

PACS numbers: 42.55.Lt; 42.60.Lh; 41.75.Fr
DOI: 10.1070/QE2013v043n11ABEH015134

Spontaneous and induced emission of $XeCl^*$ excimer molecules under pumping of $Xe-CCl_4$ and $Ar-Xe-CCl_4$ gas mixtures with a low CCl_4 content by fast electrons and uranium fission fragments

A.I. Mis'kevich, J. Guo, Yu.A. Dyuzhov

Abstract. **The spontaneous and induced emission of $XeCl^*$ excimer molecules upon excitation of $Xe-CCl_4$ and $Ar-Xe-CCl_4$ gas mixtures with a low CCl_4 content by high-energy charged particles [a pulsed high-energy electron beam and products of neutron nuclear reaction $^{235}U(n, f)$] has been experimentally studied. The electron energy was 150 keV, and the pump current pulse duration and amplitude were 5 ns and 5 A, respectively. The energy of fission fragments did not exceed 100 MeV, the duration of the neutron pump pulse was 200 μs, and the specific power contribution to the gas was about 300 W cm^{-3}. Electron beam pumping in a cell 4 cm long with a cavity having an output mirror transmittance of 2.7% gives rise to lasing on the B → X transition in the $XeCl^*$ molecule (λ = 308 nm) with a gain α = 0.0085 cm^{-1} and fluorescence efficiency $\eta \approx 10\%$. Pumping by fission fragments in a 250-cm-long cell with a cavity formed by a highly reflecting mirror and a quartz window implements amplified spontaneous emission (ASE) with an output power of 40–50 kW sr^{-1} and a base ASE pulse duration of ~200 μs.**

Keywords: *active medium, excimer, luminescence, $XeCl^*$, nuclear pumping.*

1. Introduction

Nuclear-pumped lasers operate at low specific power contributions to the gas active medium, generally less than 10^4 W cm^{-3}. Their high energy characteristics are implemented due to the large pump pulse duration (from several hundreds of microseconds up to cw lasing) and the possibility of exciting large (up to several cubic meters) volumes of the active medium [1]. Currently, the specific laser energy output under nuclear pumping reaches 32 J L^{-1} at a pulse duration of 200 μs and an efficiency $\eta \sim 3\%$ of the energy of nuclear reaction products introduced into the gas medium [2]. The working characteristics of these lasers can be improved using media with a high lasing quantum efficiency, which is typical, in particular, of halogen-containing excimer molecules of inert gases. An example of such molecules is the $XeCl^*$ molecule: the quantum efficiency of the B–X transition in it (λ = 308 nm) is ~27%. The purpose of our work was to establish the possibility of using $XeCl^*$ excimer molecules as an active medium for nuclear-pumped lasers.

A.I. Mis'kevich, J. Guo, Yu.A. Dyuzhov National Research Nuclear University 'MEPhI', Kashirskoe shosse 31, 115409 Moscow, Russia; e-mail: miskev@mail.ru, hellogjb@yahoo.com.cn, yu.dyuz@gmail.com

Received 29 January 2013; revision received 31 May 2013
Kvantovaya Elektronika **43** (11) 1003–1008 (2013)
Translated by Yu.P. Sin'kov

The radiative lifetime of the B state of $XeCl^*$ is 11 ns, and the emission band half-width is 1.4 nm [3, 4]. The potential-well depth of the X state is about 30 mV [5], a value comparable with the energy of atomic thermal motion. In this context, the inverse population of levels for the B–X transitions in the $XeCl^*$ molecule should exist even at very low pump levels. However, experimental results show that the induced emission on transitions in the $XeCl^*$ molecule arises at very high pump levels: 0.3–3 MW cm^{-3} [6–8]. This can be caused by the large width of the upper lasing level, its low excitation efficiency, and high intracavity losses.

The most efficient chlorine-containing donor for forming $XeCl^*$ and Xe_2Cl^* excimer molecules is carbon tetrachloride CCl_4 [9]. It was shown in [10] that the excitation efficiencies of the B state of the $XeCl^*$ molecule and the $4^2\Gamma$ state of the Xe_2Cl^* molecule depend strongly on the partial pressure of halogen-containing donor CCl_4 in the gas mixture and increases many times under low (30–50 mTorr) pressures. In these gas mixtures (with a low CCl_4 content), amplification of induced emission was revealed in the entire $4^2\Gamma-1,2,3^2\Gamma$ band of the Xe_2Cl^* excimer molecule with a width $\Delta\lambda$ = 90 nm at a specific power contribution to the gas of about 7 kW cm^{-3} in a laser cell 4 cm long, under pumping by 150-keV electrons [11].

In this paper we report the implementation of low-threshold quasi-cw lasing on the B–X transitions in the $XeCl^*$ molecule under pumping of $Xe-CCl_4$ and $Ar-Xe-CCl_4$ gas mixtures with a low CCl_4 content by high-energy particles. The gas mixtures were excited by a pulsed high-energy electron beam at a specific energy contribution to the gas of less than 10 kW cm^{-3} (E_e = 150 keV, beam current 5 A, pulse duration 5×10^{-9} s) and products of neutron nuclear reaction $^{235}U(n, f)$ with an energy of ~100 MeV (^{235}U fission fragments) at a specific power contribution of ~300 W cm^{-3} to the gas and neutron pump pulse duration of about 200 μs.

