SOFT X-RAY MEASUREMENT BY SPPD11-04 DETECTORS ON THE PF "TULIP" INSTALLATION

S.P. Eliseev, V.Ya. Nikulin, P.V. Silin

P.N. Lebedev Physical Institute of RAS, Moscow, Russia

The soft X-ray (SXR) measurements were received with help of the fast semiconductor detectors SPPD11-04 with exposure time about 1.5 ns. Observation directions were at 45° and 90° to the chamber axis. The SXR dependence from pressure was designed. The radiation maximum corresponded to argon pressure equals to 2 Torr. The full width at half-maximum of the pulse at this pressure and a voltage of 12 kV was 5 ns. The SXR radiation dependence was investigated from the capacitor banks voltage (8-14 kV) in the two ranges of energy 1.2-1.8 and 2.9-3.5 keV. At the voltage of 14 kV and an argon pressure of 2 Torr the quantity of radiation quanta was estimated about $8 \cdot 10^{14}$, the total radiation energy ~ 0.2 J and power ~ $7 \cdot 10^{6}$ W in 4π geometry.

PACS: 52.58.Lq, 52.59.Hq, 52.70.-m, 52.70.La

1. INTRODUCTION

High-temperature plasma in the plasma focus has attracted renewed interest in the view of the potential applications as a high-brightness source for lithography and soft x-ray microscopy, as a plasma fluxes source for material properties modification [1], fast electron beams, hard X-ray for radiography [2]. For the optimization of plasma radiation parameters it is necessary to study the dynamic processes in hot plasma and found the optimal installation settings and operation factors.

X-ray methods of plasma diagnostics by the fast semiconductor detectors are introduced in this report.

2. APPARATUS

A Mather type plasma focus device with a cylindrical outer electrode was employed to generate soft X-rays. The coaxial electrode diameters were 30 mm and 53 mm, respectively. The length of anode (inner electrode) was 60 mm and cathode length was 55 mm. The W-Cu composite material was used as an anode tip insertion to reduce the anode SXR radiation. Condenser bank consisted of 4x12 μF, 25 kV capacitors. All capacitors were switched by a reduced pressure air gap. The device was operated at the bank voltage of 8-14 kV and argon pressure of 0.6-3.1 Torr.

Fig.1 shows a Plasma Focus with diagnostic equipment.

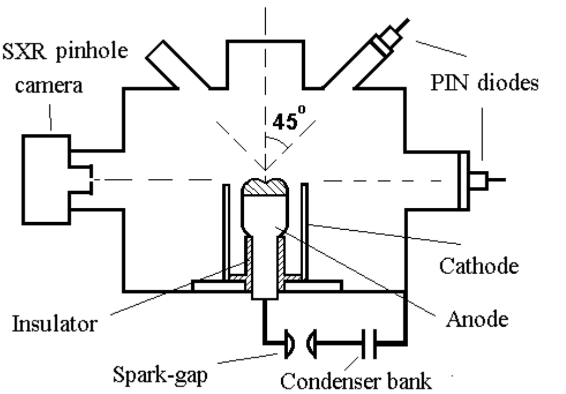

Fig.1. Schematic diagram of the experimental arrangement

The evolution of the soft X-ray emission was monitored using the SPPD11-04 PIN diode sensitive in a range of 0.4 - 40 keV and accuracy 1.5 ns. The aperture diameters of the detectors were equal 2.5 mm. The PIN diode signal was recorded by 500 MHz oscillograph (TDS-304B).

In the experiments with different voltages and constant pressure before detectors the 15, 50 and 115 thick Be filters were used. Observation directions formed angles 45° and 90° with respect to the chamber axis. In the experiments with a variable argon pressure and a constant condenser bank voltage of 12 kV (total energy of 3.6 kJ) was used a 100 μm Be filter. The vertical axis and the observation direction were separated by 90°.

3. RESULTS AND DISCUSSION

3.1. SXR MEASUREMENTS FROM ARGON PRESSURE

A moment of the soft X-ray appearance with experimental accuracy (± 10 ns) always coincided with the maximum of the current derivative peculiarity. Duration of the current derivative peculiarity impulse was about 50 ns. Fig. 2 shows the dependence of the soft X-ray intensity in the Plasma Focus from argon pressure at a voltage of 12 kV.

