Efficient XeBr excilamp excited by capacitive discharge

M.V. Erofeev, E.A. Sosnin, V.F. Tarasenko, and D.V. Shitts

Institute of High-Current Electronics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received June 15, 2000

Characteristics of radiation of XeBr* molecules (at the $B \to X$ transition, $\lambda \sim 282$ nm) under the conditions of electrodeless capacitive discharge are studied experimentally. It is shown that the high output power and efficiency of radiation of the XeBr* molecules are achieved in the pressure range from 4 to 12 mm Hg, and the maximum efficiency corresponds to the excitation power of $2\text{–}3 \cdot 10^{-18}$ W per one molecule. The mean output power up to 5.5 W is achieved at the power density up to 33 mW/cm^2 and the efficiency up to 15%. A sealed-off XeBr* excilamp is created.

High-power sources of spontaneous radiation are now widely used in various branches of science and technology. Among them, the sources of continuum UV radiation have found application in devices for open-path gas analysis of the atmosphere. As a rule, high-pressure xenon lamps are used for these purposes. However, these lamps require high power, forced cooling, and special safety measures.

For the last decade a significant progress has been achieved in the study and development of radiation sources based on excimer and exciplex molecules with a rather narrow spectral band $B \to X$ (Refs. 1–8). These sources are called excilamps.[2] The highest efficiency of radiation at the $B \to X$ transitions of the XeCl* and KrCl* molecules was achieved at excitation by glow discharge, low pressure of a working mixture, and low specific power of excitation.[3–5] However, from the viewpoint of lifetime, it is more promising to use excilamps in which the working mixture is excited in a sealed dielectric bulb, made of the material transparent to UV radiation, and the electrodes are located outside (so-called electrodeless lamps). Correspondingly, the longest lifetime for sealed-off excilamps was obtained at excitation by barrier discharge.[6] In Ref. 4 we have shown that the use of capacitive discharge for excitation of KrCl, XeCl, and XeI excilamps allows operation at low pressure and high efficiency of radiation, as well as provides for the long lifetime of the working mixture.

In this paper, we present the experimental results on the use of capacitive discharge for excitation of a XeBr excilamp.

1. Experimental setup and measurement technique

The design of the excilamp was described in detail in Ref. 6. The excilamp was made as a cylindrical tube with metal foil plates at its ends. In experiments we used tubes of 2.5 cm diameter and up to 40 cm long. The area of electrodes and the distance between them was usually varied to fit the resistance of the plasma in the tube to the wave resistance of a high-frequency oscillator. Correspondingly, the area of the emitting part of the lamp varied from 10 to 220 cm^2.

Working mixtures were excited with the help of a source of high-voltage sinusoidal pulses providing the excitation power at the excilamp up to 60 W and the pulse repetition rate of 16.5 kHz. An alternating field was applied to one electrode of the lamp, whereas another electrode was grounded. The voltage source with variable pulse amplitude (0–6 kV) and fixed pulse repetition rate consisted of a power supply unit, a master oscillator, an amplifier, and a step-up transformer. The power supply unit fed bipolar stabilized voltage to the amplifier. The master oscillator was responsible for formation of a sinusoidal signal with a variable amplitude (0–3 V). Then the signal was amplified and fed to the primary winding of the step-up transformer. The XeBr excilamp was a load of the secondary winding of the step-up transformer.

Current and voltage were measured by an ohmic shunt and a voltage divider, whose signals came to a TDS/220 double-beam oscilloscope. To separate the radiation, corresponding to the $B \to X$ transition of the XeBr* molecule, SZS (blue-green) and UFS (ultraviolet) filters were used. The mean output power in a given wavelength region was determined with a FEK–22 SPU vacuum diode having the known spectral sensitivity in the visible and UV spectral regions. The signal from the vacuum diode came to a digital voltmeter or oscilloscope. The shape of the excilamp spectrum was monitored with a MUM monochromator.

2. Experimental results

The typical spectrum of the discharge in the Xe–Br mixture in our experiments included the transitions $B_{1/2} \to X_{1/2}$ (282 nm), $C_{3/2} \to A_{3/2}$ (300 nm), and $B_{1/2} \to A_{1/2}$ (325 nm) of the XeBr* molecule. The

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$B_{1/2} \rightarrow X_{1/2}$ transition was responsible for ~90% of the total energy emitted in the region from 260 to 500 nm.

The pattern of discharge glow depends on the pressure of a mixture, its composition, and the current. For example, in the mixture Xe/Br = 35/1 and the interelectrode gap of 21 cm, a change of the pressure leads to the following changes in the pattern of glow.

At $p > 25$ mm Hg the current density in the discharge column is ~1.7 A/cm^2, and the discharge looks like a thin filament, i.e., it is close to contraction. The pressure decrease to $p = 8.5$ mm Hg decreases the current density to 0.26 A/cm^2. In this case, the discharge diameter increases up to 1 cm, and its shape becomes resembling a glow discharge.

