Spectral Line Profile Analysis Using Higher Diffraction Order in Vacuum Ultraviolet Region

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Abstract. Using a one meter VUV spectrometer and a MCP coupled to a CCD detector on TCABR tokamak, ion temperatures from impurity species have been measured and much better spectral resolution was obtained using higher order diffraction lines. Due to very small Doppler effect in the VUV region compared to large instrumental broadening, ion temperatures obtained from first order diffraction present large errors. The use of second, third and fourth order diffraction emissions increases the line broadening and results in lower error temperature measurements.

Keywords: VUV impurity lines, ion temperature, higher order diffraction emissions, tokamak plasma.

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INTRODUCTION

Most of the spectral line emissions of tokamak plasmas are from atomic ions known as impurity species. Species such as carbon, oxygen, and nitrogen, presenting high ionization level can be useful to obtain important information, such as the ion density and ion temperature at different spatial positions inside the plasma.

The line intensity profiles are Gaussian, and their full width at half maximum (FWHM) is basically a sum of the Doppler and instrumental broadening. However, the Doppler broadening effect in the VUV region is much small than in the visible region, increasing therefore the temperature measurement errors. [1]

One solution is to work with higher diffraction order, where the FWHM of line profile is increased whereas the instrumental broadening remains the same. Furthermore, in TCABR tokamak plasma [2] most of the impurity emissions occur in the VUV region, mainly at wavelengths below 155 nm, in our case, 37 first order emissions have been measured in this region [3].

Therefore the wavelength interval between about 120 nm to 320 nm has been used to register 29 second diffraction order emissions, 24 third order emissions, and 7 fourth order diffraction emissions.

The main impurity emissions are from OII to OVII, CII to CIV, NIII to NV, and FVII (from Teflon material used at the interferometer window).

MAIN CHARACTERISTICS

The VUV spectrometer is a 225 McPherson with one meter focal length and normal incidence. It has a 1200 groves/mm concave grating, with Al and MgF2 coating, and blazed at 200 nm, giving a linear dispersion of 0.83 nm /mm and covering 50nm to 350 nm.

The multichannel detector is an open 40 mm diameter MCP plate (Bright View XUV2010 G, XSI instruments) coupled to a CCD device (Marconi CCD30-11, Andor Technology) with 1024x256 pixels, with each pixel having 26 µm x 26 µm. A reducing coherent glass fiber array was used to couple the MCP to the CCD [1]. The MCP applied voltage has been kept constant at 650 V.

Taking a certain ion temperature T_i constant, one can see from Eq. 1 that the Doppler broadening, $\Delta \lambda_{D1/2,}$ due to ion temperature, will be lower for larger ion mass number M_i for a fixed wavelength $\lambda_{0.}$ At the other hand, for a fixed $M_{i,}$ $\Delta \lambda_{D1/2}$ will be small for lower wavelength.

$$T_i = 1.69 \times 10^8 M_i (\Delta \lambda_{D1/2} / \lambda_0)^2 \qquad (1)$$

This will cause much lower Doppler broadening when the measurements are taken in the VUV region and high Z impurities. Furthermore, the measured line emission FWHM $\Delta \lambda_{meas}$ will be directly affected by the instrumental broadening $\Delta \lambda_{ins}$ according to Eq. 2.

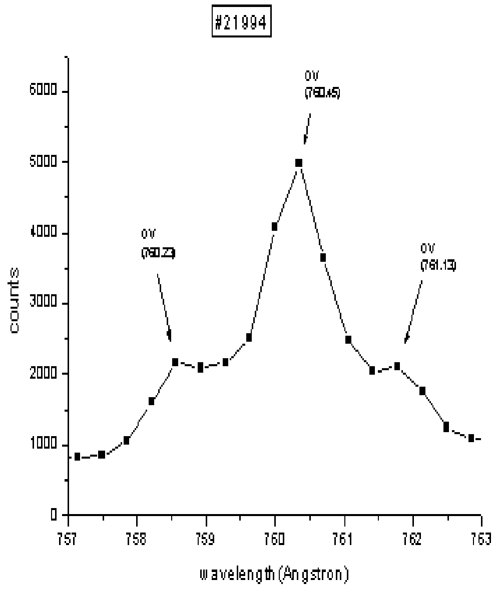
$$(\Delta \lambda_{meas.})^2 = (\Delta \lambda_{D1/2})^2 + (\Delta \lambda_{inst.})^2 \qquad (2)$$

One way to overcome these difficulties is to work using second, third and fourth order diffractions of the λ_0 line. Since at higher order diffractions, the measured line broadening, $\Delta \lambda_{meas}$, increases with order number, but not the instrumental broadening, and threfore obtaining a more accurate value of $\Delta \lambda_{D1/2}$.

