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OPTICAL CHARACTERISTICS OF A GAS DISCHARGE RADIATOR OF ORANGE-RED SPECTRAL RANGE

Purpose. To study the optical characteristics and parameters of gas-discharge plasma of the radiator in the orange-red spectral range, the working medium of which was a gas-discharge plasma based on mixtures of cadmium diiodide with helium and small additions of xenon.
Methods. The creation of a gas-discharge plasma and the excitation of the components of the working mixture were carried out by a pulse-periodic (pulse repetition rate of 18-20 kHz, pulse duration 150 ns) barrier discharge. Plasma parameters were calculated as total integrals of the electron energy distribution function (EEDF) based on the Boltzmann equation in the two-term approximation. EEDF calculations were carried out using the well-known Bolsig + program.
Results. Emission of exciplex molecules of cadmium monoiodide, cadmium atoms, xenon was revealed. Regularities have been established in the changes in the optical characteristics of the emitter depending on the repetition rate of the pump pulses, the component and quantitative composition of the mixtures. Regularities are determined in the transport characteristics of electrons in a plasma, as well as in the excitation rate constants of exciplex molecules of cadmium monoiodide, cadmium atoms, and xenon.
Conclusions. The research data are of interest for the creation of an excilamp that has simultaneous emission in the violet, green, red, and infrared spectral ranges. Such an excilamp can be used in biotechnology, agrophysics, for more efficient control of photosynthesis, growth, development of plants and algae, in research in quantum electronics, for pumping solid and liquid lasers and in medicine.
Keywords: gas-discharge radiation sources, barrier discharge, cadmium diiodide, exciplex molecules, helium, xenon.

Introduction

Plasma based on mixtures of cadmium diiodide vapor with inert gases is studied to create a highly efficient coherent and spontaneous (with a large area) source in the red spectral range of radiation for a number of scientific and technological applications [1–9].

In [2–6], it was found that in a barrier discharge in mixtures of cadmium diiodide vapor with inert gases and molecular nitrogen at frequencies of pump pulses of less than or equal to 6000 Hz, intense emission of an exciplex cadmium monoiodide CdI* molecule (transition $B^2\Sigma^+_{1/2} \rightarrow X^2\Sigma^+_{1/2}$ with a maximum of radiation at wavelength $\lambda = 650$ nm) observed. These experiments are limited to studying the plasma emission spectra and the dependences of the radiation intensity of cadmium monoiodide on the partial pressures of helium, neon, and nitrogen at low pulse repetition rates. The emission characteristics of a barrier-discharge plasma in multicomponent mixtures, the working life of mixtures at increased repetition rates of pump pulses (up to 20 kHz) and also the plasma parameters were not investigated.

This article presents the results of our studies on the emission characteristics and plasma parameters of a barrier discharge in mixtures of cadmium diiodide vapor with helium and small xenon additives at pump pulse repetition frequencies in the range of 18–20 kHz.

Technique and experimental conditions

Figure 1, shows the main nodes of an exciplex gas-discharge radiation source in which a single barrier discharge was used to create a plasma on a working mixture of cadmium diiodide and helium vapor. The source design was cylindrical. The side surface of the discharge tube served as an operation radiation zone

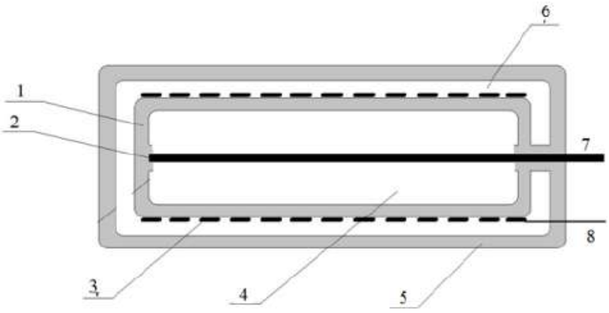

Figure 1: The main nodes of the exciplex radiation source: 1 - quartz tube, 2 - electrode, 3 - perforated electrode, 4 - discharge region, 5 - quartz tube, 6 - vacuum region, 7, 8 - electrical inputs.

