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Generation and quenching in the XeCl* excimer laser pumped by mixed gamma-neutron radiation from a nuclear reactor

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A decrease in the gain of the active medium of a nuclear-pumped excimer laser has been experimentally discovered at the B−X- and C−A-transitions of the $XeCl^*$ molecule (308 nm, 352 nm)

when the $Ar-Xe-CCl_4$ medium is pumped with mixed gamma-neutron radiation nuclear reactor. The effect is due to the quenching effect of secondary electrons formed in the active medium of an excimer laser under the influence of instantaneous gamma radiation. The effect increases significantly with increasing gamma radiation flux density, and the loss coefficient can reach values of $\sim 10^{-2}-2\cdot 10^{-2}\,\mathrm{cm}^{-1}$.

Keywords: nuclear pumping, excimer laser, gamma radiation, electron quenching.

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Introduction

Experiments performed on pulsed nuclear reactors SPR-III [1,2] and EBR-L [3,4] showed the fundamental possibility of obtaining generation of laser radiation on B−X-transitions of excimer molecules $XeCl^*$ and XeF^* with a duration in hundreds of microseconds with nuclear pumping with a low specific energy input into the active medium of the laser (up to $3.0\,\mathrm{kW/cm^3}$). In the paper [5], there was a superradiance mode at the C−A transition of the $XeCl^*$ ($\lambda = 352\,\mathrm{nm}$) molecule and lasing at the B−X-transition ($\lambda = 308\,\mathrm{nm}$) at a threshold energy input into the gas $\sim 200-250\,\mathrm{W/cm^3}$ when pumped by mixed gamma-neutron radiation from the BARS-6 nuclear reactor. The authors of the paper noted that despite the high ($\sim 0.01\,\mathrm{cm}^{-1}$) initial gain of the active medium, after the onset of generation the gain greatly decreased, which limited and did not allow generation to develop even at the moment of maximum energy input into the gas.

The observed anomalies in the gain when using gamma-neutron radiation from a nuclear reactor to initiate neutron nuclear pump reactions were due to the appearance in the active medium of the excimer laser of an additional loss channel associated with the destruction of excimer molecules under the influence of instantaneous gamma radiation. The effect was created by secondary electrons formed in the active medium of the laser and on the walls of the laser cell during Compton scattering and gamma radiation photoabsorption. As it is known, electrons destroy excimer molecules at superelastic collisions and during dissociative attachment in collisions with $XeCl^*$ molecules [6,7]:

$$XeCl^*(B,C) + e \rightarrow Xe + Cl + e', \qquad (1)$$

$$XeCl^*(B,C) + e \rightarrow Xe + Cl^-, \qquad (2)$$

$$XeCl^*(B,C) + e \rightarrow Xe^* + Cl^-. \qquad (3)$$

This paper presents experimental results on the excitation of a dense gas mixture $Ar-Xe-CCl_4$ by the products of the nuclear reaction $^{235}U(n, f)$ initiated by mixed gamma-neutron radiation from a pulsed nuclear reactor, and discusses the features of the lasing mode of an excimer laser based on the B−X-junction of the $XeCl^*$ ($\lambda_{max} = 308\,\mathrm{nm}$) molecule under these conditions.

Experimental setup

The block diagram of the experimental unit is shown in Fig. 1. A laser cell (*1*) with the gas mixture under study $Ar-Xe-CCl_4$ was located near the active zone (*2*) of a pulsed nuclear reactor and was irradiated with a mixed pulsed flux of fast neutrons with a duration of $\sim 100\mu$s ($\sim 10^{16}\,\mathrm{n/cm^2\cdot s}$) and gamma quanta ($\sim 10^{17}\,\gamma/\mathrm{cm^2\cdot s}$) with duration $\sim 100\,\mu$s at half maximum. The fission reaction of uranium-235 nuclei by thermal neutrons was used in pumping the laser element:

$$^{235}U + n \rightarrow 2\,\mathrm{fragments} + 170\,\mathrm{MeV},$$

$$\sigma_f(E_n = 0.025\,\mathrm{eV}) = 560\,\mathrm{barn}. \qquad (4)$$

The laser cell (*1*) with dimensions $\varnothing 25 \times 1000\,\mathrm{mm}$ was made of a thin-walled pipe 0.4 mm thick made of X18N9T stainless steel. A fuel layer of uranium oxide (*3*) with a thickness of $\sim 3\,\mathrm{mg/cm^2}$ was deposited on 4 rectangular substrates of $34 \times 303\,\mathrm{mm}$ made of aluminum foil with a thickness of 0.25 mm. The substrates were rolled into a tube, laid on the inner surface of the cell (*1*) and fixed with ring inserts. The active volume excited by uranium fission