2. Experimental setup

Electron-beam experiments were performed on a setup schematically shown in Fig. 1. $Xe-CCl_4$ and $Ar-Xe-CCl_4$ gas mixtures of different compositions (Ar, Xe, and CCl_4 partial pressures were, respectively, 1140, 10–150, and 0.038–2 Torr) were fed into a stainless-steel cell (*1*) (ø110 × 130 mm). The cell had two flanges (*2*) on the lateral surface for mounting quartz windows or laser mirrors (ø40 × 10 mm). An IMA-150E pulsed tube (*3*) with an explosive-emission cathode, forming a pulsed high-energy (150 keV) electron beam with an FWHM ~5 ns, was mounted on the lower end face of the cell. The electron beam was introduced into the cell perpendicular to the optical cavity axis; the length of the

excited active laser medium was ~4 cm. Figure 2 shows the shape of the current pulse for the pump electron beam introduced into the cell (measured by a plane probe) and the spatial distribution of the beam current density on the cavity axis at the beginning of the pump pulse action. Due to the strong transverse and longitudinal beam inhomogeneities and the large path length of 150-keV electrons in the gas mixture, which exceeds the transverse sizes of the active laser medium, the specific energy contribution to the active laser medium was less than 10 kW cm^{-3} for a 5-ns pump pulse.

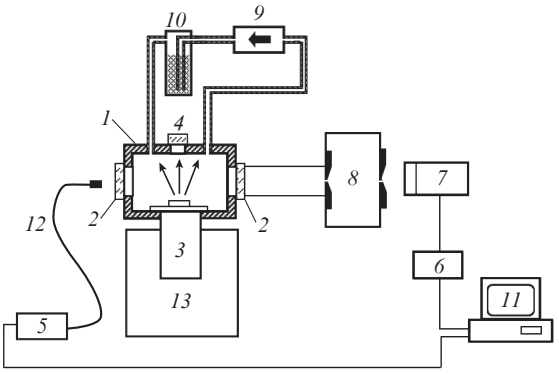

Figure 1. Schematic of the experimental setup: (*1*) chamber; (*2*) flange with a quartz window or mirror; (*3*) IMA-150E pulsed tube; (*4*) upper quartz window; (*5*) MAYA-2000Pro spectrometer; (*6*) RigolDS5022 digital oscilloscope; (*7*) FEU-106 (FEU-62) photomultiplier; (*8*) MDR-23 monochromator; (*9*) circulation pump; (*10*) titanium filter; (*11*) IBM PC; (*12*) quartz optical guide with an input lens; and (*13*) Arina-2 electron beam accelerator.

Two quartz windows or two narrow-band spherical mirrors on a quartz substrate with multilayer dielectric coatings having a high reflectance (ρ_1 = 99.8% and ρ_2 = 97.3%) at a wavelength of 308 nm were mounted on the lateral flanges of cell (*2*). Being appropriately aligned, these mirrors formed an optical cavity. The quartz windows were used to measure the spectral and temporal characteristics of spontaneous emission of Xe–CCl_4 and Ar–Xe–CCl_4 gas mixtures. There was the third quartz window (*4*) on the upper lid of the cell, through which spontaneous radiation from the gas mixture during lasing could be measured by an MAYA-2000Pro spectrometer (*5*) with a CCD array.

Time signals were recorded by an RIGOL DS 5022ME fast digital oscilloscope (*6*) using an FEU-106 or FEU-62 photomultiplier (*7*), mounted on the output slit of MDR-23 spectrometer (*8*). When carrying out experiments, the gas mixture purity was thoroughly controlled. To this end, before the final preparation stage (i.e., before leaking CCl_4), the xenon-containing buffer gas was purified from the molecular impurity gases (N_2, O_2, CO_2) desorbed from the cell walls. Purification was performed directly in the cell via multiple gas circulation [using a circulation pump (*9*)] through a filter (*10*) with a titanium sponge heated to 700 °C. The designs of the circulation pump and gas purification system were described in [12].

Pumping by products of neutron nuclear reaction ^{235}U(n, f) was performed using the laser element of facility B of the BARS-6 nuclear reactor. It had a length of 250 cm, a diameter of 4.8 cm, a 5-μm-thick layer of metallic ^{235}U on the inner surface, and two multilayer dielectric mirrors (playing the role of windows) [13]. The laser element was pumped by a neutron pulse (FWHM ~200 μs) from the BARS-6 reactor; the volume of the excited active medium was 4 L at a specific power contribution to the gas up to 300 W cm^{-3}. When mirrors were mounted or replaced, the laser element was evacuated by a turbomolecular pump to a residual pressure of 3 × 10^{-2} Torr and filled with a gas from a balloon with a previously prepared gas mixture without additional gas purification. The laser element was not refilled after each pump pulse.