An exciplex gas-discharge radiation source was made of a quartz tube with a diameter of 16 mm and a length of 220 mm (1). An electrode made of tungsten (2) of circular cross section with a diameter of 4 mm was placed in the middle of the tube along the axis. The second electrode – stainless steel (3) was perforated (with a transmittance of radiation of 50%) located on the outer surface of the tube (1). The thickness of the discharge region (4) and the burning length of the coaxial volume discharge are 12 mm and 216 mm, respectively. The exciplex source is located in a quartz tube (5), which is welded at the ends, its length is 230 mm, diameter 26 mm. Atmospheric air was removed from the volume (6) between the exciplex lamp and the quartz tube (5). A pulsed periodic voltage from a pump source was applied to the electrodes (2) and (3) through the metal – quartz inputs (7) and (8). The use of a volume (6) from which atmospheric air was removed in the design of an exciplex gas-discharge source was caused by the need to ensure high values of the partial vapor pressure of cadmium diiodide in the discharge region (4) due to an increase in the temperature of the working mixture, which in turn provided an increase in the energy characteristics of the radiation source 40% compared with the construction without volume (6).

The discharge was excited by a mixture of cadmium diiodide vapor and helium in the discharge region (4), the volume of which was 31 cm^3 from a repetitively pulsed nanosecond pulsed generator. The generator provided the amplitudes of the pulse voltage and current at the emitter electrodes at the level of 10–20 kV and 300 A, respectively, the pulse repetition rate was 18–20 kHz.

The radiation was lead out from the central region of the interelectrode space and analyzed in the visible and near UV spectral regions using an optical system (ZMR-3 monochromator and FEU-79 photomultiplier). The spectral resolution of the ZMR-3 monochromator was 44Åat a wavelength of λ = 434 nm. The optical system was calibrated by the radiation of a SI 8–200 reference tungsten lamp at a filament temperature T = 2173 K. The registration system was described in more detail in [10].

Gas mixtures were prepared directly in the interelectrode space by successively injecting heavy inert gas xenon and light buffer helium gas. Cadmium diiodide (CdI_2) in an amount of 100 mg was preloaded into the interelectrode space. Degassing of the electrode and the inner surface of the tube was carried out by heating them at a temperature of 50° C and pumping out for 2 hours. The partial vapor pressure of CdI_2 as were measured with a membrane model vacuum gauge or manometer.

The study of optical characteristics was carried out when stable electrical and emission characteristics of the plasma were achieved. A uniform discharge with the presence of filaments is visually observed. Filaments consist of two diffuse cones facing each other.

Spectral and integral characteristics

Figure 2, shows the overview radiation spectrum of a barrier discharge plasma from a mixture of cadmium diiodide vapor with helium at a pulse repetition rate of 20 kHz, voltage amplitude at the electrodes, and current through a gas discharge gap of 10 kV and 300 A, respectively. The total pressure of the mixture is 250.024 kPa.

Characteristic of this mixture is the presence of a system of spectral bands of the electronic-vibrational transition $B^2\Sigma^+_{1/2} \rightarrow X^2\Sigma^+_{1/2}$ of exciplex CdI* molecules with a radiation maximum at a wavelength of λ = 650 nm, υ' = 0-2 $\longrightarrow$ υ' = 61.62 [12], a steep increase in the intensity of these spectral bands from the side of the long-wave region and slow decline in the short-wave region. The edges of the spectral bands cover the wavelength range 470-–700 nm. With a change in the repetition rate of the pump pulses in the range of 18–-20 kHz, the shape, range, and position of the maximum emission of the spectral bands do not change; only their intensity and the ratio of intensities in the band edges change. In addition to these spectral bands, radiation is also observed on the lines λ = 479 nm and λ = 509 nm of Cd atoms, the $5p^3P_0 - 6s^3S$ transitions J = 1–1 and J = 2–1 [13,14]. With a change in the repetition rate of the pump pulses from 18 kHz to 20 kHz, the radiation intensity in the spectral bands and lines increases by 10%.

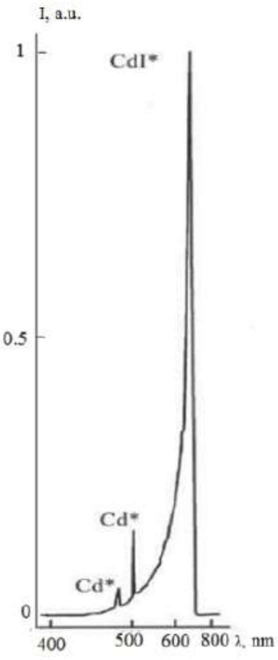

Figure 2: Survey emission spectrum of a plasma of a barrier discharge on a CdI_2: He mixture. The repetition rate of the pump pulses is f = 20 kHz, the amplitude of the voltage and current is U = 10 kV and I = 300 A, respectively. The total pressure of the mixture is p = 250. 024 kPa.

