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Repetitively pulsed VUV emitter pumped by a barrier discharge in a mixture of helium with heavy water (D_2O) vapour

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Abstract. **A gas-discharge lamp based on a barrier discharge in a He–D_2O mixture at partial pressures p_{D_2O} = 0.04–0.33 kPa and p_{He} = 10–60 kPa is studied. The emission spectrum of the discharge plasma contains mainly the A → X and C → X bands of OD hydroxyl (λ = 144–160 nm). The intensities of these bands are optimised by varying the pressure and composition of working mixtures.**

Keywords: *barrier discharge, OD radical, plasma, radiation intensity.*

Currently, sources of spontaneous VUV–UV radiation from Xe_2^* * (λ = 172 nm), $ArCl^*$ (λ = 175 nm), $KrCl^*$ (λ = 222 nm), and other molecules have been developed; they are of interest for different optical technologies, photomedicine, photochemistry, and ecology [1–3]. These lamp sources contain expensive inert gases (Xe, Kr) and, correspondingly, have a higher cost. VUV radiation sources based on mixtures of helium with water vapour have been less studied, although such sources are ecologically safe and use inexpensive working gases.

The characteristics of a cw radiation source pumped by a longitudinal glow discharge in a He–H_2O mixture were investigated in [4, 5]. At water vapour pressures of 50–300 Pa and helium pressures of 1.0–8.0 kPa, the discharge radiation was mainly in the wavelength range of 130–190 nm, which is related to the spontaneous decay of OH radicals (C → A, C → X). The use of a glow discharge reduced the lamp service life because of the contact of the lamp electrodes with plasma.

The possibility of designing a lamp with a microsecond barrier discharge in an Ar–H_2O mixture and emission peak at λ = 309.2 nm (the A → X transition in OH radicals) was investigated in [6]. The gas medium was excited by applying 5-kV meander voltage at the electrodes.

The emission characteristics of water vapour plasma in the spectral range of 200–1100 nm were obtained in [7] using excitation of a water jet in air by a nanosecond pulsed discharge; however, the VUV spectral range was not analysed in that study.

The use of heavy water vapour instead of H_2O vapour leads to an increase in the UV radiation intensity, because the intensity of the UV emission band of OD radicals exceeds that of OH radicals by a factor of 1.5–2 [8].

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Thus, the brief review of the studies aimed at developing and analysing lamps based on water vapour showed that the emission characteristics of barrier discharge plasma in gas mixtures containing H_2O (D_2O) in the spectral range of 130–200 nm have been unknown.

In this paper, we report the results of experimental study of the emission characteristics of a VUV emitter based on a barrier discharge in a He–D_2O mixture excited by nanosecond pulses. The VUV emission spectra of a nanosecond capacitive discharge in a low-pressure He–D_2O mixture were compared with the barrier-discharge spectra, recorded at a higher pressure.

A repetitively pulsed barrier discharge was ignited in a 20-cm-long cylindrical bulb with outer and inner diameters of 26 and 23 mm, respectively. The diameter of the internal quartz tube was 14 mm, a value corresponding to a distance of 4.5 mm between cylindrical barrier surfaces. The inner electrode in the form of a continuous aluminium cylinder was mounted in the inner tube. A spiral electrode (nickel wire) was placed on the outer surface of the lamp bulb; the transparency of this electrode was ~80%. To record the discharge radiation, we used a lithium fluoride window on a special viewport of the discharge bulb, which was hermetically connected to the vacuum-monochromator input.

A barrier discharge was ignited using a high-voltage pulse generator with resonant recharging of accumulating 1540-pF capacitor. The amplitude of voltage pulses at the modulator output was increased (using a cable pulse transformer) by a factor of about 3; it reached 20–30 kV at a separate surge duration of 5–20 ns (Fig. 1a). The amplitude of the main peak in the current pulse reached 50 A at a pulse width of 20–30 ns; the pulse repetition frequency f could be varied within 40–1000 Hz. The power oscillogram (Fig. 1c) indicates that about 70% of the total barrier discharge energy is concentrated in a time interval of 25–45 ns. The recording system was described in [9].

