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VUV RADIATION SOURCES

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High-power short-pulse xenon dimer spontaneous radiation source

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***Abstract*. A high-power VUV radiation source based on a self-sustained nanosecond volume discharge in an inhomogeneous electric field is developed. It is shown that the volume discharge can be formed at high xenon and helium pressures without using a preionisation source. The 8-ns (FWHM), 172-nm, 1-MW radiation pulses emitted into a total solid angle are obtained in xenon at a pressure of 12 atm.**

Keywords: *volume discharge, excitation of xenon dimers by volume discharge initiated by an avalanche electron beam.*

1. To develop lasers and high-power spontaneous radiation sources based on xenon dimers it is necessary to perform homogeneous excitation of inert gases at a pressure of ~ 10 atm and higher [1]. Studies on VUV lasing by pumping cooled inert gases were initiated by Basov as early as 1966 [2]. An electron beam produced in vacuum diodes is most convenient for these purposes [1, 3]. Inert gases at high pressures were also excited in discharges by using additional preionisation sources [4, 5]. However, the xenon pressure at which the volume discharge could be obtained did not exceed 1 atm [5]. It was shown in [6, 7] that the operating pressure in inert gases can be increased by using a cathode with a small radius of curvature by supplying high-voltage nanosecond pulses to a discharge gap. This discharge regime was called the volume discharge initiated by an avalanche electron beam (VDIAEB) [8]. The volume nature of the VDIAEB in xenon was preserved at a pressure of 1.5 atm and a radiation power of ~ 300 kW emitted into a total solid angle was obtained [6, 7].

The aim of this paper is to study radiation of xenon dimers at ~ 172 nm in an VDIAEB at high pressures.

2. A special chamber was developed for studying the parameters of radiation of the discharge plasma in various gases at high pressures. Voltage pulses from a RADAN-220 generator were supplied to the discharge gap [3]. The wave impedance of the generator was 20 Ω and formed ~ 220-kV, ~ 2-ns pulse (FWHM) with the leading edge ~ 0.5 ns. The design of a similar gas diode is presented in [6]. Our diode differed in that the length of its housing and cathode holder was reduced and radiation was extracted through a grid anode. This allowed us to reduce the inductance of the gas diode compared to that of the diode used in [6]. The internal diameter of the gas diode housing was 50 mm. We used a flat grid anode transmitting 64 % of light and a cathode with a small radius of curvature, which provided an additional enhancement of the field near the cathode. The cathode was fabricated in the form of a tube of diameter ~ 6 mm made of a 50-μm-thick steel foil. The distance between the cathode and anode could be varied from 12 to 16 mm. Gases were excited by the VDIAEB. Systems for measuring the radiation and discharge parameters and for evacuating and filling working gases are described in detail in [6].

3. We studied the discharge geometry, emission spectra in the region from 150 to 850 nm and the amplitude – temporal characteristics of radiation in xenon and helium. The volume discharge in helium was preserved over the entire pressure range (up to 12 atm). The discharge consisted, as in [6, 7], of diffusion jets, with bright spots on the cathode. The discharge in xenon at pressures of up to 3 – 4 atm had a similar shape. At xenon pressures above 4 atm, the discharge geometry began to change. The size of bright spots increased and then they elongated, transforming to bright channels occupying a part of the discharge gap. At pressures above 6 atm, the length of bright channels increased and some of them crossed the gap. Nevertheless, most of the bright channels were incomplete. The volume discharge in the form of diffusion channels was observed in the remaining part of the gas-discharge gap. Based on the spectral and amplitude – temporal characteristics of radiation obtained in experiments, we can also conclude that the volume discharge is present over the entire range of pressures studied.

