CORRELATION BETWEEN TIME-RESOLVED AND INTEGRAL MESUREMENTS OF THE SOFT X-RAY EMISSION IN A PLASMA FOCUS OPERATED IN ARGON

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The results of experiments received on the plasma focus (PF) device with energy stored equal 1.5-5 kJ are represented in this paper. Discharge integral photos were obtained with the help of the soft x-ray pinhole camera with four 250 μm apertures. Simultaneously the short X-ray pulse recording system was fulfilled by the fast semiconductor detectors SPPD11-04 hided 50 μm Be filters with exposure time about 1.5 ns. The soft X-ray measurements were fulfilled in the voltage range U=8-14 kV and argon pressure 1.3-3.2 Torr. Under some conditions transition from hot spots regime to column type was observed by the 50 μm pinhole camera. With help of the 20 μm pinhole camera was estimated size of the hot spots about 13-25 μm radiated quanta with energy ≥ 1.8 keV.

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1. INTRODUCTION

The Plasma Focus is considered as a source for the inertial confinement fusion (ICF) with homogeneous irradiation of the X-ray, but also for high density lithography, X-ray microscopy, radiography and materials modification. There is continued interest in operating plasma focus with different gases for higher soft X-ray yield. Such in a number of cases plasma focus was studied when neon [1-4], argon [4-7], hydrogen[7] or mixtures[4] were used as the filling gases.

In our work, we studied argon plasma focus discharge and intend to make the mechanism of the soft X-ray generation more clearly. For this purpose measurements with a high speed semiconductor detector SPPD11-04 and the soft X-ray pinhole camera were used.

2. PLASMA FOCUS FACILITY AND DIAGNOSTICS

A Mather type plasma focus facility was used to generate a current sheet for compressing filled argon. The discharge occurred between two single-axis electrodes. The diameter of the inner (anode) and the outer (cathode) electrons were 30 and 53 mm, respectively. Their lengths were 60 and 55 mm, respectively. The condenser bank consisted of 4x12 μF, 25 kV capacitors. The facility operated at the bank voltage from 8 to 14 kV and the total current did not exceed 0.4 MA at its maximum. Gas pressure in different experiments was from 1.3 to 3.2 Torr.

Fig.1 shows the block diagram of the experimental setup with different diagnostics.

The evolution of the soft X-ray emission was monitored using the SPPD11-04 PIN diode with a 50 μm thick Be filter and accuracy 1.5 ns. The PIN diode signal was recorded by 500 MHz oscillograph (TDS-304B). The discharge integral photos were obtained with the help of a soft X-ray pinhole camera on the RAR2494 X-ray film. Four soft X-ray images, A, B, C and D, were simultaneously taken though four pinholes of 250, 260, 250, 270 μm in diameter (Fig 3 and 5) or one soft X-ray image was taken through pinhole of 48 or 20 μm in diameter with a 50 μm Be filter. The filters, 15, 30, 50 and 150 μm Be, were attached to four pinholes, respectively. Beryllium foil filters prevented from the visible light emitted from the source. Spectral responses of the filters which were employed in this experiment, are shown in Fig. 2. Energy of radiation corresponded to an initial intensity decrease exponent times is represented in the Table. Combination of the applied film and the 50 μm Be foil filter gave a registration region from 1.8 to 10 keV. Registration was produced under 90 degrees to the vertical axis. The synchronization of the photography moment was produced with respect to the peculiarity on the current oscillogram recorded by the magnetic probe in the range of 1-3 μs with the accuracy of 10 ns.

The experimental tools were operated simultaneously to measure the plasma parameters without expecting a shot-to-shot reproducibility.

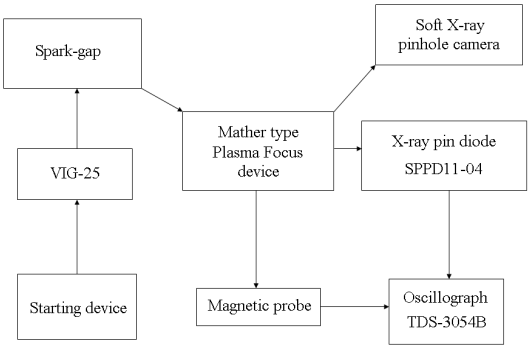

Fig.1. Block diagram of the experimental setup with different diagnostics

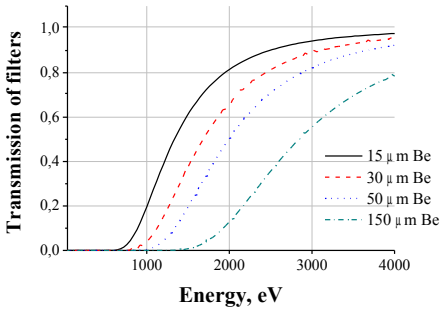

Fig.2. Spectral response of 15, 30, 50 and 150 μm Be filters

Energy of radiation corresponded to an initial intensity decrease exponent times

filter	15 μm Be	30 μm Be	50 μm Be	150 μm Be
E_e, keV	1.2	1.5	1.8	2.5

3. RESULTS AND DISCUSSION

3.1. MACROSCOPIC BEHAVIOUR OF THE SOFT X-RAY EMISSION AT DIFFERENT VOLTAGES

Examples of the PIN diode signals and the soft X-ray images which were taken simultaneously are shown in Fig. 3. Experiments were fulfilled under constant argon pressure 1.9 Torr and different voltages from 8 to 14 kV. The soft X-ray images were obtained by the four-pinhole camera.

