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The discharge for plasma Stark shift measurement and results for He I 706.522 nm line

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ABSTRACT

We present results of Stark shift measurements for He I 706.522 nm (1s2p $^3P^0_2$–1s3s $^3S_1$ and 1s2p $^3P^0_1$–1s3s $^3S_1$) lines using newly constructed pulsed arc generated at the pressure of two hundreds of milibars of helium with small admixture of hydrogen. Plasma electron number density in the range $(0.5–7.0)\times 10^{23}\ \mathrm{m}^{-3}$ was measured from the wavelength separation between the allowed He I 447.1 nm (2p $^3P^0$–4d ^3D) line and its forbidden component (2p $^3P^0$–4d $^3F^0$), while the electron temperature in the range (15,000–20,000) K was determined from the relative intensities of Si II lines using the Boltzmann plot technique. New Stark shift measurement technique was demonstrated using line shape recording of several He I lines. The shift results for He I 706.522 nm line so favorably compare with earlier lower density experimental data that best fit formula is recommended for plasma diagnostic purposes.

1. Introduction

The knowledge of good quality Stark shift data is essential for the testing of the Stark broadening theory; see e.g. [1], which can be further used to supply reliable shifts for any spectral line of interest. Apart from theory testing Stark shifts are of importance for astrophysical and laboratory plasmas' diagnostics, for correction of Doppler shift used for star velocity determination and some other application like precision astrophysical measurements of gravitational shift. Good example of the laboratory data application are the results for red Stark shift of several Balmer lines, measured precisely in the plasma of a wall stabilized arc [2,3]. It was shown that red Stark shift should be accounted for a portion of the observed red shift of these lines in white dwarfs which was earlier attributed entirely to gravitation [2].

An overview of different techniques for Stark shift measurement is presented in [4] and here only important details for explanation of the proposed technique will be described. Earlier experimental results of He I lines shift were discussed in [5,6] and references therein.

The aim of this work is to present the construction details of the pulsed arc and to explain the experimental procedure for plasma line shift measurements. The results for the He I 706.522 nm line will be compared with other experimental and theoretical data and the best fit of experimental results will be presented in convenient form for plasma diagnostic purposes.

2. Experimental

The experimental setup is shown schematically in Fig. 1. It consists of a plasma source, which is simultaneously used as a reference source of unshifted lines and an optical system for

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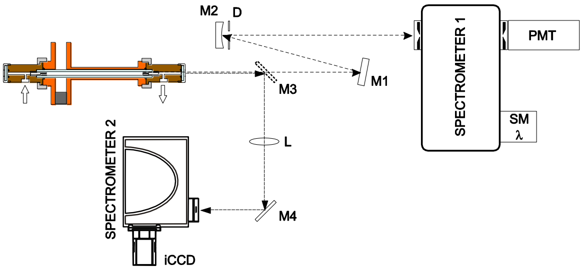

Fig. 1. Experimental setup.

focusing discharge radiation to the entrance slit of spectrometers. Thus, as seen from Fig. 1, the experimental apparatus is set up as for standard end-on plasma observation and the only essential difference is the plasma source, which will be described in detail below. Here, it is essential to stress out that this plasma source enables simultaneous observation of high density plasma inside of the discharge chamber and radiation of tiny plasma jet protruding through a small hole located at the axis of the end electrode.

2.1. Plasma source

A laboratory made linear pulsed discharge source with electrodes mounted inside of a quartz tube (inner diameter 8 mm) was used in this experiment, see Fig. 2. Both electrodes have a 0.6 mm diameter central opening to enable optical alignment and spectroscopic measurements along the axis of the plasma column. It is important to notice that the outer diameter of the electrodes is only 2 mm smaller than the inner diameter of the discharge tube. The glass tube is sealed on both ends with O-rings to restrict plasma flow primarily through the electrodes' central opening (see magnified detail of the glass tube sealings in Fig. 2). This prevents fast plasma expansion during current pulsing and enables generation of a significantly higher peak electron density [7]. Simultaneously, the small electrode opening, see Fig. 2, allows formation of a tiny plasma jet protruding along the axis of both electrodes. The results of spectroscopic characterization of these plasma jets will be reported below, in Section 3.

