VUV LIGHT SOURCES BASED ON BARRIER DISCHARGES IN INERT GASES

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ABSTRACT

Experimental results of spectral, time-amplitude and output power characteristics of emission Xe^*_2 (λ = 172 nm), Kr^*_2 (λ = 146 nm), and Ar^*_2 (λ = 126 nm) dimers molecules excited by a dielectric barrier pulsed corona discharge are presented as a function of gas pressure, pulse repetition rate, and average excitation power. It was shown that under optimal conditions, the Xe and Kr dimers emission efficiency were 45–50 % and 25–28 %, respectively. On the distance of 2 cm from a radiating surface of excimer lamp with an area 23×23=529 cm^2 on λ ~ 126 nm the density with average radiation power 1.6 mW/cm^2 and at average radiation power ~0.8 W through area of 23×23 cm was obtained.

INTRODUCTION

Nowadays, much attention is paid to studies of spontaneous radiation sources, namely, excilamps, operating in the UV and VUV spectral regions, and based on an electric discharge in inert gases and gas mixtures containing halogens [1-3], since excilamps may find wide applications in various areas of science and technology. The properties of the above mentioned sources as compared to available UV or VUV luminescence or thermal sources are a narrow-band spectrum and higher operational efficiency. Generally, the most intensive transition of an exciplex or excimer molecule has an emission spectrum with a half-width of about 10 nm. In the case of excitation in a multi-component operating gas mixture, one may have simultaneous emission with comparable power from two or more molecules [4]. The emission efficiency of the excilamps, ranging from 5 to 50 %, is dependent on the operating gas mixture and excitation conditions [1-8].

Barrier [1-7], glow or capacitive [2,8] discharges are most often used in excilamps for gas excitation. The papers [9, 10] report on the availability of an effective spontaneous VUV source, based on a continuous Xe corona discharge. The benefits of using a corona discharge are: first, the high pressure of the operation medium, which leads to the effective formation of working molecules (rare gas dimers); second, minimization of energy losses by matching excitation conditions and obtaining radiation efficiency of up to 55 % with respect to the energy deposited in a gas discharge plasma [10]. Nevertheless, it is necessary to use a ballasting resistor in order to maintain a stable corona discharge. In this case, the excitation power losses are approximately 25 % what leads to a decrease of the total efficiency in an excilamp. So, the use of a pulsed corona discharge is most preferable in order to reduce the energy losses.

This work is aimed at the studies of the time-amplitude and spectrum characteristics of Xe, Kr and Ar during excitation by a corona discharge bounded by a dielectric and to make basing on it a wide-aperture excilamp with radiating area size of ~ 500 cm^2.

EXPERIMENTAL SET–UP AND MEASUREMENT METHODS

Figure 1 presents a schematic of the experimental setup, including a gas discharge chamber, *1*, pumped by a turbomolecular pump up to residual pressure up to ~ 10^{-5} Torr, a needle cathode, *2*, a flat anode, *3*, covered with a 3-mm thick quartz layer. The discharge is formed between the needle cathode, and the quartz layer, which are separated by 10 mm. The discharge radiation passes through a LiF plate, *4,* and was registered by a vacuum monochromator VM-502 (Acton Research Corporation), *5*. Radiation power in absolute units was measured by a calibrated photodetector C8026 (Hamamatsu Photonics), *9,* with sensor heads H8025−126 and H8025−172. In the experiments with Kr, radiation power was measured using sensor head H8025−126 nm, taking into account the sensor head data and its spectral sensitivity at λ = 146 nm. The gas was excited by a voltage pulse applied to the electrodes from a generator, *6,* giving negative polarity voltage pulses of an amplitude up to 5 kV and duration of about 2 μs. Pulse repetition rate (p.r.r.) varied from 15 to 70 kHz. Power input in the gas discharge plasma was determined by the gas type and pressure, the p.r.r., and the voltage pulse amplitude, and ranged from tens of milliwatts to several watts. We used Ar, Kr, Xe under pressures of 15 to 760 Torr in the experiments. According to the certificates, the gas purity for Xe, Kr, and Ar was 99.9992, 99.9996, and 99.998 %, respectively. The upper limit of the pressure depended on the breakdown voltage, and the lower one on decrease of emitted radiation. Experimentally, the survey spectra were recorded in the range from 120 to 540 nm, as