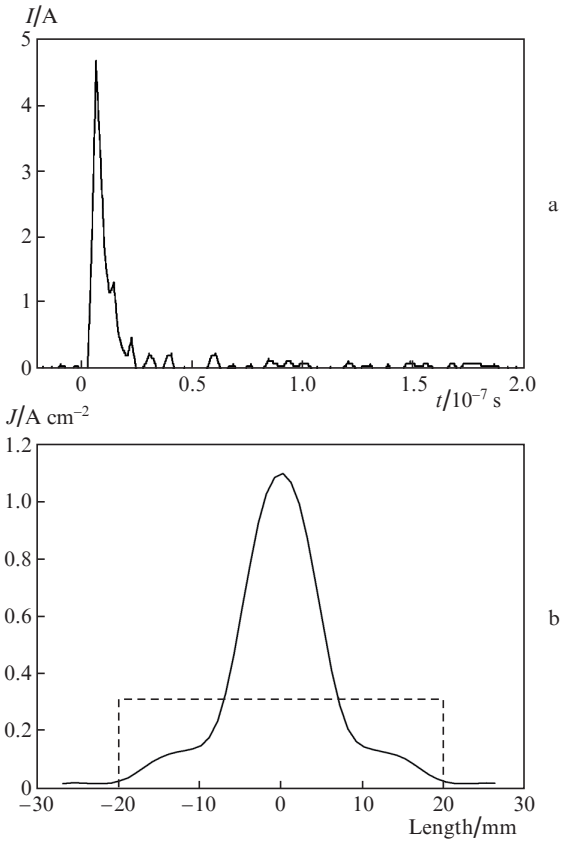

Figure 2. (a) Oscillogram of a pump pulse of electron beam current I introduced into the cell and (b) the spatial distribution of the electron beam current density J along the cell axis at the beginning of the pump pulse action. The dashed line shows the averaged value of pump electron beam current density on the laser axis (l = 4 cm).

3. Results and discussion

The spontaneous emission spectra of Xe–CCl_4 and Ar–Xe–CCl_4 gas mixtures of different compositions are shown in Fig. 3. The blue-green spectral range (430–650 nm) contains a continuum, assigned to the $4^2\Gamma - 1^2$, 2^2, $3^2\Gamma$ transitions in the Xe_2Cl^* molecule and relatively narrow bands at λ = 308, 345, and 282 nm, which are assigned to the B–X, C–A, and D–X transitions in the $XeCl^*$ molecule. All spectra were recorded under identical conditions of electron-beam excitation.

$XeCl^*$ excimer molecules are formed in the Xe–CCl_4binary gas mixture via the ion–ion recombination channel [14],

$$Xe^+ + Cl^- + (M) \rightarrow XeCl^* + (M),\ k_1 = 5 \times 10^{-9}\ cm^3\ s^{-1}, \quad (1)$$

and in the reaction with participation of CCl_4 molecules and metastable $Xe^*(6s\,^3P_2)$ atoms [15],