For a mixture with xenon Fig. 3, the partial pressure of cadmium diiodide is 24 Pa, the partial pressure of xenon is 4.05 kPa, the partial pressure of helium is 250 kPa) it is typical that in the plasma emission spectrum, in addition to the system of spectral transition bands ($B^2\Sigma^+_{1/2} \rightarrow X^2\Sigma^+_{1/2}$) λ^{max} = 650 nm CdI* molecules, there are cadmium atom lines λ = 479 nm and λ = 509 nm (transitions $5p^3P_0 - 6s^3S$ transitions J = 1–1 and J = 2–1), Xe atom lines λ = 823 nm, λ = 458 nm and λ = 450 nm ($6s[3/2]^0_2 - 6p[3/2]_2$, $6p[1/2]_1 - 6p^1[1/2]_0$ transitions, and $6s[3/2]^0_2 - 6p^1[1/2]_1$) [12–14].

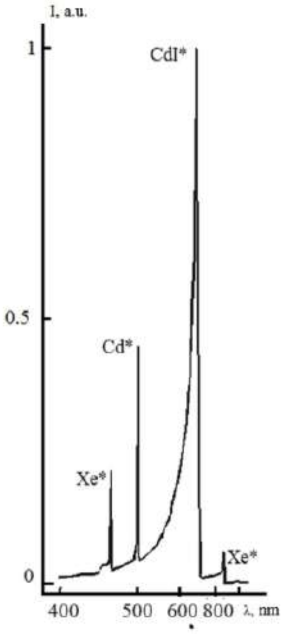

Figure 3: Survey spectrum of radiation of a barrier discharge plasma on a mixture of CdI_2 Xe: He = 0, 024: 4.05: 250 kPa (b). The repetition rate of the pump pulses is f = 20 kHz, the voltage and current amplitudes are U = 10 kV and I = 303 A, respectively.

Spectral bands and emission lines of a plasma of a barrier discharge on a mixture of cadmium diiodide vapor with helium, xenon for a pulse repetition rate of 18 kHz, their relative intensities (J/k_λ) taking into account the spectral sensitivity of the recording system (k_λ), as well as the excitation energy, are given in Table 1.

With a change in the repetition rate of the pump pulses from 18 kHz to 20 kHz, the radiation intensity in the spectral bands and lines increases by 10%. The radiation intensity of CdI* molecules in a mixture of cadmium diiodide vapor and helium at a maximum of radiation at a wavelength of λ = 650 nm exceeds the radiation intensity of cadmium atoms at wavelengths of 47 = 479.991 nm and λ = 508.582 nm by 3.4 and 1.8 times,respectively, and the radiation intensity of molecules CdI* in a mixture of vapors of cadmium, xenon and helium diiodide at a radiation maximum at a wavelength of λ = 650 nm exceeds the radiation intensity: cadmium atoms at wavelengths λ = 479.991 nm and λ = 508.582 nm, xenon atoms at wavelengths λ = 458 nm and λ = 823 nm in 3.5, 2.3, 4. 4, 8.8 times, respectively (1).

Table 1: Spectral bands and emission lines of working mixtures

λ,nm	Molecule, atom	k_λ,a.u	J/k_λ, a.u.		E,eV	References
			CdI$_2$,He	CdI$_2$:Xe:Ne		
458	Xe I	8	-	0.2	11.15	[13]
479	Cd I	13	0.82	0.25	6.39	[13]
509	Cd I	19	1.56	0.38	6.39	[13]
650	Cd I	57	2.8	0.88	5.0	[15]
823	Xe I	20	-	0.1	9.82	[13]

With an increase in the partial pressure of helium from 120 kPa to 260 kPa, a nonmonotonic change in the radiation intensity is observed: a continuous increase in the range of 120 – 250 kPa, reaching a maximum value at 250 kPa (4) and a decrease with a further increase in helium pressure.

