# Formation of short emission pulses in XeBr excilamps with the barrier discharge excitation

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We have experimentally investigated the formation of short (tens of nanoseconds) emission pulses in a planar XeBr excilamps excited by the barrier discharge. We have obtained data on the influence of pressure and mixture composition of the gas mixture, as well as of the electrode-gap spacing on the power and duration of the output emission pulse. In the excilamps with the gap of 8 mm, in the mixture of Xe : $Br_2$ = 35 : 1 under the pressure of 156 Torr the emission pulses at the wavelength of 282 nm and 55-ns duration (FWHM) were obtained.

## Introduction

Excilamps are the gas-discharge sources of ultra-violet (UV) and vacuum ultra-violet (VUV) due to nonequilibrium spontaneous emission from the excimer, or exciplex molecules.[1–3] The excilamps possess a rather narrow radiation spectrum with about 80% of the emission energy concentrated in the B–X emission band of the corresponding molecule. The excilamps with the barrier discharge excitation attract the greatest attention. It is caused by the fact, that the excilamps of this type have a number of advantages in comparison with the excilamps, excited by other types of the discharge, namely:

– they allow obtaining high-power and effective spontaneous emission in various excimer and exciplex molecules;

– within wide limits, they allow regulating the average energy and electron concentration in the discharge gap, and a specific power of excitation of the active medium;

– owing to the design features, they provide for scaling and many options for the geometric design;

– because the electrodes do not contact with the working mixture the sealed off lamps have a long life time (thousands of hours).

Thanks to these properties, the excilamps excited with the barrier discharge are widely used in research and in practice.[4–6]

As known, at high pressures, the duration of emission pulses in the barrier discharge decreases. For example, in the excilamps with the excitation by barrier discharge in $Xe_2^*$ molecules ($\lambda = 172$ nm) the pulses of 5-ns duration (FWHM) have been obtained.[7] There are also other studies (see, for example, Ref. 8) where the excilamps with a short duration of emission pulses were investigated. However, the authors of these studies did not aim at studying the conditions that would favor the shortest pulse duration and maximum power per pulse. From the preliminary analysis of the known studies[7–10] it is possible to formulate the conditions, under which the short-duration emission pulses can be obtained:

1) nanosecond duration of the excitation pulse (time of the discharge current passage through the gap);

2) high pressure of the working mixture and as high as possible concentration of the halogen molecules, which effectively damage the exciplex molecules;

3) formation of the diffuse cone-shaped microdischarges or volume discharge in the discharge gap.

The aim of this study was to systematically study the conditions for producing short-duration emission pulses in the XeBr excilamp excited by the barrier gas discharge. In our research, we have chosen the planar excilamps as their emission is easier focused by spherical optics.

## 1. Experimental equipment and technique

In the experiments, we used two excilamps of a various design, one with the discharge gap of 5 mm (Fig. 1*a* excilamp 1) and 12 mm (Fig. 1*b*, excilamp 2).

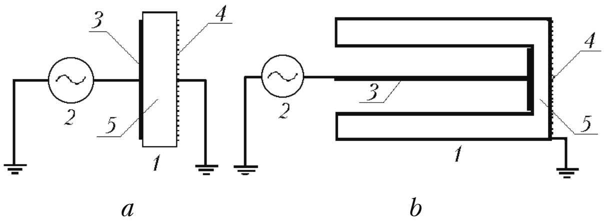


**Fig. 1.** Diagrams of the XeBr-excilamps 1 (*a*) and 2 (*b*), excited by the barrier discharge: quartz shell *1*; pulsed power source *2*; metal electrode *3*; perforated metal electrode *4*; discharge glow region *5*.

These excilamps differ in size of the buffer volume and in size of the electrodes. The excilamp 2

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had the greater buffer volume that essentially increased its life time. The excilamp shells have been made from quartz (Fused Quartz, Type 214, General Electric), having about 90% transmission at the working wavelength of 282 nm. The volume within the shells was filled with the gas consisting of xenon and bromine. Light emission exited through the perforated electrode *4* (Fig. 1), made as a metal screen with the transmission coefficient of 60%. By their design, the excilamps differed not only by the size of the discharge gap $d_{12}$ but also by the electrode area. The area of the electrodes *3* and *4* in the excilamp 1 made up 9 cm$^2$. In the excilamp 2, the area of the inner electrode *3* and the outer (perforated) electrode *4* were 3.78 and 23.75 cm$^2$, respectively. This has caused the distinctions in the discharge behavior. At the pressure change, the discharge area in the excilamp 2 could extend into the buffer volume.

