Capacitive discharge excilamps

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The characteristics of XeCl (λ ~ 308 nm), KrCl (λ ~ 222 nm), and XeI (λ ~ 253 nm) capacitive high-frequency discharge excilamps are studied. The possibility of obtaining highly efficient emission of exciplex molecules is shown for the case of excitation by high-frequency capacitive discharge that provides for a simple-design emission source. The UV radiation power of 3 W at the efficiency of electric power conversion of 12% has been achieved. Sealed-off excilamps with a lifetime longer than 1000 hours have been created.

1. Introduction

Interest in sources of spontaneous UV and VUV radiation of new types, in particular, excilamps[1–14] and in their different applications in research and technology[11,14] has been permanently growing in recent years. The highest efficiency for XeCl (λ ~ 308 nm) and KrCl (λ ~ 222 nm) excilamps can be achieved at low pressure of the working mixture and low specific power of pumping by the glow discharge.[2–13] The maximum efficiency has been obtained at continuous pumping or pumping by long pulses (tens of μs and longer) in the positive column of the low-pressure glow discharge[7] or in subnormal (high-voltage) glow discharge.[10] However, the lifetime of the working mixture in sealed-off glow-discharge excilamps is limited, because a chlorine-containing working mixture contacts the electrodes, whose temperature grows significantly during the operation, especially in excilamps with high mean output power.

Thus, at the mean radiation power of 100 W the lifetime of the working mixture in an excilamp with stainless electrodes did not exceed 1 hour, and one had to replace it from time to time.[11] Golovitskii and Kan[3] succeeded in obtaining the lifetime of the working mixture as long as 100 hours due to the decrease of the mean output power by more than an order of magnitude, as well as by making use of a ballast volume and nickel electrodes. However, this lifetime is still insufficient for many practical applications. On the other hand, the lifetime of 1000 hours, as known, can be obtained in barrier-discharge pumped high-pressure (~ 1 atm) lamps, in which the working mixture contacts only quartz bulb of the excilamp.[14] However, the efficiency in this case is usually lower than in the case of pumping by the subnormal glow discharge or a glow discharge.

In this paper we discuss a possibility of creating high-efficiency sealed-off cylindrical low-pressure excilamps excited by a high-frequency capacitive discharge. The lifetime of working mixture of these lamps is as long as 1000 hours and longer, and the emission source has a very simple design. Note that the barrier discharge is also a type of the capacitive discharge, and the cylindrical geometry was earlier used in pumping of low-pressure N_2 lasers by the capacitive discharge.

2. Experimental setup and measurement technique

Figure 1 shows the design of the emission source of the capacitive discharge excilamp. Cylindrical tubes from 2 to 4 cm in diameter and up to 40 cm in length were used. Electrodes were set at the outer surface of the tubes separated at the distance from 2 to 38 cm; their length can vary from 1 to 19 cm.

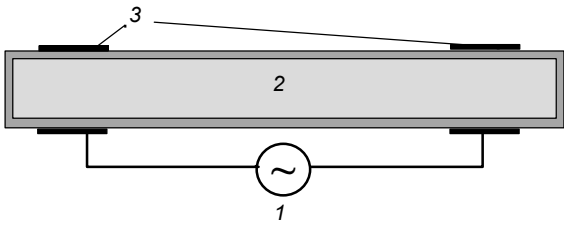

Fig. 1. Design of the high-frequency capacitive discharge emission source: excitation generator *1*, working mixture *2*, and electrodes *3*.

The working mixtures were excited by three sine-pulse generators with the power of 20, 35, and 55 W; the pulse repetition rate was 22 kHz. The voltage amplitude across the gas-discharge loads having the same working mixture composition could be changed while not exceeding 4 kV.

Current and voltage were measured with an ohmic shunt and voltage divider, signals from which were recorded with a dual-channel S8–17 oscilloscope. The mean output power in a given wavelength range was determined with a FEK–22 SPU vacuum photodiode with a known spectral sensitivity in the visible and UV spectral regions. The signal from the photodiode could be recorded with a pulsed voltmeter or a S8–17 oscilloscope.

