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STARK BROADENING OF THE He I 447.1 nm LINE AND ITS FORBIDDEN COMPONENTS IN DENSE COOL PLASMA

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Abstract. In this paper the results of an experimental study of the He I 447.1 nm line and its forbidden component at high electron number density are presented and compared with profiles calculated using computer simulation method. Michelson interferometer at 632.8 nm was used to measure plasma electron number density in the range (1 – 7) x 10^{23} m^{-3} while electron temperatures for same experimental conditions in the range 25 000 K to 35 000 K were determined using several spectroscopic techniques. The agreement of experimental overall line shape with computer simulation results is within 10% what is well within theoretical and experimental uncertainty.

1. INTRODUCTION

Helium is frequently used either as matrix gas or as an additive to matrix gas in various discharges employed for spectrochemical applications. Among other applications the addition of He enables the use of its lines for plasma diagnostic purposes. The shapes of isolated He I lines were extensively studied experimentally and theoretically. The agreement between semi-classical calculations and experiments is in several cases within ± 15% see e.g. Konjević (1999).

Concerning present study, it is important to notice that in the vicinity of several visible He I lines forbidden component or sometimes several components appear as a consequence of mixing upper energy level of allowed transition with close perturbing energy level (or levels) in plasma microfield. The overall shape of these spectrally overlapping lines attracted attention some time ago for several reasons. First, the lines appear in spectra of B-type stars, see e.g. Lecrone (1971). Second, the shape of these lines is very sensitive to variations in charged particle densities and therefore, can be very useful in astrophysical and laboratory plasma diagnostics. Finally, the comparison of the overall experimental profile of these lines with results of theoretical calculations may be used as a sensitive test of Stark broadening theories. Recently, results of computer simulation technique for evaluation of overall shape of He I lines with forbidden components at $N_e < 10^{22}$ m^{-3} has been reported by Gigosos and González (2009) and compared with several earlier semiclassical calculations. Here, we shall focus our attention on medium and high electron densities N_e range $(0.5 - 7) \times 10^{23}$ m^{-3} in order to extend and test other available data.

2. COMPUTER SIMULATIONS

Computer simulations permit to obtain the electric field that alters the emitter evolution giving rise to Stark broadening. For this, the movement of the particles in the plasma is reproduced numerically and the temporal evolution of the electric microfield undergone by the emitter is calculated. The temporal sequence of this microfield is carried to the differential equations that give the emitter evolution and the emitter dipole moment autocorrelation function is obtained, see Gigosos et al. (2006). Finally, he line shape is obtained as the Fourier transform of an average of the calculated autocorrelation functions. For more details on computer simulation technique see Gigosos et al (2003).

3. EXPERIMENT AND PLASMA DIAGNOSTICS

Linear pulsed discharge is constructed in our laboratory after Grützmacher and Johannsen (1993). The separation between tungsten electrodes (placed inside quartz tube, inner diameter 8 mm) was 8 cm. Each electrode has 0.6 mm diameter openings in order to enable interferometry and spectroscopy measurements along the axis of plasma column. The discharge was driven by the low inductance 15 μF capacitor charged up to 6 kV. With 0.17 Ohm resistor in series and by use of an ignitron switch critically dumped current pulse (up to 10 kA, the overall duration of 10 μs) is obtained. The reproducibility of the discharge pulsing is enhanced by dc glow preionization. In this discharge the electron densities up to 10^{24} m^{-3} were obtained using continuous flow of helium with or without a 3 % of oxygen.

For data acquisition a 1:1 image of the plasma source is projected, by means of: flat and focusing mirror (D = 50 mm and f = 100 cm), onto the entrance slit of a 1 m monochromator (inverse linear dispersion 0.833 nm/mm). Behind the exit slit (15 μm) of the spectrometer thermoelectrically cooled photomultiplier – PMT was mounted. The signals from PMT were led to a digital storage oscilloscope triggered by the voltage pulse from Rogowski coil. By changing the wavelength with a stepping motor (SMλ) in small steps by diffraction grating rotation the time evolution at different λ was obtained. At each wavelength step, eight (or 16) PMT signals, were averaged. From 3D matrix of recorded data, spectral line shapes at different times of plasma decay were generated.

