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RADIATION OF ELECTRIC DISCHARGES

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X-ray radiation of a spark preionisation system and volume discharge plasma in a laser with an inductive energy storage

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***Abstract*. A spark-gap preionisation system is studied in a laser pumped by a generator with an inductive energy storage and a semiconductor current interrupter. This preionisation system was shown to produce, in addition to UV and VUV radiation, soft X-ray pulses with photon energies higher than 5 keV. The X-ray radiation was recorded from the plasma of a volume discharge in nitrogen, helium, and a NF_3 – helium mixture. Shortening the rise time of the voltage pulse applied across the spark gaps of the preionisation system and the main gap was demonstrated to increase the radiation pulse duration and to improve the efficiency of exciplex lasers and of several other dense-gas lasers.**

Keywords: *spark preionisation, volume discharge, X-ray radiation.*

1. Introduction

Pulsed dense-gas lasers use different preionisation systems to obtain a volume discharge [1 – 3]. The simplest and most widely employed system is the spark-gap preionisation system, which is a source of UV and VUV radiation. The spark discharge is initiated between two electrodes with a small radius of curvature, commonly at the front of the voltage pulse applied across the gap. In this case, the pulse duration of the discharge current through the spark gaps may be either shorter or longer than the duration of the main discharge current through the laser gap. It is known that X-rays are recorded from the discharge plasma and the anode when high-voltage pulses with a short rise time (1 ns or less) are applied to the gap between a cathode with a small radius of curvature and a planar anode [4 – 8]. Soft X-rays were also obtained in a discharge with the similar geometry of the discharge gap (between fine wires and a mesh) for a voltage amplitude up to the hundreds of kilovolts and a voltage pulse rise time of $\sim$ 10 ns [9]. These systems were employed to produce preionisation in pulsed dense-gas lasers [9, 10].

Our papers [11 – 15] reported the development of high-efficiency pulsed lasers pumped by a generator with an inductive energy storage and a semiconductor current interrupter. These lasers use preionisation from spark gaps located near the potential electrode and uniformly distributed over its length. In particular, high efficiencies were obtained for HF and DF lasers, and the irradiation was shown to have a pronounced effect on the characteristics of these lasers [13 – 15]. In Ref. [16] it was found that UV irradiation in HF lasers with a cathode surface area of less than 300 cm^2 and a pulse duration of less than 150 ns stabilises the time delay and voltage amplitude of electrical breakdown of the gap and flattens the discharge current density distribution over the cathode surface due to photoeffect.

The aim of the present work is to investigate the feasibility of generating X-rays in the spark-gap preionisation system in a laser pumped by a generator with an inductive energy storage and a semiconductor current interrupter. These investigations were stimulated by the recent studies of runaway electron beams and the X-rays emitted by pulsed nanosecond discharges [17 – 20], which demonstrated that in nanosecond discharge plasmas it is possible to obtain avalanche electron beams [17] with a duration of $\sim$ 0.1 ns and an amplitude up to the hundreds of amperes as well as X-rays [20]. In this case, the X-rays were observed upon deceleration of the runaway electrons at the anode as well as at the molecules and atoms of the working mixture in the discharge gap.

2. Experimental

Experiments were staged to record X-rays from the discharge gap of a transverse-discharge laser with a simple preionisation system, in which the spark gaps were similar in design to those investigated in [11 – 15]. The laser pump generator formed an elevated-pressure volume discharge in different gas mixtures. The discharge gap and preionisation system designs are shown in the photograph in Fig. 1 and schematically represented in Fig. 2. Pulses of positive or negative polarity were applied to the potential electrode; in this case, initially there occurred a spark breakdown between 72 pointed electrodes (*3*) and the sharp edge of potential electrode (*1*). Subsequently, a volume discharge was formed between electrodes (*1*) and (*2*) due to preionisation of the gap. Figure 3 shows the oscilloscope traces of the discharge current through the main gap and of the voltage across the gap. Upon the breakdown of the spark preionisation gaps, the leading edge of the voltage pulse shows a deep dip. One can see that the breakdown voltage was $\sim$ 20 keV and the rise time of the first voltage