A simplified schematic diagram of the energy levels of hydroxyl molecule is shown in Fig. 2 [10]. The main reaction leading to formation of OD^* (OH^*) radicals in the plasma of He–D_2O(H_2O) mixtures is the dissociative formation of hydroxyl in excited states:

$$e + D_2O \rightarrow OD(C, D, B, A) + e. \quad (1)$$

The lifetime of OD radicals in the C, D, and B electronic states is 6 ns, which is much smaller than the OD(A) lifetime (770 ± 47 ns) [11, 12]; therefore, excitation by nanosecond discharge leads to effective formation of OD(C) radicals.

Figure 3a show the emission spectrum of barrier-discharge plasma in a He–D_2O mixture. At partial pressures of heavy

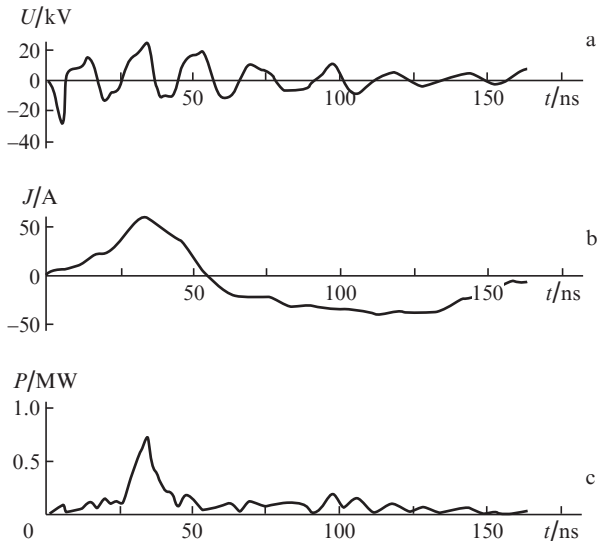

Figure 1. Oscillograms of the (a) voltage and (b) current pulses and (c) the power introduced into the barrier discharge for a lamp emitting in the C → X band of OD radicals; p_{D_2O} = 40 Pa, p_{He} = 20 kPa, and a voltage across the working capacitor U = 13 kV (f = 100 Hz).

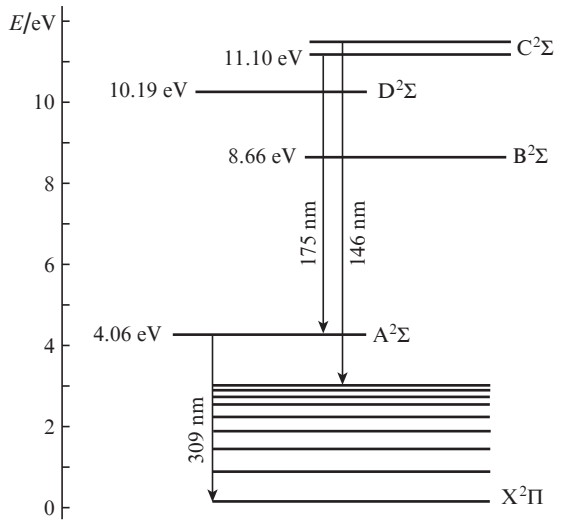

Figure 2. Schematic diagram of the terms of OD radical.

water vapour, p_{D_2O} = 0.04–0.3 kPa, and helium, p_{He} = 10–60 kPa, the radiation is mainly concentrated in the VUV range (λ = 144–160 nm). The bands in this range can also be attributed to the C → X transitions in OD radicals [10]. The spectrum contains also the A → X UV band of OD hydroxyl, peaking at λ = 309 nm. For comparison, Fig. 3b presents the emission spectrum of a repetitively pulsed capacitive discharge of nanosecond duration in a He–H_2O mixture. The strongest bands in this spectrum are the C → A bands of OH radicals, peaking at λ = 180 and 186 nm; they were not observed in the barrier discharge.

