A Powerful Source of Spontaneous Radiation at 200–350 nm

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Abstract – The studies of spectral, energy and temporal parameters of a pulse discharge in xenon as well as dynamics of discharge glowing have been carried out using a CCD-camera. It is shown that spontaneous radiation power in the range of 200–350 nm from xenon plasma greatly improves and the pulse duration (FWHM) decreases when unipoalar current pulse is used instead of oscillating excitation. Peak radiation power in the range 200–350 nm of 800 kW with pulse duration (FWHM) of ~ 2 μs was reached with the SOS-diodes connected in parallel with the discharge.

1. Introduction

At present, spontaneous radiation sources (lamps) based on pulsed or continuous discharges in gases or gas–vapor mixtures are widely known and applied in various areas of science and engineering [1–4]. The pulsed lamps with free discharge extension in dense gases, i.e. the ball pulsed lamps [4] are very promising UV radiation sources. Peculiarities of the lamps are small size of the discharge volume, high power and a broad output spectrum including continuous bands. Discharge in xenon has small electric intensity and minimal voltage drop in the near-electrode regions which can provide maximal emission efficiency [1]. The above advantages of xenon lamps can be practically used in development of efficient radiation sources for control of high-voltage diamond switches [5–7]. To date, the switches are controlled either by an electron beam [8] or UV lasers [9]. However electron accelerators and lasers are rather complicated and expensive to be used for industrial switches. Therefore problem of development of a powerful and simple UV-radiation source for diamond switch control is to be solved. The light source should emit microsecond pulses at wavelength $\lambda \leq 350$ nm, corresponding to the fundamental absorption band of a diamond crystal ($\lambda \leq 225$ nm) and impurity absorption ($\lambda \leq 350$ nm) [10–11].

Goal of the present work is determination of discharge parameters in xenon providing maximal radiation power of in the spectral range 200–350 nm and the pulse duration of several microseconds.

2. Experimental Set-up and Methods

Wiring diagram of the pulsed generator used in experiments is shown in Fig. 1. This generator was earlier used for excitation of different lasers and is described in details in [12]. In the course of our experiments, three modes of the generator operation were used: mode *1* – operation without the SOS-diodes (common LC-generator, including a storage capacitor C_0, spark switch S_0 and a pulsed lamp); mode *2* – previous generator with 8 SOS diodes connected in parallel with the lamp without the driving circuit; *3* –generator with the SOS-diodes operating as an opening switch due to the driving capacitor C_1. The use of the driving capacitor allows to interrupt current in the SOS-diodes and form a high-voltage pulse across a load [13]. The SOS-diodes have reverse voltage of up to 50 kV and interruption current up to 2 kA.

In experiments, the charging voltage of the primary capacitor U_0 = 10–25 kV, primary capacitance C_0 = = 260 nF, the discharge circuit inductance was $L_0 \sim 200$ nH.

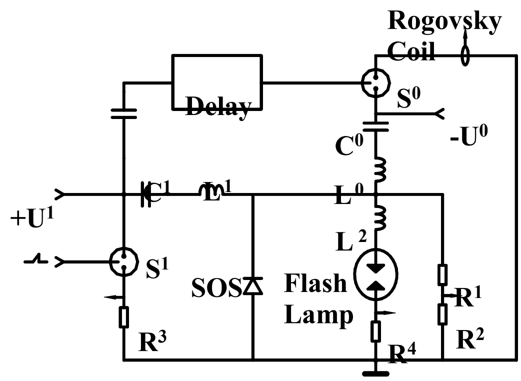

Fig. 1. Wiring diagram of the experimental set-up. C_0 = 260 nF, $L_0 \sim 30$ nH, $L_2 \sim 170$ nH

A pulsed lamp with the gap of 4 mm filled with xenon at pressure of 550 Torr was used in the experiments. The lamp cylindrical bulb was made from quartz with transmission in the spectrum range 200–350 nm not less than 85% and had internal diameter of 20 mm.

The recording system for optical parameters included a EPP2000C-25 spectrometer with a photodetector based on a CCD-array, a diamond detector produced by the AASC Company, and the FEC-22SPU coaxial photocell. The discharge glowing was taken with a "SensiCam" CCD-camera. Discharge current and voltage pulses across the lamp electrodes were recorded, by the current shunt R_4 and ohmic voltage divider R_1–R_2, correspondingly, electrical signals were applied to the Tektronix TDS-224 oscilloscope.

