Barrier Discharge Exciplex Lamps on XeCl*, KrCl*, XeBr* and KrBr* Molecules with the Nanosecond Pulse Duration[1]

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Abstract – Conditions of forming of pulse radiation with the nanosecond duration in XeCl- ($\lambda \sim 308$ nm), KrCl- ($\lambda \sim 222$ nm), XeBr- ($\lambda \sim 282$ nm) and KrBr- ($\lambda \sim 206$ nm) excilamps driven by the barrier discharge are experimentally investigated. The peak power density of radiation ~500 W/cm^2 and the pulse duration of radiation 5 ns full width at half-maximum (FWHM) are obtained at excitation of a working mixture by the high-voltage pulse generator "Radan-150" with the nanosecond duration in mixtures with the ratio of Xe/Br = 50/1 and the total pressure 500 Torr. Data about influence of the total pressure, the mixture ratio and also an the discharge gap on the power and the pulse duration of radiation are obtained.

1. Introduction

The excilamp is a gas-discharge source of ultra-violet (UV) and vacuum ultra-violet (VUV) radiation based on nonequilibrium spontaneous radiation of excimer or exciplex molecules [1–3]. Excilamps of the barrier discharge attract maximum attention [3].

Last years an interest in excilamps with the short pulse of radiation and, at the same time, with a high pulse power density of radiation has grown [4].

The purpose of this work is to investigate systematically conditions of forming of pulse radiation with the nanosecond duration in KrBr*-, KrCl*-, XeBr*- and XeCl*-excilamps excited by the barrier discharge.

2. Materials and methods

Two-barrier XeCl-, KrCl-, XeBr- and KrBr-excilamps of various geometry were used in experiments. Bulbs of excilamps were made out of quartz (Fused Quartz, Type 214, General Electric) with a transmission coefficient of ~90% at the wavelength 282 nm. The bulb volume was filled with the gas medium composed of rare gas and halogen molecules.

The high-voltage nanosecond pulse generator "Radan-150" [5] forming voltage pulses with the amplitude up to ~140 kV and full width at half-maximum (FWHM) ~4 ns was used to excite excilamps of the barrier discharge. The pulse of high voltage with the rise-time ~1 ns was applied from the generator "Radan-150" to the inner reflector electrode of the excilamp, the outer grounded electrode was made from metal mesh. Pulse rates were 1 Hz. The experimental circuit of the barrier discharge excilamp with the nanosecond pulse duration of radiation is shown in Fig. 1. The two-barrier coaxial excilamp with the discharge gap 8 mm, diameter of the outer tube 40 mm, the inner tube 23 mm and length of radiation surface 9 cm was used as a radiator.

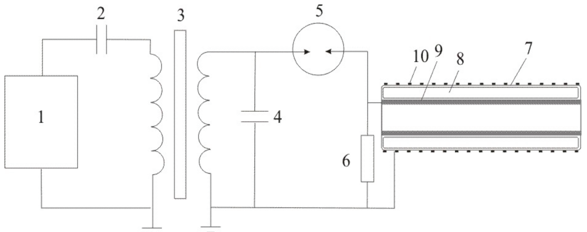

Fig. 1. Circuit of the short-pulse excilamp of the barrier discharge: 1 – DC power supply; 2 – storage capacitance; 3 – pulse transformer; 4 – peaking capacitance; 5 – peaker spark switch, 6 – resistor; 7 – bulb of the barrier discharge excilamp, 8 – discharge gap; 9 – inner reflector electrode; 10 – outer mesh electrode

Two planar radiators with discharge gaps 5 mm (Fig. 2, *a* excilamp 1) and 12 mm (Fig. 2, *b* excilamp 2) respectively were used to study the influence of the discharge gap value on the pulse duration of radiation.