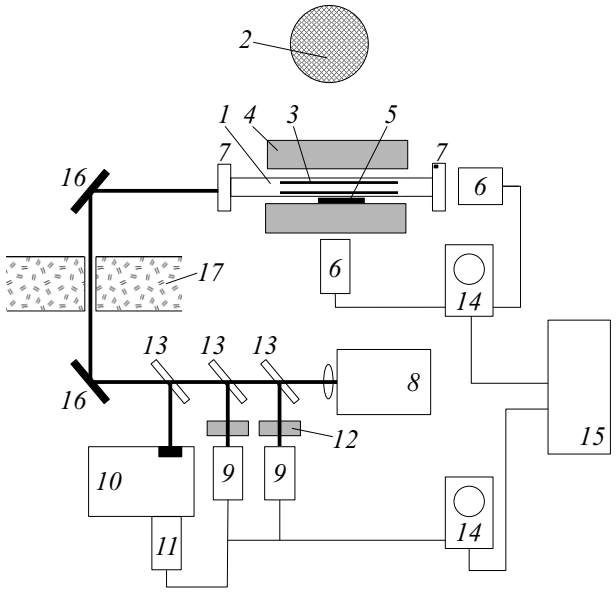

Figure 1. Block diagram of the experimental unit: *1* — laser cell, *2* — nuclear reactor core, *3* — layer $^{235}U_3O_8$, *4* — polyethylene moderator, *5* — evacuated neutron chamber KNT-5, *6* — photocell F-22, *7* — resonant cavity mirror, *8* — MAYA-2000Pro spectrometer, *9* — photomultiplier, *10* — MDR-9 spectrometer, *11* — photomultiplier, *12* — optical filter, *13* — beam splitter plate, *14* — digital oscilloscope, *15* — computer, *16* — aluminum mirror, *17* — biological shielding of the reactor.

fragments occupied the region Ø23 × 550 mm, which was approximately 60% of the total volume of the cell.

Since the energy spectrum of neutrons in a pulsed reactor is not thermal, to increase the pumping efficiency, a laser cell (*1*) was located inside a polyethylene neutron moderator (*4*), with the help of which the energy spectrum of thermal pumping neutrons produced. Thus, the pulse of thermal pumping neutrons was created from the pulse of fast neutrons when they were slowed down in a hydrogen-containing medium and had a duration at half-maximum $\sim 240\,\mu$s. The specific energy input of fission fragments into the Ar-Xe-CCl_4 gas medium during the pump pulse could be up to 250 mJ/cm^3. The neutron pumping pulse was recorded by an evacuated small-sized fission chamber KNT-5 (*5*), located inside a polyethylene moderator (*4*). The instantaneous gamma radiation pulse of the reactor was recorded by a vacuum photocell F-22 (*6*) installed outside the moderator (*4*) on its outer surface with the photocathode closed by a light-proof curtain.

When carrying out lasing experiments, the cell was sealed with two narrow-band mirrors with a high reflectance at a wavelength of 308 nm, forming an optical resonant cavity, or with a laser mirror and a quartz window — when carrying out luminescent studies.

Gas mixtures Ar-Xe-CCl_4 of various compositions (Ar — 380÷1520 Torr, Xe — 15÷580 Torr, CCl_4 — 0.05 Torr) were poured into the cell without carrying out additional cleaning.

Registration of light radiation was carried out with a MAYA-2000Pro spectrometer (*8*), two photomultiplier tubes PMT-106 and PMT-100 (*9*), and an MDR-9 spectrometer (*10*) with a photomultiplier PMT-100 (*11*) and an F-22 photocell installed on the rear mirror of the laser resonant cavity. All this equipment was located behind the biological shielding of the reactor at a distance of 18 m from the front mirror (*7*) of the laser cell. In front of the photoelectron multipliers (*9*) it was possible to install narrow-band optical filters (*12*) and glass filters of the UFS-2 grade to isolate ultraviolet radiation and grades BS-8 and KS-19 — to highlight the long-wavelength part of the spectrum. Quartz disks 6 mm thick were used as plate beamsplitters (*13*). Recording of time signals and the luminescence spectrum was carried out with fast digital oscilloscopes RIGOL DS-5022 ME, RTB 2004, TDS-1012 (*14*) and COMPUTER (*15*). The cell light emission was recorded in a constant geometry under the same pumping conditions. Spectral measurements were carried out with a MAYA-2000Pro spectrometer in the wavelength range 200 −1100 nm with a resolution of 1 nm. It should be noted that the spectra recorded by the MAYA-2000Pro spectrometer characterize the integral luminescence of the gas mixture during the action of the pumping pulse.

Primary processes of interaction of gamma-neutron radiation with the active medium of an excimer laser

The radiation pulse of the BARS-6 nuclear reactor has a duration of 100 μs and consists of two components — a pulse of fast fission neutrons with energy $E_n \sim 2.5$ MeV and a pulse of prompt gamma-rays coinciding with it in time with the energy of gamma quanta $E_\gamma \sim 0.9$ MeV . When an ^{235}U nucleus is fissioned by a thermal neutron, there are 2−3 fast neutrons with an average energy of 2.5 MeV, two fragments with mass numbers of approximately 95 and 140 with a total kinetic energy of 170 MeV and 5−7 gamma quanta with an average energy of 0.9 MeV. All fission products have ionizing properties and can create positive ions, electrons and excited atoms in a gaseous, liquid or solid medium. For pumping active medium of the laser, the reaction of fission of uranium nuclei by thermal neutrons is used, which are formed after slowing down fast neutrons in a moderator (*4*).