3. Experimental Results and Discussion

The discharge current, voltage across the lamp, and discharge radiation spectrum were recorded during experiments, as well as discharge glowing in different moments of time were photographed. Fig. 2 presents waveforms of the radiation pulses in xenon under different voltage U_0 obtained in different pumping modes. The curves *a* and *b* of the Fig. 2 correspond to oscillating discharge current, in the cases of *c* and *d* the unipolar current pulse is realized with the SOS-diodes.

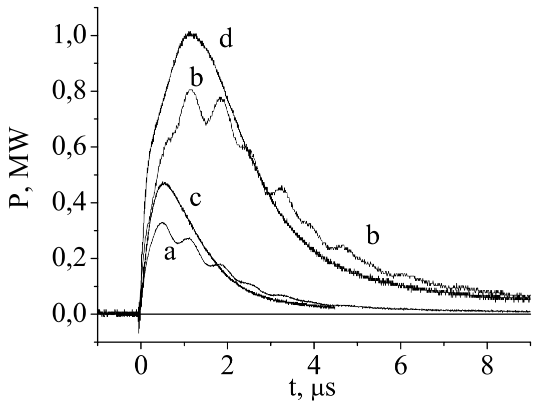

Fig. 2. Radiation power of the Xe flash lamp, C_0 = 260 nF: *a*, *b* – mode *1*; *c*, *d* – mode *3*; *a*, *c* – U_0 = 9.5 kV; *b*, *d* – U_0 = 24 kV

It is seen that unipolar current pulse allows to improve the radiation power and decrease the radiation pulse duration at half-maximum. The waveforms were taken with C_0 = 260 nF. Maximal increase of the radiation power was obtained for 2 variant of the pulsed generator (see Fig. 3).

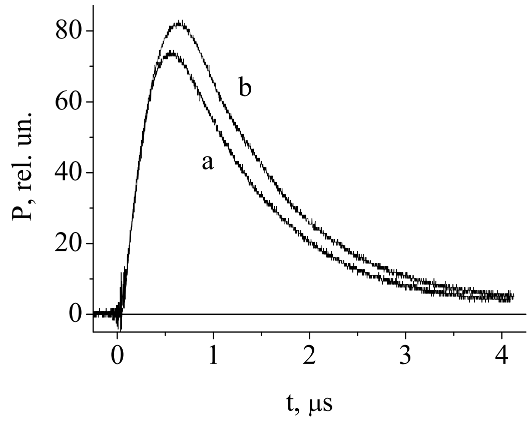

Fig. 3. Radiation power of the Xe flash lamp: *a* – mode *3*; *b* – mode *2*

The difference between the mode *2* and mode *3* was in the absence of a short high-voltage pulse forming during current interruption in the SOS-diodes which allows to ignite discharge in the lamp at high pressures and long gap. Note that the charging voltage of the capacitor C_0 was sufficient for a stable breakdown of xenon in the lamp while using the generator 2. Note that in the modes *2* and *3* the voltage across the SOS-diodes changes its polarity from opposite to direct in the course of C_0 discharge, and the diodes short-circuit the L_2 inductance. L_2 began to discharge through the lamp on the newly formed circuit L_2 – SOS-Lamp. It should be noted that by the instant the current amplitude reached its peak since the impedance of the S_0 – C_0 – flash lamp circuit was much higher as compared to the discharge resistance. Therewith main part of the stored energy was transferred into the inductance L_2 providing discharge sustaining in the lamp. Decrease of the radiation power (by ~ 10%) in the mode *3* was due to the energy losses in SOS-diodes during the current interruption phase [13].

Figure 4 depicts the radiation pulse energy as a function of the charging voltage obtained in the modes *1* and *3*. The radiation energy in the range 200–350 nm was as high as ~ 2 J, while efficiency of ~ 8.5% with respect to the deposited in the discharge energy was easily achieved (see curve *d*, Fig. 4).

