SPECTROSCOPIC INVESTIGATION OF PF-1000 DISCHARGES UNDER DIFFERENT EXPERIMENTAL CONDITIONS

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The emission from free-propagating plasma streams was studied in experiments with a 1-MJ plasma-focus PF-1000 facility operated at the IPPLM in Warsaw, Poland. The machine was filled up with a pure deuterium or a mixture of deuterium and argon. Optical spectra were recorded at a distance of 30 cm from the electrodes, at different experimental conditions, i.e. initial pressures, charging voltages and acquisition times, in the wavelength range of 350…1000 nm. The most intense lines originated from the applied working gases. In some cases distinct CuI and FeI lines resulted from the electrodes and the insulator were observed. From the Balmer lines, D_β and D_γ, an electron density as a function of time was estimated. The application of this finding made it possible to perform some experiments concerning spectroscopic research on the interaction of free-propagating plasma streams with tungsten targets. In the recorded spectra some WI and WII lines were identified, but the resolution of the spectrometer was not good enough for their quantitative analysis.
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1. INTRODUCTION

Research on high-current discharges of the plasma-focus devices has been carried out in different laboratories for many years [1-2]. This paper describes spectroscopic studies of free-propagating plasma streams in experiments with a PF-1000 facility [3]. Similar studies were performed earlier within the RPI-IBIS facility [4] as well as in experiments on an interaction of laser beams with a tungsten target [5]. The main aim of the described experiments was to record the optical emission spectra at a larger distance (z = 30 cm) from the electrodes and to investigate dynamics and contaminations of plasma-streams.

2. EXPERIMENTAL ARRANGEMENT

A scheme of the experimental arrangement used for the spectroscopic measurements within the PF-1000 facility is presented in Fig.1.

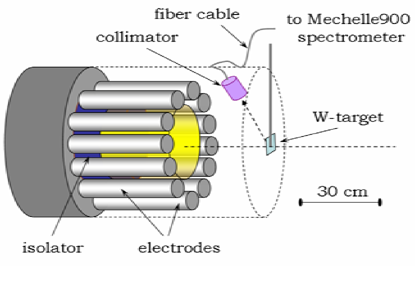

Fig. 1. Experimental set-up for spectroscopic measurements at the PF-1000

The main experimental chamber of the device was filled up with pure deuterium (D_2) at the pressure of (1…2,9) hPa or a mixture of deuterium and argon at the pressure of (1,1 hPa D_2 and 0,13 hPa Ar). Discharges were supplied from a 1,32 mF condenser bank charged up to the initial voltage varied from 21 to 27 kV, what corresponded to energy from 290 to 480 kJ. The maximum discharge current depended on the initial charging voltage and it amounted to 1,5…1,8 MA, respectively.

Optical spectra emitted from a plasma stream were recorded at a distance of 30 cm from the electrodes ends. Signal was collected by means of a quartz collimator and transferred through a fiber cable (of 10 m in length) to a Mechelle900 spectrometer with a spectral resolution equal to $\lambda/\Delta\lambda = 1050$ at $\lambda = 435$ nm. The spectroscopic measurements were performed with different acquisition times at different delays in relation to the discharge current peculiarity (so-called a "dip"). The recorded spectra were wavelength- and intensity-calibrated by means of Mercury-Argon (HgAr) and Deuterium-Tungsten (DW) lamps, respectively. On the basis of the spectral lines of HgAr lamp, the apparatus broadening was determined to be $\Delta\lambda = 0.4$ nm for $\lambda = 486{,}03$ nm, and $\Delta\lambda = 0{,}6$ nm for $\lambda = 656{,}10$ nm.

3. SPECTROSCOPIC RESULTS

An example of the optical spectra, which were recorded at different instants after the "dip", is presented in Fig.2.

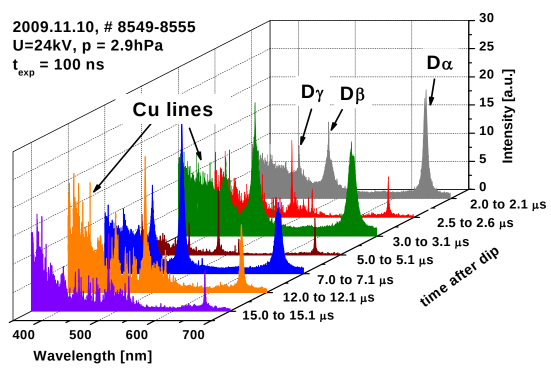

Fig. 2. Temporal evolution of the spectrum recorded within PF-1000 at a distance z = 30 cm

It should be mentioned that at the same experimental conditions there were observed only small differences in the registered spectra. A comparison of the recorded spectra (see Fig. 2) showed that an amount of the impurity lines was smallest in the period up to about 5 µs after the „dip". After that period there were observed many impurity (mainly Cu I) lines.