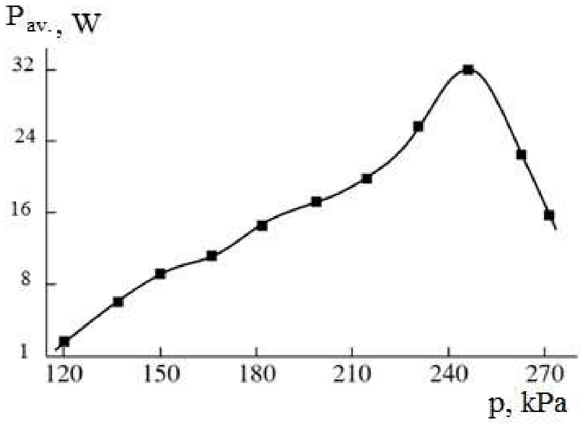

Figure 4: The dependence of the average radiation power on the partial pressure of helium. The amplitude of voltage and current is U = 10 kV and I = 300 A, respectively. The repetition rate of the pump pulses is f = 20 kHz.

Figure (5) shows the results of the dependence of the radiation intensity of the exciplex molecules of cadmium monoiodide on the xenon partial pressures. The most intense radiation of molecules occurs at a partial xenon pressure of 4 kPa.

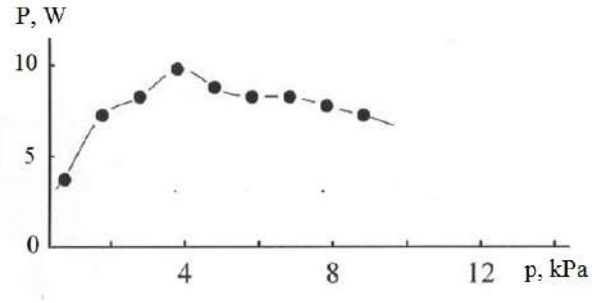

Figure 5: Dependence of the radiation power of exciplex cadmium monoiodide molecules on the xenon partial pressure in a mixture of cadmium diiodide vapor with helium and xenon. The partial vapor pressure of cadmium diiodide is 24 Pa, and helium is 250 kPa. The repetition rate of the pump pulses is 18 kHz.

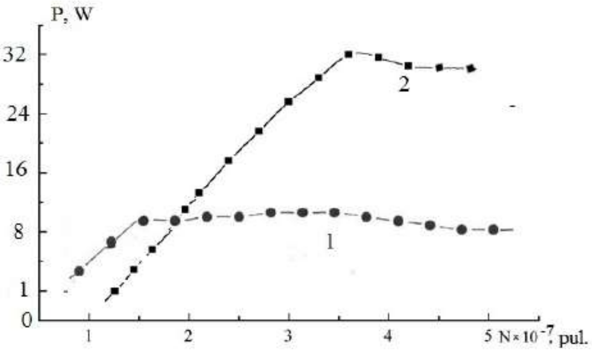

Figure 6: Dependence of the radiation power of cadmium monoiodide on the total number of pulses: 1 -CdI$_2$: Xe: He = 24 Pa: 4 kPa: 250 kPa, 2 - mixture CdI$_2$: He = 24 Pa: 250 kPa. The repetition rate of the pump pulses is f = 20 kHz.

The dependence of the radiation power of cadmium monoiodide on the number of pump pulses for a component composition (the ratio of gas components was chosen optimal – at which the maximum radiation powers of CdI* molecules are observed) is shown in 6. It is characteristic of it that the saturation of the radiation power for a mixture with xenon occurs earlier in time than for mixtures only with helium. In addition, there is a regularity – in a mixture of cadmium diiodide vapor with helium, the radiation power of CdI* molecules is higher.

Plasma parameters

Since experimental physics does not have satisfactory methods for diagnosing a dense gas-discharge plasma, the barrier discharge plasma parameters are optimal for obtaining the maximum radiation power of an electric discharge on a CdI$_2$: Xe: He mixture (0.00009: 0.01575: 0.98416) at a total pressure of 254.024 kPa numerically and calculated as total integrals of the electron energy distribution function (EEDF) based on the Boltzmann equation in the two-term approximation [16]. EEDF calculations were carried out using the well-known Bolsig + program [17]. Based on the EEDFs obtained, a number of plasma parameters are determined depending on the magnitude of the reduced electric field (the ratio of the electric field strength (E) of the total concentration of helium atoms, xenon and a small admixture of cadmium diiodide vapor (N)). The range of variation of the parameter E/N = 1-100 Td ($1 \cdot 10^{-17}$ – $1 \cdot 10^{-14}$ $V \cdot cm^2$) included the values of the parameter E/N, which were implemented in the experiment.