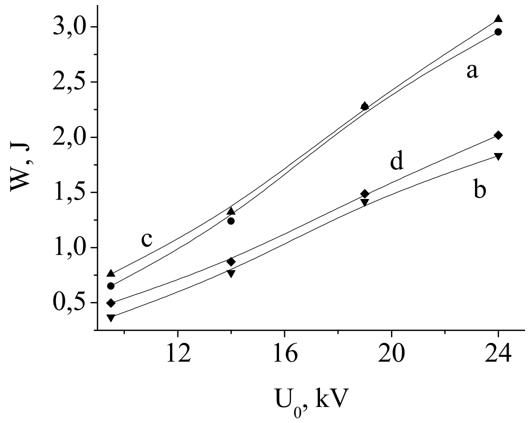

Fig. 4. The radiation pulse energy as a function of charging voltage: *a*, *b* – mode *1*; *c*, *d* – mode *3*; *a*, *c* – λ = 200–650 nm; *b*, *d* – λ = 200 – 350 nm

Radiation pulses obtained in the mode *3* and registered with the FEC-22 SPU (wavelengths λ = 200–650 nm) and a diamond detector (λ = 200–350 nm) are shown in Fig. 5. The diamond detector records the minor duration of a radiation pulse and the lower total power. That is due to different time dependencies of radiation powers in the wavelength ranges λ ≤ 350 nm recorded by the diamond and in the range 200–650 nm, corresponding to the range of the FEC-22 SPU sensitivity. Reduction of the radiation pulse duration in the range of 200–350 nm as compared to that in the range of 200–650 nm was observed in the similar conditions [14]. Maximal radiation power in the UV range was as high as ~ 0.8 MW. Therewith the radiation pulse duration did not exceed ~ 2 μs (FWHM).

The photographs of xenon discharge made by using a CCD-camera have shown that multi-channel current propagation is observed in the discharge gap just after its breakdown. Than, single channels extended and in ~ 200 ns run into one, the glowing area expanded and uniformity of the plasma channel luminescence improved, as well.

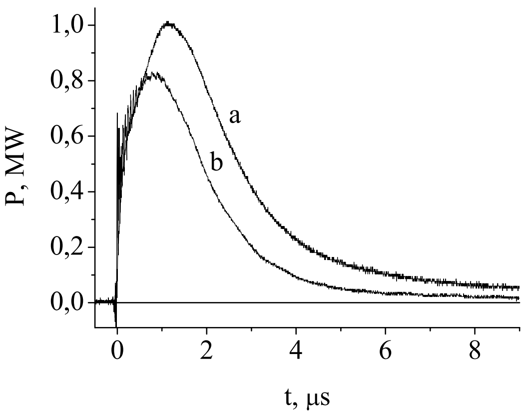

Fig. 5. Xe flash lamp radiation power measured with: *a* – FEK-22 SPU photocell (λ = 200–650 nm); *b* – diamond detector (λ = 200–350 nm)

Improve of the radiation power of the lamp in the modes *2* and *3* (as compared to the mode *1*) can be explained by absence of pulsation of the input electric power. When excitation in the mode 1 (LC-generator) is used, current oscillation through the lamp are observed when the charging voltage exceeds several kV producing unavoidable pulsation of the excitation power. Therewith the discharge plasma is cooled when the input power approaches zero. This in its turn results in the radiation power pulsation (see Fig. 2, curves *a*, *b*). At high U_0 the maximal radiation power is reached in the second peak of radiation pulse (after the second half-period of current). In the modes *2* and *3*, the current passes through the lamp in one direction, and the input power did not fall to zero. This leads to radiation power increasing and reduction in the radiation pulse duration at FWHM.

4. Conclusion

Thus, in this work, the studies of spectral, energy and time dependencies of xenon pulsed discharge have been performed using three generators. A powerful source of spontaneous radiation based on high-current pulse discharge in xenon has been developed. The radiation energy in the UV range of ~ 2 J with the energy-to-radiation conversion efficiency ~ 8.5% was obtained. In the case of the generators with SOS-diodes the UV radiation power was maximal and reached 800 kW with pulse duration at half-maximum of ~ 2 μs. It has been shown that unipolar current pulse through the lamp improves its radiation power and reduces the radiation pulse duration at FWHM.

5. Acknowledgements

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