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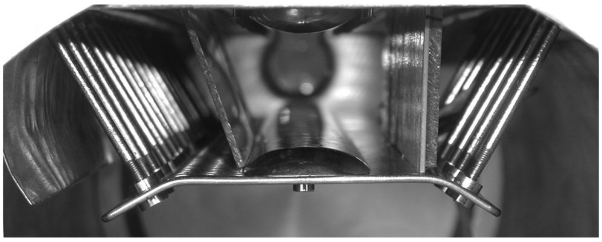

Figure 1. Photograph of the laser discharge gap with mounted patterns.

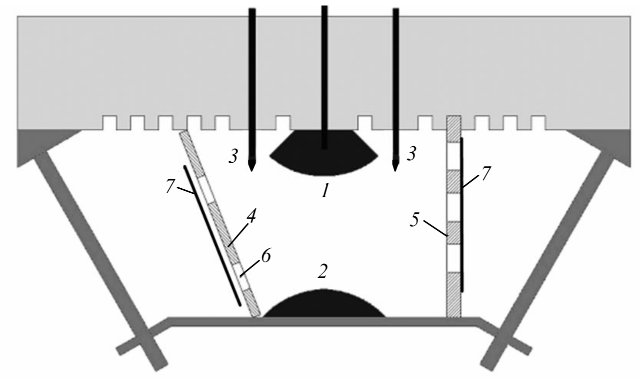

Figure 2. Scheme of the discharge gap: (*1*), (*2*) main electrodes; (*3*) pointed electrodes; (*4*), (*5*) patterns; (*6*) openings in the patterns; (*7*) packets with a photographic film.

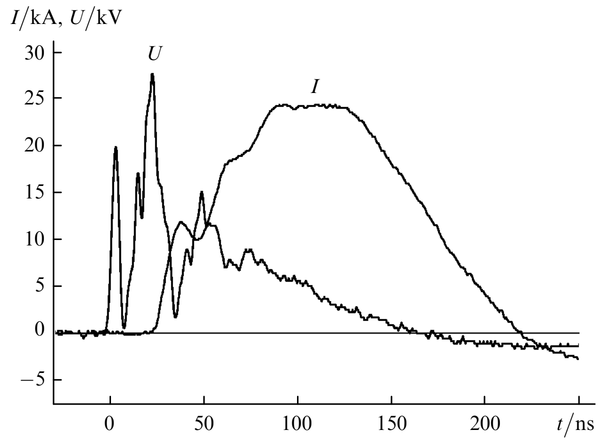

Figure 3. Typical oscilloscope traces of the pulses of discharge current *I* and the voltage *U* across the discharge gap.

peak was ~ 5 ns. We emphasise that the generator could be operated both in the inductive energy storage regime and as an ordinary *LC* generator.

We used profiled electrodes in the laser to reduce considerably the electric field nonuniformity (the local field enhancement in the main discharge gap). The electrodes were made of stainless steel. The interelectrode gap was $d = 4$ cm. The laser chamber was filled with helium, nitrogen, or a helium – NF_3 mixture; experiments were normally carried out for a total gas (or mixture) pressure of 50 – 500 Torr.

The voltage across the interelectrode gap and the discharge current were recorded with a voltage divider and a Rogowski loop, respectively. The electric signals were recorded with a TDS-224 digital oscilloscope.

X-rays were recorded from the exposure of a RF-3 photographic film with a sensitivity of 1200 R^{-1}, which was placed in a 100-μm thick black paper envelope and attached to the patterns accommodated to the left and right of the discharge gap. The patterns were plates made of 3- and 7-mm thick plexiglass and had openings with different diameters. Therefore, soft X-rays could be transmitted only through the openings in the plates.

