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Stationary radiator in the 130 – 190 nm range based on a water vapour plasma

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***Abstract*. The characteristics of a continuous radiation source pumped by a longitudinal glow He – H_2O mixture discharge are presented. For a water vapour pressure of ~ 50 – 300 Pa and helium pressure of 1.0 – 8.0 kPa, the discharge under study was shown to emit radiation primarily in the 130 – 190 nm range. The optimal water vapour pressure lies in the range from 50 Pa to 150 Pa and the optimal partial helium pressure is 1.0 kPa. In the 3 – 50 mA range of the discharge current, the brightness of the main emission bands was observed to increase linearly with current.**

Keywords: *radiator, vacuum ultraviolet emission, glow discharge, hydroxyl.*

Electric-discharge radiators at 308 nm (XeCl) and 222 nm (KrCl) pumped by a dc glow discharge are efficient and rather intense stationary radiation sources [1, 2], which is important for applications in microelectronics, photochemistry, and medicine. Water-vapour-based working media, in which the OH^* radicals are used as an active medium, hold promise for advancing to the wavelength region $\lambda < 200$ nm and replacing expensive working media based on atomic krypton and xenon.

The development of an ecologically pure OH ($A - X$; 0 – 0) radiator at 306.4 nm pumped by a glow or high-frequency discharge was reported in Ref. [3]. In a mixture of the Ar – H_2O type for a specific water vapour content of the order of $10^{14} - 10^{16}$ cm^{-3}, the resonance hydroxyl band dominated in the 300 – 1000 nm region and the lamp efficiency amounted to 25 %. The feasibility of using such active media in the vacuum UV (VUV) range was not discussed in Ref. [3].

In this paper, we studied a stationary electric-discharge radiator using a He – H_2O mixture. The longitudinal glow discharge was initiated in a quartz tube with an internal diameter of 7 mm. The separation between hollow cylindrical electrodes was 50 mm. The discharge tube was mounted in a buffer chamber with a volume of 10 litre, which was coupled with a half-meter vacuum spectrometer via a CaF_2 window. The spectral resolution of the spectrometer was 0.7 nm. The system for radiation detection was described in greater detail in papers [4, 5]. The water vapour was supplied into the mixer from a separate vessel. The discharge was initiated with the help of a high-voltage rectifier with $U < 30$ kV and $I < 100$ mA. The brightness of an emission band was measured as the area under the relevant curve recorded on a chart, which was corrected for the relative spectral sensitivity of the vacuum spectrometer.

A white glow discharge in water vapour at a pressure $p = 50 - 300$ Pa occupied uniformly the entire volume of the discharge tube. For low vapour pressures (below 50 Pa), fixed striations were observed in the discharge, with the light streaks spaced at 5 – 7 mm. Small additions of helium of the order of 0.3 – 0.5 kPa transferred the discharge to a homogeneous state. For low discharge currents ($I_{ch} < 30$ mA), the voltage drop across the electrodes lowered considerably with increasing I_{ch} (the so-called subnormal discharge) [6]. For $I_{ch} > 30$ mA, the discharge went over to the normal mode (Fig. 1). As the partial helium pressure in the mixture was increased, the ignition voltage and the quasistationary voltage U_{ch} at high discharge currents were observed to increase. The power deposited into the plasma amounted to 40 – 45 W.

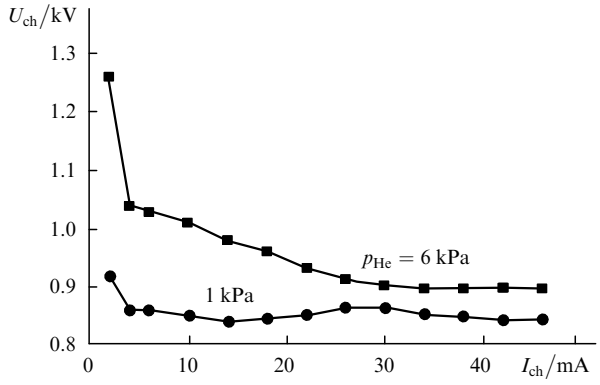

Figure 1. Volt – ampere characteristics of a glow discharge in mixtures of the composition He : $H_2O = p_{He}$: 0.15 kPa for different partial helium pressures p_{He}.

In our experiments, U_{ch} was by an order of magnitude higher and I_{ch} by an order of magnitude lower than in Ref. [3]. Under such pumping conditions, the intensity distribution in the emission spectra of the He – H_2O mixture plasma (Fig. 2) exhibits bright bands in the VUV region at 156, 180, and 186 nm, while the emission in the 306 – 315-nm region does not dominate. The VUV emission bands can be assigned to OH radicals ($C - A$, $B - X$) [3].