All calculations were performed for the discharge at partial pressures of cadmium diiodide.

The following processes are taken into account in the integral of collisions between electrons and atoms and molecules: elastic scattering of electrons by helium atoms, excitation of energy levels of helium atoms (threshold energy is 19.8 eV), ionization of helium atoms (threshold energy is 24.58 eV), dissociative excitation: $B^2\Sigma^+_{1/2}$ – states of cadmium monoiodide molecules (energy is 4.986 eV), cadmium atoms λ = 479.991 nm and λ = 508.582 nm (threshold energy is 6.386 eV): ionization of cadmium diiodide, dissociative ionization with the formation of ions: cadmium diiodide, cadmium monoiodide, cadmium and iodine (threshold energy – 10 eV, 11 eV, 13 eV, 14 eV, respectively) of elastic scattering and excitation of electronic states of the xenon atom with threshold energies: 3.4 eV, 8.31 eV, 8.44 eV, 9.69 eV, 10.0 eV, 11.0 eV, 11.7 eV, ionization of xenon atoms.

Data on the absolute values of the effective cross sections of these processes, as well as their dependences on the electron energy, were taken from the database [17] and articles [15, 18, 19].

The electric field strength (E) and the reduced electric field on the plasma (E/N), at which the maximum radiation power in the spectral band was observed in the experiment (λ_{max} = 650 nm) of the cadmium monoiodide molecule was maximal were equal to of $2.0 \cdot 10^6$ V/ m, 55.9, 54.9 Td, respectively. They were determined according to the technique described by us in [10].

Numerical simulation of electron transport characteristics on a mixture of cadmium diiodide vapor and helium at a ratio of 24 Pa: 250 kPa and a mixture of cadmium diiodide, xenon and helium vapor at a ratio of 24 Pa: 4 kPa: 250 kPa (2,3) revealed that in plasma with increasing values of the reduced field strength (E/N), an increase in the mean electron energy (ε), electron temperature (T°K), electron drift velocity (V_{dr}), and the electron concentration (N) decreased. The transport characteristics of electrons on a mixture of cadmium diiodide vapor, xenon and helium (3) had lower values.

Table 2: Transport characteristics of electrons in a plasma on a mixture of cadmium diiodide vapor and helium with a component ratio of 24 Pa: 250 kPa.

E/N,Td	ε, eV	T^0 K	V_{dr}, m/s	N, m^{-3}
7.83	4.490	52084	$1.6 \cdot 10^5$	$4.2 \cdot 10^{18}$
55.9	10.37	120292	$1.7 \cdot 10^5$	$4.0 \cdot 10^{18}$
100	14.09	163444	$1.9 \cdot 10^5$	$3.6 \cdot 10^{18}$

Table 3: Transport characteristics of electrons on a mixture of cadmium diiodide vapor, xenon and helium, with a component ratio of 24 Pa: 4 kPa: 250 kPa

E/N,Td	ε ,eV	T^{0}K	V_{dr}, m/s	N, m^{-3}
7.83	3.220	37352	$1.6 \cdot 10^5$	$4.3 \cdot 10^{18}$
54.9	8.405	97498	$1.5 \cdot 10^5$	$4.6 \cdot 10^{18}$
100	11.83	137228	$1.6 \cdot 10^5$	$4.6 \cdot 10^{18}$

The rate constants of excitation and ionization by electrons of helium atoms and cadmium monoiodide molecules (4,5) also increase with increasing the parameter E/N. The maximum values are observed for the dissociative excitation constant of cadmium monoiodide molecules in a mixture of cadmium diiodide vapor and helium (4).

Table 4: Rate constants: excitation (k), ionization (k_{CdI_2+}), (k_{He+}), elastic scattering (k_r) by electrons: $B^2\Sigma^+_{1/2}$ – states of exciplex CdI* molecules (k_{CdI^*}), levels of cadmium atoms (k_{d^*}) and helium (k_{He^*}), in a mixture of cadmium diiodide vapor and helium at a ratio of 24 Pa: 250 k Pa