The high-frequency pulse generator with the pulse repetition frequency of 100 kHz and the idle cycle voltage of 9 kV was used as a power supply. This voltage was sufficient for the discharge ignition. The voltage applied to the gap in a pulse-periodic operation depended on the composition and pressure of the mixture and under optimum operation it was 6 to 7 kV. The emission spectrum was recorded with a StellarNet EPP2000-C25 spectrometer.

The emission pulse was recorded with a vacuum photodiode FEK-22 SPU with the known spectral response, the signal from which applied to the TDS-22 four-beam oscilloscope. The current and voltage oscillograms were recorded with the help of the current shunt and voltage divider by the same oscilloscope. In Fig. 2, the oscillograms of the voltage, current, and emission pulses typical of the given excilamps are presented.

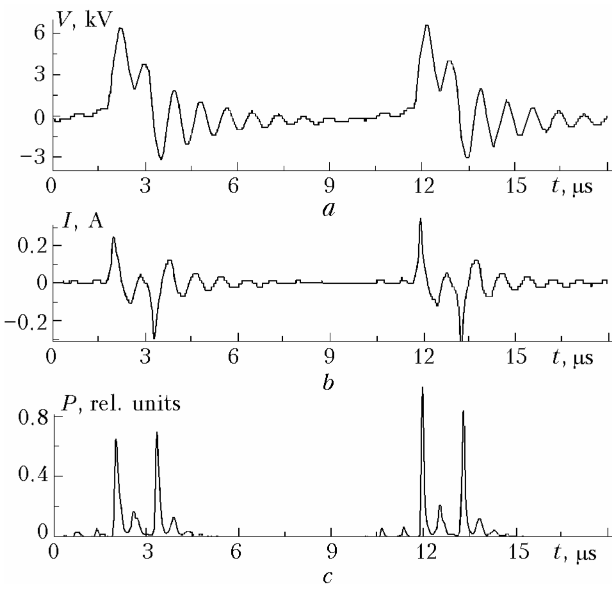


**Fig. 2.** Oscillograms of the voltage (*a*), discharge current (*b*) and emission (*c*) pulses. The excilamp 2, $p = 129$ Torr, Xe : Br = 35 : 1, $\tau(0.5) = 92$ ns.

Specific density of the average emission power was measured by means of a HAMAMATSU H8025-222 photodetector at a distance of 5 mm from the emitting surface in the case of the excilamp 1, and at about 0.5 mm in the case of the excilamp 2.

## 2. Results of the experiment and discussion

Figure 3 presents the emission spectra *S* of the barrier XeBr excilamp, containing the bands (with an extended short-wave wing) due to B–X, D–X, and B–A transitions with the maxima at 282, 221, and 325 nm, respectively.[3]

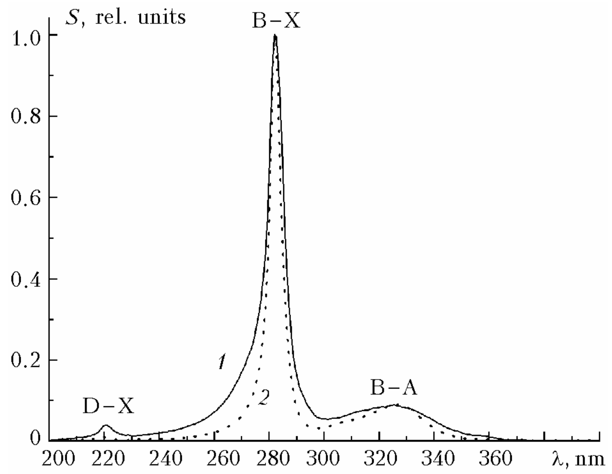


**Fig. 3.** Emission spectra of the barrier XeBr excilamp at various $Br_2$ concentrations in the mixture Xe : Br = 35 : 1, $p = 192$ Torr (*1*); Xe : Br = 200 : 1, $p = 84$ Torr (*2*).

As in Refs. 2, 3, and 10, the decrease of the contribution from D–X and the B–A transitions at increasing pressure of the mixture has been observed to the total emission power of the excilamp (at a fixed Xe : $Br_2$ ratio in the mixture). Besides, the growth of the pressure causes narrowing of the spectral width of the B–X transition (282 nm). As seen from the spectra, presented in Fig. 3, the decrease of the $Br_2$ concentration in the mixture leads to similar result.

Dependences of the radiation pulse duration $\tau(0.5)$ (FWHM) on the total pressure $p$ of the mixture for the excilamp 1 (Fig. 4) have minima at some pressure values. The minima are observed at the discharge shape such that the discharge gap is filled with a set of uniformly distributed cylinder or conic-shaped microdischarges.

