

Tests and cross calibration of two-channel prototype ITER vacuum ultraviolet spectrometer with a thin foil filter and baffles

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Introduction: The primary role of ITER vacuum ultraviolet (VUV) core survey spectrometer is to measure radiation and to identify all relevant impurities in the ITER main plasmas.[1] It is one of three ITER VUV subsystems that monitor impurities with full coverage in core, edge and divertor plasmas.[2] The VUV core survey spectrometer is designed as a five-channel spectral system.[3, 4] To verify the design, a two channel prototype spectrometer has been developed with No. 3 (14.4 – 31.8 nm) and No. 4 (29.0 – 60.0 nm) among 5 channels.[5] In this article, the prototype system was tested and relatively calibrated with a calibration source of hollow cathode lamp [6]. A thin aluminum foil filter and baffles were used to test the reduction of the stray light noise, and their effect on the signal to noise ratio was studied experimentally. The measured intensities of spectral lines were crossly calibrated by using the overlapped spectral line between the adjacent two channels of No. 3 and No. 4 .

Experimental setup: The ITER prototype system consists of a collimating mirror, two holographic diffraction gratings with toroidal geometry, and two different electronic detectors.[5] Toroidal diffraction gratings are used as the optical and dispersive components. The overall spectral resolutions ($\lambda/\Delta\lambda$) are ranged from about 382 (Ch. 3) to 465 (Ch. 4). Two gratings are placed at different positions and heights as shown in Fig. 1 (a). A common slit with 10 mm x 90 μ m size is positioned in the slit chamber. Two kinds of detectors of the micro-channel plate (MCP) electron multiplier with camera (McPherson Co.) and the back-illuminated charge coupled device (Princeton Instruments Co.) are installed at each port.

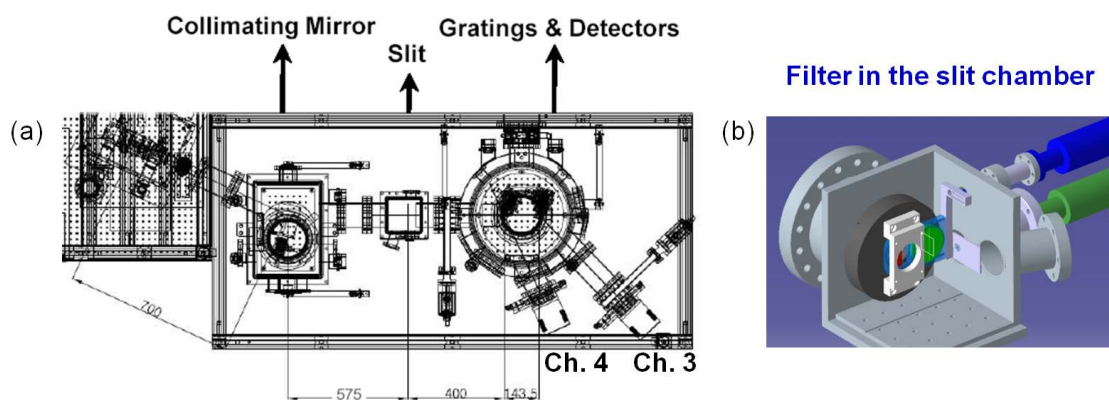


Figure 1. (a) The VUV spectrometer prototype system. (b) Filter on/off system in the slit chamber

The MCP has 40 mm diameter with CsI coating, and it is accompanied with a phosphor screen, a fiber optic taper, and a visible CCD camera, so that the effective resolution of the MCP detector would be about 80 μm . On the other hand, the back-illuminated CCD has the imaging area of 27.6 \times 6.9 mm with pixel size of $\sim 13.5 \mu\text{m}$. For test of the prototype system, a hollow cathode lamp was used as a calibrated light source. As shown in Fig. 1 (b), the thin filter is positioned in the slit chamber, and baffles are positioned in front of each detector.

