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UV-VUV excimer emitter pumped by a subnormal glow discharge

A K Shuaibov, A I Dashchenko, I V Shevera

***Abstract*. Characteristics of a small-size excimer emitter operating on an $Ar - Cl_2$ mixture excited by a subnormal glow discharge are studied. It is shown that this discharge is a source of multiwavelength emission in a range of 175 – 258 nm. The optimum pressures lie in ranges of 0.3 – 0.5 kPa for chlorine and 2 – 4 kPa for argon. The average power of UV-VUV emission reaches 0.7 W, with the emission efficiency equal to 3 %. The emitter can be used in microelectronics, high-energy chemistry, short-wavelength photometry, biophysics, and medicine.**

Keywords: *subnormal glow discharge, UV-VUV radiation source, multiwavelength excimer lamp.*

A subnormal glow discharge (SGD) in mixtures of Xe and Kr with chlorine molecules is an efficient emitter at 308 nm [XeCl $(B - X)$] and 222 nm [KrCl $(B - X)$]. In the first systematic studies of such excimer lamps, an average power of 8 – 20 W with the efficiency $\eta = 12 - 23$ % was obtained [1, 2]. Subsequently, owing to an increase in discharge tube size and the energy deposited into a plasma and the use of water cooling, the emission power of Xe and Kr chlorides was increased up to 100 – 130 W, with $\eta = 10 - 13$ % [3, 4]. The maximum efficiency was reached in a coaxial SGD ($\eta =$ 25 – 30 % [5]), but the emission power at 222 and 308 nm in this case did not exceed 8 W. The results reported above were obtained in discharge tubes with the inner diameter $d = 12 - 30$ mm and length $L \geqslant 170$ mm. No studies were performed for an SGD in mixtures of heavy inert gases with chlorine molecules excited in short ($L \leqslant 100$ mm) and narrow ($d \leqslant 5$ mm) tubes. Data on optical characteristics of an SGD in an $Ar - Cl_2$ mixture are also absent, which impedes the development of small-size sources of continuous emission in the UV-VUV region (at 175 nm for ArCl and 258 nm for Cl_2^*).

In this paper, we present characteristics of a small-size stationary UV-VUV emitter pumped by an SGD on a low-pressure $Ar - Cl_2$ mixture.

The discharge was excited in quartz or sapphire tubes with an inner diameter of 5 mm and an interelectrode spacing of 100 mm. The cathode and the anode made of nickel were mounted inside a discharge tube. To replace a heated working mixture, the ends of a discharge tube were left open and the tube itself was placed in a 10-litre buffer chamber. The buffer chamber was connected to a vacuum monochromator via a CaF_2 window. The centre of the discharge tube faced the centre of the entrance slit of the vacuum monochromator. The detection system is described in detail in Refs [6, 7]. The SGD was excited by a high-voltage rectifier ($U \leqslant 30$ kV, $I \leqslant 100$ mA). The absolute radiation power was measured by the technique described in Ref. [4], using a 'Kvarts-01' device.

The discharge was characterised by the presence of low- and high-current stages. At the discharge current $I = 0.5 -$ 2.0 mA, a jumpwise change from one stage to another occurred. Typical volt–amper characteristics of an SGD in an $Ar - Cl_2$ mixture for different partial chlorine pressures are presented in Fig. 1a. The dependences $U_{ch}(I_{ch})$ had a hyperbolic form. The discharge voltage U_{ch} decreased from 4 – 4.5 to 2 kV with increasing discharge current I_{ch} from 1 to 10 mA. For $I_{ch} \geqslant 10$ mA, the discharge was at the stage of a normal glow discharge, when U_{ch} is almost independent of I_{ch} [8]. The discharge voltage U_{ch} and the energy deposited into a plasma increased with increasing chlorine pressure (Fig. 1b). An increase in argon pressure from 0.6 to 4.0 kPa (with partial chlorine pressure being fixed in a range of 0.1 – 0.6 kPa) caused an increase in U_{ch} from 3.0 to 4.5 kV.

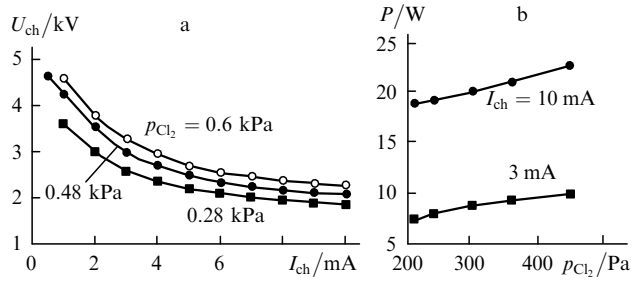

Figure 1. Volt – ampere characteristics (a) and the power P deposited into an SGD plasma in an $Ar - Cl_2$ mixture as a function of the chlorine pressure p_{Cl_2} for $p_{Ar} = 2.8$ kPa (b).

The emission spectrum of an SGD plasma produced in an $Ar - Cl_2$ mixture is presented in Fig. 2. The emission bands at 175 nm [ArCl $(B - X)$] and 180 – 195 nm [Cl_2 ($^1\Sigma -$ $^1\Pi_4$)] were dominant in the spectrum. The 200-nm maximum of the continuum of the Cl_2 molecule and the 258-nm band [Cl_2 $(D' - A')$] were also well pronounced. One can see from Fig. 2 that the plasma of the discharge under study is a multiwavelength source of emission in a region of 175 – 258 nm. The optimum partial chlorine pressure in the working mixture was 0.3 – 0.5 kPa.