E/N, Td	k_{CdI^*} $\times 10^{+15}$, m^3/s λ=650 nm	k_{Cd^*} $\times 10^{+15}$, m^3/s λ=479 nm	k_{Cd^*} $\times 10^{+15}$, m^3/s λ = 509 nm	k_{CdI2+} $\times 10^{+14}$, m^3/s	k_r $\times 10^{+14}$, m^3/s	k_{He^*} $\times 10^{+16}$, m^3/s	k_{He+} $\times 10^{+17}$, m^3/s
	CdI$_2$				He		
7.83	3.002	0.1203	0.1804	0.2265	6.930	0.017	0.002
55.6	7.481	1.205	1.827	2.113	7.757	2.448	9.359
100	9.101	2.188	3.325	3.530	7.545	6.789	51.58

Table 5: Excitation rate constants (k): $B^2\Sigma^+_{1/2}$ – states of exciplex molecules CdI* (k_{CdI^*}), cadmium atoms (k_{Cd^*}), xenon (k_{Xe^*}), elastic electron scattering (k_r) on helium and xenon atoms in the mixture cadmium diiodide vapor, xenon and helium at a partial pressure ratio: 24 Pa: 4 kPa: 250 kPa.

E/N, Td	k_{CdI^*} $\times 10^{+15}$, m^3/s λ=650 nm	k_{Cd^*} $\times 10^{+15}$, m^3/s λ=479 nm	k_{Cd^*} $\times 10^{+15}$, m^3/s λ = 509 nm	k_{Xe^*} $\times 10^{+15}$, m^3/s	k_r $\times 10^{+15}$, m^3/s	k_r $\times 10^{+15}$, m^3/s
	CdI$_2$			Xe	He	Xe
7.83	1.640	0.01741	0.02564	0.07665	63.10	171.0
54.9	6.377	0.7323	1.108	0.7665	77.92	277.8
100	8.150	1.587	2.409	0.9368	76.95	267.5

The emission of spectral bands with a maximum at a wavelength of λ = 650 nm of the electronic vibrational transition $B^2\Sigma^+_{1/2} \to X^2\Sigma^+_{1/2}$ of the CdI* molecule in a gas discharge plasma on mixtures of cadmium diiodide vapor with xenon and helium occurs as a result of processes lead to

$$CdI_2 + e \to CdI_2({}^{3,1}\Sigma^+_u \to CdI(B^2\Sigma^+_{1/2}) + I + e. \tag{1}$$

$$CdI_2 + e \to CdI_2({}^{3,1}\Sigma^+_u \to CdI(B^2\Sigma^+_{1/2}) + I^-. \tag{2}$$

$$CdI(B^2\Sigma^+_{1/2}) \to CdI(X^2\Sigma^+_{1/2}) + h\upsilon, \quad (\lambda_{max} = 650 \text{ nm}). \tag{3}$$

$$CdI(B^2\Sigma^+_{1/2}) + M \to CdI(B^2\Sigma^+_{1/2}) + M + \Delta E. \quad (\lambda = 479.991 \text{ nm}) \tag{4}$$

where M is the concentration of CdI^2, Xe, He; ΔE is the energy difference in the reaction.

Reactions ((1)) and ((2)) are the main sources of the formation of CdI* exciplex molecules (3) Electron-vibrational transitions of $(B^2\Sigma^+_{1/2} \to (X^2\Sigma^+_{1/2}$ of CdI* molecules lead to emission of spectral bands with a maximum intensity at a wavelength λ_{max} = 650 nm ((3)). In the quenching reaction ((4)), an electron-vibrational transition of the cadmium monoiodide molecule to the ground state occurs without radiation.

The emission of cadmium lines and xenon lines occurs due to reactions [19]:

$$CdI_2 + e \to Cd(5p^3P^0) + I + I^-. \tag{5}$$

$$Cd(5p^3P^0) \to Cd(6S^3S^0,\ J = 1 - 1) + h\nu. \tag{6}$$

$$Cd(5p^3P^0) \to Cd(6S^3S^0,\ J = 2 - 1) + h\nu. \quad (\lambda = 508.582 \text{ nm}) \tag{7}$$

$$Xe + e \to Xe^* + e. \quad (\lambda = 458 \text{ nm}, 823 \text{ nm.}) \tag{8}$$