At lower pressures, the discharge shape changes and the microdischarges lose sharp boundaries thus making the plasma glow diffuse and $\tau(0.5)$ increases. It is explained by decreasing $pd_{12}$ product and, according to the experimental Paschen's law, the lower voltage amplitudes are sufficient for the discharge ignition that leads to the increase of the electric current pulse duration and of the emission pulse as well.

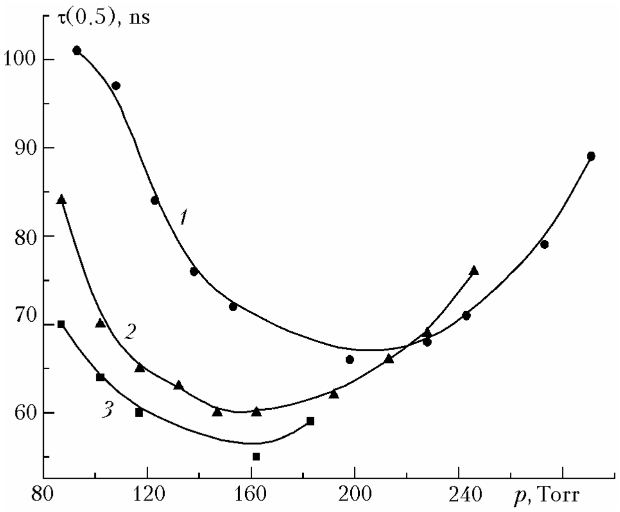


**Fig. 4.** Dependences of the emission pulse duration τ(0.5) (FWHM) on the total pressure of the mixture *p* for the excilamp 1, Xe:$Br_2$ = 200:1 (curve *1*); 100:1 (*2*); 35:1 (*3*).

At a higher pressure, bright branching channels appear and duration of the emission pulse increases due to the change of the discharge nature. In that case the efficiency of the excilamp decreases. The length of the bright glowing channel can exceed the size of the discharge gap $d_{12}$ by 1.5 to 2 times, that also can lead to the increase in duration of the emission pulse. At high pressures, the discharge ceases to be ignited because of the undervoltage produced by the excitation generator.

Dependence of the specific emission density *W* of the excilamp 1 on pressure (Fig. 5) also shows extremum. The maxima of *W* occur at pressures, close to those, at which the minima of τ(0.5) are observed.

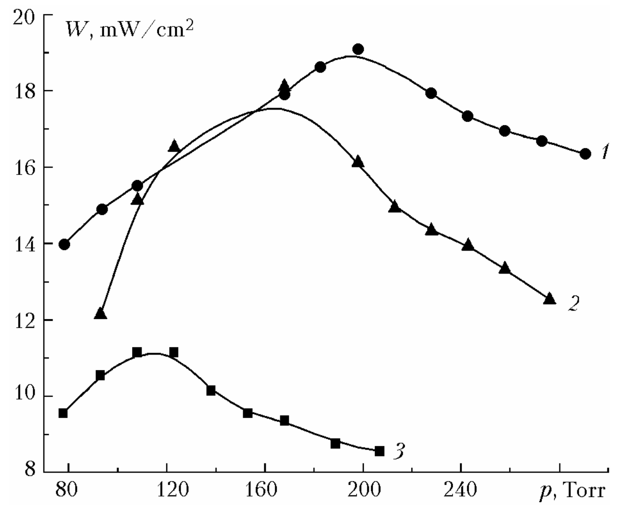


**Fig. 5.** Dependences of the specific density of the excilamp 1 emission power on the total pressure of the gas mixture, at various $Br_2$ concentrations in the working mixture: Xe:$Br_2$ = 200:1 (*1*); 100:1 (*2*); 35:1 (*3*).

Growth of the $Br_2$ concentration in the mixture leads to a significant reduction of τ(0.5), but, simultaneously, to a decrease in the emission power. This is caused by the high rate of quenching the excited XeBr* exciplex molecules by the bromine molecules. The increase of bromine molecules concentration in the working mixture causes the increase in the rate of the XeBr* molecules production, but the rate of their quenching increases too. The minimum pulse duration τ(0.5) = 55 ns in the excilamp 1 was obtained in the mixture of Xe : $Br_2$ = 35 : 1 at the pressure $p$ = 162 Torr.

A little bit different situation is observed in the excilamp 2 with the discharge gap of $d_{12}$ = 12 mm. Here the dependence of τ(0.5) on the total mixture pressure (Fig. 6) shows no extrema. However, the increase of the bromine fraction in the mixture, like in the excilamp 1, shortens duration of the emission pulse and deteriorates the conditions for the discharge breakdown – the discharge is ignited at lower *p*.

