§14. Calibration of SX-EUV Diagnostic Instruments Using LHD Plasma as a Standard Radiation Source

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High temperature plasmas that emit continuum radiation (bremsstrahlung emission) could be used as a standard source for calibration of spectroscopic instruments for soft x-ray and extreme ultraviolet (SX-EUV) diagnostics.[1,2] The diagnostic instrument to be calibrated is a flat-field SX-EUV spectrograph with a varied spacing aberration corrected concave grating which has laminar-type holographic grooves with the nominal groove density of 1200 grooves/mm. The spectrograph covers the wavelength range of 4-50 nm. The detector is a back-illuminated CCD detector.

Observed spectral intensity, $I_{ob}(\lambda)$ [counts/s/Å], and the spectral brightness from the plasma, $I(\lambda)$ [photons/s/cm^2/str/Å], are related as

$$I(\lambda) = F_C \cdot I_{0b}(\lambda) \,,$$

where F_C is the spectral sensitivity coefficient written by $h\nu$ the photon energy in eV, Ω the solid angle viewed by the plasma at the entrance slit of the spectrograph, A the viewing area at the plasma in cm^2, $C(\lambda)$ the diffraction efficiency of the grating, $\eta_{CCD}(\lambda)$ the quantum efficiency of CCD detector and 3.65α eV is the required energy to produce one CCD count, where α is the conversion factor of electron-hole pairs to one CCD count, as

$$F_C = \frac{3.65 \cdot \alpha}{\Omega \cdot A \cdot C(\lambda) \cdot \eta_{CCD}(\lambda) \cdot h\nu} \,.$$

Because the emissivity of bremsstrahlung emission can be predicted precisely when the electron temperature, density and the effective charge, Z_{eff}, are given, one can determine the absolute sensitivity of the spectroscopic diagnostic system, where the absolute calibration factor obtained through the experiments is equivalent to the above spectral sensitivity coefficient. Recently, Morita et al. have determined the absolute intensity calibration factor of the mentioned SX-EUV spectrograph, observing radial profiles of bremsstrahlung continuum in LHD.[3] The wavelength dependence of this factor comes from the reciprocal of $C(\lambda) \cdot \eta_{CCD}(\lambda) \cdot h\nu$. Diffraction efficiency of the laminar-type grating has been calculated by using the unified classical theory.[4] The result of calculation of $C(\lambda)$ which has been carried out under the shallow groove approximation is shown in Fig. 1, where the profile of laminar groove has been expressed by 5th order Fourier expansion. The reciprocal of the product of grating efficiency and photon energy is shown in Fig. 2 along with the measured calibration factor, where the plots are normalized at 49.5 nm.

The wavelength dependence of the measured calibration factor can be explained very well by that of the product of the grating efficiency and photon energy. This indicates also that the detection efficiency of CCD detector is nearly constant, especially for the longer wavelength radiation $(20<\lambda<50 \text{ nm})$.[5] Detail investigations in quantitative comparison should be carried out talking into account the characteristics of the quantum efficiency of CCD detector for the shorter wavelength region.
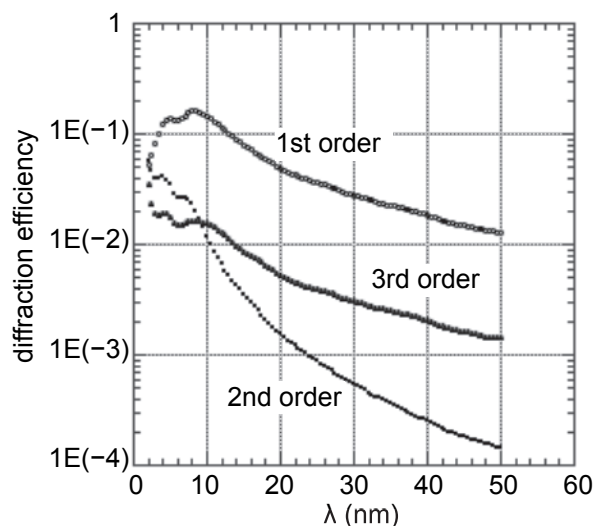

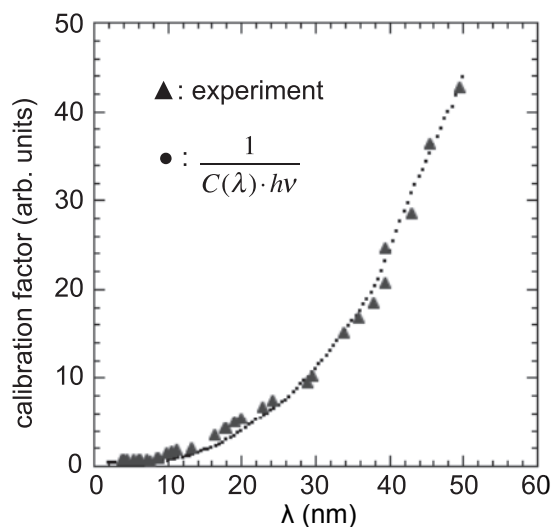Fig. 1. Calculated diffraction efficiency of the laminar-type grating.

Fig. 2. The reciprocal of $C(\lambda) \cdot h\nu$ as a function of wavelength. The measured absolute intensity calibration factor of the SX-EUV spectrograph system is also plotted.

1) Feldman, U., et al.: Astron. Astrophys. **441** (2005) 1211.
2) Chowdhuri, M. B., et al.: Rev. Sci. Instrum. **78** (2007) 023501.
3) Dong, C., Morita, Goto, M., and Wang, E.: Rev. Sci Instrum. **82** (2011) 113102 : Plasma & Fusion Res. **7** (2012) 2402139.
4) Maezawa, H. and Miyauchi, H.: J. Opt. Soc. Am. A **26** (2009) 330.
5) Poletto, L., Boscolo, A., and Tondello, G.: Appl. Optics **38** (1999) 29.