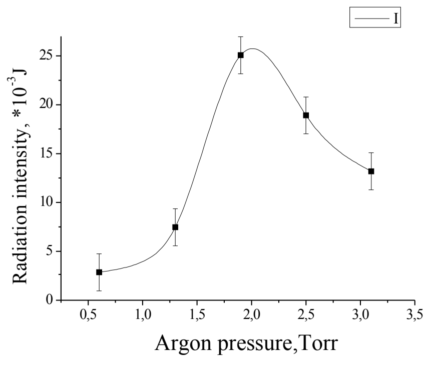

Fig.2. Soft X-ray intensity of plasma focus discharge as a function of argon pressure at a voltage of 12 kV and 100 μm Be filter

The amplitude of the soft X-ray signal was monotonic rising at an argon pressure from 0.6 to 1.9 Torr. Duration of the bell-shaped soft X-ray pulse was about 5 ns (Fig.3a, b). After that at a following pressure rising in spite of the amplitude decreasing, duration of the signal began increasing. At the same time at first, we observed two-humped shape of the signal (at 2.5 Torr the second peak was less than the first peak Fig.3c) and then, there was many-humped shape (at 3.1 Torr Fig.3 d). The signal duration amounted to 50 – 70 ns.

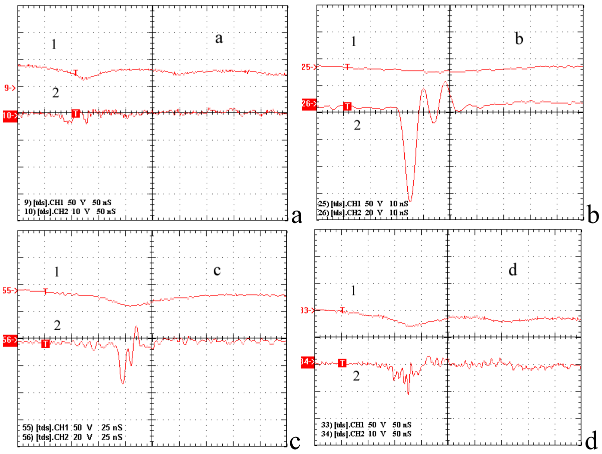

Fig.3. Oscillograph traces of the current derivative in the peculiarity region (1) and PIN diode behind 100 µm Be filter signals (2) at voltage 12 kV and argon pressure a) 0.6, b) 1.9, c) 2.5, d)3.1 Torr

As a result at a constant condenser bank voltage and changeable gas pressure the radiation intensity maximum was received about at 2 Torr argon pressure. We explain this fact by arriving the discharge circuit and the dynamic plasma load optimal correspondence i.e. coincidence of the current maximum with the moment of the maximum plasma compression. The total yield of the soft X-ray radiation is equal about 25 mJ in 4π geometry.

3.2. SXR RADIATION IN TWO ENERGETIC RANGES AT A DIFFERENT CONDENSER BANK VOLTAGES

Two mutually calibrated detectors with 15 and 50 µm Be filters were used in this experiment. The spectral response of these filters is given in Fig. 4. We considered that the transmission cutoffs of these filters are 1.2 and 1.8 keV respectively (energy corresponded to the filter transition at a level 1/e). The capacitors battery voltage was changing from 9 to 14 kV.

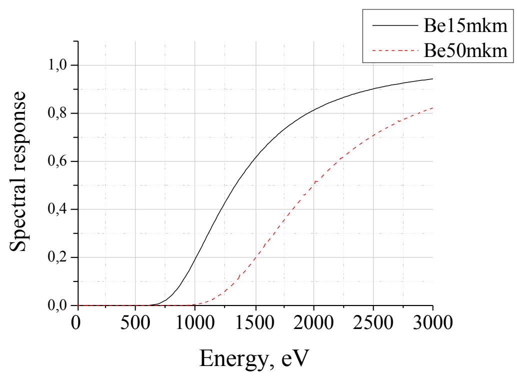

Fig.4. Spectral response of the 15 and 50 µm Be filters

In the radiation energy range more 1.2 keV the SXR signal had compressed two-humped shape and the duration > 10 ns. At the voltage increasing from 9 kV (Fig. 5a,3) to 14 kV (Fig. 5d,3), the SXR signal changed mainly due to the trailing edge broadening. At the same time the second hump was getting more distinct and removed from the fist one (Fig. 5b,3 and c,3). The amplitude growth took place most of all for the second hump.