The increase in the helium pressure in barrier discharge, as compared with capacitive discharge, leads to fast vibrational relaxation of hydroxyl molecules to the lower vibrational $C^2\Sigma^+$ state, which decays with emission in a narrow band peaking at λ = 144 nm when hydroxyl passes to higher lying vibrational levels of the $X^2\Pi$ state.

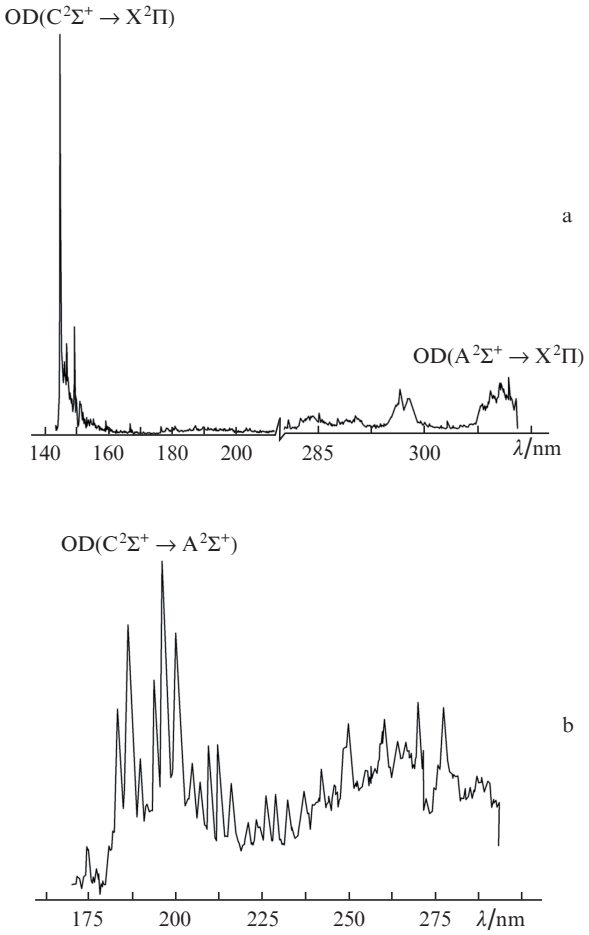

Figure 3. Emission spectra of (a) barrier discharge in a He–D_2O mixture at p_{He} = 20 kPa and p_{D_2O} = 0.33 kPa and (b) capacitive discharge in a He–H_2O mixture at p_{He} = 2.66 kPa and p_{H_2O} = 0.2 kPa.

The dependence of the barrier discharge radiation intensity for a He–D_2O mixture in the range λ = 144–160 nm on the partial heavy water vapor pressure is shown in Fig. 4. The radiation from OD radicals is strongest at the optimal pressure of water vapour: 0.06–0.2 kPa (Fig. 4a). The optimal helium pressure, which is necessary to provide the maximum intensity of the C → X bands in a discharge in a He–D_2O mixture, is 20–46.6 kPa (Fig. 4b).

Thus, the study of the spectral and optical characteristics of the barrier-discharge plasma in a He–D_2O mixture showed that the A → X and C → X bands are the strongest in the emission spectra of OD hydroxyl at helium pressures of 10–60 kPa and heavy water vapour pressures of 0.04–0.33 kPa. Based on the results of this study, a simple discharge lamp with an inexpensive working medium and radiation concentrated mainly in the A → X (λ = 309 nm) and C → X (λ = 144 nm) bands can be developed.

References

1. Lomaev M.I., Skakun V.S., Sosnin E.A., Tarasenko V.F., et al. *Usp. Fiz. Nauk*, **173**, 201 (2003).
2. Panchenko A.N., Tarasenko V.F. *Kvantovaya Elektron.*, **36**, 169 (2006) [*Quantum Electron.*, **36**, 169 (2006)].
3. Boichenko A.M., Skakun V.S., Sosnin E.A., Tarasenko V.F. *Kvantovaya Elektron.*, **23**, 344 (1996) [*Quantum Electron.*, **26**, 336 (1996)].

