Design of reflectivity measurement device of First Mirrors in ITER VUV spectrometers

Yoo Kwan Kim[1,2], Boseong Kim[2], Younghwa An[2], Changrae Seon[2], Jungmin Jo[2], Munseong Cheon[2], and Yu Kwon Kim[1*]

[1]*Department of Energy Systems Research, Ajou University, 206 Worldcup-ro, Suwon 16499, Korea*

[2]*Korea Institute of Fusion Energy, 169-148 Gwahak-ro, Daejeon 34133, Korea*

Introduction: Plasma diagnostic systems are the critical attributes in fusion reactor such as ITER(International Thermonuclear Experimental Reactor) to provide the measurements necessary to optimize plasma performance. First Mirror (FM) is an optical component of the plasma diagnostic spectrometer that plays an essential role in that it deflects the light emitted from the plasma to the detecting components. In recent years, various experiments have been performed to select a suitable material that can maintain the properties of the mirror under heat load, neutron/gamma irradiation, possible sputtering by fast particles and steam ingress environments for ITER VUV (vacuum ultraviolet) spectrometer. As a result of this previous R&D, Silicon Carbide (SiC) was chosen as the appropriate first mirror material for ITER VUV spectrometers. The mirror reflectivity of VUV mirror can be calculated as a function of the average surface roughness of the mirror from the well-known formula. However, the measurement of the average surface roughness normally has certain error, therefore the direct measurement of the mirror reflectivity is to be necessary to reduce this error. The ITER VUV spectrometer covers the wavelength range of 2.4 – 160 nm, and we intend to make an experimental device to measure the reflectivity of first mirrors.

Because of the limitations for available VUV light source and tricky experimental environment of vacuum condition, novel development of experimental device measuring the reflectivity of the mirror under the certain selected VUV wavelength is required. Laminar-type Replica diffraction grating (Shimadzu) and two apertures enable to distinguish and select out the designated wavelength of VUV light. Also, development of the VUV mirror reflectivity measurement device will offer the datasheet to confirm the uniformity of SiC mirror surface roughness regardless of the reflected area. Therefore, the paper is focused on developing the VUV mirror reflectivity measurement device to validate the uniformity of the SiC mirror surface roughness and to measure the mirror reflectivity depending on the incident angle of light radiated onto the different area (both ends and center of the mirror) of the SiC mirror (ITER VUV Edge Imaging and Divertor VUV spectrometers).

First Mirror in ITER VUV Spectrometers : Two types of first mirrors are located in ITER divertor VUV and VUV edge imaging spectrometers [1, 2]. ITER divertor VUV spectrometer locates in equatorial #11 and VUV edge imaging spectrometer in upper port #18 monitoring the impurity line emission from divertor and edge plasma such as tungsten (divertor), beryllium, Oxygen (first wall), Neon, Nitrogen (seeding) and Helium (fusion ash, GDC). The shape of mirror is elliptic cylindrical and the material is SiC requiring surface roughness less than 1 nm. The size of mirror is 400 x 30 mm (length x width) for divertor spectrometer and 470 x 30 mm for edge spectrometer. First mirrors for ITER VUV spectrometers are required to measure the reflectivity in the center and both ends of the mirror at a specific incident angle. The incident angles for both ends of divertor mirror are 13.75°, 23.98° and 21.28° for center. Also, the incident angles of both ends of edge mirror are 5.38°, 15.26° and 10° for center. Two prototype of SiC mirrors would be able to provide the error bar of the mirror reflectivity with the experimental measurement in VUV wavelength range.

Wavelength calibration with VUV light source and specifications : ITER divertor VUV and edge imaging spectrometers are in the range 15 – 32 nm and 17 – 32 nm. A 642-1 multi-anode UHV SXR source (1 - 20 nm) and high current hollow cathode lamp (23 - 160 nm) with He and Ne plasma were used for the light source in the VUV wavelength range as shown in **Figure 1**.