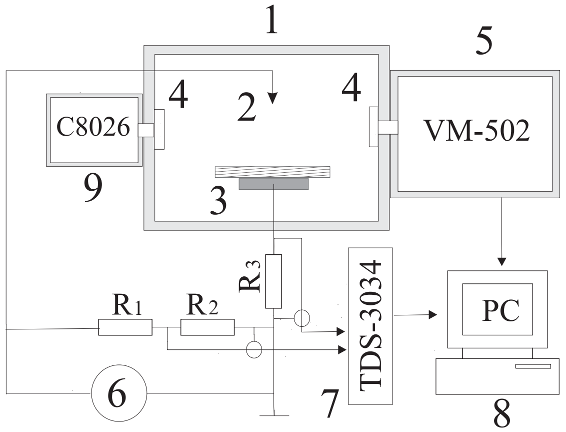

Fig. 1. Schematic of the experimental set-up: 1 – discharge chamber, 2 – needle cathode, 3 – flat anode, covered by dielectric, 4 – LiF plates, 5 – vacuum monochromator, 6 – power supply, 7 – oscilloscope TDS-3034, 8 – PC, 9 – C8026 photodetector.

well as radiation spectra from the Ar_2^*, Kr_2^*, and Xe_2^* dimers transitions. The photographs of integral discharge glowing were taken by an Olympus Camedia C-2020 Z digital camera. The input power, *P(t),* gas discharge gap V_{GAP} and dielectric V_D voltage drops were calculated from oscillograms of voltage pulses and discharge current, using the methods described in [11].

EXPERIMENTAL RESULTS AND DISCUSSION

The volt-ampere characteristics of a discharge. Peculiar property of a corona discharge is high electric field strength near the needle electrode. That is why a low electric potential between the electrodes results in sufficient electric field strength near the needle for discharge initiation. The dielectric layer of the flat anode accumulates charge, limiting the discharge current density, and thereby causing a pulsed voltage to the electrodes. In the case of applying a unidirectional voltage pulse, the discharge current at first has the same polarity and then, due to the charge accumulated in dielectric barrier capacity, the current flows in the opposite direction.

Figure 2 shows the typical oscillograms of discharge current I_0, applied voltage V_0 at p.r.r. of 70 kHz, power input ~ 120 mW, as well as calculation curves of voltage drop on the barrier capacity V_D, gas discharge gap V_{GAP}, and active part of current I_{OHM}. The volt-ampere characteristic is peculiar of: first, a considerable displacement of current; second, the difference of I_{OHM} from zero at low values of V_{GAP}. It is supposed to be the effect of the high electric field strength near cathode and high residual conductance of the gap. The electric field strength E between the needle and distant plane is [12]:

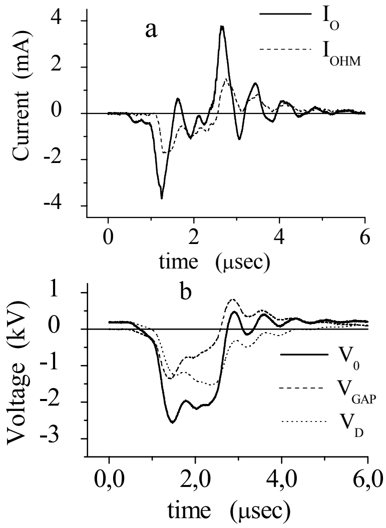

Fig. 2. Waveforms of measured discharge current (I_0), calculated curve of active part of current (I_{OHM}) (a); waveforms of applied voltage (V_0), calculated curves of V_{GAP}, and V_D voltage drops (b). Xe pressure of 380 Torr., P.r.r. is 70 kHz; average excitation power is 120 mW.

$$E(r) \approx V \cdot \frac{r_0}{r^2} \qquad (1)$$

Here V is voltage; r_0 is radius of the needle curvature; $r \geq r_0$. The strength of E in the near-needle area ($r \approx (1\text{-}2) \cdot r_0$, $r_0 \sim 1$ mm) should exceed the critical value for gas ignition for several microseconds.

