LASER APPLICATIONS AND OTHER TOPICS IN QUANTUM ELECTRONICS

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Study of a volume discharge in inert-gas halides without preionisation

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Abstract. **The energy characteristics of radiation of halides of inert gases excited by a volume discharge without additional preionisation are studied. The pressures of working mixtures and relations between the inert gas and halogen optimal for obtaining the maximum pulsed power and radiation efficiency are determined. The peak UV radiation power density achieved 5 kW cm^{-2} and the radiation efficiency was ~5.5 %. The pulse FWHM was 30 – 40 ns.**

Keywords: *excitation by a volume discharge without additional preionisation, radiation of inert gas halides.*

1. Introduction

Pulsed incoherent spontaneous UV and VUV radiation sources excited by discharges of different types continue to attract the attention of researchers. Thus, pulsed excilamps excited by capacitive, glow, and pulsed UV preionised self-sustained discharges were studied in [1]. It was shown that the maximum radiation power densities were achieved in a high-pressure volume discharge produced in a planar UV preionised excilamp. For mixture pressures of a few atmospheres, the radiation power densities were 5 kW cm^{-2} at 250 nm and 3.5 kW cm^{-2} at 222 and 308 nm. It was also pointed out that an electrodeless capacitive discharge excilamp had the longest life. In [2], the amplitude – time characteristics of radiation from capacitive discharge KrCl excilamps of different geometries were studied. The maximum pulsed radiation power density was 300 W cm^{-2} for pulses with the FWHM of several tens of nanoseconds and working pressures up to 100 Torr. High-pressure excilamps on Xe_2^* dimers excited by a barrier discharge with a distance between barriers of a few millimetres were studied in [3 – 5]. The peak power density of 6 W cm^{-2} was obtained at 172 nm at a pulse repetition rate of 50 kHz and the pulse FWHM ~150 ns.

It was shown in [2, 6 – 8] that the radiation pulse duration was determined by the pressure and composition of the working mixture, and the excitation pulse and its leading edge durations. The barrier discharge XeCl, KrCl, XeBr, and KrBr excilamps excited by a high-voltage nanosecond pulse generator were studied in papers [9, 10]. The radiation pulse duration was 4 ns at the pulsed radiation power density up to 700 W cm^{-2}. Papers [11 – 15] were devoted to the investigation of the characteristics of radiation of the plasma of a voltage nanosecond discharge in inert gases, nitrogen, and air produced at an elevated pressure in the inhomogeneous electric field without preionisation of the discharge gap. The duration of radiation pulses was from a few tens to a few hundreds of nanoseconds. The maximum pulsed powers and power densities were obtained at the transitions of inert gas dimers [14, 15].

The aim of this paper is to study the energy characteristics of radiation pulses of inert gas halides XeCl, KrCl, XeBr, and KrBr excited by a volume discharge without preionisation at elevated pressures of working mixtures. The radiative characteristics of exciplex and excimer molecules are similar, and therefore we can expect the obtaining of high radiation power densities for inert gas halides.

2. Experimental

Discharges in inert gas halides were studied in a gas-discharge chamber with the internal diameter 36 mm (Fig. 1). The discharge was ignited between flat brass anode (*1*) connected with the chamber housing through current shunt (*3*) consisting of chip resistors (2010 type) and steel foil tube cathode (*2*). The distance between the anode and cathode could be varied from 5 to 15 mm. A high-voltage pulse with the leading pulse duration ~1 ns, the amplitude ~150 kV, and the FWHM ~1.5 ns (during working with the matched load from a Radan-150 generator described in [16]) was applied to the cathode through insulator (*5*) at a pulse repetition rate of 1 Hz. The voltage across the discharge gap was measured with capacitive voltage divider (*6*). The radiation pulses were detected with a FEK-22 SPU vacuum photodiode with the known spectral sensitivity. The output signal of the photodiode was fed to a four-beam, 6-GHz, 20-Gs s^{-1} Tektronix TDS-6604 oscilloscope. The radiation power was measured on the output window of the gas-discharge chamber, and the emission spectrum of the discharge was recorded with a StellarNet EPP2000-C25 spectrometer.

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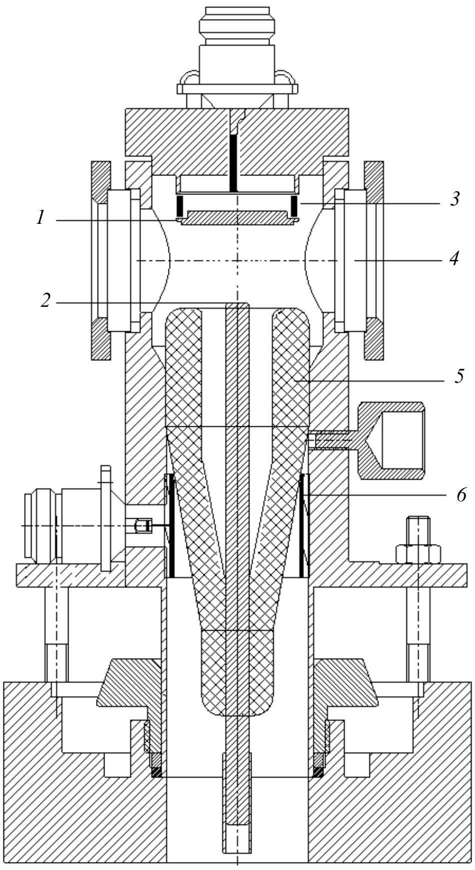

Figure 1. Design of a gas-discharge chamber: (*1*) anode; (*2*) cathode; (*3*) current shunt; (*4*) quartz window; (*5*) insulator; (*6*) capacitive voltage divider.