The electron density was determined with single wavelength Michelson interferometer at 633 nm. Spectral lines shapes were recorded by pulsing discharge, while advancing monochromator in small wavelength steps. For this purpose 1m monochromator (inverse linear dispersion 0.833 nm/mm) equipped with a cooled photomultiplier (PMT) is used. Signals from the PMT are led to a digital storage oscilloscope triggered by the signal from the Rogowski coil set around main current cable. Typical interferogram, current shapes and electron density decay are displayed in Fig. 1a. The measured overall shape of the He I 447 nm lines at different times of plasma decay in 100 mbar He are presented in Fig. 1b.

The electron excitation temperature, T_e was determined from line to underlying continuum ratio of He I 388.8, 667.8, 706.5 and 728.1 nm lines in conjunction with theoretical ratios; see Fig. 13-5 in Griem (1964)

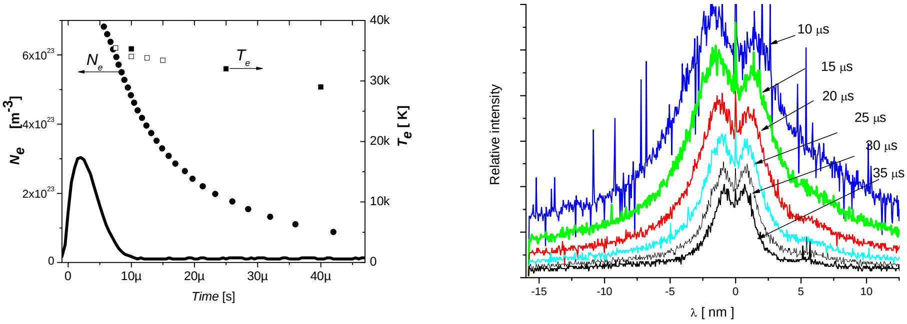

Figure 1: a) Current pulse, interferogram and electron density decay. b) The overall shape of the Hew I 447 nm lines at different times of plasma decay.

4. RESULTS

Numerical simulation results of profiles for He plasma is presented in Fig. 2.

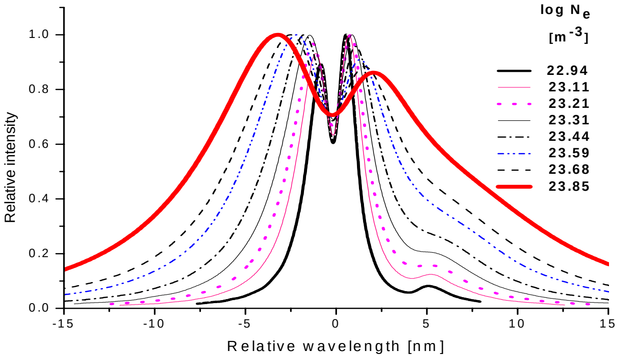

Figure 2: Overall shape of the He I 447 nm lines at different electron densities.

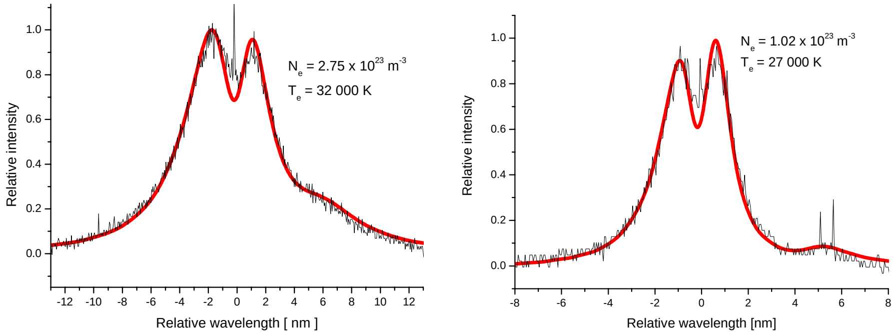

Figure 3: Comparison of profiles obtained by experiment and computer simulation.

As can be seen from the Fig. 3. agreement between experimental and numerical simulation profiles (generated for N_e and T_e determined by independant methods) are within theoretical and experimental uncertinity. The only discrepancy are lower allowed component intensity of experimental 447.1 nm line profiles. This fact can be explained by selfabsorption of allowed component due to the relatively high pressure of pure helium in the plasma. On the contrary the ratios of the forbidden – F to allowed – A component intensity is in accordance to the experimental measurements performed by Suemitsu, 1992, which also has great possibility of the He I lines selfabsorption, see Ivkovic et al, 2010. The F/A values are almost 15% greater than theoretical values obtained by Griem, 1968.

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