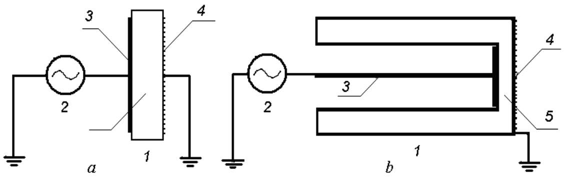

Fig. 2. Circuits of planar XeBr-excilamps 1(*a*) and 2(*b*) driven by the barrier discharge: *1* – quartz bulb; *2* – high-frequency pulse power supply; *3* – metal electrode; *4* –metal mesh electrode; *5* – discharge gap

The excilamps presented in Fig. 2 differ electrode areas, values of buffer volume and discharge gap d_{12}. The bulb volume was filled with the gas medium composed of xenon and bromine. The radiation was extracted through the metal mesh electrode *4* with a transmission coefficient 66%. Electrode areas *3* and *4* of the excilamp 1 were 9 cm^2. Areas of the inner electrode *3* and the outer mesh electrode *4* were 3.78 and 23.75 cm^2 respectively in the excilamp 2. The high-frequency pulse generator as a power supply for excilamps with the pulse repetition rate 100 kHz and the idling voltage 9 kV was applied for planar excilamps

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[1] The work was supported by ISTC (project no. 2706) and the grant from the Russian Federation President.

(Fig. 2). This voltage was sufficient to ignite the discharge. At high-frequency pulse excitation the voltage on the gap depended on proportion and pressure of a mixture and at optimum performance was 6–7 kV.

The pulse radiation was measured using a FEK-22 SPU vacuum photodiode with a known spectral sensitivity, the signal from which was applied to a Tektronix TDS-224 tetra-beam digital storage oscilloscope. The radiation spectrum of excilamps was recorded using a spectrometer StellarNet EPP2000-C25.

The bulb was filled with a corresponding gas mixture in experiments concerned with forming of short-pulse radiation in KrBr-, KrCl-, XeBr- and XeCl-excilamps of the barrier discharge. The total pressure and the ratio of mixture components rare gas/halogen changed depending on experiment conditions.

3. Results and discussion

In the case of the high-voltage nanosecond pulse generator "Radan-150" dependences of the pulse duration of radiation at half-maximum *τ* from the total pressure and the ratio of rare gas/halogen in a mixture are shown by the example of XeCl- and KrCl-excilamps (Fig. 3,4,5). As shown in the figures, the increase of the total pressure of a mixture and the halogen content leads to reducing of the pulse duration of radiation. This effect may be observed in the case of KrBr- and XeBr-excilamps too.

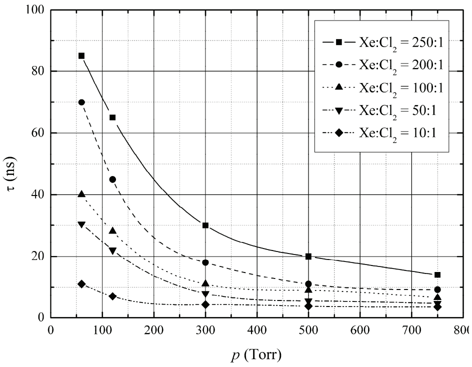

Fig. 3. Pulse duration of radiation of the two-barrier XeCl-excilamp vs. pressure of working mixtures with various ratios of Xe/Cl$_2$

The measurement of the peak power was carried out in every experiments indicated above. The maximal peak power densities of radiation were 220, 350, 450 and 180 W/cm^2 in mixtures, where the ratio of rare gas/halogen = 50/1 at pressures 400–500 Torr for XeCl-, KrCl-, XeBr- and KrBr-excilamps, respectively.

Further increase of pressure of an operating mixture leads to the discharge concentration and decrease of the radiation intensity (Fig. 5). The pulse duration of radiation was ~ 5 ns at half-maximum under optimal conditions of the radiation intensity for all investigated excilamps.

Typical waveforms of radiation pulses of the XeBr-excilamp at pressures in a working mixture in the range 60–750 Torr are presented in Fig. 6.

