OPTICAL EMISSION SPECTROSCOPY OF PULSED PLASMA STREAMS EMITTED FROM A MODIFIED PF-1000 FACILITY

E. Skladnik-Sadowska[1], R. Kwiatkowski[1], K. Malinowski[1], M.J. Sadowski[1-2], M. Kubkowska[2], M. Paduch[2], M. Scholz[2] and E. Zielinska[2]

[1]National Centre for Nuclear Research (NCBJ), 05-400 Otwock, Poland;
[2]Institute of Plasma Physics and Laser Microfusion (IFPiLM), 01-497 Warsaw, Poland
E-mail: Elzbieta.Skladnik-Sadowska@ncbj.gov.pl

The paper presents results of the recent spectroscopic studies of pulsed plasma streams generated in the PF-1000 facility at the IFPiLM in Warsaw. This facility has recently been equipped with a modified inner electrode, which had the front copper-plate with a central tungsten (W) insert of 50 mm in diameter. Interactions of the collapsing current sheath and electron beams with this insert have changed characteristics of the X-ray and VR emission considerably. New spectroscopic measurements were performed at the chosen angle and perpendicular to the discharge axis. In the second case optical emission spectra were recorded at different distances from the electrode outlets, and at various instants after the current peculiarity (dip). It enabled to determine dynamics of the VR emission in the investigated VR range.

PACS: 52.59.Hq, 52.70.Kz, 52.30.q

INTRODUCTION

The operation of Plasma-Focus (PF) devices is based on pulsed high-current discharges performed between two coaxial electrodes placed in a chamber, which is filled up with a working gas (e.g. deuterium) under an appropriate pressure [1]. During the last years the interest in PF facilities has grown considerably, because they constitute very efficient sources of the fusion-produced neutron emission [2-7]. Therefore, many PF experiments are run all over the world, but the problem of the scaling and saturation of the neutron yield is still open.

The PF-1000 machine operated at the IFPiLM in Warsaw, Poland, is the largest Mather-type PF facility in Europe. It has been investigated for many years, and it has been modified several times [3-7]. Studies of PF-1000 discharges have been carried out by means of different diagnostic techniques [6]. Recently the PF-1000 machine has been modified. It has changed some important characteristics, and particularly the X-ray and VR emission. The main aim of this paper was to present some results of the recent optical emission studies.

1. EXPERIMENTAL SETUP

The described studies were performed within the PF-1000 facility with the anode made of a thick-wall Cu tube of 230 mm in diameter, which was equipped with a central diametr 50 mm insert made of tungsten (W). The modified machine was operated at a D_2 filling under the pressure of 1.3 hPa, and powered by a condenser bank charged to 24 kV, 380 kJ. The maximum discharge current amounted to 1.8 MA. Optical measurements were started by taking time-integrated pictures of the VR emitted from plasma streams, which was observed behind an optical window and recorded by means of a CCD-camera with various filters. Spectroscopic measurements were performed behind optical windows, which looked at chosen angles and perpendicular to the z-axis (see Fig. 1).

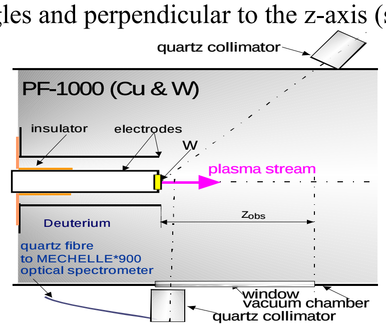

Fig. 1. Scheme of the PF-1000 experimental setup

To record optical emission spectra the use was made of an optical collimator coupled with the optical-fiber cable and a Mechelle®900-type spectrometer.

2. EXPERIMENTAL RESULTS

The first series of the spectroscopic measurements was carried out at an angle of 67^0 to the z-axis in order to record emission from plasma at the centre of the W-insert. An exemplary optical spectrum is presented in Fig. 2.