3. Experimental results and discussion

X-rays were recorded for different polarities of the pulses applied to the discharge gap; however, for the negative polarity of the potential electrode, the photographic blackening was substantially weaker than for the positive polarity. This suggests that the X-ray source is localised in the vicinity of electrodes (*1*) and (*3*). For the positive polarity of a voltage pulse at the potential electrode, there occurs the strongest enhancement of the electric field at electrodes (*3*), which had a small radius of curvature and a negative potential relative to electrode (*1*). Figures 4 – 6 display the results of experiments in which we recorded the strongest blackening of the photographic film.

The most intense photographic film blackening was observed when the $He : NF_3 = 50 : 1$ Torr mixture was used (Fig. 4). In this case, the radiation autographs were obtained even behind three layers of black paper with a total thickness of 300 μm and the 200-μm thick photographic film. This means that the X-ray photon energy exceeds 10 keV. Estimates suggest that an X-ray photon energy of ~ 5 keV is sufficient to produce an autograph behind one layer of the black paper. One can see from Fig. 4 that the X-ray autographs are flattened in their upper part. This suggests that X-rays are primarily generated in the spark gap regions.

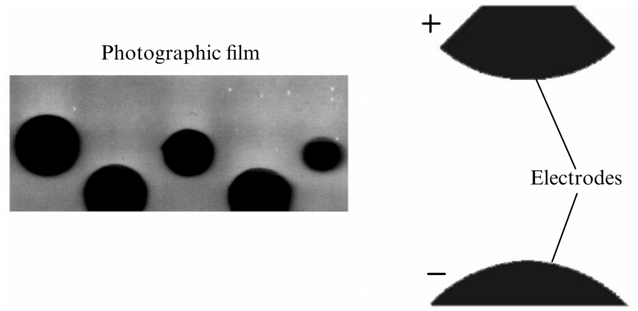

Figure 4. Photographic blackening under the X-ray irradiation by a discharge in the $He : NF_3 = 50 : 1$ Torr mixture (recorded in 350 pulses).

Figure 5 displays the autographs of X-rays at a helium pressure of 250 Torr. The autograph flattening due to screening of X-rays is also observed in the upper part of the pattern openings. Note that a weak photographic blackening was normally observed throughout the diameter of the pattern opening, which may be attributed to the generation of X-rays in the main gap. When positive-polarity pulses were applied to the potential electrode and the chamber was filled with helium at a pressure of 500 Torr, X-rays was recorded in 350 pulses. Lowering the pressure from 500 to 50 Torr increased the photographic

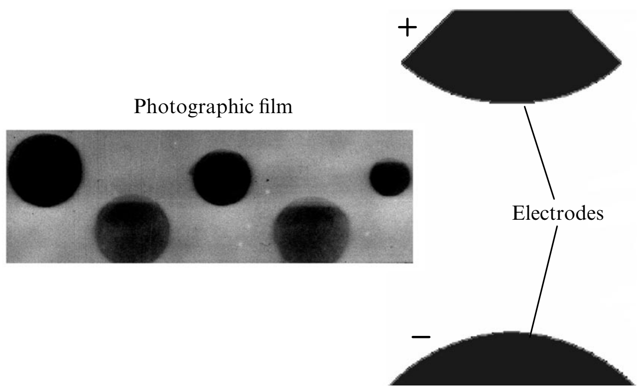

Figure 5. Photographic blackening in a one-layer package under the X-ray irradiation by a discharge in He at a pressure of 250 Torr (recorded in 350 pulses).

blackening intensity. X-rays were also recorded near the lower grounded electrode (cathode) (Fig. 6). Figure 6 clearly demonstrates the effect of X-ray screening by the pattern and the lowering of blackening intensity away from the spark gap regions.

