DESIGN AND DEVELOPMENT OF ITER VUV SPECTROMETERS WITH PROTOTYPE TESTING

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1. DESIGN AND DEVELOPMENT OF ITER VUV SPECTROMETERS

The primary role of ITER vacuum ultraviolet (VUV) spectrometer is the monitoring of all the relevant impurity ion species in plasmas. Three sets of VUV spectrometers of core survey (2 – 160 nm), edge imaging (17 – 32 nm, 1-D profile), and divertor VUV (15 − 32 nm) spectrometers facilitate the measurement in different regions of plasmas of ITER tokamak with relatively high spectral resolution of $\lambda/\Delta\lambda$ = 200 – 500. [1] Currently these ITER VUV spectrometers are at the end of the final design, and the manufacturing has partially begun from the in-port-plug components.

2. MOCK-UP TEST FOR COMPONENTS DEVELOPMENT

To optimize the design of ITER VUV spectrometers, various R&D activities for components have been performed. ITER VUV spectrometers consist of the field mirror in the port plug, the vacuum extension pipe in the interspace and the spectrometer chambers in the port cell. To absorb the relative movement between the port plug on the tokamak and the spectrometer chamber on the building (max. ~ 50 mm in one direction), one gimbal bellows and one axial bellows are employed for each vacuum extension pipe. [2] The structural integrity of each bellows has been verified by the dedicated structural analysis following codes and standards. The fatigue cycles of the bellows was assessed by the experiment of Mock-up (Figure 1 a)) as well as the structural calculation with Finite Element modelling. The rotary feedthrough is necessary for the shutter actuation to protect the first mirror during glow discharge cleaning. Mock-ups for the rotary feedthrough and the DN65 ITER standard flange to mount the rotary feedthrough were also manufactured to check the manufacturability.

3. PROTOTYPE DIVERTOR VUV SPECTROMETER AT KSTAR

To validate the optical design of ITER VUV spectrometers, two prototypes of VUV core survey and divertor VUV spectrometers have been developed and installed at KSTAR. The VUV core survey spectrometer has been operated at KSTAR from the year of 2012 in the wavelength of 15 nm – 50 nm with two wavelength channels. The divertor VUV spectrometer consists of one field mirror inside the port of KSTAR, and one spectrometer chamber outside of the port flange. This divertor VUV spectrometer was upgraded in the year of 2023 following the design update of ITER divertor VUV spectrometer replacing collimation mirror with the space-resolved slit due to lack of space in ITER port cell.

The acquired spectrum from the campaign of 2023 for the shot #33372 is shown in Figure 1 b). Tungsten quasi-continuum emission lines of 5 – 7 nm could be observed due to the tungsten divertor of KSTAR installed in the year of 2023. By employing space-resolved slit, 1-D profile of impurity emission lines for the wavelength range 5 nm – 18 nm could be observed. Different 1-D profile could be identified for W (~ +20 - ~ +44) and O VIII emission lines. The upper region of CCD image of Figure 1 b) corresponds to the divertor plasma region through the line of sight in lower edge region of the plasma, while the lower region of CCD image corresponds to the plasma core region.

a) b)

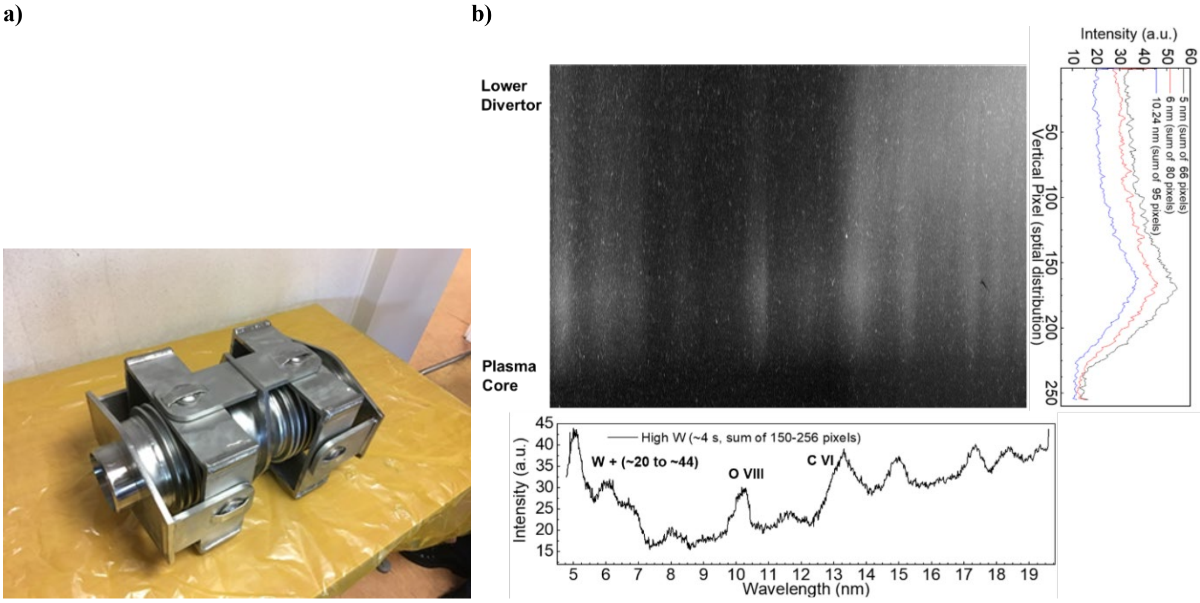

Fig. 1 a) Gimbal bellows mock-up with double bellows wall. b) 1-D profile VUV spectrum of the shot #33372 from the divertor VUV spectrometer in the experimental campaign of KSTAR (2023 - 2024). For higher quantum efficiency, the slit width was set in maximum.

The mirror reflectivity (Au coated, roughness ~3 nm r.m.s., ~ 16 deg. grazing angle) should be multiplied to derive the line integrated emission intensity from the impurity species, and this reflectivity is orders of magnitude higher in the line of sight through the plasma core region compared to that of the divertor region. This reflectivity difference become much higher in the lower wavelength region.[3] Therefore it is deduced that the tungsten emission in the divertor region is orders of magnitude higher than that of the plasma core region, while this difference of spatial distribution for O VIII 10.24 nm line is much smaller. Detailed investigation of this acquired data is to be reported in the separate paper. Stray lights on the upper right corner are to be removed by installation of appropriate blocking plate in front of the grating in the next experimental campaign.

4. SUMMARY

From the series of R&D with Mock-ups and prototypes, the design of ITER VUV spectrometer could be verified to proceed the development in the next phase of the procurement. The prototype divertor VUV spectrometer at KSTAR was modified in the year of 2023 following design update of ITER divertor VUV spectrometer replacing collimation mirror with the space-resolved slit. By employing space-resolved slit, 1-D profile of impurity emission lines for the wavelength range 5 nm – 18 nm including tungsten lines could be observed showing pattern different from the Oxygen line.

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