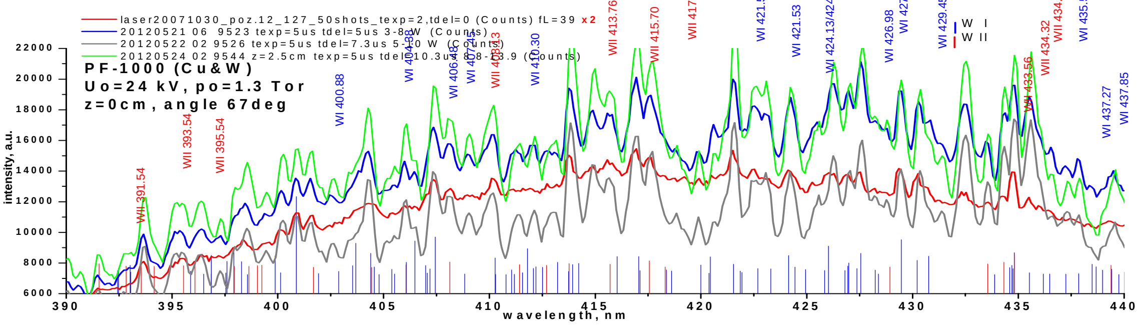

Fig. 2. Optical emission spectrum from plasma produced at the W-insert center and recorded at 67^O to the z-axis

The second series of measurements was performed side-on, with the exposition (t_{exp}) equal to 5 µs - in order to record the time-integrated optical spectra of discharges. The measurements were made at different z-distances (varied in several steps from 0 to 14 cm) from the electrode ends. An example is presented in Fig. 3.

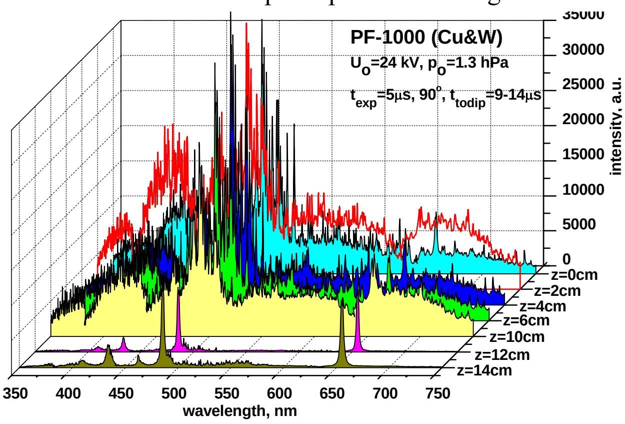

Fig. 3. Optical emission spectra recorded perpendicular to the discharge axis, at different distances and t_{exp}= 5 µs

The detailed spectroscopic measurements were carried out at distances of 3.5, 6.5 and 8.5 cm from the electrode outlets, at much shorter exposition (t_{exp} = 100 ns) in order to determine dynamics of the emission of various spectral lines, and in particular of the deuterium and tungsten (WI and WII) lines. Two examples are presented in Fig. 4.

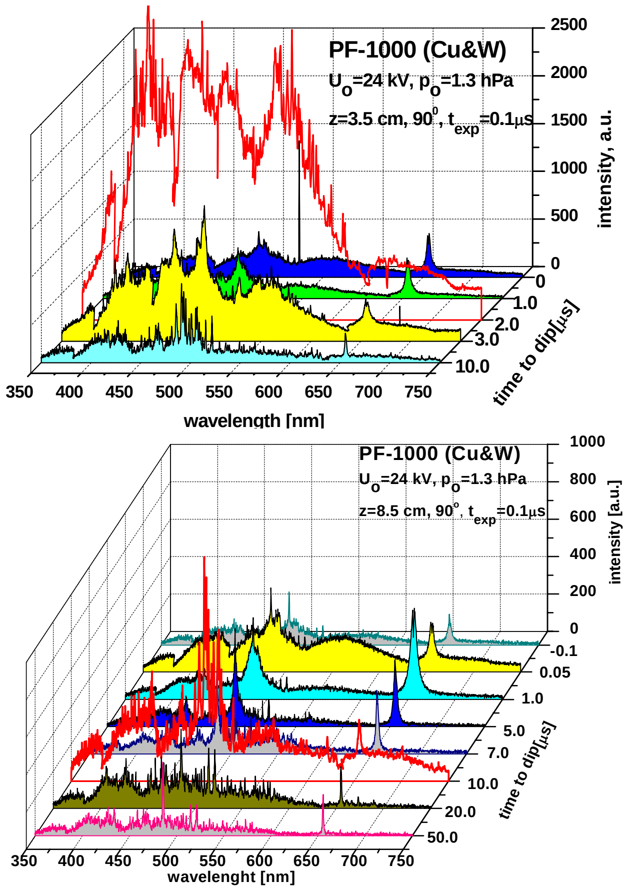

Fig. 4. Optical emission spectra recorded at t_{exp}= 0.1 µs, and different instants after the discharge current dip, at z = 3.5 cm and 8.5 cm