At the further decrease of the pressure, the discharge tends to fill the whole space of the tube between the electrodes. Note that starting from about 2 mm Hg the density of the discharge current begins to decrease due to the increasing resistance of the discharge plasma, since the discharge conditions begin to correspond to the left branch of the Paschen curve.

We have studied the influence of the mixture pressure and the excitation power on the efficiency and power of radiation of the XeBr* molecule. For analysis at different total pressure, we took the mixtures in which the Xe/Br pressure ratios varied from 1 to 50. Figure 1 shows the dependence of the mean power P and the efficiency η of the excilamp on the parameter pd for the mixture Xe/Br = 20.5/1, where p is the pressure, and d is the length of the gap between the electrodes. It is seen that although the maximum mean power is achieved at $pd = 172$ cm · mm Hg, the maximum of the efficiency curve is at $pd = 61.5$ cm · mm Hg. In this region the specific excitation power is $2-3 \cdot 10^{-18}$ W per particle. In the order of magnitude, this value coincides with the values obtained in Xe/Cl_2 mixtures under the conditions of glow discharge[3] and just in the cases of maximum efficiency. At this pressure the discharge fills a half of the working volume and looks like a glow discharge. Similarly, in mixtures with other Xe/Br ratios, the maximum efficiency was achieved at low pressures (roughly from 1.5 to 2.5 mm Hg), whereas the peaks of the mean output power were shifted towards higher pressure. Therewith, the higher is the bromine concentration in a mixture, the larger is the shift (Fig. 2).

The fact should be noted that in the pressure range from 1 to 20 mm Hg the radiation power density changes insignificantly from the high-voltage electrode to the grounded one.

For the $B \rightarrow X$ transitions of the XeBr* molecule ($\lambda \sim 282$ nm) we have obtained the mean output power up to 5.5 W and the efficiency ~15%.

In practical use of the sources of spontaneous and induced radiation, it is required, as a rule, to keep unchanged the output parameters of lamps for a long time. Therefore, we have started the resource tests of the sealed-off XeBr lamp under the conditions of increased energy deposition. It was shown that at the specific energy deposition of 10.8 W/cm^3 (specific energy deposition of $4 \cdot 10^{-17}$ W/particle) the power of the UV radiation was unchanged during 100 h. These tests are being continued now.

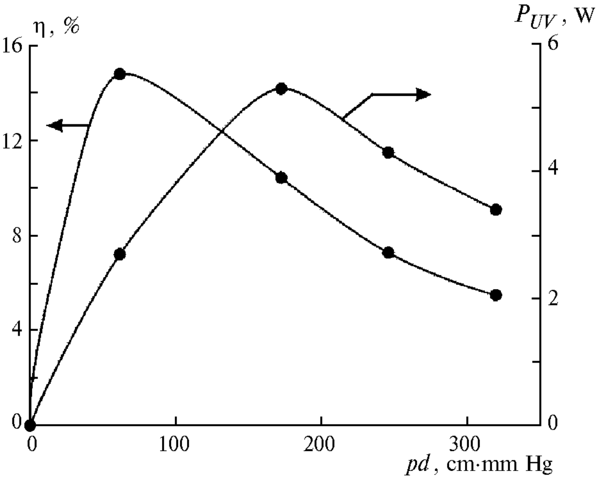

Fig. 1. Dependence of the mean power and efficiency of radiation of the XeBr lamp on the parameter pd; the space between the electrodes is 21 cm.

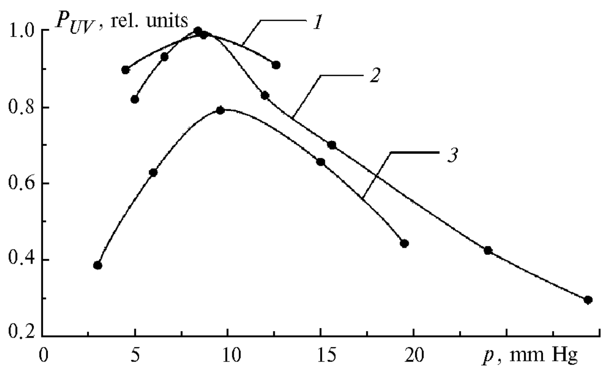

Fig. 2. Dependence of the mean output power for mixtures with different Xe/Br ratio (16/1 (*1*), 20.5/1 (*2*), and 8/1 (*3*)) on the total pressure of the mixture.

Conclusions

In this paper it is shown that as the pressure of the working mixture decreases, the radiation efficiency of the cylindrical XeBr* excilamp excited by electrodeless capacitive discharge increases 1.5 times as compared to a lamp excited by barrier discharge. We have succeeded in achieving the radiation efficiency in the UV region up to 15%, the mean output power up to 5.5 W, and the specific power up to 33 mW/cm^2. The tentative resource tests of the sealed-off XeBr excilamp have shown that no marked degradation of the working mixture was observed for 100 h of operation at high energy deposition.

Acknowledgments

The authors are grateful to Prof. E.B. Chernov for his help in development of the convenient and safe source of bromine.

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