A K Shuaibov, A I Dashchenko, I V Shevera Uzhgorod National University, ul. Pidgirna 46, 88000 Uzhgorod, Ukraine;
e-mail: ishev@univ.uzhgorod.ua

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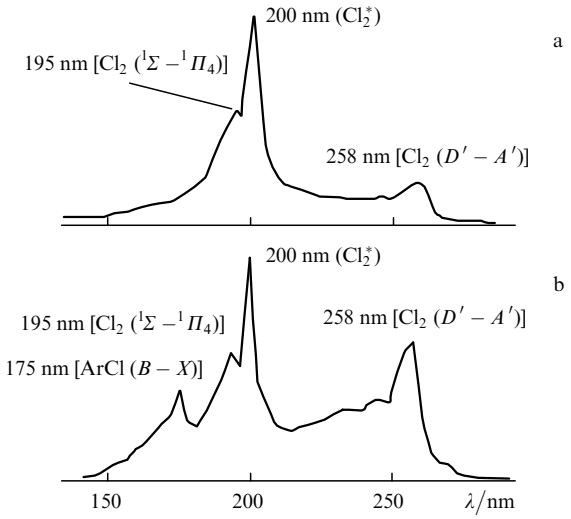

Figure 2. Emission spectra of an SGD plasma in Cl_2 (a) and $Ar - Cl_2$ mixture (b).

The dependences of the brightness of the main emission bands on the partial argon pressure are presented in Fig. 3. At the partial chlorine pressure in an $Ar - Cl_2$ mixture above 0.3–0.4 kPa, the 258-nm band [Cl_2 ($D' - A'$)] was most intense. The optimum argon pressure for obtaining the maximum radiation brightness was 2 kPa for $\lambda = 258$ and 200 nm and 4 kPa for $\lambda = 175$ nm ($ArCl^*$). At pressures above 5 kPa, the glow discharge changed to the contracted state in which the plasma filament was 1–1.5 mm in diameter.

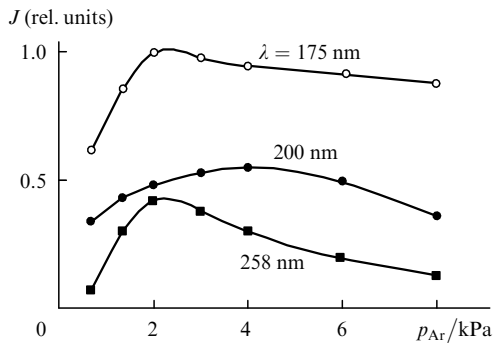

Figure 3. Dependences of the relative radiation brightness J of the bands at 175, 200, and 258 nm on the partial argon pressure p_{Ar} for an SGD in an $Ar - Cl_2$ mixture for $p_{Cl_2} = 0.4$ kPa and $I_{ch} = 10$ mA.

The power deposited into a contracted discharge in the $Ar : Cl_2 = 4 : 0.1$ mixture (with a pressure of 8.4 kPa) was 18 W (at $I_{ch} = 10$ mA). As a result, because of a considerable decrease in the plasma volume, the specific pump power increases by a factor of 15–25. It is likely that this causes overheating of the active medium of the emitter and a decrease in the brightness of the bands (Fig. 3). The total emission power from the entire side surface of the plasma filament (proportional to the filament diameter) decreases no less than by a factor of 4–5. But an important advantage of the contracted discharge is that it has no contact with the inner surface of a discharge tube. Because the service life of chlorine-containing devices is determined by the coefficient of chlorine diffusion into glass, which considerably increases with increasing tube wall temperature [9], the contracted glow discharge offers promise for lengthening the service life of a lamp.

The highest rate of an increase in the radiation brightness dJ/dI_{ch} of the ArCl ($B - X$) and Cl_2 ($D' - A'$) bands was obtained in the range of discharge currents from 1 to 4 mA (Fig. 4), when the maximum decrease in the voltage across the electrodes was observed. For $I_{ch} \geqslant 4$ mA, we observed linear dependences of brightness on the discharge current for all the bands, which suggests that no considerable heating of the gas medium occurs.

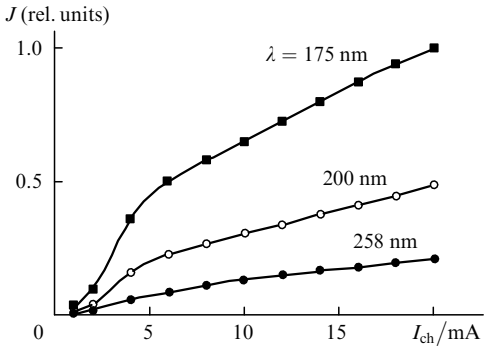

Figure 4. Dependences of the relative radiation brightness J of the bands at 175, 200, and 258 nm on the discharge current for an SGD in the $Ar : Cl_2 = 4 : 0.16$ kPa mixture.

The results obtained in this study show that an SGD in an $Ar - Cl_2$ mixture ($p = 2 - 4$ kPa, partial chlorine pressure of 0.3–0.5 kPa) in a short and narrow discharge tube is a multiwavelength source of continuous emission in a range of 170–260 nm, with maxima at 175, 200, and 258 nm. The total emission power of an SGD reaches 0.7 W, and the maximum efficiency of UV-VUV emission was obtained at small discharge currents ($I_{ch} = 1 - 4$ mA). For the total pressure of the $Ar - Cl_2$ mixture above 5 kPa, a stable contracted discharge was obtained. This discharge has no contact with the inner surface of the discharge tube and offers promise for lengthening the service life of a discharge tube. The discharge under study can be used for the development of small-size sources of continuous emission in the UV-VUV region, in particular, sources with a slow circulation of a relatively cheap (compared to $Xe - Cl_2$ and $Kr - Cl_2$ mixtures) $Ar - Cl_2$ mixture. Such sources can find application in microelectronics, short-wavelength photometry, photochemistry, biophysics, and medicine.

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