Absolute sensitivity calibration of vacuum and extreme ultraviolet spectrometer systems and $Z_{\text{eff}}$ measurement based on bremsstrahlung continuum in HL-2A tokamak\textsuperscript{a)}

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A grazing-incidence flat-field extreme ultraviolet (EUV) spectrometer has been newly developed in HL-2A tokamak. Typical spectral lines are observed from intrinsic impurities of carbon, oxygen, iron, and extrinsic impurity of helium in the wavelength range of 20 Å–500 Å. Bremsstrahlung continuum is measured at different electron densities of HL-2A discharges to calibrate absolute sensitivity of the EUV spectrometer system and to measure effective ionic charge, $Z_{\text{eff}}$. The sensitivity of a vacuum ultraviolet (VUV) spectrometer system is also absolutely calibrated in overlapped wavelength range of 300 Å–500 Å by comparing the intensity between VUV and EUV line emissions. © 2012 American Institute of Physics [http://dx.doi.org/10.1063/1.4729671]

I. INTRODUCTION

Impurity diagnostics based on spectroscopic method\textsuperscript{1} is especially important not only for impurity monitor and impurity transport study but also for active impurity feedback control. In HL-2A tokamak, a 1 m normal-incidence Rowland circle vacuum ultraviolet (VUV) spectrometer\textsuperscript{2} was adopted to measure edge impurity line emissions in the wavelength range of 300 Å–3200 Å. However, core impurity line emissions from highly ionized impurity ions cannot be measured with VUV spectrometer. A grazing-incidence flat-field extreme ultraviolet (EUV) spectrometer has been recently installed on HL-2A tokamak to observe line emissions in the wavelength range of 20 Å–500 Å and to study core impurity transport physics.

EUV spectrometers have been applied to several fusion devices such as LHD (Ref. 3–5), NSTX (Ref. 6), and SSPX (Ref. 7) to observe temporal behavior and radial profile of impurities. EUV bremsstrahlung continuum is basically much stronger than visible (VIS) bremsstrahlung continuum,\textsuperscript{9} and it is also stronger than recombination radiation by about two orders of magnitude. Therefore, the EUV bremsstrahlung becomes extremely important as an alternative technique\textsuperscript{9} for $Z_{\text{eff}}$ diagnostics in low-density ($1–3 \times 10^{13} \text{ cm}^{-3}$) discharges. In this paper, $Z_{\text{eff}}$ diagnostics of HL-2A plasmas is presented in addition to absolute sensitivity calibration of EUV and VUV spectrometers using EUV bremsstrahlung.

II. EUV SPECTROMETER SYSTEM

The EUV spectrometer system consists of a EUV spectrometer with a 1200 grooves/mm grating, a set of vacuum unit with 300 l/s turbo-molecular and 5 l/s oil-free pumps, and a computer for data acquisition and external control of spectrometer and detector. The spectrometer is installed on a radial diagnostic port perpendicular to the toroidal magnetic field at the mid-plane of HL-2A tokamak. The EUV spectrometer includes a 30 μm entrance slit, a holographic varied-line-space (VLS) grating, a back-illuminated charge coupled device (CCD) as well as a laser light source for positional calibration of the spectrometer. The grating is made with VLS grooves having nominal spacing of 1200 grooves/mm at the center. The effective area and the curvature radius of the grating are 26 mm $\times$ 46 mm and 5612 mm, respectively. The CCD (26.6 $\times$ 6.7 mm$^2$, 1024 $\times$ 256 pixels) is placed on the flat-focal plane of the spectrometer with an electric insulator flange. The wavelength can be scanned with a pulse motor in the range of 20 Å–500 Å by changing the CCD position. Data are generally taken in each 6 ms for impurity diagnostics by operating CCD at 5 $^\circ$ C through full vertical binning mode (FVB).

III. ABSOLUTE CALIBRATION OF EUV AND VUV SYSTEMS

EUV bremsstrahlung continuum is applied to absolute sensitivity calibration of the EUV spectrometer instead of traditional methods based on the line branching ratio and the synchrotron orbital radiation. For the purpose, the EUV bremsstrahlung is utilized to calibrate the system by comparing the intensity between experiment and calculation. The absolute value of the EUV bremsstrahlung is calculated from electron density and electron temperature as well as $Z_{\text{eff}}$. The electron density and temperature are measured by HCN laser...