ION TEMPERATURE MEASUREMENTS

The measurements in the VUV region of TCABR tokamak plasma covered emissions from 50 nm to 320 nm and details can be found in reference [3]. Here, we select some wavelengths to analyze the higher order diffraction effects and precaution needed to obtain ion temperatures.

In figure 1 is shown the emission from OV at 76.045 nm commonly observed in different tokamaks [4], [5], [6], and [7]. As can be noticed, there are at least two emissions nearby, 76.023 nm and 76.113 nm. However, if we look at figure 2, the third order diffraction line OV 228.134 nm of 76.045 nm is together with a complex emission of two doublets, 227.845 nm and 228.351 nm, 227.592 nm and 228.604 nm.



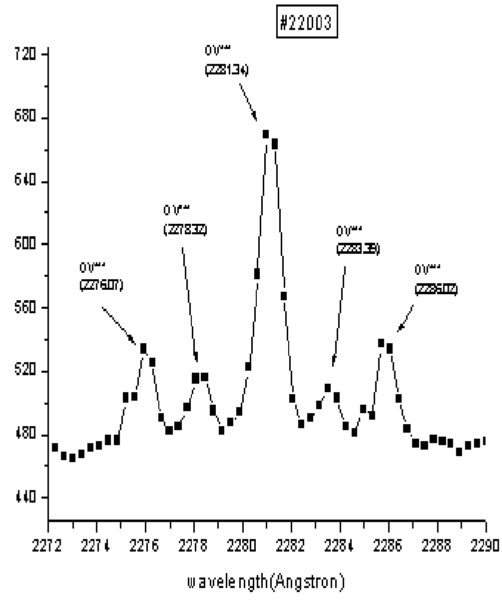
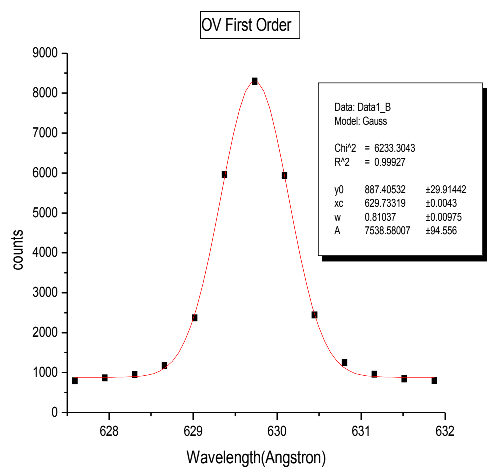


FIGURE 1. OV line at 76.045 nm first order

FIGURE 2. Third order OV line at 228.134 nm

Therefore, care need to be taken when a wavelength is chosen by looking at higher diffraction order. Also, as can be seen from Eq. 2, working at higher order, the error due to instrumental broadening is minimized.



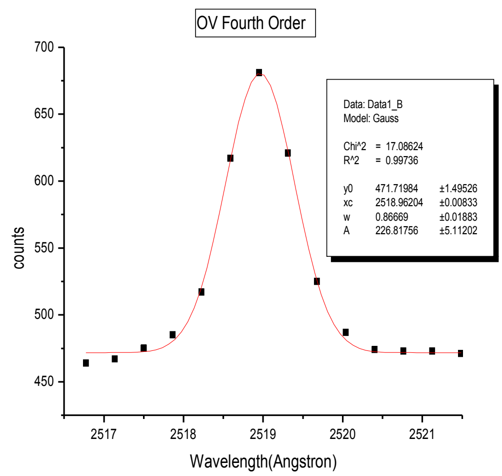
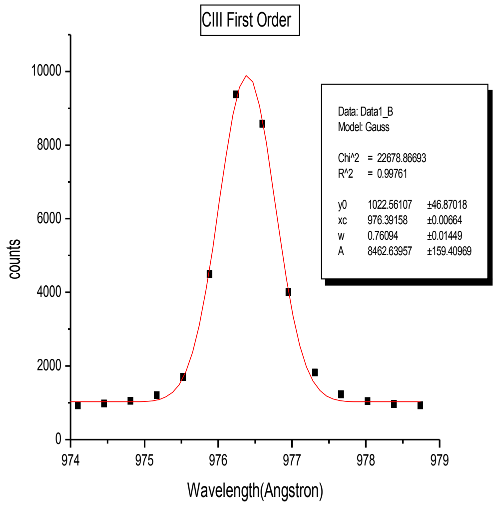


FIGURE 3. OV line at 62.973 nm first order

FIGURE 4. OV fourth order line at 251.896 nm

Figure 3 shows the first order emission of OV line at 62.973 nm with FWHM of 0.0940 nm. Considering that the instrumental broadening is 0.087 nm, it will result on very small