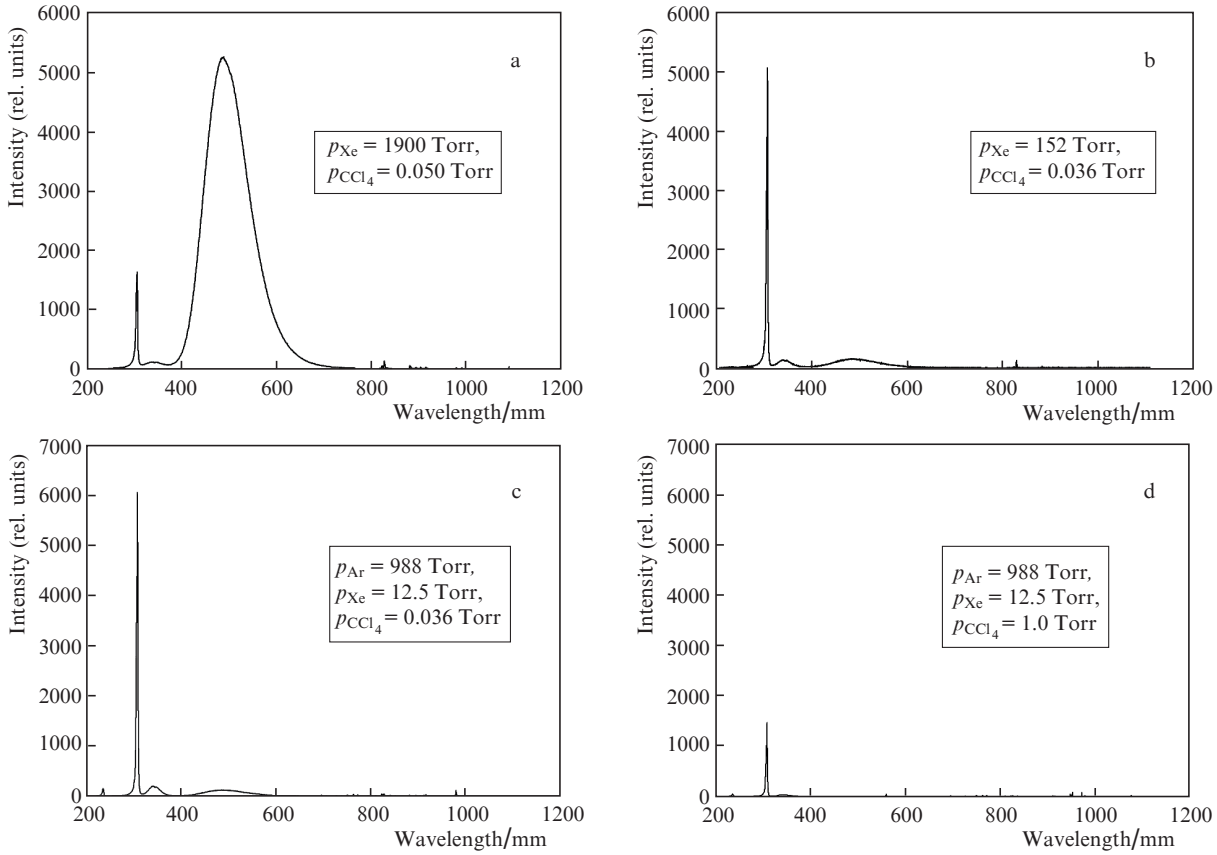

Figure 3. Spontaneous emission spectra of XeCl* and Xe_2Cl^* molecules in (a, b) $Xe-CCl_4$ and (c, d) $Ar-Xe-CCl_4$ gas mixtures of different compositions upon excitation by a pulsed high-energy electron beam with an energy of 150 keV.

$$Xe^*(6s\,^3P_2) + CCl_4 \rightarrow XeCl^* + CCl_3,$$

$$k_2 = 8 \times 10^{-11}\ cm^3\ s^{-1}. \quad (2)$$

Xe^+ ions and excited Xe^* atoms are formed directly by a primary charged high-energy particle during its moderation in the gas medium. Among all possible excited states of Xe atom, the low-lying levels, optically coupled to the ground state of the atom, have the highest excitation probability [16]. Negative Cl^- ions are formed in the reaction of dissociative attachment of low-energy electrons to CCl_4 molecules [17]:

$$CCl_4 + e \rightarrow CCl_3 + Cl^-. \quad (3)$$

CCl_4^- ions are not formed because the dissociation energy in the reaction

$$CCl_4^- \rightarrow CCl_3 + Cl^- \quad (4)$$

is 0.5 eV below the energy of the ground state of the CCl_4^- molecule. Being attached, high-energy (few electronvolts) electrons can more efficiently destroy CCl_4 molecules and form CCl_3^-, CCl_2^- and Cl_2^- ions [17, 18]. According to the data of [18], the attachment cross section of electrons with an energy $E_e = 0.05$ eV to CCl_4 molecules is $2.22 \times 10^{-14}\ cm^2$. This value corresponds to the attachment rate constant $k_a \approx 2.2 \times 10^{-7}\ cm^3\ s^{-1}$. At a partial pressure of halogen-containing donor of 30 mTorr, the electron attachment time amounts to few nanoseconds.

$XeCl^*$ molecules in a $Xe-CCl_4$ gas mixture are quenched during their collisions with CCl_4 molecules and Xe atoms. At low donor pressures (below 1 Torr), the reaction constant rates for XeCl* quenching by CCl_4 molecules and Xe atoms are, respectively, 1.98×10^{-9} and $1.4 \times 10^{-12}\ cm^3\ s^{-1}$ at p_{Xe} = 500 Torr [10]. An increase in the Xe pressure leads to an increase in the conversion rate of atomic Xe^+ ions into molecular Xe^{2+} ions [3]:

$$Xe^+ + 2Xe \rightarrow Xe_2^+ + Xe,\ k_3 = 2.5 \times 10^{-31}\ cm^6\ s^{-1}. \quad (5)$$

This channel leads to a decrease in the concentration of Xe^+ ions in the mixture and, therefore, to a decrease in the concentration of $XeCl^*$ molecules produced in reaction (1).

Thus, to implement efficient lasing on the B–X transition in the $XeCl^*$ molecule (λ = 308 nm) using a $Xe-CCl_4$ binary gas mixture, one should maintain low partial pressures of CCl_4 ($p_{CCl_4} \ll 1$ Torr) and Xe ($p_{Xe} \ll 100-200$ Torr) in it. To increase the energy contribution to a gas mixture with a low xenon content, it is necessary to introduce a buffer gas (Ne, Ar) at a pressure of few atmospheres.

Lasing experiments with mixtures having a low content of CCl_4 donor were performed using pumping of $Xe-CCl_4$ and $Ar-Xe-CCl_4$ gas mixtures by a pulsed low-power electron beam; $Ar-Xe-CCl_4$ mixtures were also pumped by ^{235}U fission fragments. We used mixtures of the following compositions: Xe (152 Torr)–CCl_4 (36 mTorr) and Ar (1140 Torr)–Xe (12.5 Torr)–CCl_4 (37 mTorr) for electron beam pumping and Ar (1000 Torr)–Xe (15 Torr)–CCl_4 (50 mTorr) for pumping by ^{235}U fission fragments.

