VUV SPECTROSCOPY OF THE He II - LYMAN SERIES FOR ELECTRON DENSITY ESTIMATION

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Abstract. We report use of the spectral line shapes of the Lyman series of ionized helium for diagnostics of high temperature plasmas. As a light source the low pressure pulsed arc was used. Electron density was determined from width of the He II Pashen alfa line and parameters of the He I 447.1 nm line, while electron temperature was determined from Boltzmann plot of the He II lines. The use of the Inglis-Teller relation on merging of spectral lines along series and on condition for partial local thermodynamic equilibrium was tested as methods for electron density estimation.

1. INTRODUCTION

Vacuum ultra violet, VUV spectroscopy is very important since most intense spectral lines of various elements are in this wavelength region. Special attention was devoted to study of hydrogen and helium lines important for diagnostics of astrophysical and fusion plasmas. Among them, in high temperature plasmas the shape and width of ionized helium Lyman series lines are extensively studied both theoretically, (Kepple, 1971) and experimentally (Wrubel, 2001) and (Mijović, 1989). Since lower members of a series are often highly self-absorbed, in this work methods for plasma diagnostics based on higher member of Lyman series are analyzed.

2. EXPERIMENT

Experimental setup is shown in Figure 1. Plasma source is low pressure pulsed arc, whose inner diameter is 10 mm and distance between electrodes 130 mm. Pressure in the source was set and controlled by needle valve, with the gas flow of 0.2 l/min. One side of plasma source is mounted on VUV spectrometer, and on the other end there is a quartz window. Light emission was obtained by discharging capacitor of Experimental setup is shown in Figure 1. Plasma source is low pressure pulsed arc, whose inner diameter is 10 mm and distance between electrodes 130 mm. Pressure in the source was set and controlled by needle valve, with the gas flow of 0.2 l/min. One side of plasma source is mounted on VUV spectrometer, and on the other end there is a quartz window. Light emission was obtained by discharging capacitor of 5 μF (previously charged using high voltage supply unit) with ignitron switch BK7703. The discharge process is controlled via automatic trigger unit. Around the source, Rogowski coil was placed, in order to measure current shape and its value. The radiation from this source is projected 1:1 onto the slit of VIS spectrometer using optical mirrors M1 and M2. Mirror M1 is plane mirror, while M2 is focusing mirror (f = 2m). Visible spectrometer is McPherson 2061 Cherny-Turner type spectrometer, who has the slit widths of 15 µm, focal length of 1 m and grating with 1200 grooves/mm. As light detector we used

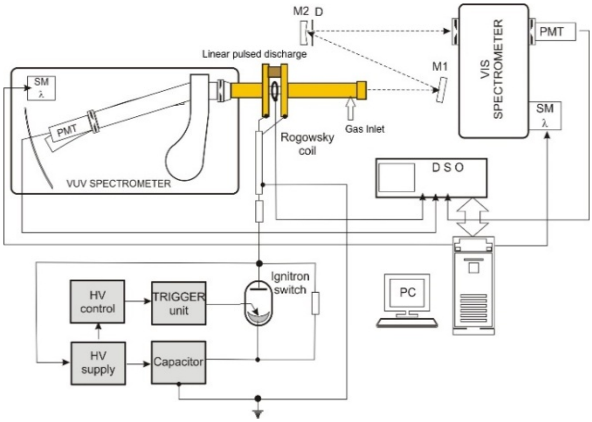

Figure 1: Experimental setup

photomultiplier, PMT mounted on spectrometer exit slit. Wavelength scanning was performed by rotation of diffraction grating with stepper motor, controlled by PC.

As we said above, the other end of plasma source is mounted on VUV spectrometer McPherson 247, which have concave grating of radius 2.2 m and 600 grooves/mm.Wavelength scanning is performed by moving the exit slit around the Rowland circle with help of stepper motor controlled by the PC. Spectrometer is grazing incidence spectrometer (large incidence angle), so we can observe EUV wavelengths from 0 to around 125 nm.

3. RESULTS AND DISCUSSION

In order to compare results obtained by different methods for electron density determination, N_e was determined from spectral lines recorded in visible spectral range. The N_e in early times of plasma evaluation was determined from full width at half maximum, FWHM of He II Pashen alpha line using formula (Busher et al, 1996):

$$N_e[\mathrm{cm}^{-3}] = 3.58\cdot 10^{17} \cdot \mathrm{FWHM}\ [\mathrm{nm}]^{1.204} \quad (1)$$

In plasma decay N_e was determined from separation between forbidden and allowed component of the He I using formula (Ivković et al, 2010):

$$\log_{10}(N_e) = 21.5 + \log_{10}\left(\left(\frac{s}{0.1479}\right)^{b(T_e)} - 1\right),\ b(T_e) = 1.46 + \frac{8380}{T_e^{1.2}} \quad (2)$$

using T_e = 32000 ± 4000 K determined from Boltzmann plot of He II Lyman lines, see Figure 2 and 5. The correction of self-absorption using additional mirror was not possible due to window-less opreration of the discharge tube, since neither air not MgF_2 window are not transparent for radiation at 30 nm and below.