Test of spectral resolution: In experiments, the spectra were obtained from two channels at the same time, as shown in Fig. 2. The spectral lines measured from the back-illuminated CCD detector are shown in Fig. 2 (a) He discharge of $I_{\text{hc}} = 2 \text{ A}$ at Ch. 3, and in Fig. 2 (b) Ne discharge of $I_{\text{hc}} = 2 \text{ A}$ at Ch. 4. The spectral lines measured from the MCP detector are shown in Fig. 2 (c) He discharge of $I_{\text{hc}} = 2 \text{ A}$ at Ch. 3, and in Fig. 2 (d) Ne discharge of $I_{\text{hc}} = 2 \text{ A}$ at Ch. 4. The measured FWHM of the Ne II spectral line of $\lambda = 46.07 \text{ nm}$ is 0.045 nm in Fig. 2 (b), and it is comparable to the expected imaging line width of 0.048 nm from the calculation by ray-tracing software.[4, 5] Spectral lines from two different detectors are compared in the same discharge condition. The measured FWHMs of 30.4 nm He II line are (a) 0.046 nm for the back-illuminated CCD detector and (c) 0.080 nm for the MCP detector, respectively. In other words, the spectral resolution of the back-illuminated CCD is superior to the MCP detector in this experiment setup. This difference is caused by the fact that the back-illuminated CCD shows negligible contribution to the instrumental line width, while the MCP detection system, including phosphor screen, fiber optic taper, and visible CCD camera, has a relatively higher detector resolution of $\sim 80 \mu\text{m}$.