3. ANALYSIS OF EXPERIMENTAL DATA

The preliminary analysis concerned the experimental data shown in Fig. 2, which presents a comparison of the optical emission spectrum recorded in a laser & W-target experiment (red line) with three spectra recorded in the PF-1000 facility at an angle of 67^0 to the z-axis, but at different temporal instants (ranging from 5 µs to 10 µs). One could easily notice that these optical spectra, emitted from a region near the anode center and the W-insert, contained many WI and WII spectral lines. The emission of those lines could be explained by interactions of the collapsing current sheath and electron beams with the W-insert surface. It should be mentioned that such lines were also recorded in earlier laser-experiments with W targets [10]. Unfortunately, the detailed analysis of rich tungsten spectra in Fig. 2 could hardly be performed because of an interference of numerous W-lines and intense continuum emission. It constituted an experimental evidence that the erosion of the W-insert was relatively strong. Effects of this erosion could also be observed upon the surface of the W-insert after series of discharges, as shown in Fig. 5.

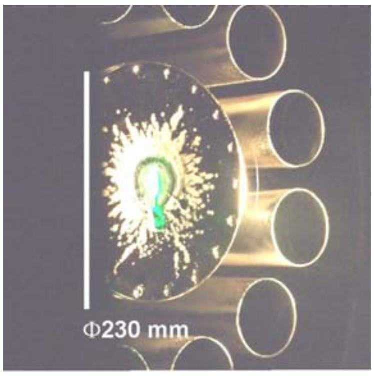

Fig. 5. Picture of PF-1000 electrodes ends, which shows distinct tracks of the erosion of the anode (Cu-plate and W-insert). The center of the anode was illuminated with an auxiliary laser beam

Analyzing the spectra presented in Fig. 3, which were recorded perpendicular to the z-axis of the PF-1000 facility, at different distances from the electrode outlet and at a relatively long exposition time t_{exp}= 5 µs, one could also observe intense continuum and very rich spectrum containing not only D- and W-lines, but also Cu-lines and other impurities. Intensity of the optical emission was considerably lower at distances larger than 10 cm from the electrode ends. In that case the identification of D_α and D_β lines was possible, but their quantitative analysis could hardly be performed because these lines were deformed by other near lines and re-absorption effects. In spite of the careful calibration, the observed ratio of D_α and D_β intensities was found to be different from the correct value, what could be explained by a lack of the complete thermalization.

Considering the optical spectra presented in Fig. 4, which were recorded at various instants after the characteristic peculiarity (dip) of the discharge current and at different z-planes (z = 3.5 cm and 8.5 cm), one could notice that relative intensities of some WI lines observed in the earlier phase decreased in the period from t = 0 to t = 10 μs. In contrary, the relative intensities of some distinct WII lines recorded in the plane z = 8.5 cm increased during that period (until t = 10 μs) noticeable. It delivered some information about dynamics of the W-plasma production and expansion. It should, however, be noted that information about W-ions with a higher ionization could not be collected because of limitations of the applied optical spectrometer and a lack of data (about WIII and higher W-lines) in available databases. A quantitative analysis of the $D_β$ line could hardly be performed, but estimates based on the analysis of the $D_α$ line delivered information that the plasma concentration at distances from z = 3.5 cm to z = 8.5 cm varied in a range from 9 x 10^{15} cm^{-3} to 6 x 10^{16} cm^{-3}, respectively.

SUMMARY AND CONCLUSIONS

The most important results of the reported studies can be summarized as follows: 1. The use of optical emission spectroscopy made it possible to record the spectral lines emitted from the plasma-ion streams generated in the modified PF-1000 facility; 2. A quantitative analysis of the recorded W-lines could hardly be performed because of the very rich spectrum and intense continuum, but some information about dynamics of the optical emission was obtained; 3. In some cases the quantitative analysis of the $D_α$ line was performed and approximate values of the electron concentration were calculated.

One can conclude that spectroscopic studies of the optical emission in the present version of the PF-1000 facility should be continued, and particularly more accurate space- and time-resolved optical measurements should be performed in order to collect information about behavior of free-propagating plasma streams and their interactions with different solid targets.

