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ELECTRON DENSITY DIAGNOSTICS OF LASER INDUCED PLASMA IN HELIUM

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Abstract. The results of an optical emission diagnostics of helium LIBS plasma are presented. The average axial plasma electron density of 5.2 10^{16} cm^{-3} is determined after Abel inversion from the peak separation between allowed and forbidden component of the He I 447.1 nm and 492.2 nm line and from the width of an isolated He I 501.6 nm and Mg I 583.8 nm line. The electron temperature of 8300 K is determined from the Boltzmann plot of Mg I lines.

1. INTRODUCTION

For measurement of Stark broadening parameters of atomic and singly charged ion spectral lines of elements relevant for LIBS diagnostics an experiment is set up. As an ambient gas, instead of most frequently used argon for LIBS studies, helium is employed. The primary reason for this choice of ambient gas: Stark broadening parameters of isolated He I lines are well known and tested for electron density, N_e, diagnostics, see e.g. Konjević (1999). In addition, the He I lines with forbidden components represent another possibility for precision N_e diagnostics. Thus, helium offers good prospective for an independent and reliable N_e LIBS diagnostics. We plan to use such well diagnosed LIBS source for Stark broadening parameters measurements for variety of elements important for plasma diagnostics. The usefulness of helium, however, has to be tested under LIBS conditions where helium lines as well as studied lines of heavy elements have to be observed from the same plasma region.

2. EXPERIMENT

The material ablation was produced by the Nd:YAG laser (Quantel, model Brilliant) delivering pulses of 400-mJ energy with 4-ns duration. The laser was operated at 1064 nm. The laser pulse energy was attenuated to 20 mJ by turning the beam polarization with the aid of a half-wave plate and crossing through a polarization analyzer. The laser beam was focused at a distance of 2 mm beyond the sample surface using a plano-convex lens of 150-mm focal length, see Fig. 1. According to a spot diameter of 120 µm at $1/e^2$ of the Gaussian beam a laser fluence of about 180 Jcm^{-2} was obtained on the sample surface. The sample of 30×20-mm^2 area and 5-mm thickness was an aluminum alloy of 92.5% Al, 7.0% Mg and 0.45% SiO_2. It was placed on a motorized sample holder in a vacuum chamber of 10^{-4} Pa residual pressure. During the experiment, the chamber was filled with helium at predetermined pressure.

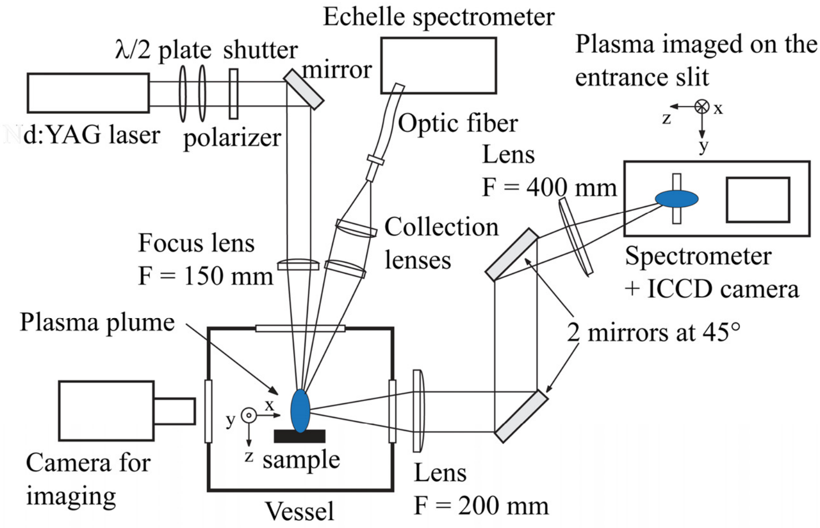

Figure 1: The experimental setup.

The time- and space-resolved spectroscopic analyses were performed using an imaging spectrometer (Jobin-Yvon, model FHR 1000) of 1 m focal length. The plasma plume was imaged onto the spectrometer entrance slit with a magnification of 2 using two MgF_2 lenses of 200 and 400 mm focal length. The lenses were mounted on a motorized translation stages to adjust focal lengths in accordance with the observed wavelength. The photon detection at the spectrometer output was ensured using an intensified charge-coupled device (ICCD) matrix detector (Princeton Instruments, model PI-MAX2). Using a grating of 2400 grooves mm^{-1}, the linear dispersion was 0.34 nm mm^{-1} at 300 nm. An optical filter was placed at the spectrometer entrance to avoid overlapping with the second observation order of the grating. According to the spectrometer slit width of 100 µm, the emission was captured from a plasma layer of 50 µm thickness. The distance of the observation zone with respect to the target surface was varied by translating both, the sample and the laser focusing lens perpendicularly to the sample surface along the *z*-axis as shown in Fig. 1.

