INFLUENCE OF EXTERNAL MAGNETIC FIELD ON INTENSITY AND DIRECTIVITY OF EUV RADIATION FROM HIGH-CURRENT PULSE PLASMA DIODE

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This work is devoted to evaluate the influence of the additional external magnetic field on dynamics of the radiation in the extreme ultraviolet (EUV) range from multi-charged tin plasma of high-current pulse diode. Investigations have shown that the use of an additional external magnetic field has improved the stability of the plasma diode, enhanced the intensity of radiation, and changed the radiation profile.

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INTRODUCTION

In our previous studies [1, 2] we have obtained the radiation pulses in extreme ultraviolet (EUV) wavelength range as series of peaks of different intensities and preferential directions of the radiation. This paper is devoted to investigating additional methods of the control of the intensity and orientation of the extreme ultraviolet radiation from high-current pulse plasma diode in the tin vapor.

EXPERIMENTAL SETUP

The experiments are carried out using a longitudinal plasma diode shown in Fig. 1. The current in the diode is excited between the rod and tubular electrodes by discharge of the capacitor C_0 of 2.0 μF at starting pressure of 2×10^{-6} Torr after filling discharge space by preliminary plasma. The side surface of a rod electrode is covered by tubular ceramic insulator to provide a current density of about 0.1…0.7 MA/cm^2 on this electrode face.

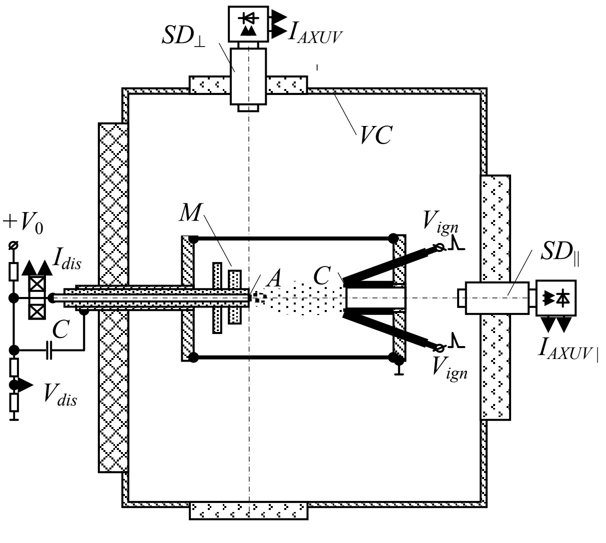

Fig. 1. Scheme of the experimental setup: VC is the vacuum gap, SD is the detector AXUV-20, A is the rod electrode, at first anode, C is the tubular electrode, at first cathode, I_d is the Rogowski coil, V_d is the voltage divider, V_{ig} is the igniting electrode

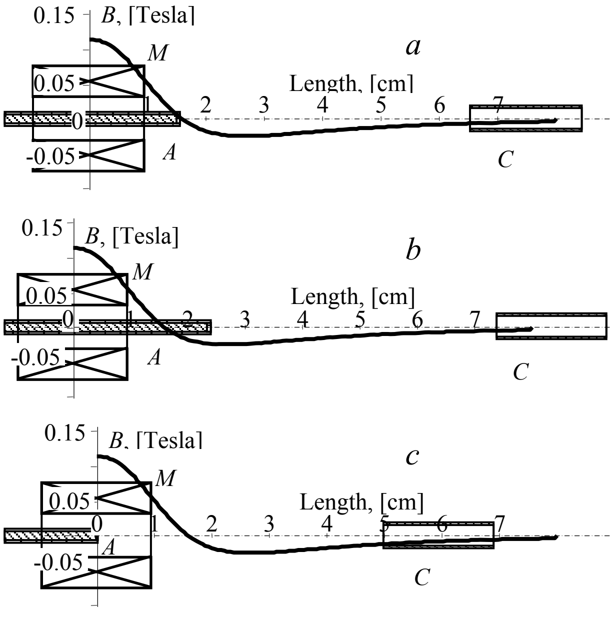

Fig. 2. Three cases of magnetic field distribution: a) the anode face is set in the inversion point of the magnetic field; b) the anode face is set in the minimum of the magnetic field; c) the anode face is set in the maximum of the magnetic field

The diameter of the tubular electrode equals 10 mm, diameter of the rod electrode – 5 mm, and the length of the discharge gap is 4.5 cm. The working surface of the electrodes is coated with 0.5 mm-thick tin layer. The discharge voltage is from 4 to 15 kV, the current amplitude – from 5 to 35 kA, half-period of current oscillations – 1.7 μs. The intensity of the radiation in the 12.2…15.8 nm wavelength range is measured, in addition to the discharge characteristics, with the help of two semiconductor detectors AXUV-20 being set longitudinal and transverse to the discharge axis.