The active medium of the laser is excited by fission fragments ^{235}U emerging from a thin layer of uranium located on the inner surface of the laser cell. Uranium fission fragments are highly ionizing multiply charged ions ($z \approx 22$ e) and have a short range in matter. Due to energy losses in this layer, the average fragment energy is approximately 30 MeV. All the kinetic energy of the fragment is released in the track — a narrow area of space along the path of the particle — in the form of ionized and excited atoms of the buffer gas and fast δ electrons. All plasma-chemical processes of formation of

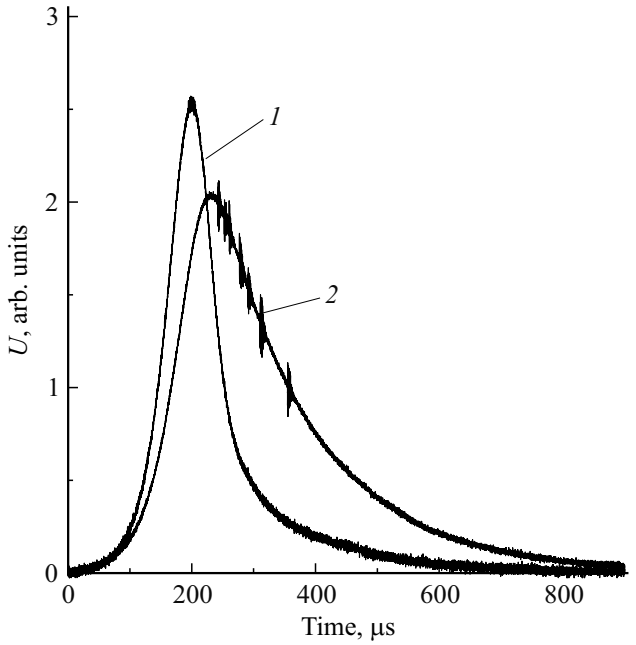

Figure 2. The pulse of prompt gamma-rays from the reactor (*1*) and the pulse of thermal pumping neutrons on the axis of the laser tube in the center of the polyethylene moderator (*2*).

plasma components take place within the track volume; the characteristic lifetime of the track is $0.1-1.0\,\mu$s [8]. In an Ar-Xe-CCl_4 mixture of atmospheric pressure, the track of a fission fragment with energy $E_0 = 30$ MeV has the following characteristics: length $1.2-1.3$ cm, diameter $10^{-3}-10^{-2}$ cm, concentration of ions and electrons in the track $10^{12}-10^{14}\,\mathrm{cm}^{-3}$.

The addition of electronegative gas CCl_4 to the Ar-Xe gas mixture leads to the formation of excimer molecules $XeCl^*$ and Xe_2Cl^* due to ion-ion recombination of positive ions Xe^+ and Xe_2^+ with negative ions Cl^-:

$$Xe^+(Xe_2^+) + Cl^- + (Ar, Xe) \rightarrow XeCl^*(Xe_2Cl^*) + (Ar, Xe). \quad (5)$$

Negative ions Cl^- are formed due to the attachment of slow electrons to the CCl_4 molecules. This results in the dissociation of the molecule, since during electron capture the Rydberg excited state of the CCl_4 molecule is formed, which decays during the time 7.56 ± 2.5 ps into negatively charged radicals [9]. At electron energy $E_e = 0.05$ eV, the cross section for attachment to CCl_4 molecules is equal to $(1.2-1.4)\cdot 10^{-14}\,\mathrm{cm}^2$ [10], which corresponds to the cohesion rate coefficient $\sim 1.2\cdot 10^{-7}\,\mathrm{cm}^3/\mathrm{s}$. At a partial pressure CCl_4 30 mTorr, the cohesion time is $6\cdot 10^{-9}$ s. At high gas pressures, the contribution of harpoon reactions to the formation of excimer molecules is small and can be ignored.

The optimal concentration of a halogen-containing donor (CCl_4) in the gas mixture should be comparable to the concentration of free electrons in the track of a nuclear particle, since its increased concentration causes quenching of $XeCl^*$ molecules and does not lead to an increase in the number of negative ions due to the absence of free electrons in the track. According to [7,11], the reaction rate coefficients for the quenching of excimer molecules $XeCl^*$ by the components of the gas mixture Ar-Xe-CCl_4 are equal to:

$$XeCl^* + CCl_4 \rightarrow \text{quenching } k \sim 10^{-9}\,\mathrm{cm}^3/\mathrm{s} \quad (6)$$

and

$$XeCl^* + (Ar, Xe) \rightarrow \text{quenching, } k \sim 10^{-13}\,\mathrm{cm}^3/\mathrm{s}. \quad (7)$$

For the effective formation of excimer molecules $XeCl^*$ (and Xe_2Cl^*), the concentration of CCl_4 molecules should not greatly exceed $10^{15}\,\mathrm{cm}^{-3}$, which corresponds to the partial pressure of CCl_4 in the mixture $\sim 0.05-0.1$ Torr. A further increase in the content of CCl_4 causes quenching of excimer luminescence.

