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Broadband low-density radiation source utilising argon, krypton, and xenon chlorides

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***Abstract*. The parameters of a broadband excimer radiation source emitting in the 175 – 310-nm range and excited by a dc glow discharge in an Ar – Kr – Xe – Cl_2 mixture are studied. The emission spectrum of the discharge consists of the ArCl, KrCl, XeCl, and Cl_2 molecular emission bands. The optimal partial pressure of argon in the mixture is 1.3 kPa, those of krypton and xenon are 0.24 kPa each, and the partial chlorine pressure is in the 0.15 – 0.30-kPa range. The UV – VUV radiation power emitted from the entire side surface of the discharge tube amounts to 4 – 6 W for an efficiency of 15 % – 25 %. The radiation source is of interest for applications in photometry, microelectronics, photochemistry, and medicine.**

Keywords: *glow discharge, broadband radiation source, heavy rare-gas chlorides.*

By using a longitudinal low-density glow discharge in an Ar – Cl_2 mixture, we developed a radiation source utilising the system of ArCl* and Cl_2^* molecular bands and emitting in the 175 – 260-nm range [1]. To extend the spectral range to 310 nm, raise the output power, and improve the efficiency of the radiation source through the incorporation of krypton and xenon chlorides into the active medium, advantage can be taken of an Ar – Kr – Xe – Cl_2 working mixture. The results of optimisation of this gas medium in radiation sources pumped by a transverse discharge of short duration are outlined in Refs [2, 3].

Because the vibrational relaxation inside the *B*, *C*, and *D* states of rare-gas monochlorides is incomplete for low pressures of the working mixtures (compared to pulsed atmospheric-pressure excimer lamps) [4] employed in dc excimer lamps, the RCl (*B, C, D – X*) emission bands are significantly broadened. This results in the formation of a single broad emission band in the UV – VUV spectral range, which is of interest for several applications. When the partial argon pressure is so selected that it is significantly higher than the partial pressures of krypton and xenon, the saving in the costly gases is effected in the gas-flow mode. The efficiency of energy transfer from argon atoms in metastable states to unexcited krypton and xenon atoms is rather high, and therefore the output characteristics of the radiation sources utilising mixtures of the Ar – Kr – Xe – Cl_2 type can approximate the corresponding characteristics of the radiation sources utilising Xe – Cl_2 and Kr – Cl_2 mixtures. The operating mode of the radiation sources utilising Ar – Kr – Xe – Cl_2 mixtures pumped with a longitudinal dc discharge has never been accomplished.

In this paper, we investigate the characteristics of a broadband excimer dc radiation source utilising a Ar – Kr – Xe – Cl_2 mixture. The dc glow discharge was ignited in a discharge tube with an internal diameter of 5 mm and an anode – cathode distance of 100 mm. The discharge current I_{ch} ranged between 1 and 30 mA, the voltage U_{ch} across radiation-source electrodes was 1 – 4 kV. Other experimental conditions are similar to those specified in our earlier papers [1, 5].

The glow discharge exhibited a weak-current stage ($I_{ch} \leqslant 1$ mA) and a high-current stage ($I_{ch} \geqslant 1 - 2$ mA), the latter being employed to pump the broadband excimer radiation source. Fig. 1a shows the current – voltage char-

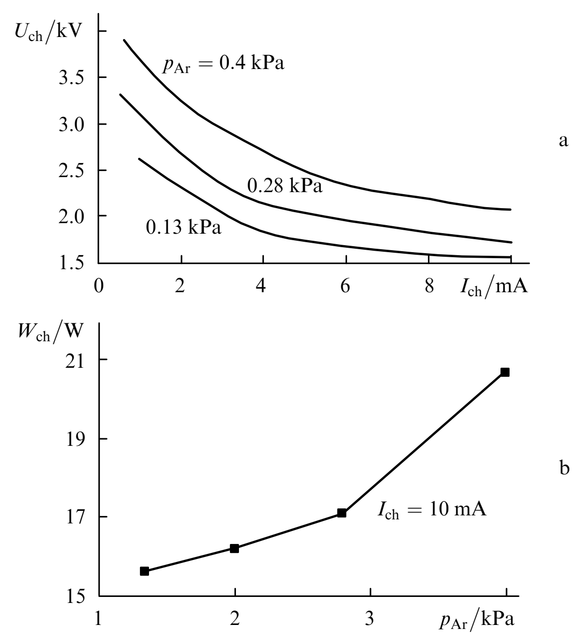

Figure 1. Current – voltage characteristics of a longitudinal glow discharge in a mixture of composition Ar : Kr : Xe : Cl_2 = p_{Ar} : 0.24 : 0.24 : 0.16 kPa (a) and power W_{ch} supplied to the plasma of the same mixture as a function of partial argon pressure (b).

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acteristics of the glow discharge in the $Ar - Kr - Xe - Cl_2$ mixture for different partial argon pressures. In these curves one can distinguish the region of subnormal glow discharge ($I_{ch} = 1 - 7$ mA) [6] and the region of a regime close to a normal glow discharge ($I_{ch} \geqslant 7$ mA). Increasing the argon content in the mixture raised the discharge initiation voltage from 2500 to 4000 V and the quasistationary voltage drop from 1750 to 2500 V. Variations of partial xenon pressure $p_{Xe} = 40 - 400$ Pa did not result in significant variations of the current – voltage characteristic. Increasing the partial argon pressure raised the power supplied into the glow discharge plasma from 15.5 to 21 W (Fig. 1b). Increasing p_{Xe} from 40 to 400 Pa raised the discharge power from 17.5 to 18.5 W.