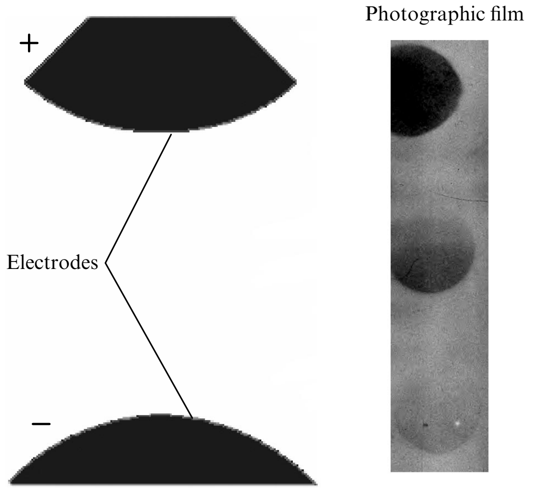

Figure 6. Photographic blackening under the X-ray irradiation by a discharge in He at a pressure of 50 Torr (recorded in 175 pulses).

Experiments on discharge formation in nitrogen showed that the photographic blackening is weaker in the heavier gas for the same gas pressure, although all the main tendencies of X-ray autograph variation are retained. In particular, for a nitrogen pressure of 38 Torr we obtained autographs with X-ray screening by the patterns and a weaker exposure of the photographic film than in helium for the same pressure.

The shape of imprints produced by X-rays changed on changing the polarity of the pulses applied. The photographic blackening was substantially lower for a negative polarity of the potential electrode. In this case, the imprints of the openings took on a regular round shape and the blackening was stronger in the vicinity of main electrodes (*1*) and (*2*). The opening located opposite the centre of the discharge gap was least irradiated. This means that X-rays are produced both near the electrodes and in the entire gap, and X-rays emitted from the near-electrode regions have a higher intensity.

Note that when the rise time of the voltage pulse was increased, which was achieved in our experiments by disconnecting the inductive energy storage and employing only the capacitive storage device, we also observed X-rays emitted from the spark gap regions of the preionisation system, but its intensity was substantially lower. To obtain the same exposure, the number of voltage pulses had to be increased by several times.

Our experiments have demonstrated that the use of generators with inductive energy storage leads to a substantial rise in lasing efficiency and to lengthening of the output radiation pulses of nitrogen and exciplex molecular lasers, as well as of nonchain HF and DF lasers. A slower buildup of the voltage across the discharge gap, which is typical for a capacitive storage device, usually upsets the discharge homogeneity. In this case, integral photographs of the discharge gap showed, against the volume glow background, diffuse channels of different length 'attached' to bright cathodic spots. Using the inductive energy storage raised the buildup rate of the voltage across the gap by a factor of 1.5 – 2; in this case, the X-ray intensity from the spark gaps was higher. This led to an improvement in uniformity of the discharge glow: the cathodic spots and the channels practically vanished in optimal pump regimes. The internal gas-discharge laser efficiency was close to the efficiency of lasing obtained under electron beam pumping, which provides a higher energy input uniformity and eliminates the problem of discharge contraction. Experiments show that shortening the pulse rise time of the voltage across the discharge gap and the electrodes of the preionisation system enables initiating a stable volume discharge in different gas mixtures. The high discharge quality in its turn leads to a substantial increase in energy and efficiency of lasing of gas lasers. For XeCl, XeF, HF, and DF lasers, the facility made in our work yielded the respective lasing efficiencies of 4 %, 3 %, 10 %, and 7 % relative to the input energy.

4. Conclusions

Our investigations have shown that the preionisation systems of dense-gas lasers which utilise spark gaps can emit radiation not only in the UV and VUV ranges, but also in the soft X-ray range with photon energies above 5 keV. Furthermore, X-ray photons (also with energies above 5 keV) can be emitted also by the main discharge gap, the highest X-ray emission intensity being observed near the electrodes. The intensity of X-rays and their penetrability depend on many factors: the amplitude and rise time of the voltage pulse, the composition and pressure of the working mixture, the preionisation system and main electrodes designs, as well as the material they are made of. These features of spark preionisation systems should be taken into account in the development of pulsed dense-gas lasers.