Prompt gamma-rays from a nuclear reactor interact with the gas active medium of the laser and with the walls of the laser cell, creating high-energy secondary electrons due to the photoelectric effect and Compton scattering. Compton scattering is the predominant process in the gamma ray energy range from 100 keV to 10 MeV [12]. With the Compton effect, the maximum energy of the recoil electron $(E_e)_{\max}$ for quanta with energy of 0.9 MeV, according to [12], is equal to

$$(E_e)_{\max} = E_\gamma/[1+0.5/(E_\gamma/mc^2)] = 0.704\,\mathrm{MeV}. \quad (8)$$

Taking into account the photoelectric effect, the energy spectrum of secondary recoil electrons covers the entire energy range from 0 to 0.9 MeV. Due to the high density of the cell wall material (stainless steel X18N9T), the ground contribution to the formation of secondary electrons is made by the wall, in which approximately 0.6% of prompt gamma rays are absorbed. The absorption of gamma quanta in a gas medium is small (less than 0.02%), and it can be ignored.

When recoil electrons exit the wall of the laser cell into the gas medium, part of their initial energy is lost in the wall material itself.

Experimental results and discussion

Figure 2 shows the pulse of prompt gamma rays from a pulsed nuclear reactor, recorded by the F-22 photocell, and the pulse of thermal pumping neutrons on the axis of the laser tube in the center of the polyethylene moderator, recorded by the evacuated neutron fission chamber KNT-5. The shape of the gamma-ray pulse corresponds to the pulse of fast fission neutrons from a nuclear reactor. The time shift between the pulses of fast fission neutrons and thermal pumping neutrons is due to the slowing down of fast neutrons in the moderator (*4*) and is $35\,\mu$s.

Despite the general increase in the efficiency of using fast neutrons from the reactor for pumping due to their moderation to thermal energies, in general, when moderating in polyethylene, the effective flux of pumping thermal

neutrons decreases almost 10 times and the flux of gamma rays weakens by approximately 50%. In real conditions, at a power of energy input into the gas $\sim 250\,\mathrm{W/cm^3}$ per pulse, a laser cell with a polyethylene moderator is irradiated by the fluence of thermal pumping neutrons $\sim 5 \cdot 10^{11}$ th.n/cm^2 and the fluence of instantaneous fission gamma quanta $3 \cdot 10^{13}\gamma/\mathrm{cm^2}$ with average energy 0.9 MeV.

The light emission spectra of an excimer laser based on a gas mixture Ar-Xe-CCl_4 excited by uranium fission fragments are shown in Figs 3 and 4. Recording was carried out with a MAYA-2000Pro spectrometer installed at a distance of 18 m from the laser output mirror (Fig. 1, position *8*). The laser resonant cavity (Fig. 3) was formed by two narrow-band (at a wavelength of 308 nm) mirrors with transmittance $T = 0.87\%$ (for the output mirror) and reflection $R = 98.04\%$ (for the rear mirror), and the resonant cavity in Fig. 4 — output narrow-band mirror with transmittance $T = 0.29\%$ at a wavelength of 352 nm and a rear quartz window.

The spectrum (Fig. 4) was recorded from the mirror side. The emission spectra (Fig. 3 and 4) in the long-wave area ($\lambda > 600$ nm) consist of $4p-4s$-lines of the ArI buffer gas and $6p-6s$-XeI lines, and in the short-wavelength region of D−X-, B−X- and C−A-bands of the excimer molecule

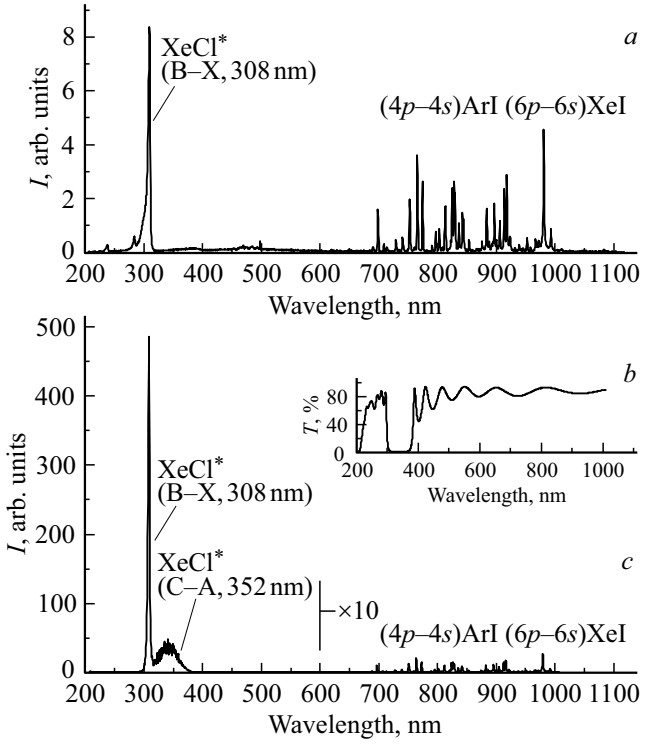

Figure 3. Emission spectrum of an excimer laser at the B−X-transition of the XeCl* ($\lambda_{max} = 308$) molecule upon excitation of a gas mixture Ar−Xe−CCl_4 by fission fragments of uranium-235. (*A*) Instrument spectrum measured at a distance of 18 m, (*B*) transmittance of the output mirror, (*C*) spectrum corrected for transmittance of the output mirror. In the wavelength range 600−1100 nm, the scale along the ordinate axis is increased by 10 times.