Spatially integrated spectroscopic measurements were performed by the plasma plume imaging in the direction parallel to the surface normal onto the entrance of an optical fiber of 600 μm diameter. Two lenses of 150 and 37.5 mm focal length were used to reduce the image by a factor of 1/4. The captured plasma emission was transmitted via optical fiber to an Echelle spectrometer (LTB, model Aryelle Butterfly) having a square entrance of $50\times50\ \mu m^2$ dimension. The spectrometer was equipped with an ICCD array (Andor, model iStar 734) to ensure photon detection. The spectral resolution was of about 1×10^4.

For both spectrometers, see Fig. 1, the spectral width was measured as a function of wavelength using a low-pressure argon-mercury lamp. An intensity calibration was performed in the visible and UV spectral range using a calibrated tungsten lamp (Oriel, model 63358) and a deuterium lamp (Heraeus, model DO544J), respectively.

The synchronization between laser pulse and ICCD gates was ensured using the Q-switch pulse trigger output of the Nd:YAG laser. To enhance the signal-to-noise ratio, each recording was performed by accumulating the signal over several ablation events. Therefore, different sites were irradiated by applying one or several laser pulses on each site. The sites were separated by a distance of 400 μm.

3. RESULTS AND DISCUSSION

First part of the experiment is devoted to determination of optimum helium pressure to achieve plasma expanding from the target surface in the form of symmetric plume. This is essential for all spectroscopic measurements since the Abel inversion procedure for axially symmetric optically thin plasma source observed side-on is applied. After a number of experiments the optimum helium pressure of $5\cdot10^4$ Pa is determined and all reported results are for this pressure. Further, it is important to notice that all reported intensity and line shape measurements were result of the Abel inversion of side-on emitted plasma radiation see Djurovic (1999). An example of the He I 447.1 nm line with a forbidden component at the blue wavelength side is presented in Fig. 2. In this case N_e is determined from separation *s* of the line peaks using an empirical relation $s(N_e)$ derived by Czernichowski and Chapelle (1985) on the bases of large number of experimental data. Another formula of the same type derived by Perez et al. (1996) was used to determine N_e from the He I 492.2 nm line, see Table 1. The recording of Mg I multiplet with the line 383.8 nm used for N_e measurement in conjunction with results of semiclassical calculations, see Griem 1974, is presented in Fig. 3. Same set of theoretical data was used with the He I 501.6 nm line. All results of plasma N_e and T_e diagnostics at the axis of plasma plume are given in Table I. Although the scatter of ±12% from the average $N_e = 5.2\cdot10^{16}\ cm^{-3}$ in Table 1 is still too large the results are encouraging and suggest that radiation of both emitters comes from the same plasma region. Further studies of helium LIBS plasma are in progress.

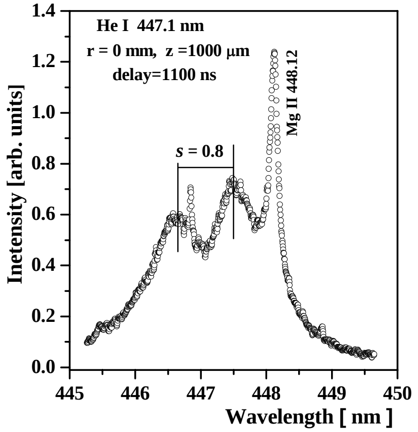

Figure 2: Helium line He I 447.1 nm with its forbidden component.

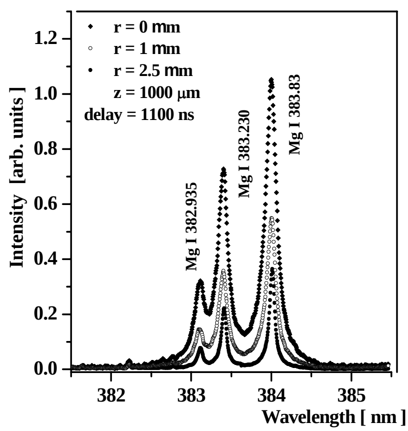

Figure 3: Magnesium multiplet Mg I (3) $3p^3P^0$ -$3d^3D$.

Table 1. Experimental results at the axis of plasma plume

	He I 477.1 [nm]	He I 492.2 [nm]	He I 501.6 [nm]	Mg I 383.83 [nm]
T [K]	8300			
N_e [cm^{-3}]	$5.8 \cdot 10^{16}$	$4.7 \cdot 10^{16}$	$4.4 \cdot 10^{16}$	$5.9 \cdot 10^{16}$

Acknowledgements

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