

Spectroscopic Investigation of Time Evolution of Laser-Produced Tungsten Plasma

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Abstract. The paper reports on optical emission spectroscopic studies of tungsten plasma generated using 1064 nm, 3.5 ns pulses from a Nd:YAG laser. The spectra emitted from the plasma plume were characterized by means of an optical spectrometer Mechelle5000 in the wavelength range of 200–900 nm and were recorded by an iCCD. The vacuum chamber was also equipped with ion diagnostics, namely an ion collector (Faraday cup) and an electrostatic ion energy analyzer with a windowless electron multiplier to observe time-of-flight spectra of emitted ions.

The experimental work was devoted to investigations of time evolution of the optical spectrum of tungsten plasma. To observe spectra emitted by expanding plasma the triggering delay of the photomultiplier was being changed in the range from 0 to 500 ns from the laser shot. The acquisition time was 100 ns. In the observed wavelength range the emission spectra consisted mainly of W I and W II lines; however, the ratio of intensity of lines of different charge states depended on the observation time. The average electron temperature during plasma expansion was estimated as 1.5 eV and electron density as $5.5 \times 10^{17} \text{ cm}^{-3}$.

A signal from the ion collector made it possible to estimate the average energy of tungsten ions as the laser beam. In the spectra collected by the ion energy analyzer tungsten ions up to 4+ ion charge were observed.

1. Introduction

Tungsten is a component of many alloys, which are often used in various parts of experimental facilities designed for high-temperature plasma research. At a time when a big project such as ITER is under development the information about the behaviour of different metal targets irradiated by laser pulses is needed. Spectroscopic studies of tungsten behaviour under intense laser irradiation has not yet been completely realized and understood mainly due to the complexity of the spectrum and the lack of good database of spectral tungsten lines

contributed to ions of high charge state (+2 and higher) [1-3]. To perform an extensive study of the behaviour of tungsten it is also necessary to investigate the temporal behaviour of the laser produced plasma to observe the evolution of its electron density and temperature as well as the average charge state.

2. Experimental set-up

The tungsten target, located in the center of the vacuum chamber (7×10^{-5} Torr), was irradiated by 3.5 ns laser pulses of energy up to 0.8 J. The pulses were delivered by the Nd:YAG laser operating at a fundamental harmonic with a repetition rate of up to 10 Hz. The laser beam was focused by a quartz lens with a focal length of 50 cm onto the W target. The spectra emitted from plasma plumes were recorded by the computer-controlled Mechelle5000 spectrometer in the spectral range from 200 nm to 900 nm. The light was collected 5 mm from the target parallel to the target surface as presented on Fig. 1a. The spectrometer was triggered by the use of Nd:YAG laser system (see Fig. 1b). The spectra were recorded during 100 ns (exposition time) for a different delay between a laser pulse and an opening of the gate of the spectrometer.

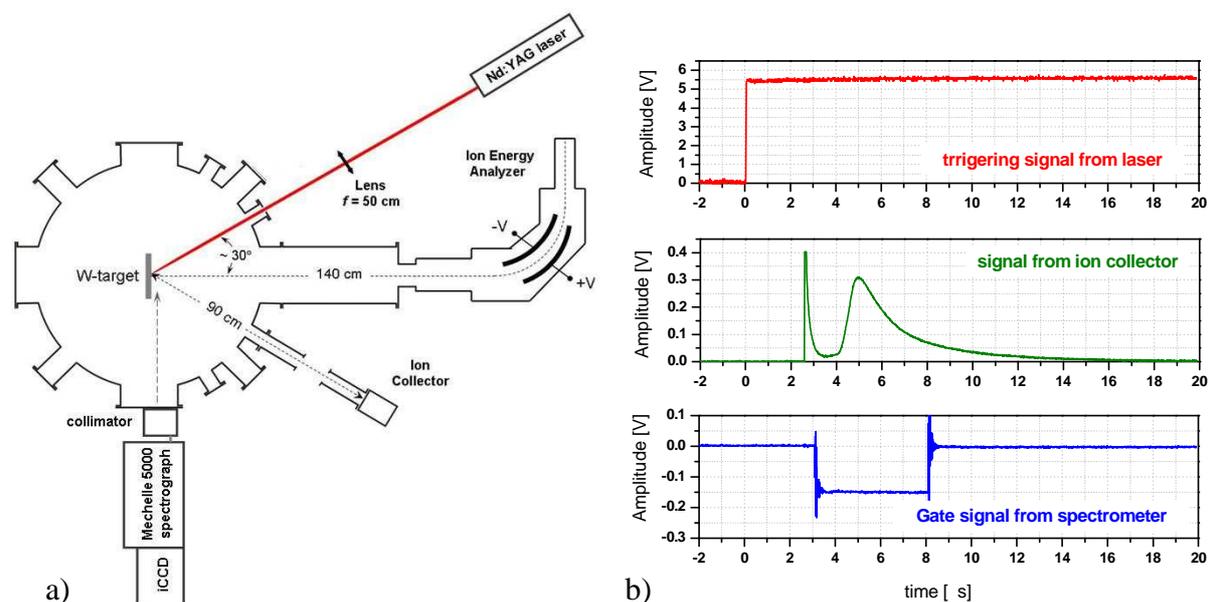


Fig. 1. The experimental set-up (a) with synchronization and triggering of spectrometer (b).

The vacuum chamber was additionally equipped with two ion diagnostics: electrostatic ion energy analyzer [4] and ion collector. These diagnostics make it possible to observe the ion composition of plasma and to estimate an average value of ion energy.