Excitation rate constants of the $B^2\Sigma^+_{1/2}$ – state of exciplex molecules of cadmium atoms are equal to $7.481 \cdot 10^{-15}$ m^3/s and cadmium atoms $1.203 \cdot 10^{-15}$ m^3/s and $1.804 \cdot 10^{-15}$ m^3/s for the reduced electric field strength E / N = 55.9 Td, which is existed under experimental conditions for a mixture of cadmium diiodide vapor and helium (4). And for a mixture of cadmium diiodide vapor, xenon, and helium, the rate constants of the $\Sigma^+_{1/2}$ – state of the exciplex molecules of the cadmium monoiodide is equal to $6.377 \cdot 10^{-15}$ m/s, cadmium atom $0.7323 \cdot 10^{-15}$ m/s, $1.108 \cdot 10^{-15}$ m/s and xenon atom $0.7665 \cdot 10^{-15}$ m/s for the given electric field strength E / N = 54.9Td, which existed under experimental conditions. A sharp increase in the intensity of the emission spectral band of exciplex molecules of cadmium monoiodide from the side of the region in the spectrum with long wavelengths and its slow decrease in the region of short wavelengths (2,3) is explained by the course of potential curves (excited $B^2\Sigma^+_{1/2}$ — state is shifted toward large internuclear distances relative to the $X^2\Sigma^+_{1/2}$ – state) and by processes of relaxation of the population of the upper vibrational sates of the excited electronic state, which occur faster than the electron-vibrational transition to the main $X^2\Sigma^+_{1/2}$ – state [20].

An increase in the intensity of the spectral emission bands of exciplex CdI* molecules, as well as the intensity of the spectral lines of cadmium and xenon atoms at an increased pulse repetition rate in the range of 18–20 kHz, is caused by an increase in the number of excitation events of plasma components and, correspondingly, the number of radiation pulses per unit time, which fall into the registration system. In addition, an increase in the intensity of the emission spectral bands of exciplex CdI* molecules and cadmium atoms is also caused by a change in the temperature of the working mixture (the dissipation power of the discharge energy increases with increasing pulse repetition rate [21] and, accordingly, the partial pressures of cadmium diiodide increase [11]). And this leads to an increase in the concentration of cadmium diiodide vapors and, ultimately, to different concentrations of excited CdI* molecules in the $B^2\Sigma^+_{1/2}$ – state, which leads to an increase in the radiation intensities in the spectral bands and lines λ = 479.991 nm and λ = 508.582 nm.

The dependence of the radiation power on the partial pressure of helium and xenon (4, 5) is related to the fraction of the discharge energy that is spent on heating the working mixture [21]. Numerical modeling of the specific losses of the discharge power due to the elastic scattering of electrons by atoms and molecules for mixtures of cadmium diiodide with helium and xenon has established that when the total pressure of the mixture increases, the reduced electric field strength decreases. This leads to an increase in the specific losses of the discharge power due to the elastic scattering of electrons by atoms and molecules (heating the mixture) and, accordingly, to an increase in the partial pressure of the cadmium diiodide vapor and the radiation intensity of CdI* molecules. The presence of a maximum of power and its further decrease is caused by a decrease in the mean electron energy (2 and 3), and this, in turn, leads to a decrease in the rate constants of the dissociative excitation of the $B^2\Sigma^+_{1/2}$ – CdI* states by electrons (4 and 5) in processes ((1) and (2)). In addition, the process ((4)) contributes to a decrease in the radiation power in quenching the luminescence of cadmium monoiodide molecules by helium and xenon. The lower radiation power of exciplex CdI* molecules in a mixture of cadmium diiodide, xenon and helium vapors (5) compared to a two-component mixture of cadmium diiodide vapor with helium (4.) is caused by the fact that the discharge energy is spent on additional excitation channels of energy states, namely xenon atoms, as well as the process of quenching the luminescence of cadmium monoiodide molecules by xenon (reaction (4)).

The saturation of power for a mixture with xenon occurs earlier in time than for mixtures only with helium (6, curves 1 and 2) due to the different rate of dissipation of the discharge energy for a multicomponent plasma and which depends primarily on the probability of elastic collisions of electrons with plasma components, which for the mixture with the addition of xenon is higher [21]. To determine the quantitative characteristics of this regularity, it is necessary to carry out numerical calculations of the kinetics of the process of dissipation of the discharge energy in such a multicomponent mixture.