In the radiation energy range more 1.8 keV the SXR impulse at a voltage of 9 kV usually consisted of one narrow (~5 ns) peak (Fig. 5.a.2). At a voltage of 11 kV the second peak appeared (Fig. 5.b.2), it was remaining less amplitude than the first one at all voltages. As shown in Fig. 5.c the second peak of the channel 2 almost amounted to the corresponded signal of the channel 3 at a voltage of 12 kV. At a following voltage increasing the signal broadened to 15 ns at a 14 kV (Fig. 5.d.2) and obtained careless many-humped shape.

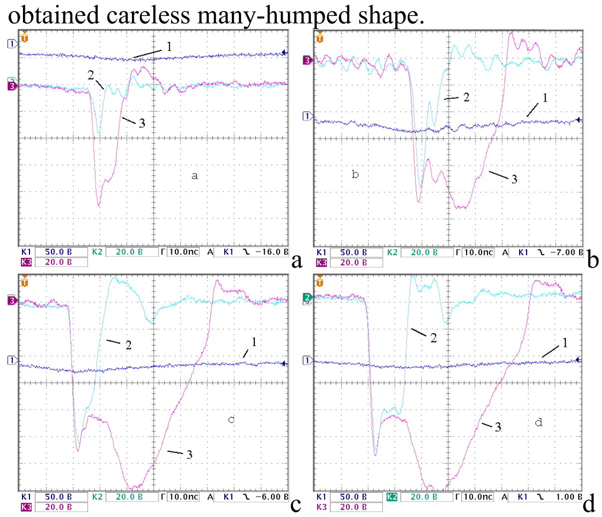

Fig.5. 1– current derivative signal in the peculiarity region; 2 and 3 – the signals of PIN diodes, where detector 2 was protected from plasma by 50 µm Be filter and 3 - by 15 µm Be filter. The argon pressure was equaled to 2.1 Torr in all experiments. a) voltage 9 kV, b) 11 kV, c) 12 kV, d) 14 kV

At a voltage > 10 keV the beginning of the X-ray signal is more energetic than another radiation and it pass through the filters with little losses. The following part of the signal, with 2-4 times more duration, always consists of less energetic quanta and is fully absorbed by 50 µm Be foil. This registered soft X-ray radiation lies in the energy range 1.2-1.8 keV (7-10 Å). Its intensity is greatly rising at a voltage increasing. The duration of this radiation is changing from 5 to 40-60 ns when condenser bank voltage is increased from 9 to 14 kV.

Fig.6 shows the diagram of the total SXR energy for range E (1.2 - 1.8) keV from the applied voltage. The evolution of the total number of quanta $N \approx 7.5 \cdot 10^{14}$, the total energy $E = 0.18$ J and the power of radiation $P = 3.5 \cdot 10^{6}$ W emitted in 4π geometry was carried out for this energy range at a voltage of 14 kV.

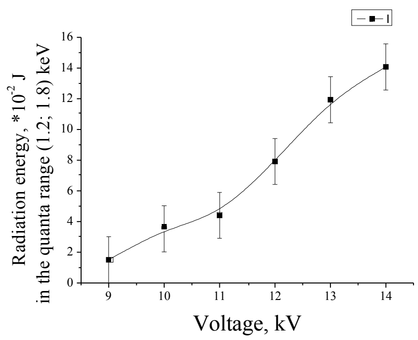

Fig.6. Soft X-ray radiation intensity- applied voltage diagram for the quanta energy range 1.2-1.8 keV

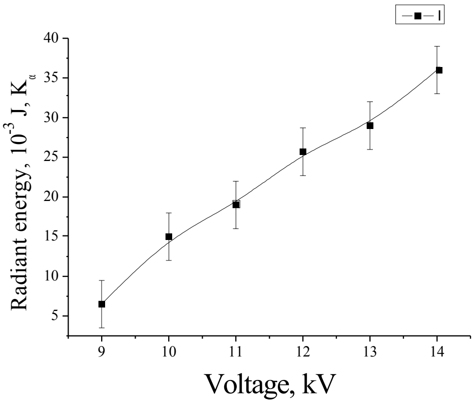

Fig.7. Soft X-ray radiation intensity- applied voltage diagram for the quanta energy range 2.9-3.5 keV

The radiation with the quanta energy > 2.5 keV always passed ahead of the radiation with smaller quanta energy and had duration from 5 to 12 ns. The amplitude of this radiation was changing significantly at a voltage rising from 8 to 10 kV only and then almost didn't increase. The fulfilled experiments with 115 μm Be filters showed that at a voltages > 10 kV the radiation intensity passed through 50 μm Be filters was 2-5 times as large the radiation intensity passed through 115 μm Be filters. This fact shows that the quanta energy was less than 3.5 keV. The radiation apparently corresponds to Ar K_α and another Ar lines and lies in the spectral range 2.9-3.5 keV (3.6 - 4.2 Å). For this energy range at a voltage of 14 kV the evaluation of the total number of quanta $N \approx 1.2 \cdot 10^{14}$, the total energy E = 36 mJ and the power of radiation $P = 3.5 \cdot 10^6$ W emitted in 4π geometry was carried out. The diagram of the SXR total energy as a function of the applied voltage for this quanta energy range is showed in Fig. 7.