In order to decrease the electrodes' holes wear, they were made of thoriated tungsten. The absence of tungsten spectral lines confirms that the cathode sputtering was very low. The anode of the pulsed arc was always grounded, while the cathode was connected to negative high voltage. The discharge was driven by a low inductance 15 μF capacitor charged to 9 kV. In order to decrease the circuit inductance three electric cables were coaxially connected with the cathode. The critically dumped current pulse shape was obtained by placing 0.17 Ω resistors in series with the discharge by connecting them in series with each of the three cables attached to the cathode. With an ignitron switch the current pulse having overall time duration of 10 μs and peak current of 8 kA is obtained. Typical critically dumped discharge current pulse is recorded with a Rogowski coil, displayed by an oscilloscope and shown in Fig. 6. Such aperiodic current shape prevents plasma oscillations and fluctuation of the emitted radiation. Using continuous flow of gas mixture (He+3% of H_2 by volume) and by triggering the discharge at an initial gas pressure of 200 mbar plasma with smooth afterglow decay of electron density, N_e and electron temperature, T_e with the peak electron density of $7\times10^{23}\ \mathrm{m}^{-3}$ is generated. This result is achieved without any further discharge tube optimization. The pulse-to-pulse peak and current shape reproducibility was significantly improved by using 90 mA dc glow pre-ionization. In this way the achieved current shot-to-shot reproducibility was better than 1%. This improved significantly the signal to noise ratio during line shape recordings.

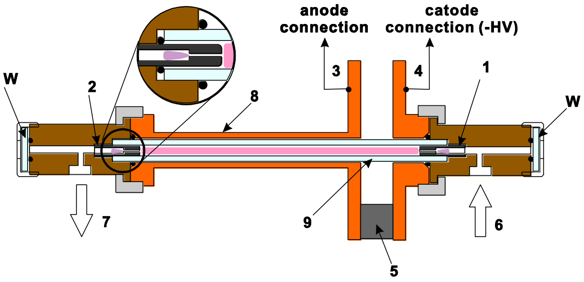

Fig. 2. Discharge tube: (1) cathode, (2) anode, (3) and (4) cathode and anode electric connection with capacitor, (5) insulator, (6) gas inlet, (7) gas outlet, (8) coaxial current connector with the cathode made of brass tubing, (9) glass tube and W – window.

2.2. Experimental details and procedure

For data acquisition two line shape recording systems were used. In both cases 1:1 image of the plasma source is projected onto the entrance slit of a monochromator, by the use of a focusing mirror or achromatic lens, see Fig. 1. One of two grating monochromators employs a stepping motor for grating rotation. For plasma radiation intensity measurement this monochromator (inverse linear dispersion 0.833 nm/mm) was equipped with thermoelectrically cooled photomultiplier (PMT) EMI 9813QB mounted behind the exit slit. The instrumental profile used in this experiment was recorded with a low pressure Hg pen light source and it had a Gaussian shape with full width at half maximum (FWHM) $w_i=0.02$ nm. During plasma line shape recording eight, or, in some cases, 16 PMT signals were registered for each wavelength step and then averaged by digital storage Tektronix TDS360 oscilloscope (200 MHz bandwidth). The observed wavelength λ along the line profile was scanned by the fine rotation of the monochromator's diffraction grating while the time evolution and decay of plasma radiation intensity was simultaneously recorded. From these data a 3D matrix $I=f(\lambda, t)$ was formed and spectral line shapes were determined for various times of plasma decay. It is obvious that step-by-step technique for line shape recording may be used only with a plasma source having high shot-to-shot reproducibility.

The second line shape recording system was based on a 0.3 m Shamrock 303 imaging spectrometer supplied with diffraction grating 1200 g/mm and equipped with Andor ICCD camera DH724. The instrumental width measured with 20 μm slits was 0.09 nm. For all spectral recordings the same detector exposure time (0.2 μs gate width) was employed. The shapes of a line recorded with two different monochromators agree