3.1. Experimental data on pumping XeCl* excimer molecules by a high-energy electron beam

The distance between the mirrors in the laser cell (Fig. 1) was 19 cm, while the length of the active laser medium was only 4 cm. The amplitude value of the fast-electron current density on the laser-cell axis, averaged over the active-medium length, was ~0.4 A cm^{-2} (Fig. 2b). The input lens of the optical guide of Maya-2000Pro spectrometer was located on the cavity optical axis at a distance of 100–200 mm from the output mirror. The spectrometer recorded the radiation passing through the output mirror, with the resonator either tuned or untuned. The spectrometer resolution was 1 nm. Simultaneously with measuring the radiation spectral composition using an RIGOL DS 5022 ME oscilloscope and an MDR-23 monochromator, the shape of 308-nm pulse was recorded. The corresponding spectrograms and oscillograms are shown in Figs 4 and 5.

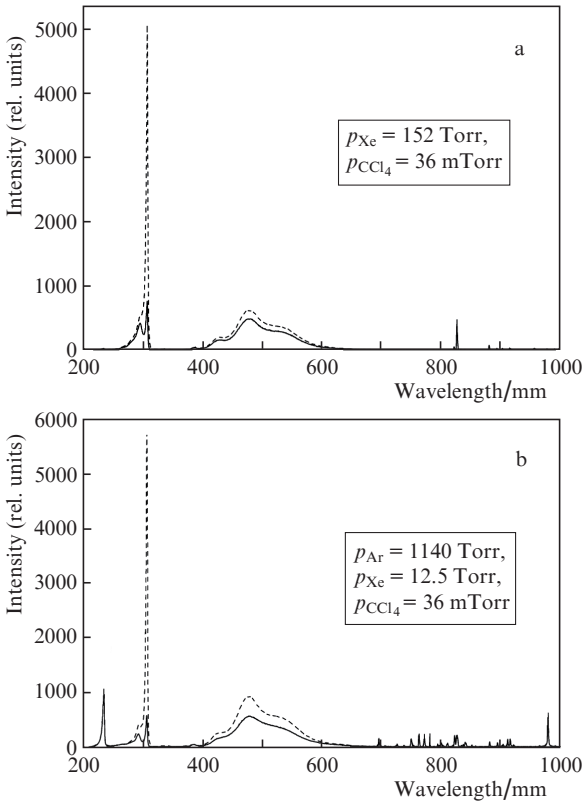

Figure 4. Emission spectra at a wavelength of ~308 nm in (a) Xe–CCl_4 and (b) Ar–Xe–CCl_4 mixtures for (dashed lines) tuned and (solid lines) untuned resonators (pumping by a pulsed high-energy electron beam with an energy of 150 keV and a pulse duration of 5 ns at a specific power contribution to the active laser medium of ~7 kW cm^{-3}).

The experiments revealed low-threshold lasing at $\lambda = 308$ nm on the B–X transition in the XeCl* molecule using mirrors with reflectances of 99.8 and 97.3% at $\lambda = 308$ nm and a transmittance of 60%–80% beyond this wavelength. The lasing time for Ar–Xe–CCl_4 gas mixtures was about 120 ns, a value greatly exceeding the pump pulse duration (5 ns) and the radiative time of the B–X transition in the XeCl* molecule (11 ns). This fact indicates the possibility of implementing quasi-cw lasing on the B–X transition in the XeCl* molecule under pumping by a long pulse.

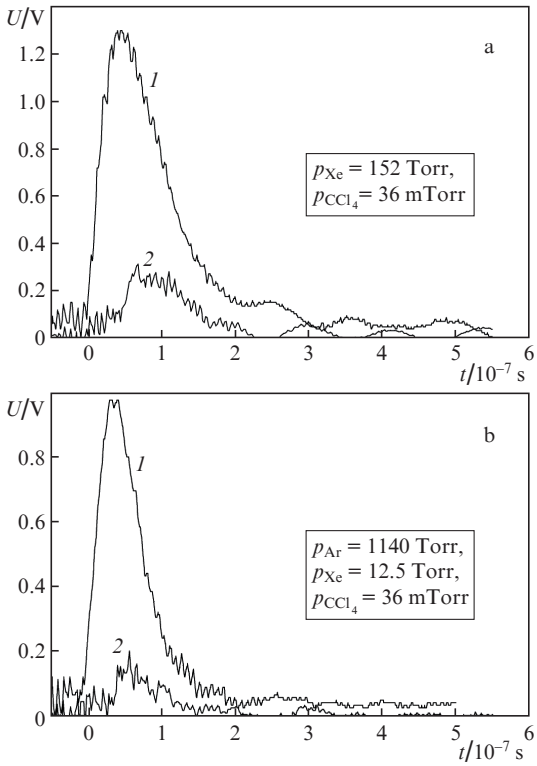

Figure 5. Oscillograms of radiation pulses with a wavelength of ~308 nm in (a) Xe–CCl_4 and (b) Ar–Xe–CCl_4 mixtures for (*1*) tuned and (*2*) untuned resonators (pumping by a pulsed high-energy electron beam with an energy of 150 keV and a pulse duration of 5 ns at a specific power contribution to the active laser medium of less than 10 kW cm^{-3}.