CONCLUSION

Measurements of the SXR radiation in the quanta energy ranges 1.2-1.8 and 2.9-3.5 keV dependence on applied voltage and argon pressure were carried out. The optimal argon pressure about 2 Torr corresponded to the signal duration of 5 ns was detected. The monotonic growth of emission yield in the different energetic ranges was observed. The evaluation of the total number of quanta, the total energy and the power of radiation emitted in 4π geometry was carried out for this energy ranges at a voltage of 14 kV and argon pressure of 2 Torr. As a result of these experiments, it can be drawn a conclusion, that under some conditions, it is possible to use plasma focus as the intense nanosecond spectral switched source of the soft X-ray radiation for different applications.

REFERENCES

1. L.I. Ivanov, A.I. Dedyurin, I.V. Borovitskaya, O.N. Krokhin V.Ya. Nikulin, S.N. Polukhin, A.A. Tikhomirov // *Proc. of the 31st EPS Conference on Plasma Physics, London.* ECA. 2004, v. 28G, P-4.151.
2. S. Hussian, M. Shafig, R. Ahmad, A. Waheed, M. Zakaullah // *Plasma Sources. Sci. Technol.* 2005, v. 14, p. 61-69.

Article received 23.09.08.

ИЗМЕРЕНИЕ МЯГКОГО РЕНТГЕНОВСКОГО ИЗЛУЧЕНИЯ С ПОМОЩЬЮ ДЕТЕКТОРОВ СППД11-04 НА УСТАНОВКЕ ПЛАЗМЕННЫЙ ФОКУС (ТЮЛЬПАН)

С.П. Елисеев, В.Я. Никулин, П.В. Силин

С помощью быстродействующих полупроводниковых детекторов типа СППД11-04 проведены измерения мягкого рентгеновского излучения (МРИ) с временным разрешением 1.5 нс. Осуществлено наблюдение под углами 45 и 90° к вертикальной оси системы. Исследована зависимость интенсивности МРИ от давления газа. Максимум излучения соответствовал давлению аргона 2 Торр. Ширина рентгеновского импульса по полувысоте при данном давлении и напряжении 12 кВ равнялась 5 нс. Была исследована зависимость МРИ от напряжения конденсаторной батареи (8-14 кВ) в двух энергетических диапазонах квантов 1.2-1.8 и 2.9-3.5 кэВ. Для данных диапазонах при напряжении 14 кВ и давлении аргона 2 Торр оценены полное количество квантов $8 \cdot 10^{14}$, полная энергия ~ 0.2 Дж и мощность излучения ~ $7 \cdot 10^6$ Вт в 4π.

ВИМІР М'ЯКОГО РЕНТГЕНІВСЬКОГО ВИПРОМІНЮВАННЯ ЗА ДОПОМОГОЮ ДЕТЕКТОРІВ СППД11- 04 НА УСТАНОВЦІ ПЛАЗМОВИЙ ФОКУС (ТЮЛЬПАН)

С.П. Єлисєєв, В.Я. Нікулин, П.В. Силін

За допомогою швидкодіючих напівпровідникових детекторів типу СППД11-04 проведені виміри м'якого рентгенівського випромінювання (МРВ) з часовим дозволом 1.5 нс. Здійснено спостереження під кутами 45 і 90° до вертикальної осі системи. Досліджено залежність інтенсивності МРВ від тиску газу. Максимум випромінювання відповідав тискові аргону 2 Торр. Ширина рентгенівського імпульсу по напіввисоті при даному тиску і напрузі 12 кВ дорівнювала 5 нс. Була досліджена залежність МРВ від напруги конденсаторної батареї (8-14 кВ) у двох енергетичних діапазонах квантів 1.2-1.8 і 2.9-3.5 кеВ. Для даних діапазонів при напрузі 14 кВ і тиску аргону 2 Торр оцінені повна кількість квантів $8 \cdot 10^{14}$, повна енергія ~ 0.2 Дж і потужність випромінювання ~ $7 \cdot 10^6$ Вт у 4π.