ANALYSIS OF TUNGSTEN SPECTRAL-LINES RECORDED FROM LASER-TARGET EXPERIMENT

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The paper is devoted to an analysis of selected experimental results obtained from space- and time-resolved spectroscopic measurements, which were performed during the interaction of an intense laser-beam (0.7 J, 2 ns) with a tungsten (W) target placed under high-vacuum conditions. The spectroscopic measurements were carried out by means of a Mechelle®900 optical-spectrometer, and for the first time some tungsten spectral lines (WI and WII) were recorded. The most important parameters of a tungsten plasma plume were estimated using the fitting procedure. The appearance of the tungsten ions was also confirmed by a series of corpuscular measurements.

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1. INTRODUCTION

Information about spectral lines emitted from tungsten (W) exited atoms and ions are of great importance for plasma research and fusion technology. Unfortunately such information is very scarce [1]. Therefore, it was decided to perform dedicated laser-target experiments under controlled experimental conditions. In general, studies of laser-produced plasmas are of importance for different branches of science and technology.

The main aim of the described experiments was to record and analyze some optical W-spectra, which might be used e.g. for a comparison with results of spectroscopic measurements of plasma-target interactions inside various tokamak facilities. This study is important because tungsten is often used in different plasma facilities and it is the constructional material for ITER.

2. EXPERIMENTAL SET-UP AND SPECTROSCOPIC DIAGNOSTICS

The experimental system used in our studies consisted of the main vacuum chamber, equipped with a movable target holder and ion diagnostic equipment, an external laser system and an optical spectrometer adapted for time-resolved measurements [2], as shown in Fig.1.

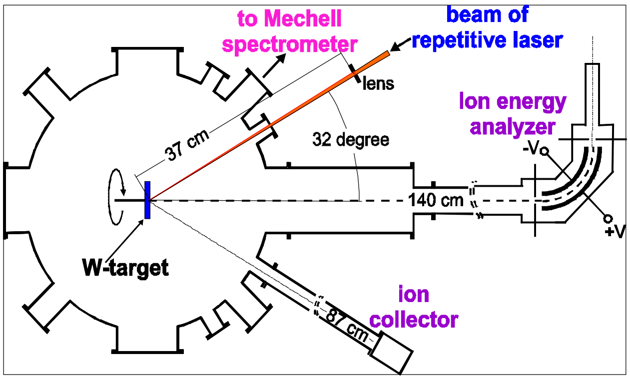


Fig. 1. Experimental arrangement

The ion measuring equipment consisted of ion collectors and an electrostatic ion energy analyzer. The applied repetitive Nd-glass laser system could deliver a beam of λ = 1.06 µm and E = 0.8 J in 3.5 ns pulses. The laser beam was introduced at an angle of 30° in relation to the target axis and focused upon the target center.

During the experiments to be described the laser was operated with the repetition of ν = 10 Hz, and the power density upon the target amounted to about 10^{11} W/cm^2. It was satisfactory to produce a W-plasma plume in front of the irradiated W-target. Each laser pulse had energy 540 mJ, and the focal spot had diameter equal to D_f = 0.4 mm. The laser power density was $I_L = 1.4 \times 10^{11}$ W/cm^2.

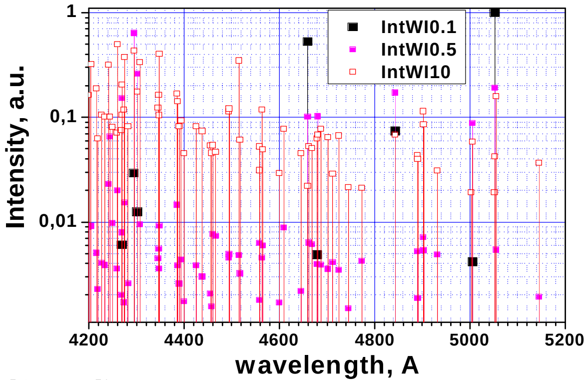
The spectroscopic measurements were carried out by means of a Mechelle®900 optical-spectrometer, which might be operated within the spectral range from 300 to 1100 nm. The system contained a special collimator, which was situated between a quartz observation window and a quartz optical cable coupled with the spectrometer. That collimator assured the spatial resolution of about 1 cm. The spectrometer had the spectral resolution equal to about 900 and the instrumental contour width of 0.5 nm within central region of the investigated spectrum. The applied exposure time was equal to 2 µs. The recorded spectra were read with a cooled CCD camera coupled with a computer equipped with the GRAMS32-v.6.0 software, which made possible the fast and effective processing of the collected experimental data.