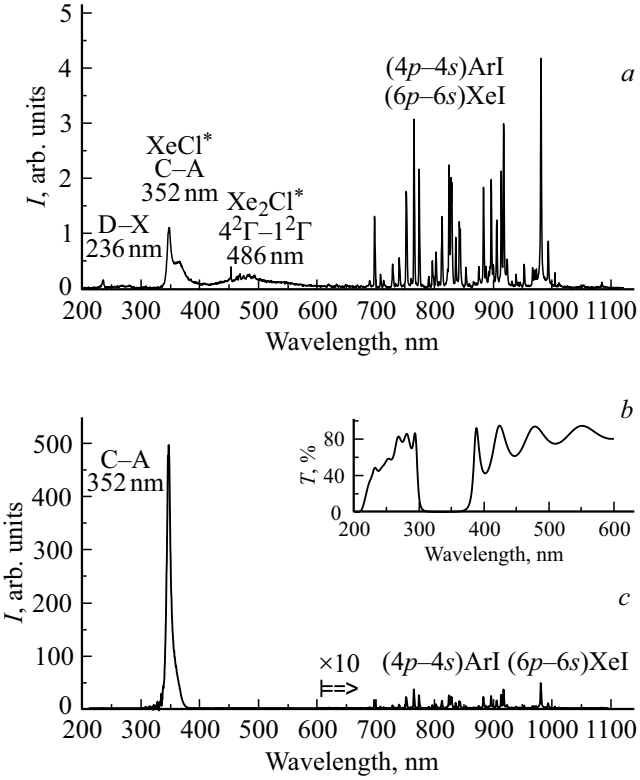

Figure 4. Emission spectrum of a gas mixture Ar−Xe−CCl_4 excited by fission fragments of uranium-235 at a distance of 18 m from the output mirror Powder mixture: Ar — 780 Torr, Xe — 15 Torr, CCl_4 — 50 mTorr. (*A*) Instrument spectrum, (*B*) transmittance of the output mirror, (*C*) spectrum corrected for the transmittance of the output mirror. In the wavelength range 600−1100 nm, the scale along the ordinate axis is increased by 10 times.

XeCl* and $4^2\Gamma-1^2\Gamma$-bands of the Xe_2Cl^*molecule. The spectra corrected for the transmittance of the resonant cavity output mirror are shown in Fig. 3, *c* and 4, *c*. For clarity, in these figures the scale of the image in the wavelength range 600−1100 nm is increased by 10 times.

Figure 5 shows a section of the radiation spectrum B−X- and C-A-bands of the excimer molecule XeCl*, measured at equal energy inputs into the gas in the presence of a resonant cavity (a cell with two selective mirrors at a wavelength of 308 nm) and at absence of a resonant cavity (cell with two quartz windows). A comparison shows that when pumped by uranium fission fragments in the presence of a resonator, the radiation intensities of the B−X- and C−A-bands of the excimer molecule XeCl*E increase 10−30 times (Fig. 5).

Time oscilloscope records of laser radiation pulses excited by fission fragments of uranium-235 are shown in Fig. 6−8. Generation at the C− A transition of the XeCl* molecule (Fig. 6) occurred at a threshold energy input into the gas 200−250 W/cm^3 when using resonant cavities „quartz window-narrow band mirror“at a wavelength of 352 nm with a coefficient radiation losses are 96% for one round of

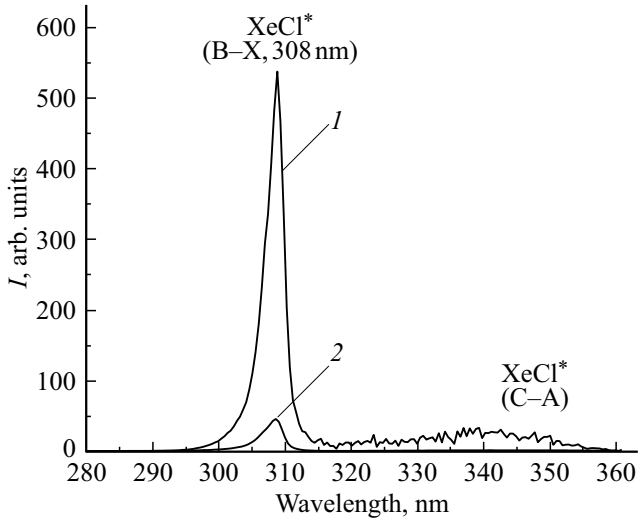

Figure 5. UV section of the radiation spectrum of the excimer molecule $XeCl^*$ (B–X- and C–A-bands), measured at the same energy inputs into the gas in the presence of a resonant cavity at a wavelength of 308 nm (*1*) and in the absence of a resonant cavity (cell with two quartz windows) (*2*).