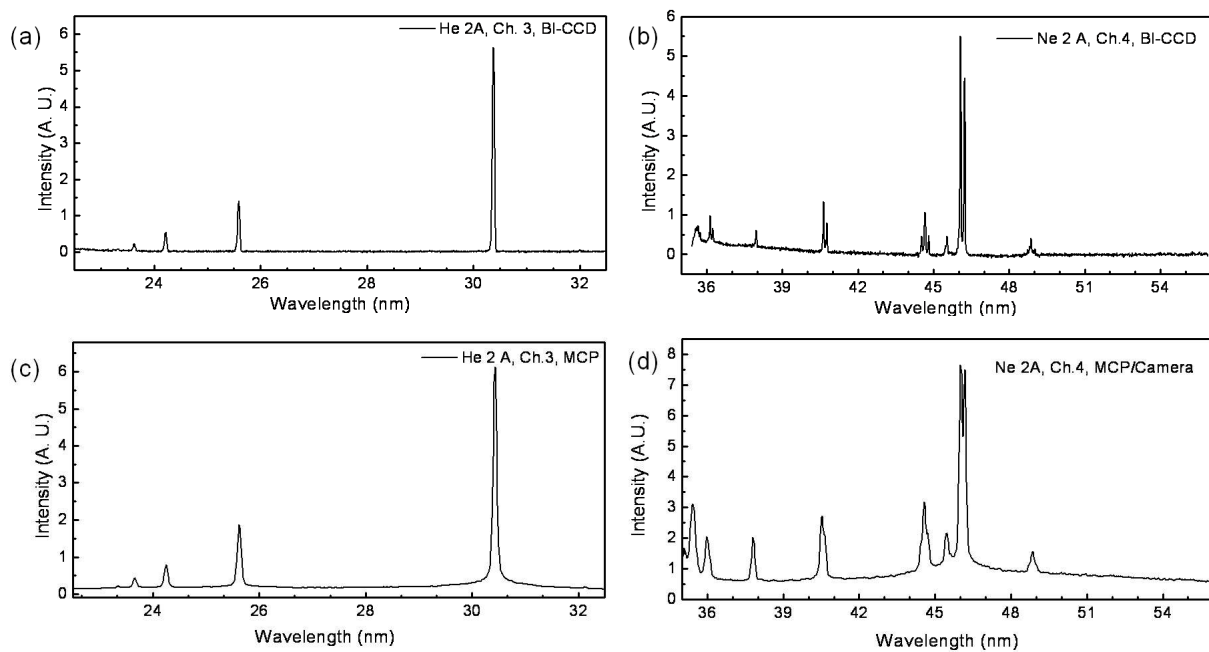


Figure 2. Measured spectra (a) He 2 A at Ch. 3 with Back-illuminated CCD, (b) Ne 2 A at Ch. 4 with Back-illuminated CCD, (c) He 2 A at Ch. 3 with MCP, (d) Ne 2 A at Ch. 4 with MCP.

Test of baffle and filters: To reduce the stray light noise, the effects of the baffle and the filter were studied. A thin Al foil filter with 0.2 μm thickness was used as a filter and a filter on/off system was installed in the slit chamber. The filter provides full cut-off on the visible light noise effectively, even though the visible laser was illuminated into the spectrometer for test. However, the filter also makes the reduction of the VUV light about 60 % as shown in Fig. 3 (a), (b), and moreover the filter should be carefully handled to prevent it from being easily fragile due to gas flow or vacuum stress. As another option for reducing the stray light noise, the baffles composed of several disks with 50 mm inner diameter and 100 mm outer diameter were installed in front of detectors. To find the effect of baffles, images on the back-illuminated CCD detector were compared in two cases between with and without baffles. In case of without baffles, visible stray light reflected on the port could make several dots to the detector, as illustrated in Fig. 3 (d). However, if baffles are positioned in front of detectors, the dots from stray light are removed as shown in Fig. 3 (c). So, the baffles effectively reduced the stray light. To evaluate the effect of the dots on the spectra, the noise level was assessed in both cases. The standard deviations of base signals from the mean values are analyzed about 23 counts/ms for the case of without baffle and 15 counts/ms for the case of with baffle, respectively. This effect of baffles was confirmed from the ray tracing in the prototype system. In the calculation, the spot diagrams on the detector showed a number of dots in the case of without baffle, but they were significantly reduced if the baffles are assumed in front of detector. Furthermore, it is noted that the baffles of special geometry such as inclined disks were more effective than the flat disks in the ray tracing calculation. Consequently, the baffle with the optimized geometry is a good candidate for reducing the stray light.