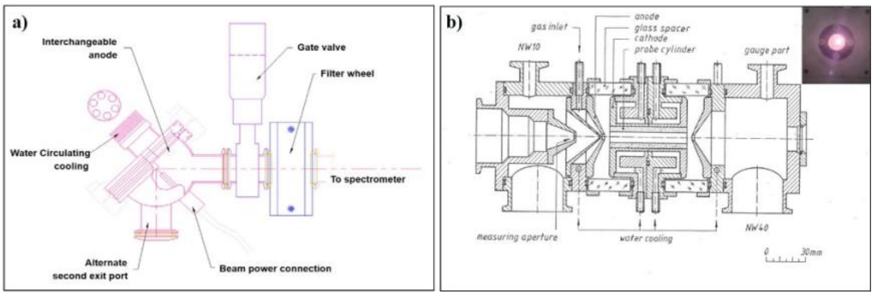
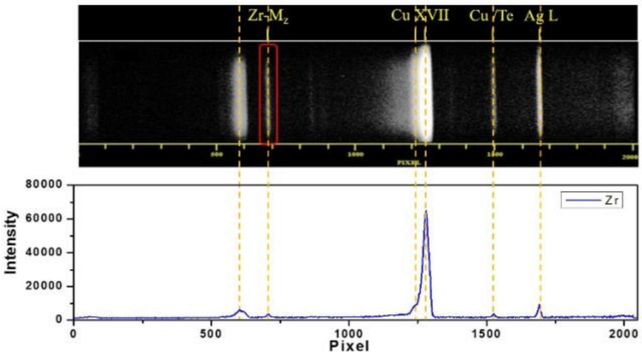


Figure 1. Two VUV light source : a) 642-1 multi-anode UHV SXR, b) High current hollow cathode lamp [3]

VUV light identification was also conducted for the VUV source, Model # 642-1 multi-anode UHV SXR source (Mcpherson Inc) using the other VUV spectrometer is currently available. The electrons generate x-rays when free electrons generated by a hot filament energetically hit the anode. The flux in bright lines is about 10^{11} photons s^{-1} sr^{-1} and targets are consistd of Mg, Mo, Ti, Zr .etc. with rotatable 6 anode target holder. The operation pressure should be lower than 10^{-6} Torr. The cooling water+ethanol mixture begins to circulate on the back of anode target as soon as source power supply is started. Peaks that appear in common through the spectrum can be seen as structural materials emission line near the target. Cu / Te came from tellurium copper (4 to 7 % Te with Cu) target holder and silver peaks appeared from silver coating around the target to reduce oxidation as shown in **Figure 2**. Even other structures near the anode holder consisted of stainless steel which might appear as Si or O in the spectrum. With linear calibration fitting, $R^2 = 0.997$ which shows quite well wavelength calibrated.



Element	Wavelength (nm)	Pixel
Zr	8.2	707
Cu XVII	5.279	1224
Cu XVII	5.098	1265
Cu/Te	3.80	1508
Ag	2.93	1672

Figure. 2 Spectral images acquired by the CCD for Zr anode target

Design of the reflectivity measurement device: Design of the experimental device is consisted of three different vacuum chambers, which are slit chamber, grating chamber and mirror chamber, respectively as shown in **Figure 3**. The slit chamber consists of XY entrance slit with 2 picomotor actuator (8302-UHV, Newport) for vertical and horizontal motorized movements. Picomotor actuator connects to the 9 pin 2.75” CF flange manipulating with picomotor controller (8742-4-KIT, Newport). XY slit enables fine control of the incident photons area with motorized system. The grating chamber consists of Laminar-type Replica Diffraction Gratings for VUV / Soft X-ray Region (30-002, Shimadzu) and XYZ translation (TSDS-655S-M6, Sigmakoki), rotation (KSPS-606M, Sigmakoki) and tilt stages (GOHS-40B15, Sigmakoki) for manipulating the grating location. Spectral range for the grating is 1- 20 nm and the groove density is 1200 grooves/mm. Incident angle against grating normal is 87°. The distance from entrance slit to grating is 237 mm and 235 mm to detector surface. For zeroth-order visible cutting, 40 x 60 mm(width x height) stainless steel board which connects to the linear feedthrough is horizontally moving as means of blocking shield. Teflon-covered stainless steel baffle system is installed between the grating and mirror chamber beam port to mitigate the stray light.A 5 x 10 mm (width x height) aperture size slit is discerning the certain designated light by horizontally control with the linear feedthrough. Mirror holder, comprehensively assembled stages (XYZ translation, rotation and tilt stages) and motorized linear stage (VSGSP26-200, Sigmakoki) are equipped with SiC mirror to control its location along with the reflected area of the mirror and angles. Vacuum Motorized stages is travelling vertically to be off from light path for Reference light (w/o reflection) measurement. Sliding system is applied in the reference light port to widely accept the various angled light. Available range for sliding system is around 25 mm and extra board which 6” CF flange located on the right side is ready for wide range measurements. 5-axis manipulation stage is installed for measuring Reflected light, especially, for the various acceptance angle of reflected light measurements. Three different length of controlling bolts enable the 5-axis manipulation stage bellow covers the wider range of sight. Reflectivity of the mirror would be calculated with the intensity ratio of Reflected light / Reference light measured through Charged Coupled Device (CCD). Also, its reflectivity would be double-checked by calibrated XUV-100C photodiode measurements.