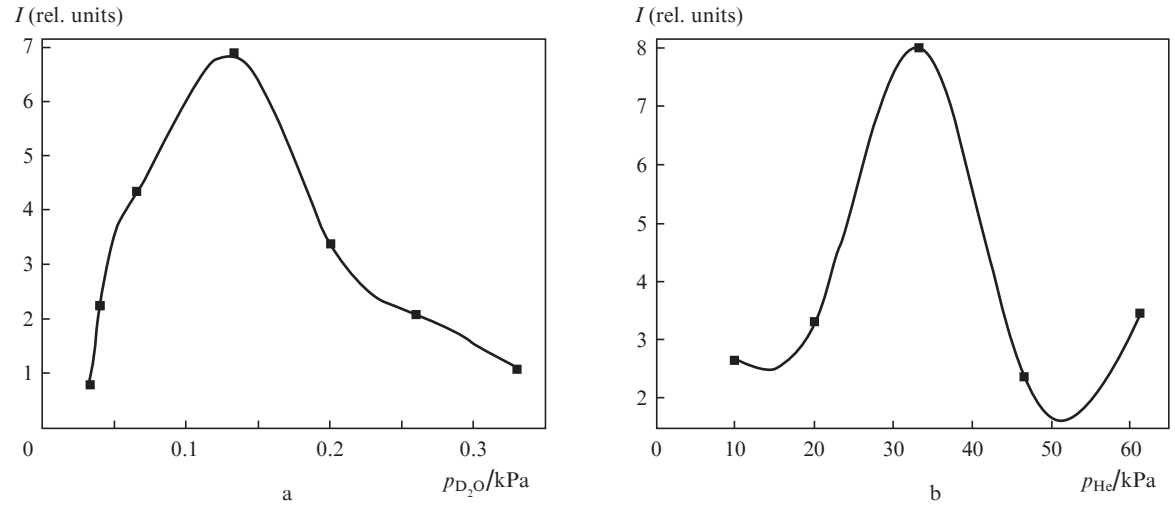

Figure 4. Dependences of the intensity of the OD ($C \rightarrow X$) emission band of barrier-discharge plasma in a $He-D_2O$ mixture (a) on the heavy water vapour pressure at $p_{He} = 20$ kPa and (b) on the helium pressure at $p_{D_2O} = 0.2$ kPa .

4. Shuaibov A.K., Dashchenko A.I., Shevera I.V. *Kvantovaya Elektron*., **31**, 547 (2001) [*Quantum Electron*., **31**, 547 (2001)].
5. Shuaiabov O.K., Malinin O.M. *Naukovii Visnik UzhNU, Ser. Fiz.*, **27**, 50 (2010).
6. Sosnin E.A., Erofeev M.V., Avdeev S.M., Panchenko A.N., et al. *Kvantovaya Elektron*., **36**, 981 (2006) [*Quantum Electron*., **36**, 981 (2006)].
7. Krivonosenko A.V., Krivonosenko D.A., Prokop'ev V.E. *Opt. Atmos. Okeana*, **25**, 268 (2012).
8. Shuaibov A.K., General A.A., Shpenik Yu.O., Zhmenyak Yu.V., Shevera I.V., Hrytsak R.V. *Zh. Tekh. Fiz*., **79**, 153 (2009).
9. Shuaibov A.K., Minya A.I., Malinin A.N., Gomoki Z.T., Hrytsak R.V. *Zh. Prikl. Spektrosk*., **78**, 927 (2011).
10. Vul' A.Ya., Kidalov S.V., Milenin V.M., Timofeev N.A., Khodorkovskii M.A. *Pis'ma Zh. Tekh. Fiz*., **25**, 10 (1999).
11. Kuznetsova L.A., Kuz'menko N.E., Kuzyakov Yu.Ya., Plastinin Yu.A. *Veroyatnosti opticheskikh perekhodov dvukhatomnykh molekul* (Probabilities of Optical Transitions in Diatomic Molecules) (Moscow: Nauka, 1980) p. 319
12. Huber K.P., Herzberg G. *Constants of Diatomic Molecules* (Van Nostrand Reinhold, New York, 1979; Moscow: Mir, 1984) Pt 2.