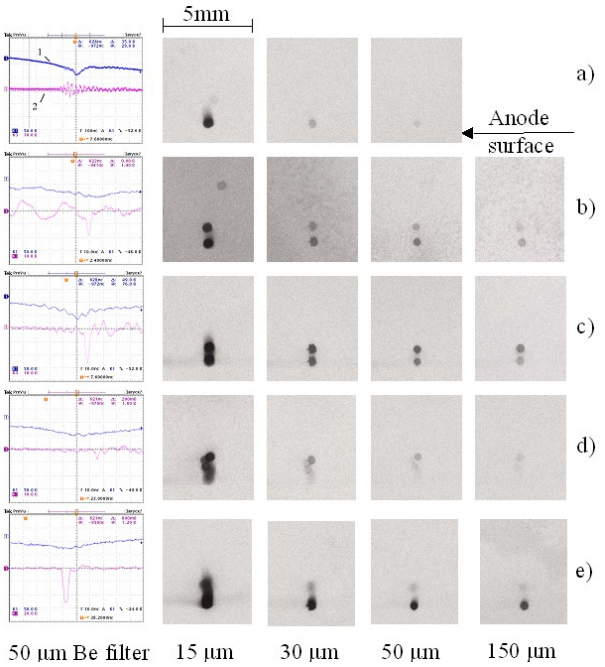

Fig.3. Oscillogram of the current derivative in the peculiarity region (1), PIN diode behind 50 μm Be filter signal (2) and the X-ray pinhole pictures at argon pressure 1.9 Torr and voltage a)-9 kV, b)-10 kV, c)-11 kV, d)-12 kV, e)-14 kV. Pinholes' dimensions are equal about 250 μm

It has been observed that the soft X-ray signal obtained by the PIN diode rises almost at the moment of the first current peculiarity (pinch maximum). The soft X-ray image appeared only through pinhole A under voltage 8 kV (E~1.6 kJ). Hot spots with quanta energy ≤ 2.5 keV were recorded under voltage 9 kV (Fig. 3b). Hot spots with quanta energy ≥ 2.5 keV and intensive radiation appeared at more voltages. Usually 1-2 most intense hot spots set one above another at a distance about 1 mm were generated. As shown in Figs. 3b and 3e the lower spot was more intense generally and produced the harder radiation. Plasma radiated in the 1.2-1.5 keV region is also detected around and between hot spots. It can be seen in the pinhole A that this plasma radiation increases greatly under the more voltages. The surface of anode tip became to radiate (E>2.5 keV) at the voltage ≥ 11 kV and its intensity changes slightly in the voltage range from 11 to 14 kV. Dimension of the radiate region equals about 1 cm and coincide with the W-Cu insert dimension. The soft X-ray PIN diode with a 50 μm Be filter became to record a signal at a voltage 10 kV (Fig 3c). The signal mainly consisted of one-two impulses with duration about 3-4 ns. Taking into account experiments accomplished by the PIN diode with a 15 μm thick Be filter at the voltage equals 14 kV, X-ray radiation consisted of two pulses with different energy. The first impulse could pass through 50 μm thick Be filter has duration about 10 ns. The second impulse with less quanta energy have 40-50 ns duration and can be absorbed by 50 μm Be filter.

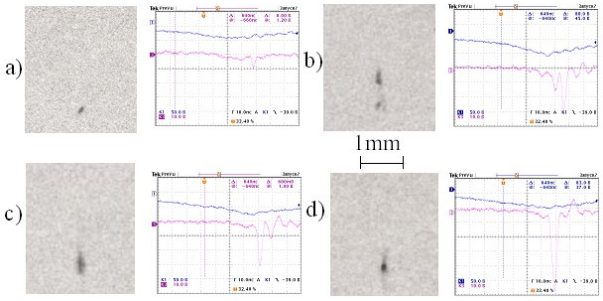

Fig.4. Discharge integral photos of the 50 μm pinhole camera and PIN diode signal behind 50 μm Be filter at argon pressure 2 Torr and voltage a)10, b)12, c)13, d)14 kV

It can be seen in the pinhole picture Fig. 4a that the soft X-ray emission at 10 kV voltage occur from one hot spot. At 12 kV, as shown in Fig. 4b, the radiation is generated in some hot spots. Further voltage increasing creates conditions for combination of the pinch and hot spots radiation regime (Fig. 4c and d).

In experiments with help of the 20 μm pinhole camera was estimated size of the hot spots about 13-25 μm radiated quanta with energy ≥ 1.8 keV.