In the described experiment there were recorded interesting profiles of the deuterium Balmer lines. An analysis of the D_β line profile is presented in Fig. 3.

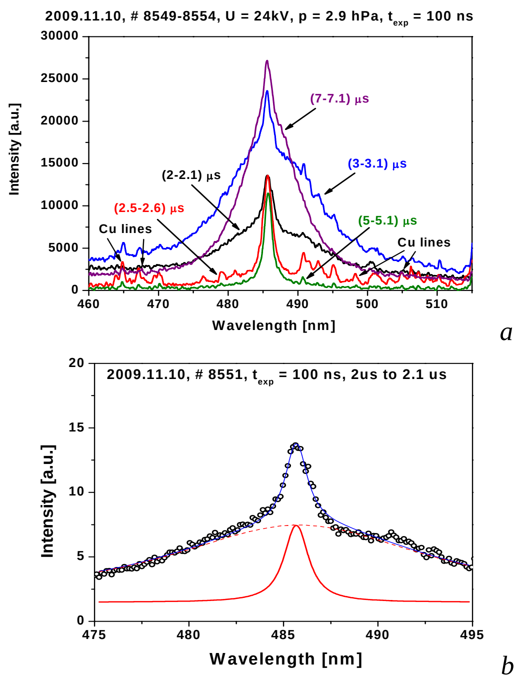

Fig. 3. Temporal changes of D_β 486.03 nm line observed in the PF-1000 experiment (a) and an example of D_β line shape recorded with the acquisition time t_{exp} = 100 ns in a period of 2 – 2.1 µs after the current „dip" and compared with the corresponding fitting curve (b)

It should be noted that one can easy distinguish at least two parts of the D_β line: a broad profile and a narrow central part of that. Similar shapes of the deuterium Balmer series have also been observed in other experiments [6-8], but in those cases FWHM values of these lines were many times smaller than in the described experiment.

In the first approach the observed line shapes, and in particular the broad part of line, can be explained by the appearance of fast deuterons, what has been confirmed by other diagnostics, e.g. ion measurements with SSNTD [9]. Nevertheless, more measurements and detailed analysis are needed to explain the observed profiles.

In this analysis to estimate plasma parameters, e.g. an electron temperature and density, only the central part of the observed D_β line has been taken into account. Assuming a dominant role of the Stark broadening, the electron density has been calculated on the basis of the known formula [10]. Some results of the computations are presented in Fig. 4 where neutron yields are also shown.

It should be noted that the error bars in the electron density values originated from the fitting of a Lorentz profile (since the contribution of Gauss in Voigt profiles was negligible). Unfortunately, the obtained values cannot be compared with the results determined with other diagnostic techniques (e.g. a laser interferometry) because interferometric measurements were performed by another team in a region from 0 to 10 cm from the end of electrodes only.

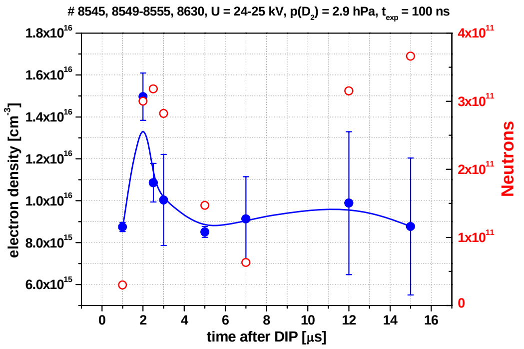

Fig. 4. Electron density versus time after the „dip", as observed in the PF-1000 experiment at z = 30 cm. For a comparison there are also given neutron yields

The electron temperature value T_e has been calculated using intensities of two CuI lines: λ = 510,55 nm and 515,32 nm. Temperature changes at different time delays after the „dip" were very small and the T_e value varied form 0,65 to 0,7 eV. The determination of the T_e value by means of a Boltzmann plot was impossible because of a small number of CuI lines with different energy levels of the upper state. The higher temperature values (at comparable values of the electron density), using ArII lines, have been obtained (e.g. 3 eV) in a case of discharges performed with the deuterium and argon mixture [11]. A sample of the recorded spectrum is presented in Fig. 5.