The magnetic field source is the permanent ring magnet shown in Fig. 2. The maximum value of magnetic field is about 0.11T. It is set coaxially with the axis of the discharge. In the experiments the permanent magnet is shifted along axis to three positions, which correspond to the values of the minimum, maximum, and an inversion point of the magnetic field.

EXPERIMENTAL RESULTS

Fig. 3 demonstrates the typical temporal dependence of the longitudinal (*a*) and transverse (*b*) radiation intensity, discharge voltage (*c*) and current (*d*). The narrow spike pulses of radiation are observed in three half-periods of the discharge current oscillation. The radiation pulses have different intensity and orientation coefficients for each oscillation half-period. The orientation coefficient is the ratio of the longitudinal radiation intensity to transverse radiation intensity ($I_{long}/I_{tran} < 1$ – transverse, $I_{long}/I_{tran} > 1$ – longitudinal).

Fig. 4 shows the dependence of the radiation energy in transverse (a, b, c) and longitudinal (d, e, i) direction on discharge voltage in the three half-periods of the discharge current oscillations for the different magnetic field distributions. As it can be seen from Fig. 4 the longitudinal radiation intensity did not change in the cases with the additional external magnetic field. While the transverse radiation intensity has essentially increased in the 1st and 3rd half-periods of the current oscillations. But for 2nd half-period of the current oscillations higher transverse radiation intensity was obtained in the case of absence of the external magnetic field.

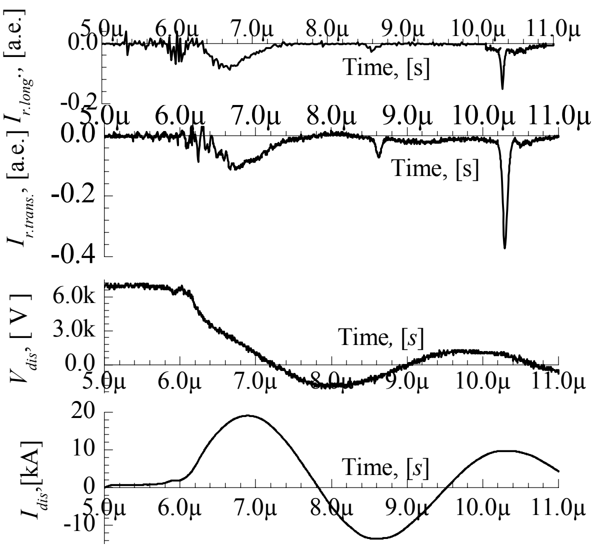

Fig. 3. The temporal dependence of the radiation intensity in the longitudinal (a) and transverse (b) directions, discharge voltage (c) and current (d)

The experimental results show that in the case of maximum magnetic field at the anode in the all half-periods of current oscillation the radiation is observed to be isotropic. The radiation intensity is remained almost unchanged compared with the case of without magnetic field. In the case of minimum magnetic field at the anode the intensity is increased with increasing the voltage. At lower discharge voltages the radiation is longitudinal and at the high – transverse. The radiation intensity achieved the highest value when the inversion point of the magnetic field is set at the anode. Herewith at all discharge voltages the radiation has been transverse.