In the emission spectrum of the discharge in an $Ar - Kr - Xe - Cl_2$ mixture (Fig. 2), bands with peaks at $\lambda = 175$ nm [ArCl (B–X)], 199 nm [KrCl ($B - X$)], 236 nm [XeCl ($D - X$)], 222 nm [KrCl ($B - X$)], 258 nm [Cl_2 ($D' - A'$)], and 308 nm [XeCl ($B - X$)] were prominent against the background of a broad band with $\lambda = 175$–310 nm. The optimal partial chlorine pressure was in the 0.15 – 0.30-kPa range. To obtain emission of approximately the same power at all $B - X$ RCl bands, the partial pressures of krypton and xenon in the $Ar - Kr - Xe - Cl_2$ mixture should lie in the 0.2 – 0.3-kPa range. The intensity distribution in the spectrum of the broadband excimer radiation source was most sensitive to the partial pressure of xenon in the working medium.

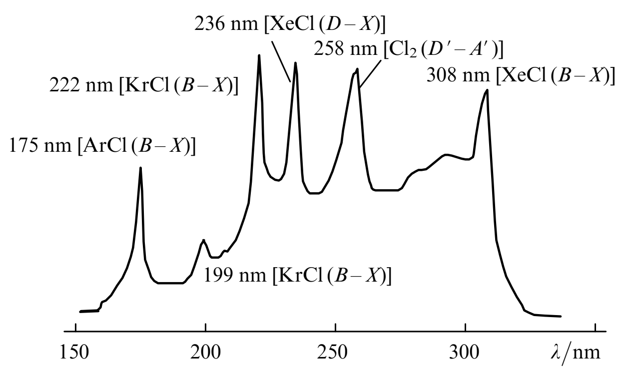

Figure 2. UV – VUV emission plasma spectrum of the glow discharge in an $Ar - Kr - Xe - Cl_2$ mixture.

Fig. 3 shows the output power of the glow discharge in the $Ar - Kr - Xe - Cl_2$ mixture in the 175 – 310 nm range as a function of partial argon pressure. To maximise the output power of short-wavelength radiation, the partial argon pressure in the working medium should not be greater than 1.3 kPa. Increasing p_{Ar} to 3.0 kPa lowered the discharge output power by nearly a factor of two, and for $p_{Ar} \geqslant 4 - 5$ kPa the glow discharge passed into the contracted state. In this case, the plasma of the current column is of the ion – ion type (consists primarily of positive rare-gas ions and negative chlorine ions), because all electrons of the electronegative plasma of this discharge diffuse to the walls of the discharge tube in a finite period of time [7].

As for a dc radiation source utilising an $Ar - Cl_2$ mixture [1], the highest build-up rate for the UV – VUV radiation power of the discharge under investigation was obtained in the subnormal regime for $I_{ch} = 1 - 10$ mA.

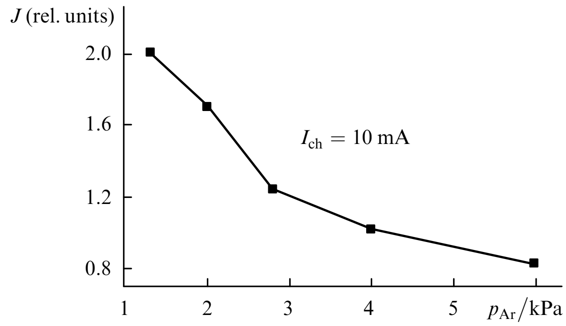

Figure 3. Brightness J of the emission of a longitudinal glow discharge in the mixture of composition $Ar : Kr : Xe : Cl_2 = p_{Ar} : 0.24 : 0.24 : 0.16$ kPa in the 175 – 310-nm spectral range as a function of partial argon pressure.

When I_{ch} was raised to 24 mA, the build-up rate of the short-wavelength radiation power lowered by a factor of 2 – 3, and for $I_{ch} = 25 - 30$ mA we observed a reduction in output power, which is related to the overheat of the working mixture of the radiator.

The total output power of UV – VUV radiation at 175, 222, 236, 258, and 308 nm amounted to 4.0 – 6.0 W in the discharge utilising the mixture of composition $Ar : Kr : Xe : Cl_2 = 1.30 : 0.24 : 0.24 : 0.16$ kPa. The radiation source efficiency lowered with increasing discharge current and lay in the 15 % – 25 % range.

Therefore, a longitudinal glow discharge in an $Ar - Kr - Xe - Cl_2$ mixture at a total pressure of no higher than 2 kPa is a broadband radiation source in the 175–310 nm range with peaks at $\lambda = 175$, 222, 236, 258, and 308 nm. This is related to the radiative decay of ArCl (B), KrCl (B, C), XeCl (B, C), and Cl_2 (D') molecules and the incompleteness of vibrational relaxation in the B, C, and D states of Ar, Kr, and Xe chlorides and the D' state of the Cl_2 molecule. The optimal partial pressures of Ar, Kr, Xe, and Cl_2 in the mixture are equal to 1.30, 0.24, 0.24, and 0.15 – 0.30 kPa, respectively. The output radiation power does not exceed 6.0 W and the efficiency 25 %. The broadband excimer radiation source can be employed in short-wavelength photometry, microelectronics, and medicine.

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