Lasing pulse oscillograms (Fig. 5) make it possible to estimate the active-medium gain. Considering the successive light beam passage between mirrors in an amplifying medium, one can show that, under unsaturated-gain conditions, the pulse current amplitudes U_1 and U_2, recorded by the photodetector at the initial instants of lasing development, t_1 and t_2, are related as follows:

$$U_1/U_2 = (\rho_1\rho_2)^m \exp(2m\kappa L). \quad (6)$$

Here, ρ_1 and ρ_2 are, respectively, the reflectances of the highly reflecting and output mirrors; κ is the active-medium gain; $m = c(t_1 - t_2)/2L_0$ is the number of light beam passes between the mirrors per a time interval $t_1 - t_2$; L is the active-medium length; and L_0 is the distance between the mirrors. Thus, we have

$$\kappa = [\ln(U_1/U_2) - m\ln(\rho_1\rho_2)]/(2mL). \quad (7)$$

For our experimental conditions, $\rho_1 = 0.998$, $\rho_2 = 0.973$, $L = 4$ cm, $L_0 = 19$ cm, and $U_1/U_2 \approx 1.207$ (for the instants $t_1 = 15$ ns and $t_2 = 10$ ns after the lasing onset; the range $t_1 - t_2 = 5$ ns corresponds to four cavity passes). Hence, $\kappa = 0.0085$ cm^{-1}.

The induced-emission cross section for the B–X transition in the XeCl* molecule is determined by the molecular properties and amounts to [3]

$$\sigma(308\text{ nm}) = (1/4\pi)(\ln 2/\pi)^{0.5} A\lambda^4/(c\Delta\lambda) = 7.275 \times 10^{-16}\text{ cm}^2. \quad (8)$$

Here, $\lambda = 3.08 \times 10^{-5}$ cm, $\Delta\lambda = 1.4 \times 10^{-7}$ cm, and $A = 10^9/11 = 9.09 \times 10^7$ s^{-1}.

Since $\kappa = \sigma(308\text{ nm})\Delta N$, one can determine the inverse population ΔN of the upper working level of $XeCl^*$ molecule:

$$\Delta N = \kappa/\sigma(308\text{ nm}) = 0.0085/7.286 \times 10^{-16} = 1.16 \times 10^{13}\text{ cm}^{-3}. \quad (9)$$

The specific power contribution to the $Ar-Xe-CCl_4$ gas mixture is $w = I_{av}E_0/R(E_0)$, where $I_{av} = 0.4$ A cm^{-2} is the averaged current density on the laser-cell axis (Fig. 2b), $E_0 = 1.56 \times 10^5$ eV is the electron-beam energy, and $R(E_0) = 8.51$ cm is the electron path length in the $Ar-Xe-CCl_4$ gas mixture ($p_{Ar} = 1.5$ atm, $p_{Xe} = 12.5$ Torr, and $p_{CCl_4} = 0.036$ Torr). Using these values, we obtain $w = 7.05$ kWcm^{-3}. Hence, the fluorescence efficiency on the B–X transition in the $XeCl^*$ molecule is

$$\eta = \Delta NAhv/w = 668/7.05 \times 10^3 = 9.48\%. \quad (10)$$

These experimental results make it possible to design an excimer nuclear pumped laser, because the specific power contribution to the gas medium that is necessary for its operation (less than 10 kW cm^{-3}) can be attained with the existing pulsed nuclear reactors. To verify this suggestion, we performed experiments on pumping an $Ar-Xe-CCl_4$ gas mixture by products of nuclear reaction $^{235}U(n, f)$ using the BARS-6 nuclear reactor.

3.2. Experimental data on pumping $XeCl^*$ excimer molecules by ^{235}U fission fragments

The laser element was placed near the active cores of the two-core BARS-6 nuclear reactor at a distance of 45 cm from their lateral surface [13]. The peak specific power contribution to the active laser medium for a nominal neutron pulse of the reactor (2×10^{17} divisions in both reactor regions), averaged over the laser-element length, was 300 W cm^{-3}. The laser-element resonator was formed by narrow-band mirrors with multilayer dielectric coatings, which had a maximum reflectance in the vicinity of 308 nm. We used three sets of these mirrors with the following reflectances: (1) 99.5% and 99% at $\lambda = 308$ nm with an output-mirror transmittance $T = 0.3\%$ at $\lambda = 308$ nm and a transmittance of 60%–80% beyond this wavelength, (2) 99.5% and 98.25% at $\lambda = 308$ nm with an output-mirror transmittance $T = 1.4\%$, and (3) 99.5% at $\lambda = 308$ nm and a quartz window used as an output mirror with a transmittance $T = 91.3\%$.

The spectral composition of the radiation was recorded on an MAYA-2000Pro spectrometer. An MDR-52 monochromator with a photomultiplier was used for temporal measurements of 308-nm radiation intensity. Both instruments were located at a distance of ~20 m from the laser-element output mirror. A thermocouple meter of radiation energy with a narrow-band reflection filter tuned to $\lambda = 308$ nm was mounted at a distance of 2 m from the output mirror. The shape of the reactor neutron pulse in the neutron moderator was recorded in a KNT-5 fission chamber.