3. Experimental results and discussion

Experiments were performed in the pressure range of working mixtures from 60 to 750 Torr for different relations between amounts of inert gas and halogen. The pulsed radiation power of the volume discharge plasma increased with increasing the interelectrode gap; however, the internal diameter of the chamber restricted its value: when the interelectrode spacing exceeded 12 mm, the discharge was shunted by the chamber housing. At low pressures (60 – 120 Torr) and the interelectrode spacing of 12 mm, the discharge represented a homogeneous diffusion emission of the conic form. As the pressure was increased, the discharge acquired the form of a diffusion channel of diameter ~3 mm, which contracted at the pressure exceeding 500 Torr and transformed to a spark. As the content of halogen in the working mixture was increased, the discharge contracted at lower pressures and the radiation power decreased. The maximum radiation power densities of the volume discharge in $Xe-Cl_2$, $Kr-Cl_2$, and $Xe-Br_2$ mixtures were obtained at a pressure of 500 Torr and the inert gas : halogen ratio = 50 : 1. The maximum power density for the $Kr-Br_2$ mixture was achieved at a pressure of 750 Torr and the ratio $Kr:Br_2 = 100:1$. Figure 2 shows the dependences of the pulsed radiation power density for $KrCl^*$, $XeCl^*$, $XeBr^*$, and $KrBr^*$ molecules on the working mixture pressure. The maximum pulsed power densities for $KrCl^*$, $XeCl^*$, $XeBr^*$, and $KrBr^*$ molecules were 3.7, 3.1, 4.5, and 2.1 kW cm^{-2} at efficiencies 5 %, 4.8 %, 5 %, and

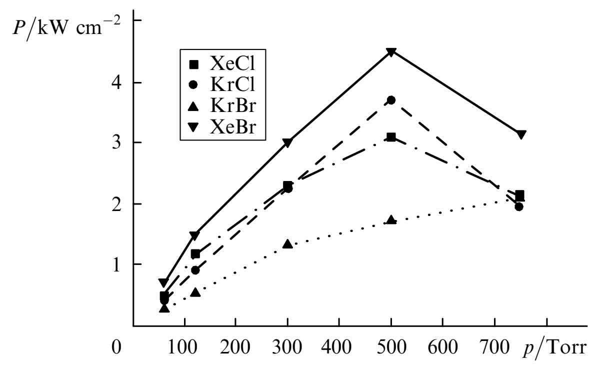

Figure 2. Dependences of the pulsed radiation power density of $KrCl^*$, $XeCl^*$, $XeBr^*$, and $KrBr^*$ molecules on the pressure of the working mixtures of compositions $Xe:Cl_2 = 50:1$, $Kr:Cl_2 = 50:1$, $Xe:Br_2 = 50:1$, and $Kr:Br_2 = 100:1$.

4 %, respectively. The energy supplied to the discharge plasma under these conditions was 1 J.

Figure 3 shows the voltage across the discharge gap, the discharge current, and the time dependence of the radiation pulse intensity for $XeBr^*$ molecules at a pressure of 500 Torr. The current pulse was recorded at the front of the voltage pulse and was slightly delayed (less than by 1 ns) with respect to the voltage pulse. In this case, the voltage pulse did not contain a pre-breakdown peak whose amplitude usually exceeds the voltage level in the quasi-stationary