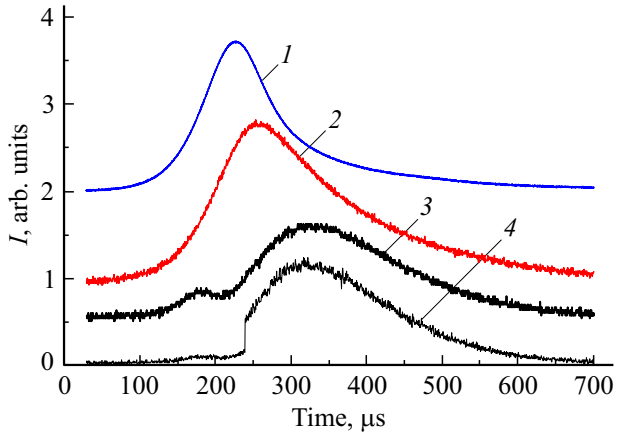

Figure 6. Oscilloscope records of pulses of instantaneous gamma radiation from the reactor (*1*), a pulse of thermal pump neutrons (*2*), a pulse of light radiation with a wavelength of 302 nm (*3*) and a generation pulse at the C–A transition of the excimer molecule $XeCl^*$ ($\lambda = 352$ nm) upon excitation of the gas mixture Ar–Xe–CCl_4 by fission fragments of uranium-235 (*4*). Resonant cavity „quartz window – narrow-band mirror" with mirror reflectance at a wavelength of 352 nm $R = 99\%$. Gas mixture: Ar — 760 Torr, Xe — 15 Torr, CCl_4 — 50 mTorr. Oscilloscope records (3) and (4) were recorded from the side of the quartz window and were not mutually normalized in amplitude.

the resonator, and generation on the B–X-junction $XeCl^*$ ($\lambda = 308$ nm, Fig. 7) with a resonant cavity „mirror – mirror" with a loss coefficient of 3% occurred at a threshold energy input into gas $\sim 100-125$ W/cm^3.

The generation duration was $\sim 50-100\,\mu$s or more. At the initial stage of generation development, the gain coefficient of the Ar-Xe-CCl_4 active medium was ~ 0.01 cm^{-1}, but then (after $20-40\,\mu$s after the onset of generation) the gain greatly decreased, which limited and did not allow generation to develop even at the moment of maximum energy input into gas

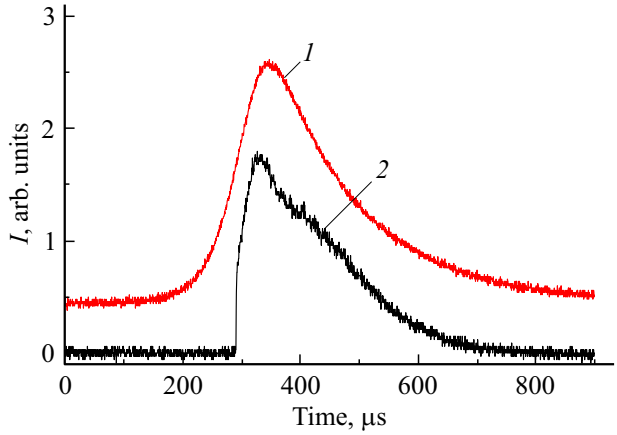

Figure 7. Oscilloscope records of the neutron pumping pulse (*1*) and generation pulse (*2*) at the B–X-transition of the excimer molecule $XeCl^*$ ($\lambda_{max} = 308$ nm) upon excitation of the gas mixture Ar–Xe–CCl_4 fission fragments of uranium-235. Resonance cavity „narrow-band mirror – narrow-band mirror" with a transmittance at a wavelength of 308 nm $T = 0.41\%$ for the output mirror and a reflectance $R = 99.2\%$ for the rear mirror. Gas mixture composition: Ar — 760 Torr, Xe — 40 Torr, CCl_4 — 135 mTorr.

The observed anomalies in the gain are due to the appearance in the active medium of the excimer laser of additional losses associated with the formation of Compton electrons and photoelectrons under the influence of prompt gamma rays from a nuclear reactor, which destroy excimer molecules during dissociative attachment and superelastic collisions of slow electrons. At the initial moment of time, exposure to gamma radiation promotes the formation of $XeCl^*$ molecules due to the ionizing effect of gamma radiation. However, as the population of these molecules increases, the process of their destruction by the resulting electrons in the (1)–(3) reactions increases. It was shown in the papers [13–15] that the rate constants of these reactions lie in the range of values from $2 \cdot 10^{-7}$ to $4 \cdot 10^{-7}$ cm^3/s.