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3. Results and discussion

High-frequency volume discharge emitting with high efficiency at the $B–X$ transitions of exciplex molecules can be easily obtained in mixtures of inert gases with halogens (chlorine and iodine in this paper) at low pressure. The main results obtained are shown in Figs. 2–6. The optimal pressure depends on the mixture composition, distance between the electrodes, and lamp diameter. It is from several fractions of mm Hg to several mm Hg, what coincides with the range of the working pressure in glow discharge excilamps.[2–13] The ratio among components in the working mixture for chlorine-containing mixtures is also close to that used in the glow discharge. Figures 2 and 3 show the dependence of the output power and the efficiency on the product pd of the pressure by the distance between the electrodes for XeCl* and KrCl* exciplex molecules at the constant distance between the electrodes. The highest efficiencies of emission correspond to those obtained at excitation by the glow discharge.

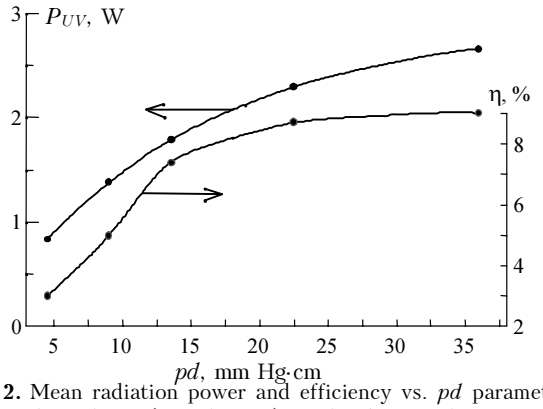

Fig. 2. Mean radiation power and efficiency vs. pd parameter for XeCl excilamp (Xe:Cl = 8:1) at the distance between the electrodes d = 15 cm.

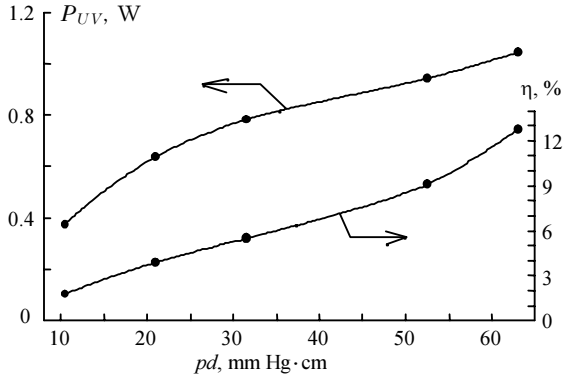

Fig. 3. Mean radiation power and efficiency vs. pd parameter for KrCl excilamp (Kr:Cl = 8:1) at the distance between the electrodes d = 15 cm.

The duration of an individual emission pulse at the high-frequency excitation depends on the mixture pressure and composition, distance between the electrodes, and working pressure, electrode area, and diameter of the quartz tube. For example, for a XeI excilamp 4 cm in diameter with the electrodes separated by 9 cm, at the mixture pressure of 10 mm Hg the duration of individual radiation pulses corresponded to each half-period of the discharge current and was about 20 μs (see Fig. 4). As the working pressure increased and the electrode area decreased, the duration of individual pulses became shorter.

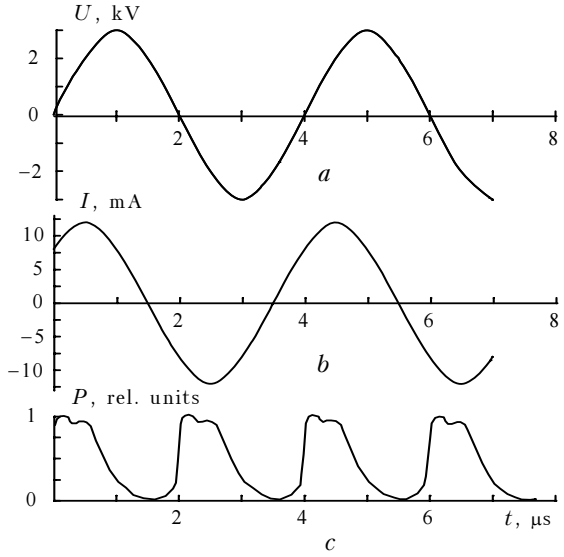

Fig. 4. Oscillograms of the pulses of voltage (*a*), discharge current (*b*), and emission (*c*) for XeI excilamp at the mixture pressure about 10 mm Hg, tube diameter of 4 cm, and d = 9 cm.