3.2. MACROSCOPIC BEHAVIOUR OF THE SOFT X-RAY EMISSION AT DIFFERENT FILLING PRESSURES

The maximum X-ray intensity was record at an argon pressure about 2 Torr (Fig. 5b). Radiation region has more Z vertical elongation at lower pressure.

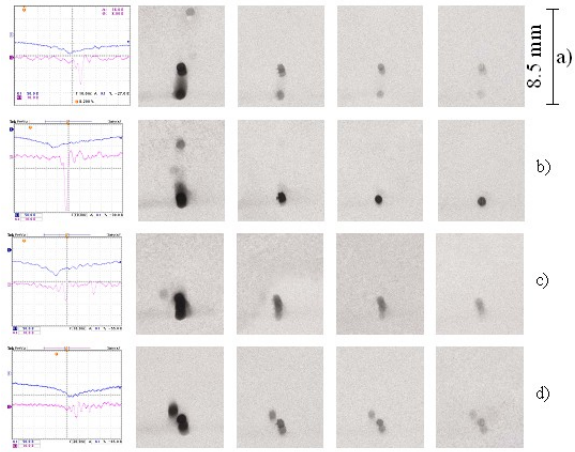

Fig.5. Oscillogram of the current derivative in the peculiarity region (1), PIN diode behind 50 μm Be filter signal (2) and the X-ray pinhole pictures at a bank voltage 12 kV and an argon pressure a) 1.3, b) 1.9, c) 2.5, d) 3.2 Torr. Pinholes' dimensions are equal about 250 μm

The region of hot spots generation contracts in vertical to 3 mm and expands in axial direction ~ 1mm at higher pressure (Fig. 5c and d). X-ray signal consist of many impulses lied in time interval from 40 to 70 ns. The signal amplitude is lower at these conditions. The brightest hot spot lies about anode in the most experiments and responsible for X-ray radiation with E > 2.8 keV.

CONCLUSION

Mainly the Soft X-ray radiation of argon plasma is generated in the hot spots regime. In some cases of condenser bank energy increasing the transition to columned regime was registered. Minimal size of the hot spots estimated in our experiment was about 20 μm. It was determined that usually quantity of the hot spots and impulses, registered by PIN diode detectors, are equal. The exceptions can be explained by that some impulses were not resolved by register system < 1.5 ns. It was defined that duration of each X-ray impulse ≤ 3-4 ns.

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СВЯЗЬ МЕЖДУ ИЗМЕРЕНИЯМИ МЯГКОГО РЕНТГЕНОВСКОГО ИЗЛУЧЕНИЯ С ВРЕМЕННЫМ И ПРОСТРАНСТВЕННЫМ РАЗРЕШЕНИЯМИ ДЛЯ ПЛАЗМЕННОГО ФОКУСА, РАБОТАЮЩЕГО С АРГОНОМ

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Представлены результаты экспериментов, проведенных на плазменном фокусе (ПФ) с энергией конденсаторной батареи 1.5-5 кДж. С помощью 4-х кадровой рентгеновской камеры-обскуры с размерами диафрагм около 250 мкм были получены интегральные рентгеновские снимки разряда. Одновременно с этим, с помощью полупроводниковых детекторов СППД11-04, закрытых 50 мкм Be фильтром, осуществлялась регистрация рентгеновского излучения с временным разрешением около 1.5 нс. Измерения мягкого рентгеновского излучения осуществлялись в диапазоне напряжений конденсаторной батареи 8-14 кВ и давлений аргона 1.3-3.2 Торр. При определенных условиях рентгеновской камерой-обскурой с 50 мкм-диафрагмой наблюдался переход от пинчевого режима к режиму горячих точек. С помощью 20мкм- камеры-обскуры были получены размеры горячих точек с энергией квантов > 1.8 кэВ на уровне 13-25 мкм.

ЗВ'ЯЗОК МІЖ ВИМІРАМИ М'ЯКОГО РЕНТГЕНІВСЬКОГО ВИПРОМІНЮВАННЯ З ЧАСОВИМ І ПРОСТОРОВИМ РОЗДІЛЕННЯМ ДЛЯ ПЛАЗМОВОГО ФОКУСА, ЩО ПРАЦЮЄ З АРГОНОМ

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Представлено результати експериментів, проведених на плазмовому фокусі (ПФ) з енергією конденсаторної батареї 1.5-5 кДж. За допомогою 4-х кадрової рентгенівської камери-обскури з розмірами діафрагм близько 250 мкм були отримані інтегральні рентгенівські знімки розряду. Одночасно з цим, за допомогою напівпровідникових детекторів СППД11-04, закритих 50 мкм Be фільтром, здійснювалася реєстрація рентгенівського випромінювання з часовим розділенням близько 1.5 нс. Виміри м'якого рентгенівського випромінювання здійснювалися в діапазоні напруг конденсаторної батареї 8-14 кВ і тисків аргону 1.3-3.2 Торр. За певних умов рентгенівською камерою-обскурой з 50 мкм- діафрагмою спостерігався перехід від пінчевого режиму до режиму гарячих точок. За допомогою 20мкм- камери-обскури були отримані розміри гарячих точок з енергією квантів > 1.8 кеВ на рівні 13-25 мкм.