At excitation power below ~150–170 mW, a ball–like plasma, which is a characteristic of a corona discharge, was observed near the needle. With increasing excitation power and gas pressure, in Xe this plasma formation becomes stretched, right up to complete discharge-gap bridging. A similar tendency is observed with increasing p.r.r. and at fixed average excitation power and Xe pressure . In Ar and Kr, the shape of the gas discharge plasma is usually conic with an extended base on the dielectric surface. In this case, the higher excitation powers were reached.

Spectral characteristics and efficiency of radiation

Wide radiation bands have been observed in Ar on the range 115–135 nm (with a maximum at ~126 nm) and similarly in Kr at 135–155 nm (146 nm) and in Xe at 155–185 nm (172 nm). The half-width of the spectral radiation bands increases with decreasing pressure, being stable with respect to excitation power from tens to several hundreds of milliwatts. Figure 3 presents a Xe radiation spectrum at a pressure of 600 Torr, a p.r.r. of 20 kHz, and an excitation power of 65 mW. The highest radiation power is achieved in case of xenon. The highest values of radiation and efficiency in xenon under 380 Torr were ~ 320 mW and ~50%, respectively for krypton under ~ 1 atm, the efficiency amounted to ~ 25–28 %. Substantially

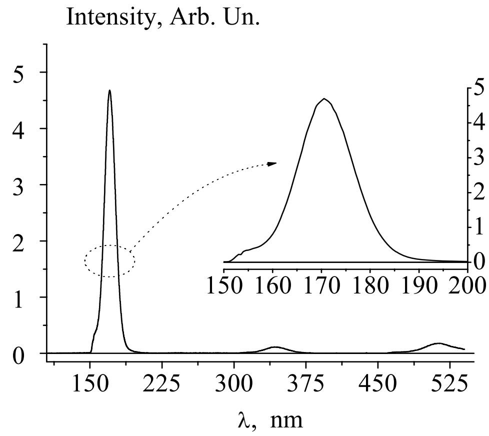

Fig. 3. Spectrum of corona barrier discharge. Xe pressure is 600 Torr; p.r.r. is 20 kHz; average excitation power is 65 mW.

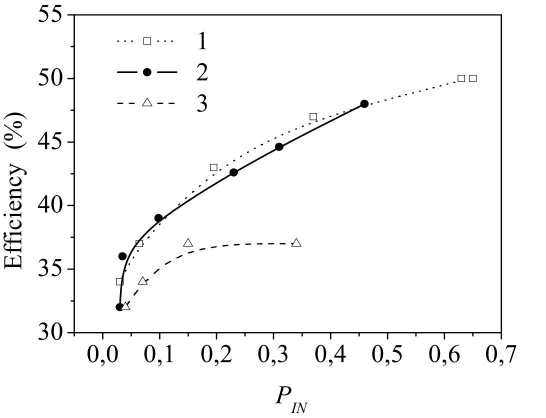

Figure 4. Calculated efficiency of emission at 172 nm as function of Xe pressure and excitation power P_{IN} at p.r.r. of 70 kHz. Curves *1 – 3* correspond to pressure values of 380 Torr, 600 Torr, 1 atm, respectively.

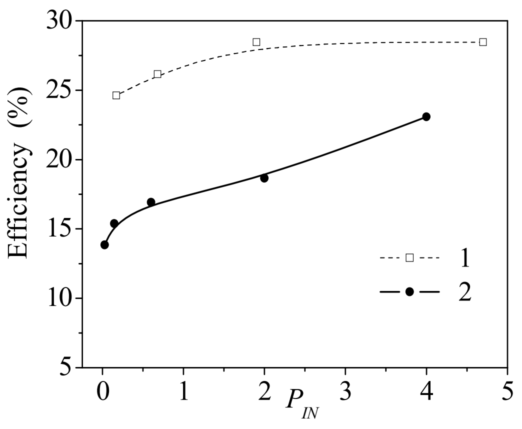

Fig. 5. Calculated efficiency of emission at 146 nm as function of Kr pressure and excitation power P_{IN} at p.r.r. of 70 kHz. Curves *1 – 2* correspond to pressure values of 1 atm, 600 Torr, respectively.

smaller radiation efficiencies (by an order or more) were obtained in Ar. The most likely reason for that are the gas impurities, a conclusion confirmed by radiation lines at 110–160 nm.