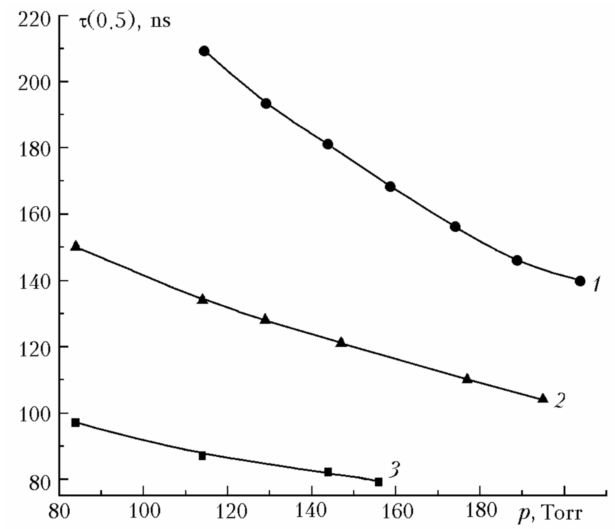


**Fig. 6.** Dependences of the emission pulse duration τ(0.5) (FWHM) on the total mixture pressure *p* for the excilamp 2, Xe:$Br_2$ = 200:1 (*1*); 100:1 (*2*); 35:1 (*3*).

Distinctions between the curves depicted in Figs. 4 and 6, apparently, are connected with the design features of the excilamps. Thus, in the excilamp 2, microdischarges refluxing from the peripheral region of the inner electrode *3* to the edges of the outer (perforated) electrode *4* are observed in addition to the microdischarges originating directly in the discharge gap. For this reason, due to the electrode areas *3* and *4* are different, there appears a time lag in scintillation of the edge microdischarges relative to the central ones, and the emission pulse is additionally extended. Another reason is a comparatively large gap $d_{12}$ = 12 mm, which does not allow the operation at higher pressures of the working mixture at the given voltage provided by the generator.

Thus, the minimum duration of the emission pulse τ(0.5) = 55 ns was obtained in the excilamp 1 at Xe : Br = 35 : 1, $p$ = 162 Torr. In the excilamp 2 under the same conditions, τ(0.5) = 79 ns was obtained. This indicates that the pulse duration in the exilamps is determined by the gap width $d_{12}$, other conditions being equal. The minimum duration is realized at narrower discharge gaps.

## Conclusion

We have carried out experimental research the possibilities to obtain emission pulses of short duration by an example of two planar XeBr excilamps of barrier discharge having different design. It is shown, that the key excilamp parameters, influencing the duration of emission pulses, are the bromine concentration in the working mixture, the total pressure of the gas mixture, the width of the discharge gap, the electrode structure and their relative position. Thus, further decrease of the emission pulse duration can be achieved by narrowing the discharge gap, increasing the total pressure of the gas mixture, as well as by making the amplitude of the excitation pulse higher and its duration shorter.

The excilamps of short pulse durations can be applied to making the diagnostic equipment, in systems of information transmission, for studying of fast physical processes, in photochemistry, and in photobiology.

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## References

1. B. Eliasson, and U. Kogelschatz, IEEE Trans. Plasma Science **19**, No. 2, 309–329 (1991).
2. U. Kogelschatz and B. Gellet, Appl. Phys. B **52**, No. 1, 15–19 (1991).
3. M.V. Lomaev, V.S. Skakun, E.A. Sosnin, V.F. Tarasenko, D.V. Shitz, and M.V. Erofeev, Usp. Fiz. Nauk **173**, No. 2, 201–217 (2003).
4. T. Oppenländer, Trends Chem. Eng. **8**, 123–136 (2003).
5. U. Kogelschatz, Proc. SPIE **5483**, 272–286 (2004).
6. E.A. Sosnin, S.M. Avdeev, E.A. Kuznetsova, and L.V. Lavrentieva, Prib. Tekh. Exp., No. 5, 111–114 (2005).
7. U. Kogelschatz, Pure & Appl. Chem. **62**, No. 9, 1667–1674 (1990).
8. M.V. Erofeev, M.I. Lomaev, E.A. Sosnin, V.F. Tarasenko, and D.V. Shitz, Opticheskii Zh. **68**, No. 10, 75–77 (2001).
9. X. Xu, Thin Solid Films. **390**, 237–242 (2001).
10. A.A. Lisenko and M.I. Lomaev, Atmos. Oceanic Opt. **15**, No. 3, 265–266 (2002).