CCD detector of the spectrograph was operated in the 10x5 pixels binning mode with resulting effective channel numbers of 102x50 and with accumulation time of 500 ms per frame. A space-resolved image of spectra around 15 nm is shown in Fig. 1, where the whole distribution in the plasma can be obtained.

Diffraction efficiency of gratings has been calculated by using the unified classical theory.[2)] Comparison of diffraction efficiency has been made between the laminar-type grating whose groove has a rectangular profile and the mechanically ruled grating with a saw-tooth groove profile. It has been confirmed that the higher order diffraction for the laminar-type grating is kept low throughout the wavelength range of this spectrograph. Especially it is one order lower than that for the mechanically ruled grating in the wavelength range longer than 30 nm. The first order diffraction efficiency for the laminar-type grating is higher than that for the mechanically ruled grating. Therefore the laminar-type grating is a suitable optical element for EUV spectroscopy.

laminar-type concave holographic grating		spectrograph mounting	
groove density	1200 g/mm varied specing	incident angle	87°
groove depth	13 nm	plasma-entrance slit distance	8880 mm
effective area	$44^{W}\times20^{H}$ mm^2	entrance slit-grating center distance	237 mm
radius of curvature	5606 mm	grating center-detector distance	235 mm

Table 1. Specifications of grating and spectrograph.

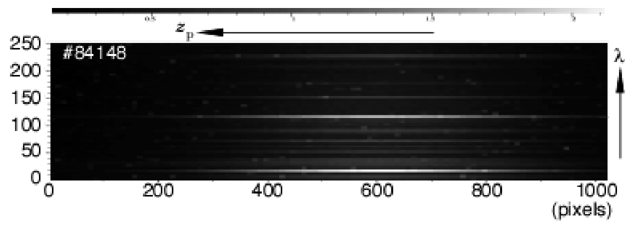

Fig. 1. Space-resolved EUV spectral image at around 15 nm. The numbers are channels on CCD. Spectral line of highly ionized Fe and Cr are observed with full radial coverage.

1) Chowdhuri, M. B., et al.: Rev. Sci. Instrum. **78** (2007) 023501.
2) Maezawa, H. and Miyauchi, H.: J. Opt. Soc. Am. A **26** (2009) 330.
3) Yamaguchi, N., et al.: Rev. Sci. Instrum. **65** (1994) 3408.