It is known that dimers of inert gases form in three–particle association reactions, with the reaction rates dependent on the gas pressure [13]. Furthermore, the radiation efficiency of inert gases dimers may decrease due to the energy losses [5]. Therefore the dependence of the radiation efficiency on the gas pressure and the excitation power has been investigated. Such results are presented for Xe in Figure 4. The maximal average radiation power

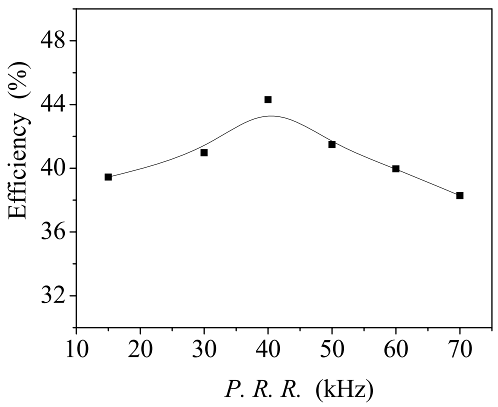

Fig. 6. Calculated efficiency of emission as function of p.r.r. at Xe pressure of 380 Torr. Deposited energy per one excitation pulse *Q* is constant (*Q* = 3 μJ).

was reached with a Xe pressure of 380–600 Torr and with an excitation power of 0.4–0.6 W. In our work, unlike [9, 10], the maximal radiation efficiencies were obtained at lower Xe pressure values, as consistent with [14]. Figure 5 presents the radiation power of Kr dimers as a function of excitation power.

Figure 6 shows radiation efficiency of Xe as a function of p.r.r. at a constant deposited energy per excitation pulse $Q = 3 \cdot 10^{-6}$ J. It is seen here that the radiation efficiency is practically constant. On the contrary, at constant average power and decreased value, *Q,* the radiation efficiency of Xe dimers decreases with increasing p.r.r.

The results mentioned above were obtained for one-needle barrier corona discharge. As for practical applications, due to the interest in light sources with larger emitting areas, an excilamp having a radiation area of 23×23 cm, driven by one generator was constructed. In this excilamps, 230-pulsed corona discharges, restricted by the dielectric, were burning in parallel. Excilamp testing at 1 atm of Ar showed that ignition of all the pulsed corona discharges was stable, and their radiation intensity was approximately equal. Exilamp's photo in a working mode is giving on Figure 7. Average

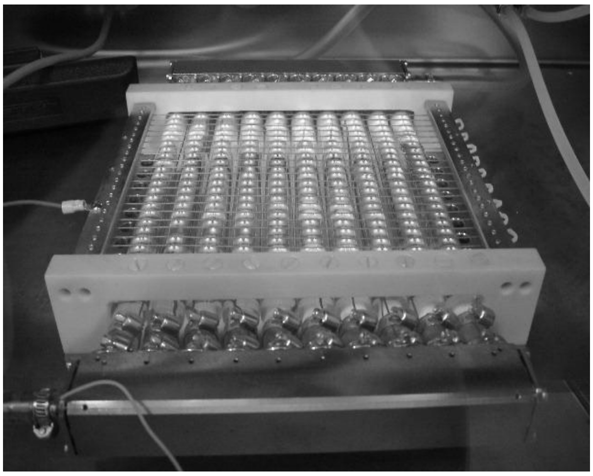

Fig. 7. Excilamp's photo in working mode

radiation power measured on the distance of 2 cm from cathode reached 1.6 mW/cm^2. Full radiation power through the area of 23×23 cm sizes on the distance of 2 cm from cathode counted ~ 0.8 W. Significantly higher average radiation powers can be realized on this set up at chamber fillup by krypton and xenon, due to high cost of these gases and big sizes of chamber such experiments were not curried out.

CONCLUSIONS

Volt-ampere characteristics of a pulsed corona discharge bounded by dielectric and its spectrum in Xe, Kr, and Ar have been studied. In optimal conditions, the efficiency of Xe and Kr dimers radiation was 45–50 % and 25–28 %, respectively. In this work, for the case of a pulsed corona discharge, Xe dimers efficiency agrees with earlier results. However, for a pulsed corona discharge there is no need for a ballasting resistor, which may lead to energy losses.

An excilamp with an emission area of 23×23 cm^2, based on a pulsed corona discharge bounded by a dielectric, has been manufactured, with a power density for Ar_2^* dimers of approximately 1.6 mW/cm^2 and full radiation power ~ 0,8 W.

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