Conclusions

Thus, as a result of the study of the optical characteristics of the radiator, the working medium of which was a gas-discharge plasma of a barrier discharge on two-component and three-component mixtures (cadmium diiodide with helium and a small addition of xenon), radiation was revealed in the visible and near infrared spectral regions of exciplex molecules of cadmium monoiodide, cadmium atoms, xenon. The edges of the spectral bands covered the wavelength range of 470 – 700 nm (systems of spectral bands of the electronic-vibrational transition $B^2\Sigma^+_{1/2} \to X^2\Sigma^+_{1/2}$ of exciplex CdI* molecules with emission maxima at wavelengths λ = 650 nm, $\upsilon' = 0-2 \to \upsilon'' = 61.62$), In addition, there were lines of cadmium atoms λ = 479 nm and λ = 509 nm ($5p^3P^0 - 6s^3S$, $J = 1-1$ and $J = 2-1$), and in the three-component mixture there were lines of Xe atoms λ = 823 nm, λ = 458 nm and λ = 450 nm.

The radiation power of the exciplex cadmium monoiodide molecules in two component mixtures is higher than the radiation power in the three component mixture, which is explained by the lower value of the discharge power that is introduced in the excitation of the $B^2\Sigma^+_{1/2}$ – state of the CdI* exciplex molecules due to the presence of additional channels for the loss of discharge power in the vapor mixture of cadmium diiodide, xenon and helium.

As the pump pulse repetition rate increases to 20 kHz, the radiation power of the spectral bands, cadmium and xenon lines in the studied mixtures increases. These changes are caused both by an increase in the number of radiation pulses per unit time (due to an increase in the number of acts of excitation of the plasma components) that enter the recording system, and by an increase in the partial pressures of cadmium diiodide due to an increase in the rate of dissipation of the discharge energy.

Different rates of achieving saturation of the radiation power depending on the time the mixture was used are caused by different rates of dissipation of the discharge energy in two component and three component mixtures.

No noticeable (within the measurement error of 10%) changes in the radiation power of exciplex CdI* molecules (after reaching their maximum values) were not observed for $5 \cdot 10^7$ pump pulses for the studied mixtures.

The research data are of interest for the creation of an excilamp that has simultaneous emission in the violet, green, red, and infrared spectral ranges. Such an exilamp can be used in biotechnology, agrophysics, for more efficient control of photosynthesis, growth, development of plants and algae, in research in quantum electronics, for pumping solid and liquid lasers and in medicine.

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ОПТИЧЕСКИЕ ХАРАКТЕРИСТИКИ ГАЗОРАЗРЯДНОГО ИЗЛУЧАТЕЛЯ ОРАНЖЕВО-КРАСНОГО СПЕКТРАЛЬНОГО ДИАПАЗОНА

Приведены результаты исследования оптических характеристик излучателя оранжево - красного спектрального диапазона, рабочей средой которой была газорозрядная плазма на смесях дииодида кадмия с гелием и малыми добавками ксенона. Создание газоразрядной плазмы и возбуждение компонент рабочей смеси осуществлялось импульсно- периодическим (частота следования импульсов 18-20 кГц, длительность импульсов $\sim$150 нс) барьерным разрядом. Выявлено излучение эксиплексных молекул моноиодида кадмия, атомов кадмия, ксенона. Установлены закономерности в изменениях оптических характеристик излучателя в зависимости от частоты следования импульсов накачки, компонентного и количественного состава смесей.

Ключевые слова: ексилампа видимого спектрального диапазона, барьерный разряд, дииодид кадмия, эксиплексные молекулы, гелий, ксенон.

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ОПТИЧНІ ХАРАКТЕРИСТИКИ ГАЗОРАЗРЯДНОГО ВИПРОМІНЮВАЧА ПОМАРАНЧЕВО-ЧЕРВОНОГО СПЕКТРАЛЬНОГО ДІАПАЗОНУ

Приведено результати дослідження оптичних характеристик випромінювача помаранчево - червоного спектрального діапазону, робочим середовищем якої була газорозрядна плазма на сумішах дийодиду кадмію з гелієм і малими добавками ксенону. Створення газорозрядної плазми і збудження компонент робочої суміші здійснювалося импульсно- періодичним (частота проходження імпульсів 18-20 кГц, тривалість імпульсів 150 нс) бар'єрним розрядом. Виявлено випромінювання ексиплексних молекул монойодиду кадмію, атомів кадмію, ксенону. Встановлено закономірності в змінах оптичних характеристик випромінювача в залежності від частоти проходження імпульсів накачки, компонентного і кількісного складу сумішей.

Ключові слова: ексилампа видимого спектрального діапазону, бар'єрний розряд, дийодид кадмію, ексиплексні молекули, гелій, ксенон.

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