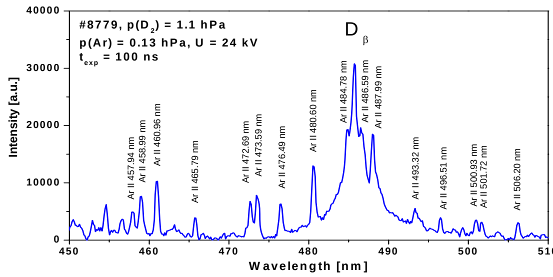

Fig. 5. Optical spectrum recorded for a PF-1000 discharge performed with the argon-deuterium mixture

After the determination of a period when the spectra did not contain many impurity lines, it was possible to perform some preliminary spectroscopic measurements during an interaction of free-propagating plasma streams with a pure tungsten target placed at z = 30 cm. In that case, in the obtained spectra, besides the distinct Cu and Fe lines, there were also recorded lines identified as WI and WII. In future experiments, a larger tungsten target will be used to assure the creation of a plasma pillow at the target surface.

4. CONCLUSIONS

The temporal evolution of the optical emission spectra from PF-1000 was investigated. Besides the lines of the working gases (D_2 or D_2 and Ar mixture), there were recorded many lines of some elements from the materials of the PF-1000 electrodes (mostly Cu and Fe) and insulator (mostly Al and O). The observed shapes of the deuterium Balmer lines (mainly D_β and D_γ) suggested a strong influence of fast deuterons emitted from the PF-1000 discharges. Further detailed analysis and additional measurements will be perform with the use of other complementary diagnostics.

ACKNOWLEDGEMENT

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СПЕКТРАЛЬНЫЕ ИССЛЕДОВАНИЯ РАЗРЯДА В ПФ-1000 ПРИ РАЗЛИЧНЫХ ЭКСПЕРИМЕНТАЛЬНЫХ УСЛОВИЯХ

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Исследовано излучение свободно распространяющихся плазменных потоков, генерируемых мегаджоульным плазменным фокусом ПФ-1000 (ИФПЛМ, Варшава, Польша). В качестве рабочего газа использовался чистый дейтерий и смесь дейтерия с аргоном. Оптические спектры в диапазоне 350...1000 нм регистрировались на расстоянии 30 см от электродов при вариации экспериментальных условий (начального давления, напряжения и времени обработки). Наиболее интенсивными спектральными линиями, зарегистрированными в экспериментальных спектрах, являются линии рабочего газа. В некоторых случаях наблюдались также линии примесных элементов: CuI – материала электродов и FeI – изолятора. Временная зависимость электронной плотности плазмы оценивалась из уширения бальмеровских линий D_β и D_γ. Представлены также результаты спектрального анализа процесса взаимодействия плазменных потоков с вольфрамом. Идентифицированы спектральные линии WI и WII, однако разрешение спектрометра не позволило провести количественный анализ.

СПЕКТРАЛЬНІ ДОСЛІДЖЕННЯ РОЗРЯДУ В ПФ-1000 ПРИ РІЗНИХ ЕКСПЕРИМЕНТАЛЬНИХ УМОВАХ

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Досліджено випромінювання плазмових потоків, що генеруються мегаджоульним плазмовим фокусом ПФ-1000 (ІФПЛМ, Варшава, Польща). В якості робочого газу використовувався чистий дейтерій і суміш дейтерію з аргоном. Оптичні спектри в діапазоні 350...1000 нм реєструвалися на відстані 30 см від електродів при варіації експериментальних умов (початкового тиску, напруги і часу обробки). Найбільш інтенсивними спектральними лініями, зареєстрованими в експериментальних спектрах, є лінії робочого газу. У деяких випадках спостерігались також лінії домішкових елементів: CuI – матеріалу електродів і FeI – ізолятора. Часова залежність електронної густини плазми оцінювалась з розширення бальмерівських ліній D_β та D_γ. Представлено також результати спектрального аналізу процесу взаємодії плазмових потоків з вольфрамом. Ідентифіковано спектральні лінії WI і WII, проте роздільність спектрометра не дозволила провести кількісний аналіз.