The emission spectrum of xenon in the region between 150 and 200 nm belongs to the $\mathrm{B}\,^1\Sigma_u^+ \rightarrow \mathrm{X}\,^1\Sigma_g^+$ and $\mathrm{A}^3\Sigma_u^+ \rightarrow \mathrm{X}\,^1\Sigma_g^+$ bands. The half-width of the emission band of xenon dimers recorded on spectrograms was independent of pressure. Figure 1 presents the pressure dependences of the emission power in this band and duration of the emission pulse of xenon dimers. One can see that the emission power of xenon dimers increases with pressure, while the pulse FWHM decreases. We managed for the first time to increase the emission power of xenon dimers at a high pressure in a self-sustained discharge. This proves that the volume discharge is formed in xenon at high pressures (up to 12 atm in our experiments). As shown in

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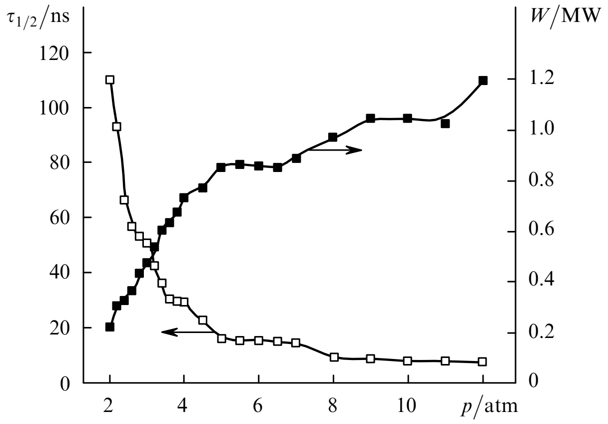

Figure 1. Dependences of the power W and FWHM pulse duration $\tau_{1/2}$ of xenon dimers on the xenon pressure p.

[6], the emission power of xenon dimers in a contracted discharge considerably decreases, and in the spectral region from 150 to 200 nm the most intense are the lines of xenon ions. In our experiments, no emission lines of xenon were observed in this spectral region over the entire pressure range.

The maximum power of emission of xenon dimers into a total solid angle from the excited volume of ~ 1 cm^3 in our setup was ~ 1 MW. Because excitation was performed by nanosecond pulses and the xenon pressure was high, the minimum duration of the emission pulse did not exceed 8 ns. The duration of VUV emission pulses was measured by using a specially developed vacuum photodiode providing the time resolution ~ 1 ns. The emission energy of xenon dimers at a pressure of 12 atm was 18 mJ, the two thirds of the VUV energy being emitted after the achievement of the emission power maximum. The emission band of helium dimers could not be recorded with our spectral equipment, but we assume that the intensity of their emission also increased with increasing pressure up to 12 atm.

A volume discharge is produced in the gap in an inhomogeneous electric field due to the preionisation of the gap by fast electrons, which are formed due to the enhancement of the electric field strength on the cathode, cathode spots, and in the gap. Fast electrons produce a high concentration of initial electrons, providing the overlap of electron avalanches up to the achievement of their critical size, resulting in the formation of the volume discharge.

Note that, under our experimental conditions, an electron beam was recorded behind a 50-μm-thick AlBe foil anode. For all helium and xenon pressures (up to 12 and 2 atm, respectively) used in our experiments, the amplitude of a negative signal from a collector exceeded by a few orders of magnitude the noise level, which was recorded with a 250-μm-thick copper foil collector placed behind the anode. The amplitude of the beam current behind the foil in helium was considerably higher that that in xenon.

4. Thus, our study has shown that a volume discharge can be produced at high helium and xenon pressures without using a preionisation source. The 1-MW, 8-ns emission pulses of xenon dimers were obtained in xenon at a pressure of 12 atm. We have found that the VUV emission power of xenon dimers in the VDIAEB increases with increasing pressure up to 12 atm. This allows one to develop high-power short-pulse spontaneous VUV radiation sources based on dimers of xenon and other inert gases. The VDIAEB can be also used as the active medium of electric-discharge VUV lasers on dimers of inert gases. This is confirmed by the calculations of the gains upon excitation by this discharge performed for xenon [9] and krypton [10] dimers.

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