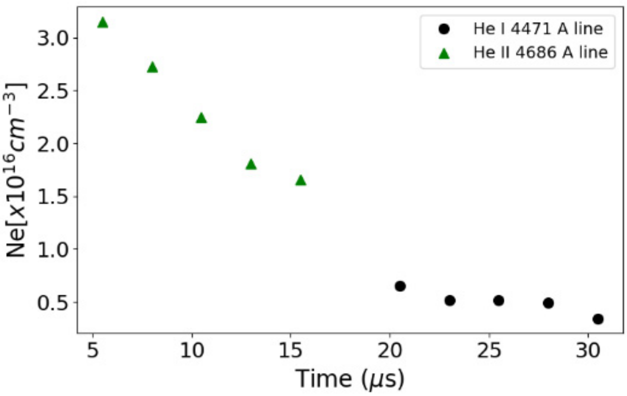

Figure 2: Time dependence of the electron densities in He at 3 mbar and 7 kV

Shapes of the He II lines belonging to the Lyman series were recorded using VUV spectrometer. Recordings were performed at different He gas pressures and different voltages.

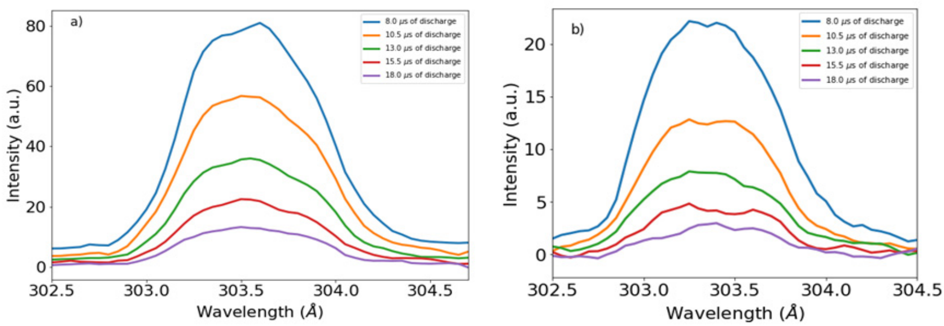

Figure 3: Line shapes of the He II Lyman alpha line at He gas pressure of 3 mbar at discharge voltages V of : a) 7 kV and b) 6 kV

It can be seen that He II Lyman alpha line at 30.2 nm is self-absorbed and becomes even self-reversed, see Figure 3.

Therefore, additional methods based on the recordings of higher members of the He II Lyman series shape for N_e determination were tested. First method is based on relation, see (Inglis-Teller, 1939), between N_e and principal quantum number of the upper level of the last resolved line in series n_{max}:

$$\log_{10}(N_i + N_e\ [cm^{-3}]) = 23.26 - 7.5 n_{max} + 4.5 \log_{10} Z \quad (3)$$

The second one is based on determination of n for which partial local thermo-dynamic equilibrium-PLTE criteria, see (Griem, 1963) was satisfied:

$$N_e(cm^{-3}) \geq 7.4 \cdot 10^{18} \frac{Z}{n^{17/2}} \sqrt{\frac{k_B T_e}{E_H}} \quad (4)$$

Here Z is the nuclear emitter charge, E_H is the hydrogen atom ionization energy and T_e is electron temperature.

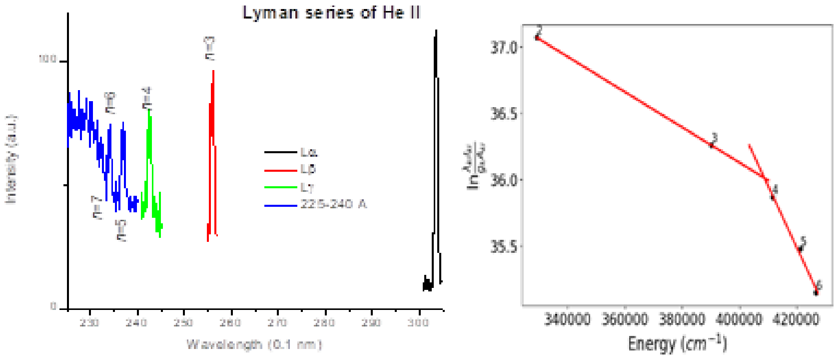

Figure 4. He II Lyman series lines at He gas pressure of 3 mbar at V = 7kV Spectra recorded (left) and Boltzmann plot (right)

In order to estimate the range of application and accuracy of these methods N_e calculated by these two methods for T_e = 32 000 K is presented in Table 1. It can be seen that both methods can be used only for $N_e < 10^{16}$ cm^{-3}.

Table 1: N_e determined by relation (3) – IT and (4) – PLTE for T_e = 32 000 K

n	2	3	4	5	6	7	8	9
N_e IT [cm-3]	5.02 E20	2.4 E19	2.77 E18	5.2 E17	1.32 E17	4.17 E16	1.53 E16	6.34 E15
N_e PLTE [cm-3]	2.94 E17	9.35 E15	8.11 E14	1.22 E14	2.58 E13	6.97 E12	2.24 E12	8.23 E11

It should be stressed that for He gas pressure of 3 mbar, discharge voltage 7 kV the N_e determined from He II P_α line is 3.15, from IT relation between 1.53 and 4.17 and from PLTE criteria using n = 3.8, see (Konjević et al, 2009) is 0.13 times 10^{16} cm^{-3}. Increasing accuracy of IT method by using envelopes i.e. curves through min and max of series lines proposed by (Vidal, 1966) is under development.

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