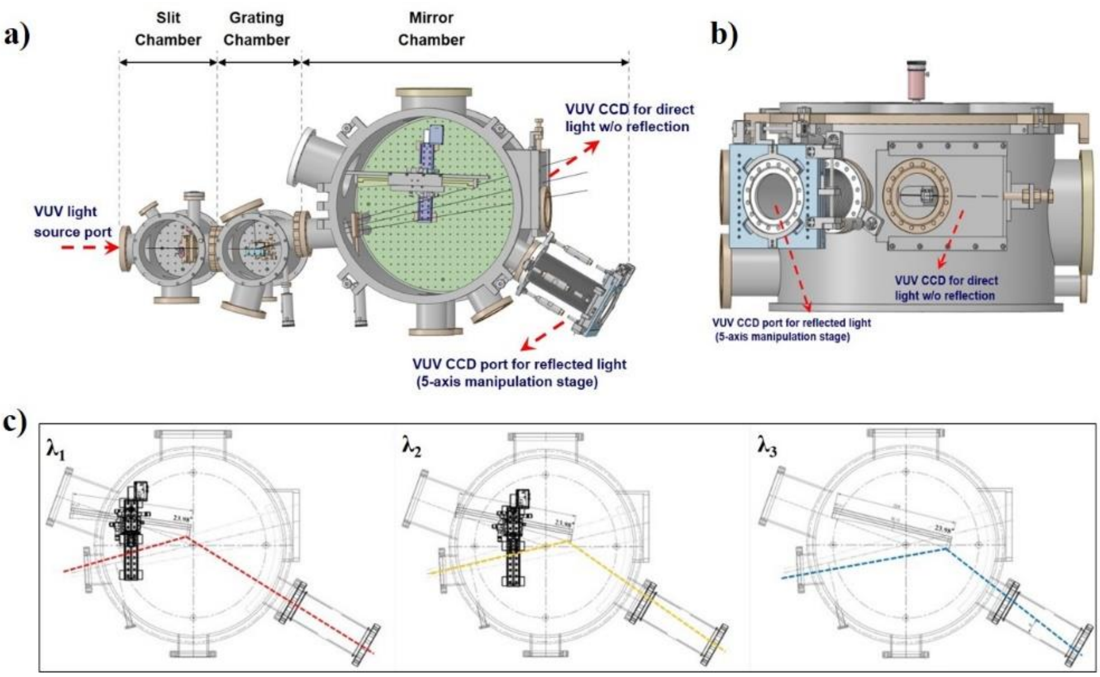


Figure 3. a) Current design status of ITER VUV mirror reflectivity measurement device, b) Sliding system and 5-axis manipulation stage for reference and reflected light measurement, c) Simulation of the reflected beam path collision with divertor mirror at 23.98°at differenet wavelength light.

Acknowledgement: This work was supported by the Ministry of Science and ICT of Korea, through the ITER project contract (RS-2022-00154842). The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

References

[1] C. R. Seon, S. H. Choi, M. S. Cheon, S. Pak, H. G. Lee, W. Biel, R. Barnsley, Rev. Sci. Instr. **81**, 10E508 (2010)

[2] C. R. Seon, J. H. Hong, J. Jang, S. H. Lee, W. Choe, H. H. Lee, M. S. Cheon, S. Pak, H. G. Lee, W. Biel, and R. Barnsley, Rev. Sci. Instr. 85, 11E403 (2014)

[3] See https://mcphersoninc.com/pdf/642-SXR-source.pdf McPHERSON website.