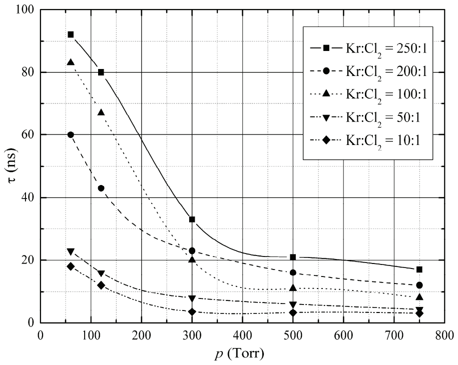

Fig. 4. Pulse duration of radiation of the two-barrier KrCl-excilamp vs. pressure of working mixtures with various ratios of Kr/Cl$_2$

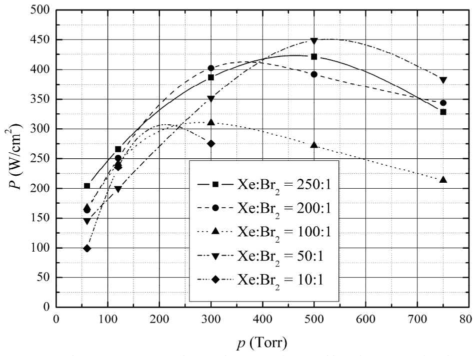

Fig. 5. Peak power density of radiation of the two-barrier XeBr-excilamp vs. pressure of working mixtures with various ratios of Xe/Br$_2$

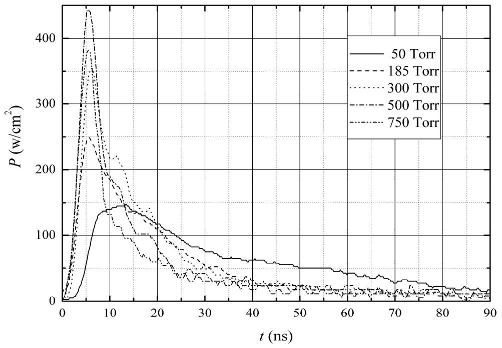

Fig. 6. Waveforms of radiation pulses of the two-barrier XeBr-excilamp at various pressures of a working mixture (Xe/Br$_2$=50/1)

The radiation spectra of the barrier XeBr-excilamp consist of bands of B-X, D–X and D–A transitions with peaks 282, 221 and 325 nm respectively (Fig. 7). As shown in presented spectra, the decrease of the Br$_2$ concentration in a mixture leads to narrowing the band of radiation.

In the case of planar XeBr-excilamps (Fig. 2) for given discharge gaps and the break-down voltage, dependences of the pulse duration of radiation at half-maximum τ and the power of radiation on different parameters of a working mixture were also obtained.

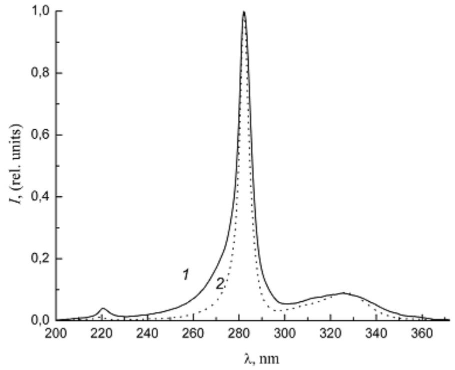

Fig. 7. Radiation spectra of the barrier XeBr-excilamp at various concentration of Br_2 in the mixture Xe:Br = = 35:1, p = 192 Torr (*1*); Xe:Br = 200:1, p = 84 Torr (*2*)

Thus, in the case of the excilamp 1 (Fig. 2, *a*) the pulse duration of radiation at half-maximum τ has the pressure optimum (Fig. 8). To the given optimum corresponds such discharge shape, at which the discharge gap is filled with multitude homogeneous cylinder or cone microdischarges. The discharge shape changes at lower pressures: microdischarges lose precise frames up to diffuse plasma glow, τ increases at the same time. At increase of the pressure, intence branching canals appear which augment the pulse duration of radiation because of changing the discharge shape. Length of the intence discharge canal can exceed the discharge gap value d_{12} in 1.5–2 times, that can also lead to the augmentation of the pulse duration of radiation.