ACKNOWLEDGEMENTS

The research was performed in the frame of the task No.2 of the research project realized under the contract No. SP/J/2/143234/11 between NCBiR and IFPiLM, Poland. This work was also partly supported by grants W32/IAEA/2012 and W33/IAEA/2012 from the Ministry of Science and Higher Education in Poland.

REFERENCES

1. A. Bernard et al.// *J. Moscow Phys. Soc.* 1998, v 8, p. 93-170.
2. M.J. Sadowski, M. Scholz // *Plasma Sources Sci. & Technol.* 2008, v. 17, p. 024001.
3 M. Scholz et al. // *Nukleonika* 2001, v. 46(S1), p. 35-39.
4. M.J. Sadowski, M. Scholz // *PAST. Series « Plasma Phys.».* 2010, v. 16, p. 194-198.
5. M.J. Sadowski, M. Scholz // *Nukleonika.* 2012, v. 57, p. 11-24.
6. P. Kubes et al. // *IEEE Trans. Plasma Sci.* 2012, v. 40, p. 1075-1081.
7. M. Scholz et al. // *Nukleonika* 2012, v. 57, p. 183-188.
8. M. Kubkowska et al. // *PAST. Series «Plasma Phys.».* 2010, v. 16, p. 202-204.
9. E. Skladnik-Sadowska et al.// *Contrib. Plasma Phys.* 2011, v. 51, p. 288-292.
10. M.J. Sadowski et al .// *Rad. Eff. & Def. Solids.* 2008, v. 163, p. 569-577.

Article received 20.09.12

ОПТИЧЕСКО-ЭМИССИОННАЯ СПЕКТРОСКОПИЯ ИМПУЛЬСНЫХ ПЛАЗМЕННЫХ ПОТОКОВ, ИЗЛУЧАЕМЫХ ИЗ МОДИФИЦИРОВАННОЙ УСТАНОВКИ PF-1000

E. Skladnik-Sadowska, R. Kwiatkowski, K. Malinowski, M.J. Sadowski, M. Kubkowska, M. Paduch, M. Scholz and E. Zielinska

Представлены результаты недавних спектроскопических исследований импульсных потоков плазмы, генерируемых установкой ПФ-1000, которая расположена в ИФПиЛМ в Варшаве. Эта установка недавно была оснащена модифицированным внутренним электродом, который имел переднюю медную пластину с центральной вольфрамовой (W) вставкой диаметром 5 мм. Взаимодействие схлопывающейся токовой оболочки и электронных пучков с этой вставкой значительно изменило характеристики рентгеновского и излучения в видимом диапазоне. Новые спектроскопические измерения проводились при выбранном угле и перпендикулярно к оси разряда. Во втором случае оптические спектры излучения были зарегистрированы на разных расстояниях от среза электродов и в различные моменты после токовой особенности осциллограммы тока (провала). Это позволило определить динамику ВИ в исследованном диапазоне.

ОПТИЧНО-ЕМІСІЙНА СПЕКТРОСКОПІЯ ІМПУЛЬСНИХ ПЛАЗМОВИХ ПОТОКІВ, ЯКІ ВИПРОМІНЮЮТЬСЯ З МОДИФІКОВАНОЇ УСТАНОВКИ PF-1000

E. Skladnik-Sadowska, R. Kwiatkowski, K. Malinowski, M.J. Sadowski, M. Kubkowska, M. Paduch, M. Scholz and E. Zielinska

Представлені результати недавніх спектроскопічних досліджень імпульсних потоків плазми, що генеруються установкою ПФ-1000, яка розташована в ІФПіЛМ у Варшаві. Ця установка нещодавно була оснащена модифікованим внутрішнім електродом, який мав передню мідну пластину з центральною вольфрамовою (W) вставкою діаметром 50 мм. Взаємодія оболонки струму, яка схлопується, і електронних пучків з цією вставкою значно змінило характеристики рентгенівського випромінювання у видимому діапазоні. Нові спектроскопічні вимірювання проводилися при заданому куті та перпендикулярно до осі розряду. У другому випадку оптичні спектри випромінювання були зареєстровані на різних відстанях від зрізу електродів, і в різні моменти після особливості осцилограми струму (провалу). Це дозволило визначити динаміку ВВ у дослідженому діапазоні.