Doppler broadening, and giving ion temperature of about 850 eV, which is too high to be accepted. Nevertheless, if one takes the fourth order emission of same line, figure 4, the result will be an ion temperature of about 110 eV, which is reasonable for this tokamak



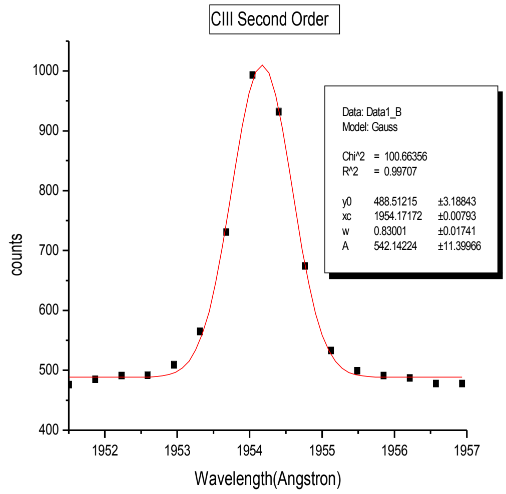


FIGURE 5. CIII line at 97.639 nm first order

FIGURE 6. Second order line of CIII at 195.417 nm

Another example is the CIII line at 97.639 nm as can be seen in figure 5. From the first order emission we obtain FWHM of 0.0883 nm as total broadening measurements which give the ion temperature of 54 eV. However, when the second order emission is analyzed, figure 6, the FWHM increases to 0.0963 and obtaining ion temperature of 105 eV. Since it must be unique ion temperature for one wavelength related to one atomic transition and the measurements have been taken from a small tokamak, where the ion temperature should not change too much, the measurement from second order diffraction line should give more precise result.

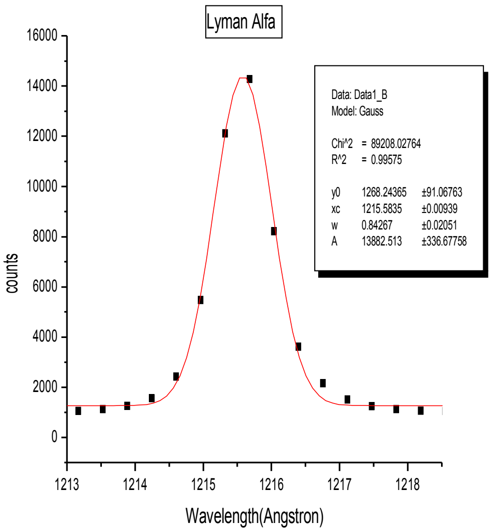


FIGURE 7. Lyman alpha line at 121.558 nm

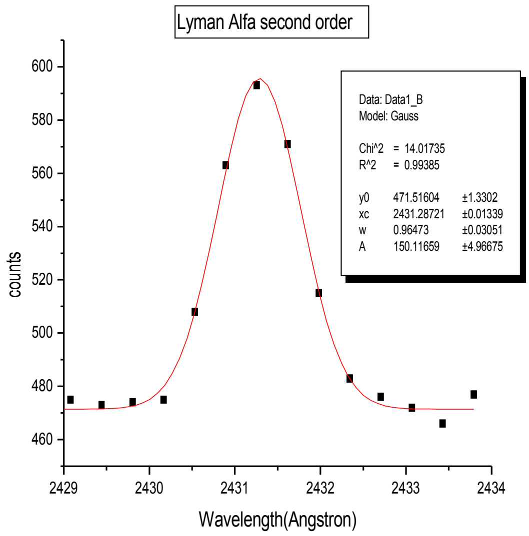


FIGURE 8. Lyman alpha second order at 243.129 nm

Ion temperature obtained from Lyman alpha spectra also gives the similar results. Since this emission occurs mainly at the border region, we expect much lower temperature. The first order gives ion temperature of 23 eV according to figure 7, whereas from figure 8, the second order emission results in 14.3 eV. The second order result is in accordance with Langmuir probe measurements.

CONCLUSIONS

The use of a VUV Spectrometer with MCP and CCD detectors is a very powerful tool for the impurity line emission studies, since most of the spectral line emissions occur at wavelengths below 150 nm, and the interval between 150 nm to 320 nm can be used to study the higher order diffraction spectral lines.

Ion temperature determination from first order line Doppler broadening may give wrong results, because of the small Doppler broadening effect against large instrumental broadening. Higher order diffraction line gives much better resolution since the resolving power is directly proportional to the order number and the temperature determination is more accurate. The limitations come from the high intensity lines are required to study higher order diffraction, since these are much less intense than the first order. Also, it is clear that the procedure could hardly be applied to the visible region of the spectra where higher order diffraction lines are more difficult to observe. Finally, the CCD pixel distribution along spectral line must be the same for all signals. Otherwise, measurements of a spectral line with different pixel distributions can result in different line broadenings.

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