The loss coefficient of the active medium Ar–Xe CCl_4 of the laser at the moment of action of the gamma radiation pulse can be determined in the time interval $150-250\,\mu$s from the oscilloscope records of the pumping thermal neutron pulse and the luminescence pulse of the laser active medium at the lasing wavelength (Fig. 8) . Previously carried out measurements of luminescence curves at pumping of the Ar-Xe-CCl_4 gas mixture with a short ($T_u = 5$ ns) pulse of fast electrons with energy $E_e = 150$ keV showed that the plasma-chemical processes of formation and luminescence of excimer molecules $XeCl^*$ in B- and C-states at pressure of 760 Torr are completed within a few hundred nanoseconds. In this regard, at pumping by a

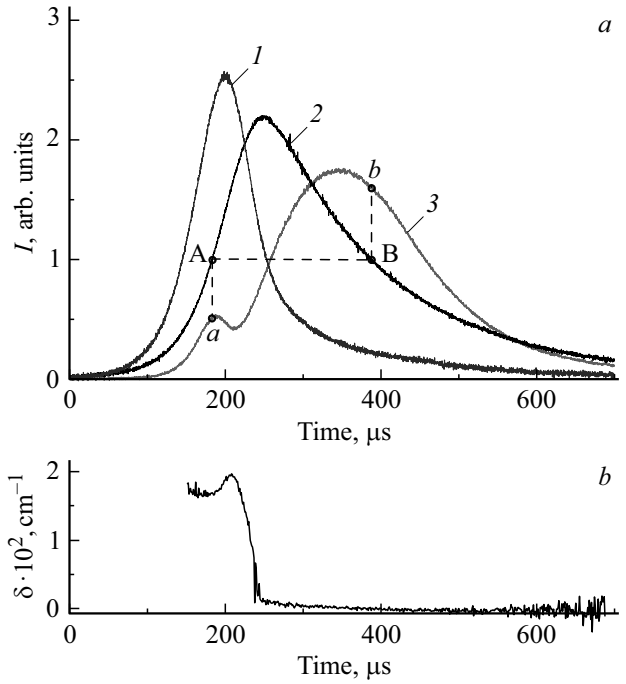

Figure 8. (*A*) Time oscilloscope records of gamma radiation pulses of a nuclear reactor (*1*), thermal pumping neutrons (*2*) and luminescence (*3*) of the gas mixture Ar–Xe–CCl_4 on wavelength 308 nm (B–X-transition $XeCl^*$) when pumped by uranium fission fragments, (*B*) time dependence of the loss coefficient δ created by gamma radiation. Gas mixture: Ar — 750 Torr, Xe — 15 Torr, CCl_4 — 50 mTorr. Resonator cavity „quartz window-narrow-band mirror" with mirror reflection $R = 99\%$ ($\lambda = 352$ nm).

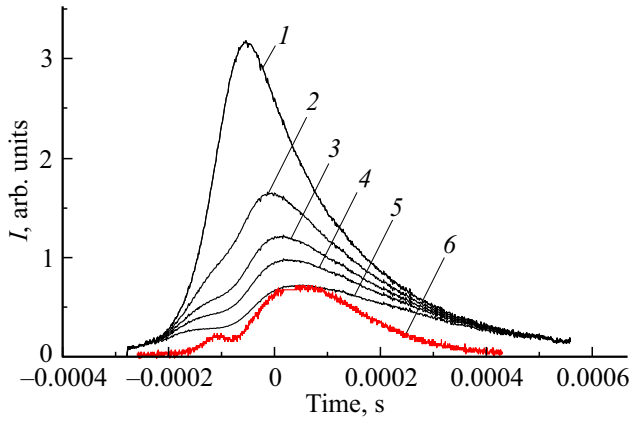

Figure 9. Calculations of temporal luminescence spectra of the B–X-band of the excimer molecule $XeCl^*$ ($\lambda_{max} = 308$ nm) at pumping by mixed gamma-neutron radiation from a nuclear reactor. *1–5* — results of solving equation (12) at $k = 2 \cdot 10^{-7}$ (*1*), $4 \cdot 10^{-7}$ (*2*), $6 \cdot 10^{-7}$ (*3*), $8 \cdot 10^{-7}$ (*4*), 10^{-6} cm^3/s (*5*); *6* — measured spectrum.

pulse lasting hundreds of microseconds, the features of the formation process dynamics of excimer molecules can be ignored and considered as a quasi-continuous process.

We will assume that the processes of formation and quenching of excimer molecules $XeCl^*$ linearly depend on the level of energy input into the gas, determined by the flux of thermal pumping neutrons and prompt gamma rays. Then the points „*A*" and „*B* " (Fig. 8) characterize the same energy input into the active medium from the neutron pumping component, obtained at different levels of exposure to gamma radiation on the active medium of the laser. Denoting I_a and I_b as the radiation intensities B– of the X-band $XeCl^*$ ($\lambda_{max} = 308$ nm) at the times t_a and t_b, we find

$$I_a(t_a) = I_0 \exp[\mu L - \delta(t_a)L], \tag{9}$$

$$I_b(t_b) = I_0 \exp(\mu L). \tag{10}$$

Here I_0 characterizes the pumping level; $\mu(\lambda)$ and $\delta(\lambda)$ — gain and loss factors of the active medium; L — resonant cavity length.