The main results are presented in Figs 6 and 7. The oscillograms of the thermal-neutron pump pulse and laser-element radiation pulse ($\lambda = 308$ nm) under pumping by uranium fission fragments are shown in Fig. 6, and the spectrogram of output radiation of the laser element with cavities of three aforementioned types are presented in Fig. 7. Note narrowing of the emission band width at $\lambda = 308$ nm and an increase in its intensity with an increase in the output mirror transmittance. The highest intensity of output radiation is obtained when a quartz window is used as an output mirror (Fig. 7c). In this case, the output radiation is formed mainly during two passes through the laser element; its intensity differs only slightly from the intracavity radiation intensity, determined from the spectra presented in Figs 7a and 7b (with allowance for the transmittance of highly reflecting mirrors). This fact indicates that enhanced spontaneous emission occurs in the 250-cm-long laser element pumped by uranium fission fragments. This radiation power, measured with a quartz window and recalculated with allowance for the measurement geometry, was found to be 40–50 kW sr^{-1} with a base pulse duration of ~200 μs, at a fluorescence efficiency on the B–X transition in the $XeCl^*$ molecule of ~10%.

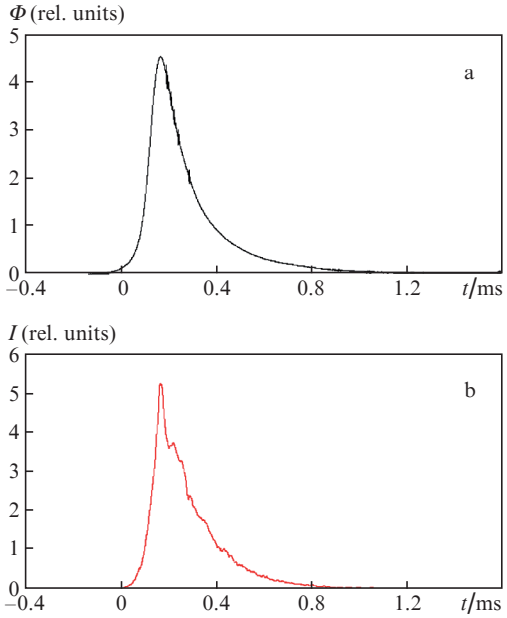

Figure 6. Oscillograms of (a) a pump neutron pulse from the BARS-6 reactor and (b) the 308-nm laser pulse.

Questions concerning the stability of the properties of gas mixtures with a low CCl_4 donor content, possible burning out of this component under pumping, and its radiation resistance may arise. Three experimental studies [19–21] devoted to these problems did not reveal any obstacles for using CCl_4 donor in low concentrations (~30 mTorr) under pumping by uranium fission fragments [19] and products of nuclear reaction $^3He(n, p)^3T$ [20, 21]. Our experiments confirmed the long-term (30 days) stability of the $Ar-Xe-CCl_4$ gas mixture and the possibility of using it multiply under pumping by a pulsed electron beam and products of nuclear reaction $^{235}U(n, f)$.

4. Conclusions

The experimental study of the luminescence of $Xe-CCl_4$ and $Ar-Xe-CCl_4$ gas mixtures pumped by a pulsed high-energy electron beam showed that a necessary condition for efficient lasing on the B–X transition in $XeCl^*$ molecules ($\lambda = 308$ nm) in $Ar-Xe-CCl_4$ and $Xe-CCl_4$ gas mixtures is to maintain a low partial pressure of chlorine-containing donor CCl_4 ($p_{CCl_4} \ll 1$ Torr) and low Xe partial pressure ($p_{Xe} \sim 12$ Torr) in the working mixture. Pumping of these CCl_4-poor gas mixtures by a pulsed high-energy electron beam of moderate

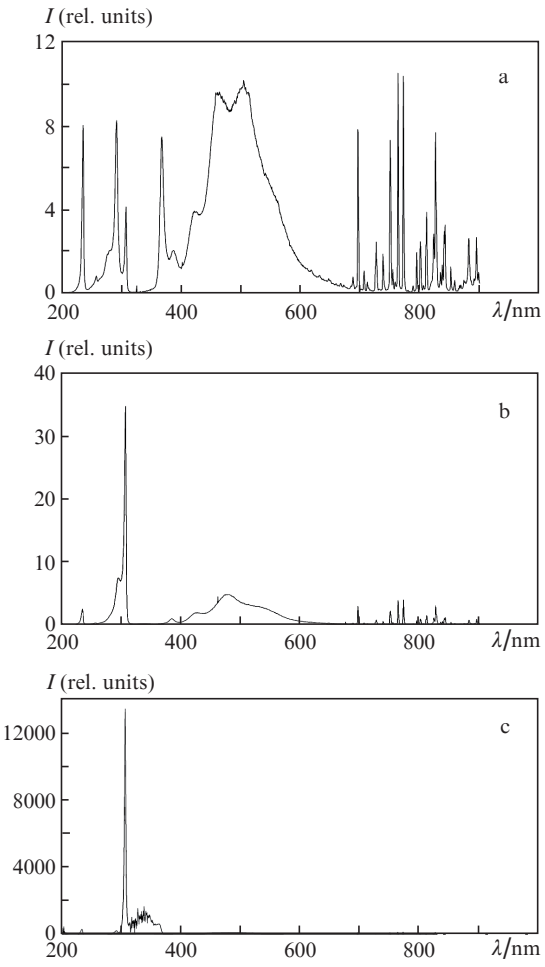

Figure 7. Output radiation spectra for a laser element 250 cm long, with a cavity formed by a totally reflecting mirror ($R = 99.5\%$) and an output mirror with T = (a) 0.3, (b) 1.4, and (c) 91.3% (pumping by uranium fission fragments with a specific power contribution to the gas mixture of ~300 W cm^{-3}). The spectra in panels (a) and (b) are mutually normalised.