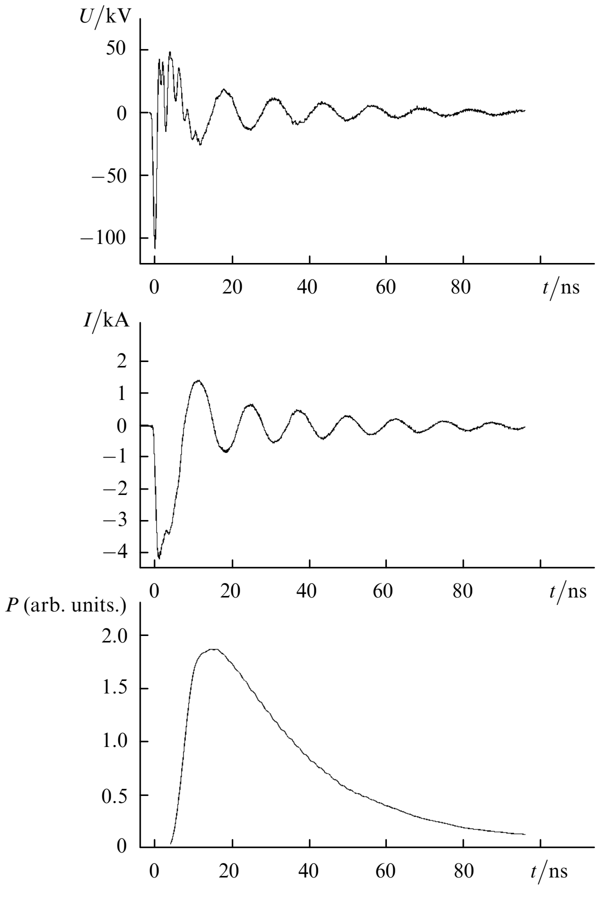

Figure 3. Typical oscillograms of the voltage pulse, discharge current, and radiation pulse of the volume discharge in the $Xe:Br_2 = 50:1$ mixture at a working pressure of 500 Torr.

stage of the volume discharge, which is realised in the case of intense preionisation. Similar oscillograms were obtained in [13], where this discharge regime was called the volume discharge initiated by an avalanche electron beam (VDIAEB).

The FWHM of radiation pulses of the volume discharge plasma in inert gas halides obtained under conditions providing the maximum emission intensity was 30 – 40 ns.

The emission spectra of the plasma of volume nanosecond discharges in Kr – Cl, Xe – Cl, and Xe – Br mixtures consisted of narrow (FWHM of a few nanometres) intense B – X transition bands and weak D – A and C – A bands of the corresponding exciplex molecules. As the working mixture pressure was increased, the fraction of energy emitted in the D – A and C – A bands decreased, and up to 90 % of the total emission energy was concentrated in the B – X bands at a pressure of 500 Torr. Figure 4 shows the emission spectrum of $KrCl^*$ molecules. The emission spectrum of the discharge in the Kr – Br mixture consisted of the B – X bands of $KrBr^*$ (206 nm) and Br_2^* (289 nm) molecules and the 222-nm C – A and 228-nm B – A bands of $KrBr^*$ molecules. The intensity ratio of the bands of $KrBr^*$ and Br_2^* molecules depended on the content of Br_2 in the working mixture: the greater the fraction of Br_2, the weaker the B – X, C – A, and B – A bands of the KrBr* molecule became.

To increase the life of pulsed $KrCl^*$, $XeCl^*$, $XeBr^*$, and $KrBr^*$ radiation sources, we added neon and argon to working mixtures. The addition of Ne (10 Torr) to Kr – Cl_2 and Xe – Cl_2 mixtures resulted in the increase in the operating life (the number of radiation pulses reducing the output pulse intensity by 50 %) by 5.4 and 4.5 times, respectively. For example, the radiation power density of $KrCl^*$ molecules decreased by 24 % after 250 pulses, whereas in the mixture with neon it was reduced only by 4 %. After the addition of Ar (15 Torr) to the Kr – Br_2 and Xe – Br_2 mixtures, the life of radiation sources increased twice and by a factor of 1.5, respectively. In this case, the emission spectra of the mixtures did not change.

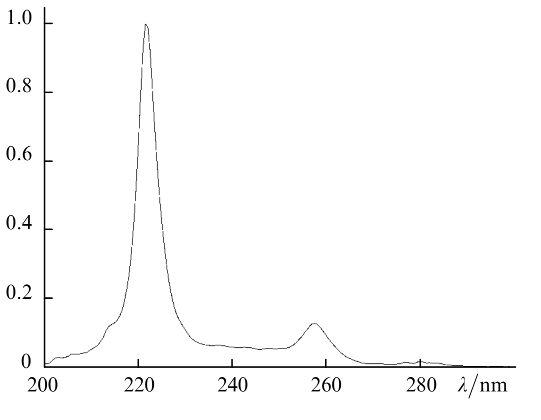

Figure 4. Emission spectrum of $KrCl^*$ molecules in the volume discharge at a pressure of 500 Torr.

4. Conclusions

We have obtained volume pulsed discharges in inert gas halides without preliminary ionisation. This regime was used to produce the high radiation density. The optimal working pressure for the Kr – Cl_2, Xe – Cl_2, and Xe – Br_2 mixtures was 500 Torr for the ratio inert gas : halogen = 50 : 1. The working pressure for the Kr : Br_2 mixture was 750 Torr for the ratio Kr : Br_2 = 100 : 1. The maximum pulsed radiation power densities for $KrCl^*$, $XeCl^*$, $XeBr^*$, and $KrBr^*$ molecules were 3.7, 3.1, 4.5, and 2.1 kW cm^{-2} with efficiencies 5 %, 4.8 %, 5.5 %, and 4 %, respectively. The pulse FWHM obtained under optimal conditions were 30 – 40 ns. The emission spectra of the volume discharge plasma in the Kr – Cl, Xe – Cl, and Xe – Br mixtures consist of the intense B – X bands of the corresponding molecules (of width of a few nanometres). The addition of neon and argon to the working mixtures leads to the increase of the operation life of radiation sources.

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