For a single-pass cell (angle cuvette), dividing (9) by (10), we obtain

$$\delta(t_a) = -(1/L)\ln[I_a(t_a)/I_b(t_b)],\ \text{cm}^{-1}. \tag{11}$$

The value of the loss coefficient $\delta(t)$ caused by the action of prompt gamma rays is shown in Fig. 8 for the time interval 150–250 μs. The data were obtained by processing oscilloscope records (2) and (3) with a time step 0.7 μs using formulas (9) – (11). For our experimental conditions, the maximum value of the loss coefficient ($\delta \approx 2 \cdot 10^{-2}$ cm^{-1}) is achieved at the moment of the maximum gamma radiation flux. The coefficient δ is not a constant value, but depends on the population of the operating level, when the process of direct destruction of excimer molecules by electrons begins, since the presence of an additional external source of fast pumping electrons in the form of gamma radiation changes the electronic balance of the plasma and leads to the appearance of electrons capable of participating in reactions (1)–(3).

The formation and decay of excimer molecules $XeCl^*$ in the active medium of a laser in the presence of prompt gamma rays can be described by the balance equation

$$d[XeCl^*]/dt = \alpha(R_\gamma + R_f) - A[XeCl^*] - k[XeCl^*]R_\gamma. \tag{12}$$

Here $R_\gamma(t)$ and $R_f(t)$ — rates of electron formation by prompt gamma rays and electron-ion pairs of buffer gas by uranium fission fragments at the moment of time t, $cm^{-3} \cdot s^{-1}$; $\alpha \approx 0.1$ — efficiency of formation of excimer molecule $XeCl^*$ per one electron-ion pair of buffer gas; $[XeCl^*]$ - population of the B-state of the molecule $XeCl^*, cm^{-3}$ The terms of the equation $A[XeCl^*(t)]$ and $k[XeCl^*(t)]R_\gamma(t)$ describe the rates of spontaneous decay of $XeCl^*$ molecules and their destruction by electrons created by instantaneous gamma-quanta. The numerical values of $R_\gamma(t)$ and $R_f(t)$ are determined based on measurements of the dose of prompt gamma rays at the location of the laser element and the specific energy input of fission fragments into the active medium of the laser per pulse. The measurements showed that the gamma radiation dose per pulse

is 37 Gr (1 Gr= 100 rad= $2.37 \cdot 10^{11}$ pair ion/cm^3), and the specific energy input from uranium fission fragments was 250 mJ/ cm^3 These values correspond to the formation in the active medium of the laser $8.773 \cdot 10^{12}$ electron/cm^3 due to prompt gamma rays and $5.823 \cdot 10^{16}$ pair ion Ar/cm^3 due to uranium fission fragments [16]. If $G(t)$ — the flux density of instantaneous gamma-quanta recorded by the F-22 detector at the time instant t, and $N(t)$ — respectively the flux density of pumping thermal neutrons recorded by the evacuated neutron chamber KNT-5, then $R_\gamma(t)$ and $R_f(t)$ can be written as

$$R_\gamma(t) = 8.773 \cdot 10^{12} G(t) / \int G(t)dt \qquad (13)$$

and

$$R_f(t) = 5.823 \cdot 10^{16} N(t) / \int N(t)dt. \qquad (14)$$

Integration is performed over the entire duration of the pulses.

The time equation (12) was solved in a quasi-stationary approximation with respect to [XeCl*] for various values of the coefficient k- from 0 to 1.10^{-6} cm^3/s with step 1 μs. The calculation results are shown on Fig. 9. There is a satisfactory agreement with experiment for the values $k \approx 8.10^{-7} - 10^{-6}$ cm^3/s.

Conclusion

Experimental studies have been carried out on the lasing characteristics of a nuclear-pumped laser using the B−X- and C−A-transitions of the XeCl* excimer molecule with excitation of the active medium by mixed gamma-neutron radiation from a nuclear reactor. Quasi-continuous lasing with a duration of more than100 μs with a wavelength of 352 nm occurred at a threshold energy input into the gas $\sim 200-250$ W/cm^3 when using a resonant cavity„window − narrow-band mirror“ with a mirror reflectance $R = 99\%$, and with a wavelength 308 nm with a threshold energy input into the gas $\sim 100-125$ W/cm^3 when using a resonant cavity „mirror − mirror“ with transmittance coefficients $T = 0.41\%$ for the output mirror and reflection $R = 99.2\%$ for the reflective mirror at a wavelength of 308 nm. In the presence of a resonator, the radiation intensities of the B−X- and C−A-bands of the excimer molecule XeCl* increased by 10−30 times. There was a decrease in the gain of the active medium of the laser at the moment of exposure to a gamma radiation pulse from a nuclear reactor due to the destruction of excimer molecules XeCl* during superelastic collisions and dissociative attachment of electrons formed during Compton scattering and photoelectric absorption of gamma quanta. For our experimental conditions, the maximum value of the loss coefficient ($\delta = 2.10^{-2}$ cm^{-1}) is achieved at the moment of the maximum gamma-quanta. The coefficient δ is not a constant value, but depends on the population of the operating level, when the process of direct destruction of excimer molecules by electrons begins.

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