3. SPECTRAL ANALYSIS

In order to obtain reliable information about W-plasma parameters a detailed analysis was performed using the well-known NIST database. Preliminary evaluations, which were performed on the basis of separate and randomly taken pairs of the recorded spectral lines, gave electron temperature (T_e) values ranging from 0.5 to about 2 eV. Estimates of the electron concentration (N_e) gave values within the range from 10^{14} to 10^{19} cm^{-3} [3]. Although these estimates are close to those made in other laser-target experiments [4], one can easily notice considerable differences in the reported experiments.

Our recent computational analysis of the recorded W spectra concerned normalized W-lines, which might be observed at different temperatures (T_e = 0.1, 0.5, and 10 eV), as shown in Fig. 2.

a) WI lines



b) WII lines

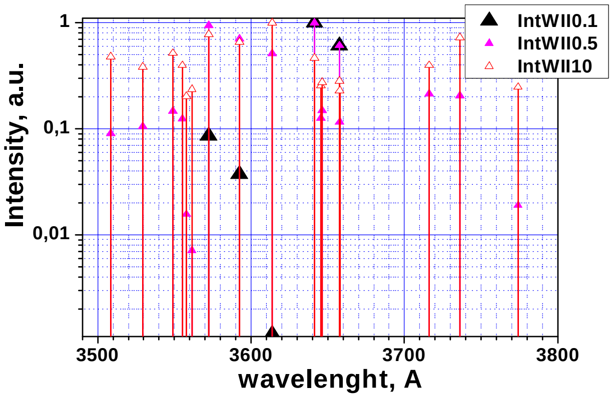


Fig.2. Normalized W-spectra computed for different electron temperatures T_e = 0.1 eV , 0.5 eV and 10 eV

The performed analysis has indicated:

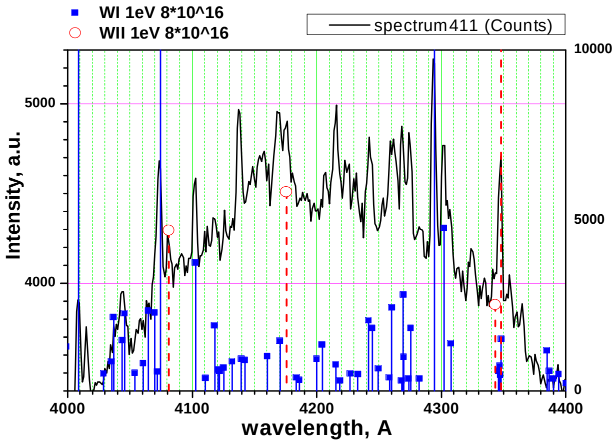
- The strongest lines of WI and WII for the wide range of T_e values;
- The appearance of pure (separate) lines with the minimal overlapping;
- The spectral lines (or groups of them), which are more or less sensitive to the electron temperature;
- The lines undergoing the re-absorption (we selected the strongest lines with close energies of the excitation only).

As for the observed spectra lines (and/or peaks) intensities have been verified with the object to self-absorption. Some peaks of the strongest lines, as expected, demonstrated a relatively high self-absorption. We took into consideration the lines having similar excitation energies only, because in such cases the intensity ratio is not a function of T_e, but it depends on the A_{ki} (or gf-values). For example, the WI 4294.6 and 4302.1 lines, for which the observed and calculated relative intensities were considerably different, are shown in Figs. 3,a and 3,b.