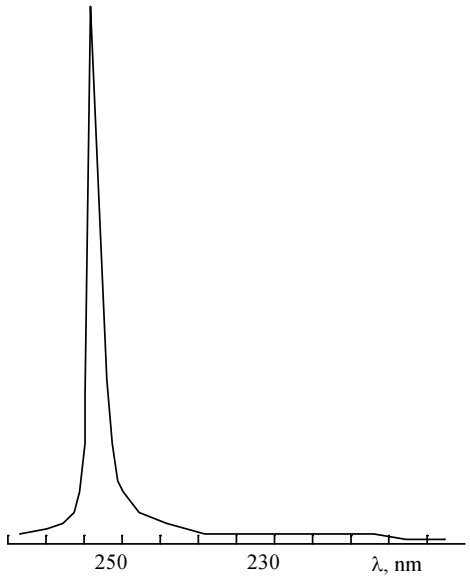

Fig. 5. Spectrogram of the XeI excilamp emission at the mixture pressure about 10 mm Hg.

The spectral characteristics of the emission from the XeCl and KrCl excilamps are similar to the spectral characteristics obtained at excitation by the glow discharge.[2–4,6,11] The bandwidth of emission from XeI* molecules at λ ~ 253 nm (see Fig. 5) was 2 nm and also corresponded to that we obtained in the glow

discharge. However, the efficiency for XeI* molecules was lower by about 5–10 times at excitation by both the capacitive and glow discharge as compared to that for XeCl* and KrCl* molecules.

The dependence of the mean emission power of the KrCl excilamp on the mean discharge current is shown in Fig. 6*a*. If the excilamp is not overheated, the linear growth of the mean emission power with the discharge current growth is observed.

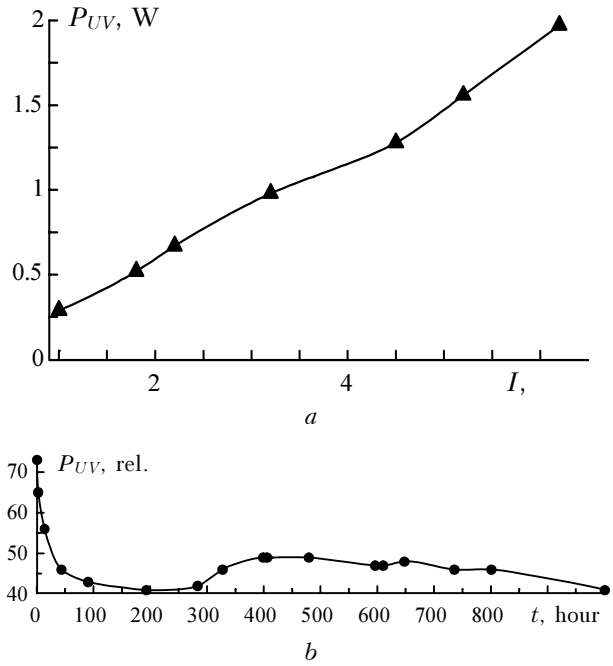

Fig. 6. Mean radiation power of the excilamps vs. mean discharge current (*a*) and time (*b*): KrCl excilamp, $Kr:Cl_2 = 8:1$ at the pressure of 2.1 mm Hg (*a*) and sealed-off XeCl excilamp, $Xe:Cl_2 = 8:1$ at the pressure of 3.3 mm Hg (*b*).

The main advantages of excitation by the capacitive discharge as compared with the glow discharge are simple design, absence of contact of the working mixture with the electrodes, and a significant increase in the lifetime of the sealed-off excilamps. Figure 6*b* shows the dependence of the mean emission power on the time of operation of the XeCl lamp. The lamp was usually operated during 7 to 8 hours a day, and the test lasted more than half a year. Similar results were obtained for the XeI excilamp. The tests, which are yet unfinished, showed that the lifetime of the working mixture of sealed-off excilamps exceeds 1000 hours.

As compared to excitation by the barrier discharge, the capacitive discharge provides more homogeneous excitation (separate filaments are absent), and more narrow emission bands, and allows one to efficiently deposit energy in the working mixture at low pressure and, correspondingly, to achieve higher total efficiency of a source of UV radiation.

4. Conclusions

In this paper we have studied the low-pressure sources of spontaneous radiation pumped by high-frequency capacitive discharge. The high-efficiency sealed-off cylindrical XeCl ($\lambda \sim 308$ nm), KrCl ($\lambda \sim 222$ nm), and XeI ($\lambda \sim 253$ nm) excilamps have been created for the first time. These excilamps have very simple design. The efficiency about 12% from the XeCl* and KrCl* molecules and the mean output power about 3 W have been achieved with the working volume of 250 cm^3. The lifetime of the sealed-off XeCl and XeI excilamps of 1000 hours as long and more has been obtained.

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