3. Results

Several series of measurements were performed in different experimental conditions. Figure 2 presents an evaluation of tungsten spectra according to the delay between a laser pulse and the opening of the gate of the spectrometer. It is seen that with the increase of the delay the maximum of lines intensity was shifted towards the longer wavelength range, where mainly atomic lines dominate. In the spectra almost all lines were identified as WI or WII. Line intensities from the same ionization stage of tungsten species were used in the Boltzmann plot for determination of electron temperature [5]. An example of such a plot for 100 ns of delay time is presented in Fig. 3. Based on WI lines the average electron temperature was estimated as 1.5 eV. The electron density was calculated on the basis of the line intensities of WI and WII [5]. In our experiment this average value was estimated to be $5.5 \times 10^{17} \text{ cm}^{-3}$.

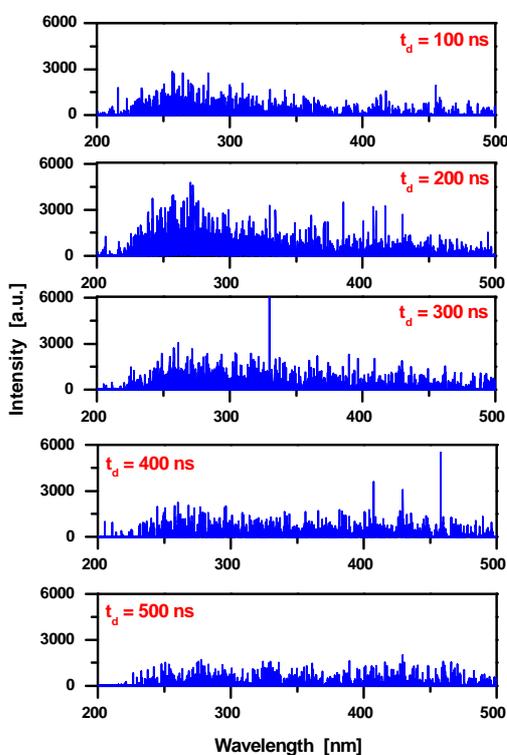


Fig. 2. Example of collected spectra with delay time from 100 to 400 ns and exposure time 100 ns.

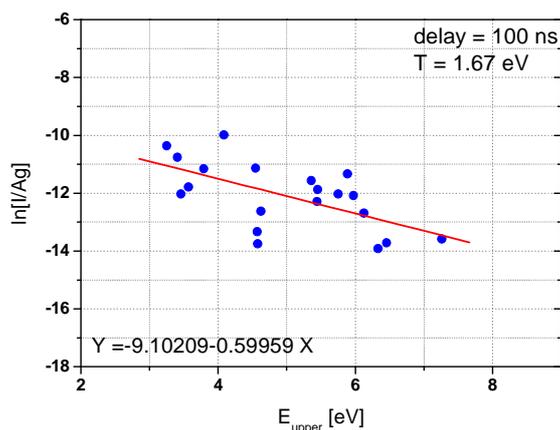


Fig.3. An example of Boltzmann plot used for estimating temperature of the plasma for the delay time equal to 100 ns.

A signal from the ion energy analyzer showed that the plasma plume includes tungsten ions of up to 4+ ion charge state, as presented in Fig.4a. A signal from the ion collector (Fig.4b), distanced 90 cm from the target surface, allowed to determine an average value of energy of tungsten ions escaping from the tungsten plasma plume. This value was estimated to be 2.8 keV.

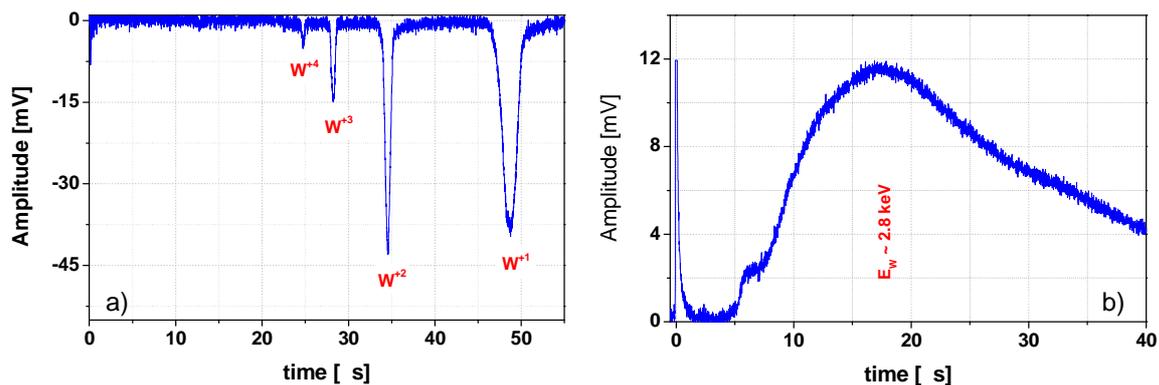


Fig.4. Signals from ion diagnostics. a) signal from electrostatic ion energy analyzer, b) signal from ion collector located at 90 cm from the target surface.

Conclusion

The spectroscopic investigation of the time behaviour has shown that the spectra emitted by laser produced tungsten plasma strongly depends on the time of observations (delay time). From the point of view of identification of the atomic and low charge state ion lines it is better to introduce a high enough delay – in the case of our experiment between 300 and 400 ns. Spectra taken for the delay in this range offer a reasonable signal to noise ratio and are good for further investigation. In the future we are planning to estimate the time dependence of the electron temperature and density.

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