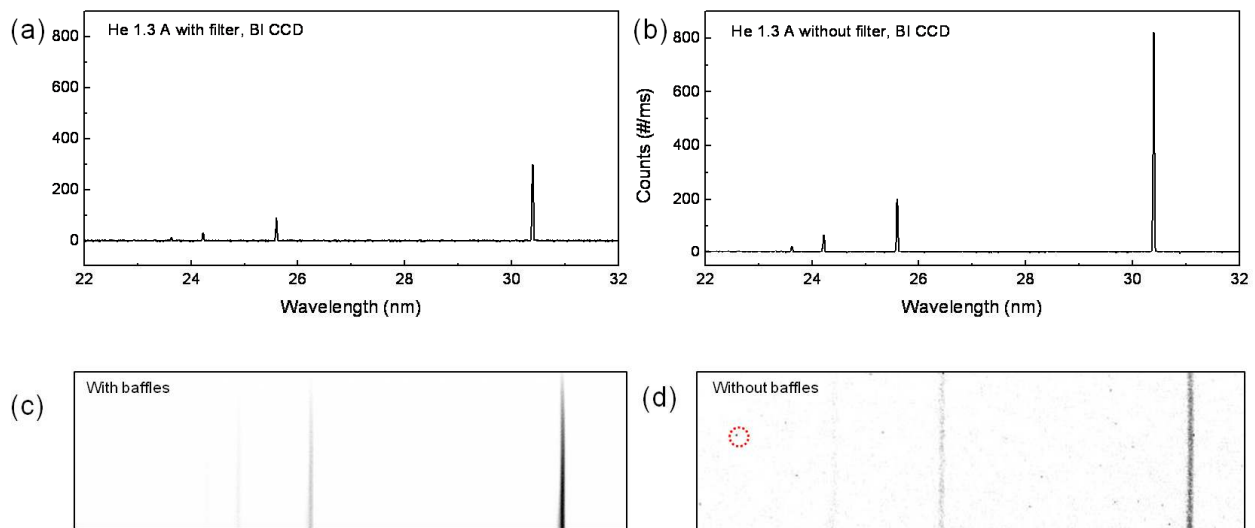


Figure 3. Spectra in the same discharge (a) with Al thin filter (b) without filter. Baffles in front of the detector are installed in the experiment (a) and (b). Measured images on the back illuminated CCD detector (c) with baffles, (d) without baffles in front of detectors.

Relative calibration: The cross calibration between Ch. 3 and Ch. 4 was performed by using the common spectral line of He II 30.4 nm, as shown in Fig. 4 (a) and (b). The measured photon counts at the two detectors are plotted in Fig. 4 (c), in which the solid curve is the calibrated emission of the hollow cathode lamp.[6] It shows that the calculated emission is proportional to the measured detector counts because the grating efficiency and the detector efficiency are nearly flat in this wavelength range. As a result, the measured photon counts are in a good agreement with the expected counts from the calibrated emission power. The lower detector counts near the 48 nm are due to the low reflectivity of the collimating mirror. The mirror surface roughness is about 10 nm, so that its reflectivity of near 48 nm wavelength is especially lower at the 20 degree incidence in case of Au coated mirror. The lower counts near 31 nm and 46 nm of the MCP detector is caused by the error in integrating detector counts of the spectral lines, because the MCP has large instrumental broadening. Besides these error points, the detector counts show similar behavior to the expected ones from the emission power.

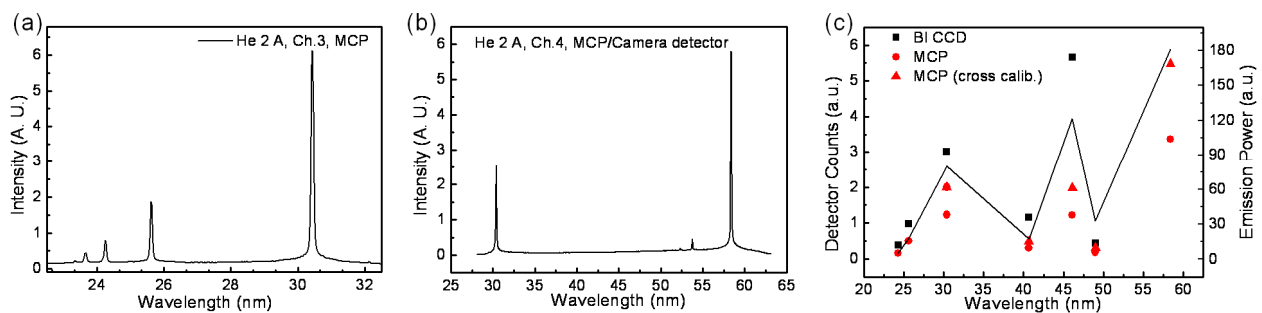


Figure 4. (a) Measured spectra in the discharge He 2A at Ch. 3 with MCP. (b) Measured spectra in the discharge He 2A at Ch. 4 with MCP. (c) Detector counts number in each detector and the expected emission power (curve).

Summary: In this work, the two-channel prototype spectrometer was tested and relatively calibrated. It is noted that baffles are sufficient to effectively reduce the stray light. A thin filter cut off visible light but it impact strongly the transmission of VUV light intensity. Two channel spectra were crossly calibrated via overlapping spectral line. The measured calibration curve was compared to the expected emission power of the hollow cathode lamp, and the overall system performance was verified.

Acknowledgments: This work has been supported by the Ministry of Education, Science and Technology of the Republic of Korea under the Korean ITER project contract.

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