In a laser pumped by a generator with an inductive energy storage and a semiconductor current interrupter, we recorded X-rays emitted from the spark gap regions of the preionisation system and from the volume discharge plasma in the main gap when using different gases as the active medium. It was shown that shortening the rise time of the voltage pulse applied to the spark gaps of the preionisation system and the main gap increases the output energy and efficiency of lasing of electric-discharge lasers.

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References

1. McDaniel E.W., Nigan W. (Eds) *Applied Atomic Collision Physics* (New York: Academic Press, 1982) Vol. 3.
2. Baranov V.Yu., Borisov V.M., Stepanov Yu.Yu. *Elektrorazryadnye eksimernye lasery na galogenidakh inertnykh gazov* (Electric-Discharge Excimer Noble-Gas Halide Lasers) (Moscow: Energoatomizdat, 1988).
3. Mesyats G.A., Osipov V.V., Tarasenko V.F. *Pulsed Gas Lasers* (Bellingham, Washington, USA: SPIE, Opt. Eng. Press, 1995).
4. Frankel S., Highland V., Sloan T., Van Dyck O., Wales W. *Nuclear Instruments and Methods*, **44**, 345 (1966).
5. Stankevich Yu.L., Kalinin V.G. *Dokl. Akad. Nauk SSSR*, **177**, 72 (1967).
6. Noggle R.C., Krider E.P., Wayland J.R. *J. Appl. Phys.*, **39**, 4746 (1968).
7. Tarasova L.V., Khudyakova L.N. *Zh. Tekh. Fiz.*, **39**, 1530 (1969).
8. Kremnev V.V., Kurbatov Yu.A. *Zh. Tekh. Fiz.*, **42**, 795 (1972).
9. Pavlovskii A.I., Bosamykin V.S., Karelin V.I., Nikol'skii V.S. *Kvantovaya Elektron.*, **3**, 601 (1976) [*Sov. J. Quantum Electron.*, **6**, 321 (1976)].
10. Buranov S.N., Gorokhov V.V., Karelin V.I., Pavlovskii A.I., Repin P.B. *Kvantovaya Elektron.*, **18**, 891 (1991) [*Sov. J. Quantum Electron.*, **21**, 806 (1991)].
11. Baksht E.Kh., Panchenko A.N., Tarasenko V.F. *Kvantovaya Elektron.*, **30**, 506 (2000) [*Quantum Electron.*, **30**, 506 (2000)].
12. Baksht E.H., Panchenko A.N., Tarasenko V.F., Matsunaga T., Goto T. *Jap. J. Appl. Phys.*, **41**, 3701 (2002).
13. Tarasenko V.F., Orlovskii V.M., Panchenko A.N. *Kvantovaya Elektron.*, **31**, 1035 (2001) [*Quantum Electron.*, **31**, 1035 (2001)].
14. Panchenko A.N., Orlovskii V.M., Tarasenko V.F., Baksht E.Kh. *Kvantovaya Elektron.*, **33**, 401 (2003) [*Quantum Electron.*, **33**, 401 (2003)].
15. Panchenko A.N., Orlovskii V.M., Tarasenko V.F. *Kvantovaya Elektron.*, **34**, 320 (2004) [*Quantum Electron.*, **34**, 320 (2004)].
16. Belevtsev A.A., Kazantsev S.Yu., Saifulin A.V., Firsov K.N. *Kvantovaya Elektron.*, **34**, 111 (2004) [*Quantum Electron.*, **34**, 111 (2004)].
17. Tarasenko V.F., Orlovskii V.M., Shunailov S.A. *Izv. Vyssh. Uchebn. Zaved., Fiz.*, **46** (3), 94 (2003).
18. Tarasenko V.F., Yakovlenko S.I. *Plasma Devices and Operations*, **13** (4), 231 (2005).
19. Tarasenko V.F., Shpak V.G., Shunailov S.A., Kostyrya I.D. *Laser Part. Beams*, **23**, 545 (2005).
20. Tarasenko V.F., Kostyrya I.D. *Izv. Vyssh. Uchebn. Zaved., Fiz.*, **48** (12), 40 (2005).