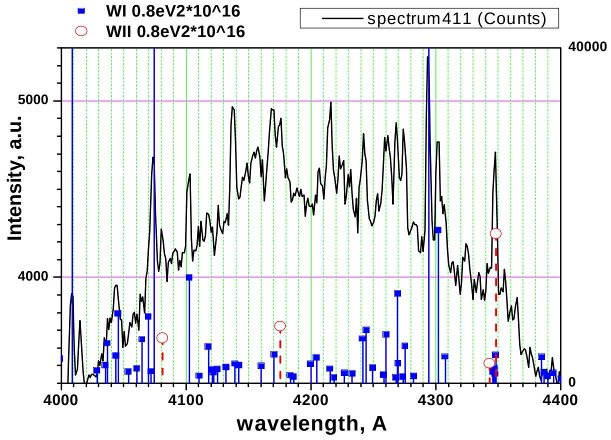
The effects described above were taken into consideration during subsequent fitting procedures. It should, however, be noted that for the ion spectral lines it is in general very difficult to take into account the considered effects quantitatively.

Some of the spectral lines with the strong self-absorption (e.g. WI 4008 Å peak) are shown above as those exceeding the limits of graphs. It should be noted that for a group of the W spectral lines within a wavelength range of 3572…3660 Å one can observe some discrepancy in the computed and recorded spectra (see Fig. 3a).

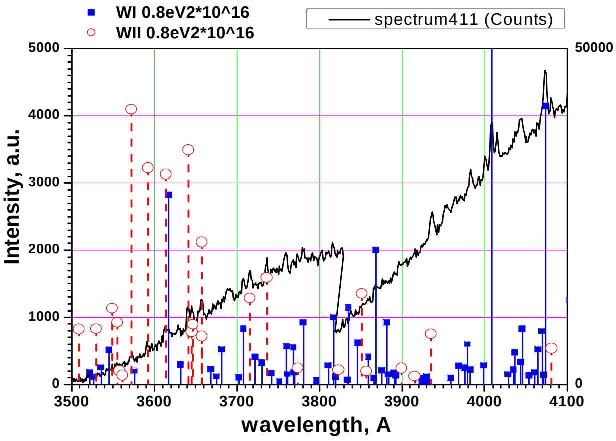
For the shortest waves it might be explained by the fact that the transmission of the applied optical parts decreases in this range very sharply. In other wavelength regions the mentioned discrepancy might be due to differences in atomic (spectral) data from NIST and the spectroscopic data taken from other publications [5]. It seems that the observed spectral lines are closer to the old data.



a) T_e = 1 eV, N_e = 8 x 10^{16} cm^{-3}



b) T_e = 0.8 eV, N_e = 2 x 10^{16} cm^{-3}

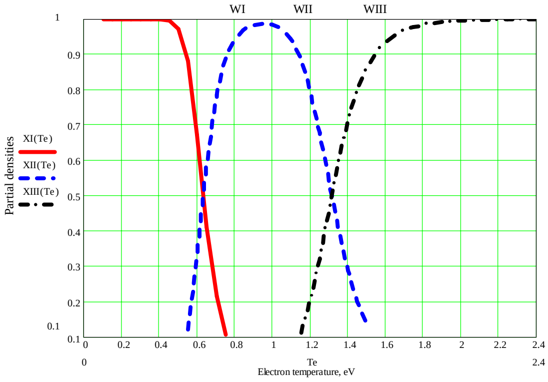


c) T_e = 0.8 eV, N_e = 2 x 10^{16} cm^{-3}

Fig.3. Recorded optical spectra and their fitting to those computed on the basis of the Saha-Boltzman equations. The rapid drop in the middle of the spectrum is an artificial effect induced by the spectrometer construction

In the next phase of the analysis the most important parameters of a W-plasma plume were estimated using the fitting procedure as follows: in the first step we estimated electron temperature values to obtain a relatively good agreement for the recorded intensities of WI and WII spectral lines separately; and in the second step the electron concentration value was determined to achieve the good agreement between the whole WI and WII spectra. As a result it was found that the most probable parameters of the investigated laser-produced W-plasma were as follows: $T_e \approx 0.8…1$ eV, $N_e \approx (2…8) \times 10^{16}$ cm^{-3}. Using spectroscopic methods and it was also possible to estimate the concentration of the excited neutral W-atoms. Such an analysis is presented in Fig. 4.