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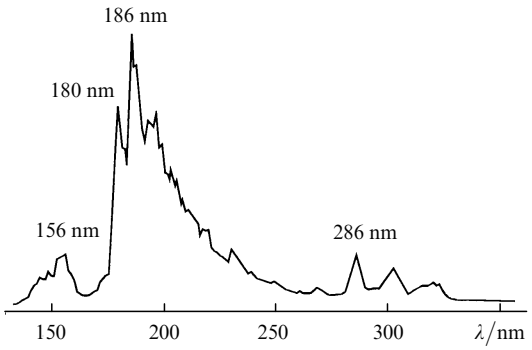

Figure 2. Plasma emission spectrum of the mixture of the composition He : H_2O = 1.0 : 0.15 Pa.

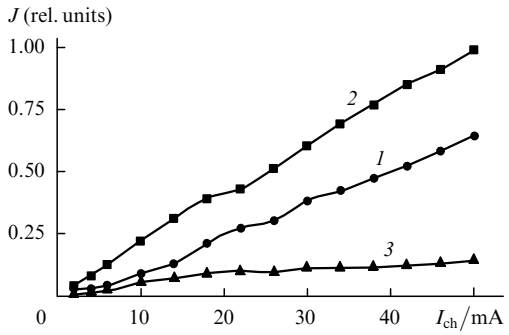

Figure 4. Brightness J of the 156-nm (*1*) and 186-nm (*2*, *3*) emission bands as a function of the current I_{ch} of the glow discharge in a mixture of compositions He : H_2O = 1.0 : 0.2 kPa (*1*, *2*) and Xe : H_2O = 4.0 : 0.2 kPa (*3*).

The pressure of water vapour has the strongest effect on the VUV emission bands. As the water vapour pressure was increased to 1.0 – 2.5 kPa, the brightness of the VUV radiation decreased by a factor of 50 – 100 and the broad band in the 307 – 315 nm region became dominant. The positions of the maxima in this band do not correspond to those of the known OH ($A - X$) bands. A similar broad band at 309.1 nm was also observed in the plasma of a high-frequency discharge [7]. This emission may arise from the spontaneous decay of the $(OH)_n^*$-type cluster molecules (where $n \leqslant 2$).

An increase in the partial helium pressure in the $He - H_2O$ mixture with a low density of water vapour resulted in the reduction in the brightness of all characteristic bands (Fig. 3). The effect of helium on the brightness of the 156-nm band was most pronounced. The optimal partial helium pressure in the discharge in the $He - H_2O$ mixture was 1.0 kPa. In the operating range of discharge currents, the brightness of all the bands increased linearly with current, no saturation effects being observed (Fig. 4). Replacing helium with a heavy rare gas (Xe) resulted in the significant reduction in the brightness of the VUV emission bands. Comparison of the parameter E/N obtained in our experiment (over 1 Td) with the data of Ref. [3] shows that in the latter case it is lower by an order of magnitude.

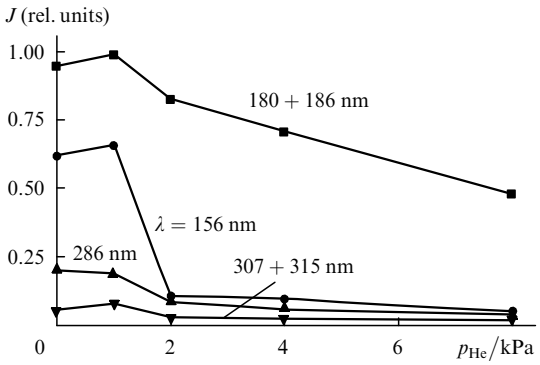

Figure 3. Brightness J of the characteristic plasma emission bands of a $He - H_2O$ mixture as a function of p_{He} for a water vapour pressure of 50 – 150 Pa and I_{ch} = 50 mA.

With a $He - H_2O$ mixture, the average output power in the 130 – 190 nm region is comparable with the output of the corresponding ArCl lamp at 175 nm ($B - X$) and amounts to 1 W.

Therefore, the investigation of characteristics of a stationary radiator pumped by a dc glow discharge shows that, for a voltage across the discharge gap U_{ch} = 800 – 1000 V and pump currents less than 50 mA, the plasma emission is mainly concentrated in the 130 – 190 nm region and is related to the spontaneous decay of the hydroxyl molecules OH ($C - A$; $B - X$). The optimal water vapour pressure lies between 50 and 150 Pa and the optimal pressure of atomic helium is 1.0 kPa. Replacing helium with xenon reduces the brightness of VUV emission bands by about an order of magnitude. The brightness of the bands increases linearly with discharge current, which suggests that the direct electronic excitation of the radiating plasma particles prevails.

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