power (E_e = 150 keV, I_{av} = 0.4 A, T_p = 5 ns) and a specific power contribution to the gas mixture of less than 7 kW cm^{-3} in a cell 4 cm long yielded quasi-cw lasing on the B–X transition in the XeCl* molecule (λ = 308 nm) with a gain α = 0.0085 cm^{-1} and fluorescence efficiency $\eta \sim 10\%$. Pumping of $Ar-Xe-CCl_4$ gas mixtures by uranium fission fragments formed as a result of irradiation of an uranium layer by a thermal-neutron pulse with a power contribution of ~300 W cm^{-3} to the gas mixture in a cell 250 cm long in a cavity with a totally reflecting mirror and a quartz window provided amplified spontaneous emission on the B–X transition in the XeCl* molecule (λ = 308 nm), with an output radiation power of 40–50 kW sr^{-1} and a base pulse duration of ~200 μs at fluorescence efficiency $\eta \sim 10\%$.

Our experimental results open a possibility of designing an efficient excimer nuclear-pumped laser on the B–X transition in the XeCl* molecule (λ = 308 nm), because the minimum specific power contribution to the gas medium that is necessary for lasing (less than 10 kW cm^{-3}) can be attained using the existing pulsed nuclear reactors.

Acknowledgements. This work was supported by the Russian Foundation for Basic Research (Grant No. 12-02-00382-a).

We are grateful to B.P. Merkulov (Plasma Co Ltd, Ryazan') for his technical assistance and useful consultations on the operation of the pulsed electron beam accelerator.

References

1. Mel'nikov S.P., Sizov A.N., Sinyanskii A.A. *Lazery s yadernoi nakachkoi* (Nuclear Pumped Lasers) (Sarov: FGUP RFYaTs–VNIIEF, 2008) p. 439.
2. Zagidulin A.V., Bochkov A.V., Mironenko V.V., Sofienko G.S. *Pis'ma Zh. Tekh. Fiz*., **38** (23), 31 (2012).
3. Rhodes C.K. (Ed.) *Excimer Lasers* (Berlin: Springer-Verlag, 1979; Moscow: Mir, 1981) p. 245.
4. Mavlyutov A.A. et al. *Prib. Tekh. Eksp*., (3), 114 (2001).
5. Huber K.P., Herzberg G. *Constants of Diatomic Molecules* (New York: Van Nostrand Reinhold, 1979; Moscow: Mir, 1984) p. 366.
6. Abdullin E.N., Ivanov N.G., et al. *Laser Phys*., **16**, 89 (2006).
7. Tang K.Y., Lorents D.C., Huestis D.L. *Appl. Phys. Lett*., **36** (5), 347 (1980).
8. Tittel F.K. et al. *Appl. Phys. Lett*., **36** (6), 405 (1980).
9. Marowsky G. et al. *Chem. Phys. Lett*., **98** (2), 167 (1983).
10. Mis'kevich A.I., Guo J. *Kvantovaya Elektron*., **43**, 489 (2013) [*Quantum Electron*., **43**, 489 (2013)].
11. Mis'kevich A.I., Guo J. *Pis'ma Zh. Tekh. Fiz*., **39** (8), 33 (2013).
12. Kopai-Gora A.P., Mis'kevich A.I., Salamakha B.S. *Prib. Tekh. Eksp*., (5), 171 (1986).
13. Dyuzhov Yu.A., Kukharchuk O.F., Poletaev E.D., Smol'skii V.N., et al. *Kvantovaya Elektron*., **40**, 11 (2010) [*Quantum Electron*., **40**, 11 (2010)].
14. Johnson T.H., Cartiand H.E., et al. *Appl. Phys. Lett*., **66**, 5707 (1989).
15. Kolts J.H., Velazco J.E., Setser D.W. *J. Chem. Phys*., **71**, 1247 (1979).
16. Bennett W.R. Jr. *Ann. Phys*., **18**, 367 (1962).
17. Scheunemann H.-U. et al. *Phys. Chem*., **84**, 580 (1980).
18. Braun M. et al. *J. Phys. B: At. Mol. Opt. Phys*., **42**, 125202 (2009).
19. Mel'nikov S.P., Porkhaev V.V. *Trudy II Mezhdunar. konf. 'Fizika yaderno-vozbuzhdaemoi plazmy i problemy lazerov s yadernoi nakachkoi' (Proc. II Int. Sci. Conf. 'Physics of Nuclear-Excited Plasma and Problems of Nuclear-Pumped Lasers')* (Arzamas-16, 1995) Vol. 1, p. 307.
20. Khasenov M.U., Nakiskozhaev M.T., Syrlybaev A.S., Smirnova I.I. *Opt. Atmos. Okeana*, **22**, 1057 (2009).
21. Mavlyutov A.A., Mis'kevich A.I. *Pis'ma Zh. Tekh. Fiz*., **22** (8), 48 (1996).