a) $N_e = 2 \times 10^{16}$ cm^{-3}



b) $N_e = 8 \times 10^{16}$ cm^{-3}

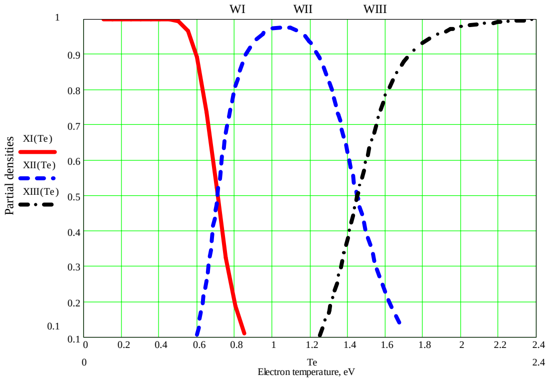


Fig.4. Distributions of ionization states of W-species computed on the basis of LTE relations

Since, the estimated electron temperature was 0.8...1 eV, in the both considered cases one gets an approximated value N (WI) ≈ (1...3) x 10^{15} cm^{-3}. The large uncertainty in the determination of N_e-values has been induced by a lack of additional experimental data. It is evident that more information about temporal evolutions of WI and WII spectral lines intensities or the total radiation is needed.

4. CONCLUSIONS

The most important results of this study can be summarized as follows:

1. The tungsten spectral lines have been recorded and identified in the described laser-beam W-target experiments.
2. The electron temperature of W-plasma was estimated using the ratio of WII and WI spectral lines, and it was found that the most probable value was $T_e = 0.8…1$ eV. It means that the recorded spectra were obtained from a late phase of that plasma expansion.
3. An estimate of the electron concentration value $N_e \approx (2…8) \times 10^{16}$ cm^{-3} was performed using spectroscopic methods in order to achieve the good agreement between the whole recorded WI and WII spectra.
4. Information about the tungsten spectral lines and some procedures, which were used for the analysis, might be helpful in future studies, e.g., of the erosion of W-based constructional parts in fusion facilities.

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АНАЛИЗ СПЕКТРАЛЬНЫХ ЛИНИЙ ВОЛЬФРАМА, ЗАРЕГИСТРИРОВАННЫХ В ЭКСПЕРИМЕНТАХ ПО ВЗАИМОДЕЙСТВИЮ ЛАЗЕР-МИШЕНЬ

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Статья посвящена анализу отдельных экспериментальных результатов, полученных при помощи спектральных измерений с пространственным и временным разрешением в экспериментах по взаимодействию интенсивного лазерного луча (0.7 Дж, 2 нс) с вольфрамовой мишенью, находящейся в условиях высокого вакуума. Спектроскопические измерения проводились оптическим спектрографом Mechelle$^{®}$900 и впервые были идентифицированы спектральные линии вольфрама (WI и WII). Наиболее важные параметры вольфрамового плазменного образования оценивались посредством процедуры подбора. Появление ионов вольфрама также подтверждается серией корпускулярных измерений.

АНАЛІЗ СПЕКТРАЛЬНИХ ЛІНІЙ ВОЛЬФРАМУ, ЗАРЕЄСТРОВАНИХ У ЕКСПЕРИМЕНТАХ ПО ВЗАЄМОДІЇ ЛАЗЕР-МІШЕНЬ

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Стаття присвячена аналізу окремих експериментальних результатів, які були отримані за допомогою спектральних вимірів з просторовим та часовим розділенням у експериментах по взаємодії інтенсивного лазеру (0.7 Дж, 2 нс) з вольфрамовою перешкодою, яка знаходилась в умовах високого вакууму. Спектральні виміри проводились оптичним спектрографом Mechelle$^{®}$900 та вперше були ідентифіковані спектральні лінії вольфраму (WI и WII). Найбільш важливі параметри вольфрамового плазмового потоку оцінювались за допомогою процедури підбору. Поява іонів вольфраму також підтверджується серією корпускулярних вимірів.