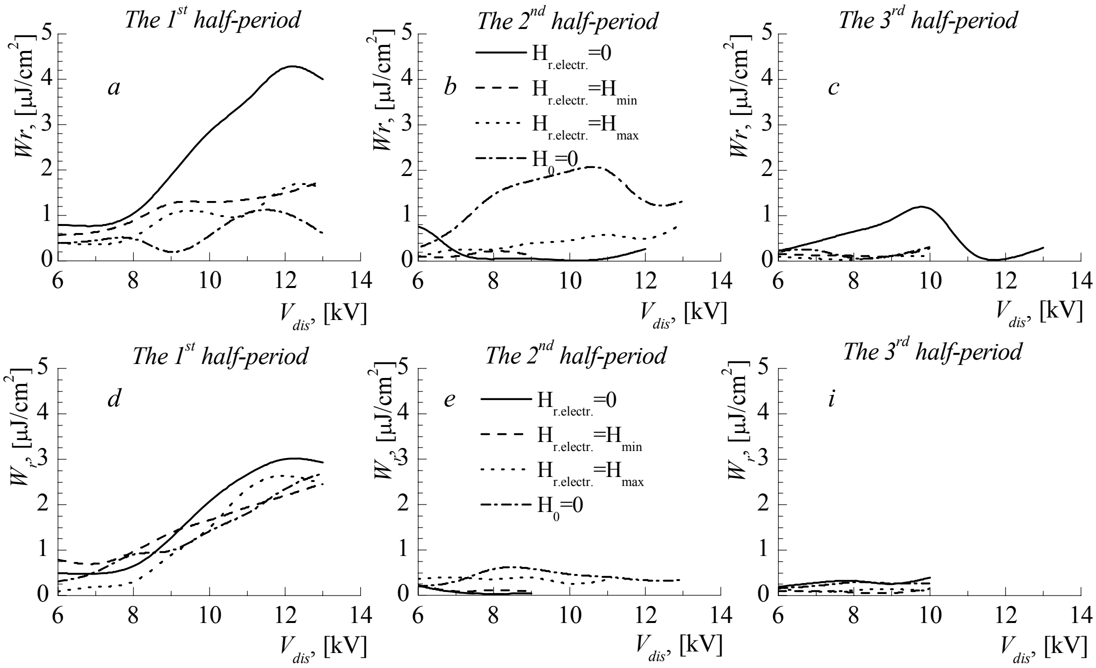

Fig. 4. The dependence of radiation energy in transverse (a, b, c) and longitudinal (d, e, i) directions on discharge voltage in the three half-periods of the discharge current oscillations

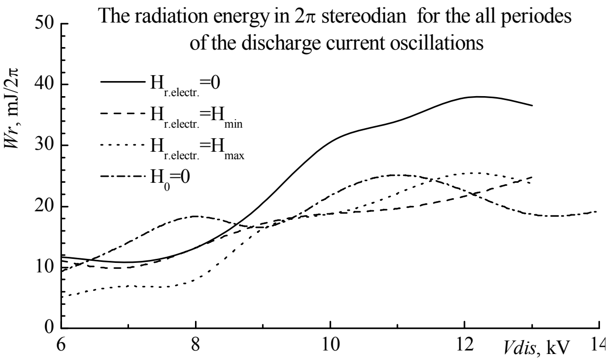

Fig. 5. The dependences of pulse radiation energy in 2π steradian on the discharge voltage for different magnetic field distributions

CONCLUSIONS

In the experiments it was shown that the external magnetic field with a maximum value 0.11 T promotes improvement of stable operation of the pulse high-current plasma diode.

Although such a magnetic field is on the two orders of magnitude lower intrinsic magnetic field in high-current discharge stage, but it significantly influences the primary plasma column, which determines the subsequent dynamics of the discharge.

The peculiarity of the research is the use of a permanent magnet ring, having an inversion point of the magnetic field. So, the axial shift of the permanent magnet can considerably change the topology of the magnetic field in the discharge gap, and therefore gives different distributions of the primary plasma.

Since the generation of multi-spikes pulses of EUV radiation from the high-current pulse plasma diode is due to the double electric layer formation [2]. The electron beam, formed in the double layer, provides a beam-plasma mechanism of local plasma heating.

Specifying certain distribution of the primary plasma, with the help of external magnetic field, determines the place of localization of the double electric layer and the local heating area.

Moreover, the distribution of the primary plasma determines and the shape of the emitted dense plasma formation.

In the presence of radiation-induced effects the shape of the dense plasma formation determines the radiation direction from the plasma.

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ВЛИЯНИЕ ВНЕШНЕГО МАГНИТНОГО ПОЛЯ НА ИНТЕНСИВНОСТЬ И НАПРАВЛЕННОСТЬ ВУФ-ИЗЛУЧЕНИЯ ИЗ СИЛЬНОТОЧНОГО ИМПУЛЬСНОГО ПЛАЗМЕННОГО ДИОДА

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Работа посвящена оценке влияния дополнительного внешнего магнитного поля на динамику излучения в диапазоне вакуумного ультрафиолета (ВУФ) из многозарядной плазмы олова сильноточного импульсного диода. Исследования показали, что использование внешнего магнитного поля позволяет улучшить стабильность работы плазменного диода, повысить интенсивность излучения и изменять диаграмму направленности излучения.

ВПЛИВ ЗОВНІШНЬОГО МАГНІТНОГО ПОЛЯ НА ІНТЕНСИВНІСТЬ ТА СПРЯМОВАНІСТЬ ВУФ-ВИПРОМІНЮВАННЯ З СИЛЬНОСТРУМОВОГО ІМПУЛЬСНОГО ПЛАЗМОВОГО ДІОДУ

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Робота присвячена оцінці впливу додаткового магнітного поля на динаміку випромінювання в діапазоні екстремального вакуумного ультрафіолету (ВУФ) з багатозарядної плазми олова сильнострумного імпульсного діода. Дослідження показали, що використання зовнішнього магнітного поля дозволяє покращити стабільність роботи плазмового діода, збільшити інтенсивність випромінювання та змінювати діаграму спрямованості випромінювання.