The dependence of the average power of radiation of the excilamp 1 on the pressure (Fig. 9) has optimum too. The peak intensity is situated in the field of pressures near to the values at which minimum of τ is observed. Somewhat different situation occurs in the excilamp 2 with the discharge gap d_{12} = 12 mm. In that case the dependence of τ on the total pressure of the mixture does not have the pressure optimum (Fig. 10). Distinctions between dependences τ on p in the case of excilamps 1 and 2 (Fig. 8 and 10) involve their design characteristics.

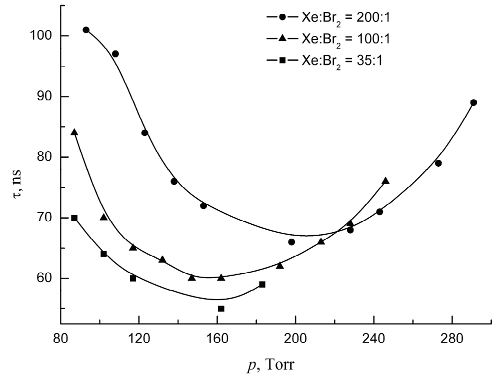

Fig. 8. Pulse duration of radiation at half-maximum τ vs. the total pressure of the mixture p for the excilamp 1

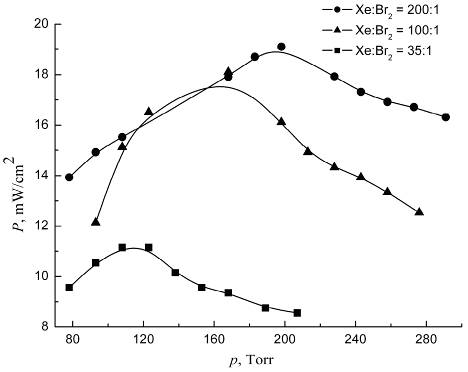

Fig. 9. Specific power density of radiation of the excilamp 1 vs. the total pressure at various concentration of Br_2 in a working mixture

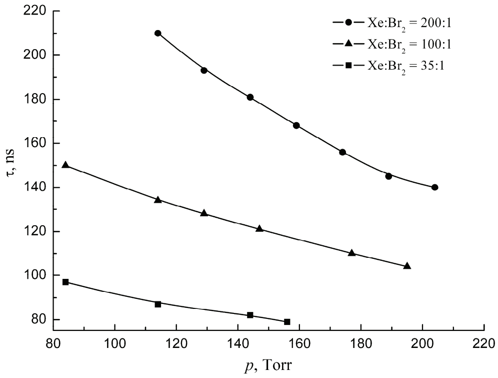

Fig. 10. Pulse duration of radiation at half-maximum τ vs. the total pressure of the mixture p for the excilamp 2

In addition to microdischarges appeared directly in the discharge gap, microdischarges flowing from the edge of the inner electrode *3* to edges of the outer (metal mesh) electrode *4* are observed in the excilamp 2. Because of this fact, by virtue of difference of electrodes areas *3* and *4*, periphery discharges ignite later than central microdischarges; moreover the pulse duration of radiation encreases. Another reason of distinctions between dependences τ on p consists in rather high value of d_{12} = 12 mm at given voltage of the generator (Fig. 2), that does not allow to extend in the field of higher pressures of a working mixture.

Thus, the minimum pulse duration of radiation τ = 55 ns was obtained in the excilamp 1 at Xe:Br = 35:1, ~ 162 Torr. In the excilamp 2, at the same conditions, τ = 79 ns. It indicates that at other equal conditions (p, Xe/Br) the minimum pulse duration of radiation is carried out at smaller values of the discharge gap.

4. Conclusion

By the example of the barrier discharge excilamps of various geometry, experimental investigations demonstrate the opportunity to receive the short duration of pulse radiation.

It is shown that the main characteristics of excilamps influencing on the pulse duration of radiation are: the halogen concentration in a working mixture, the total pressure value in a mixture, the discharge gap value, design of electrodes and their relative position.

Excilamps with the short duration of pulse radiation can be applied to the development of diagnostic apparatus, information transmission systems, fast physics process study, photochemistry and photobiology [6].

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