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Abstract

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PHYSICS

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SPECTROSCOPIC INVESTIGATION OF A GAS DISCHARGE FOR ARGON ION OPTICAL QUANTUM GENERATORS

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To clarify the question of the mechanism that provides inversion of levels in argon ion OQGs, data on the parameters of the gas discharges used for these OQGs—and, above all, on the concentrations of charged particles—are of decisive importance ⁽¹⁾. The determination of the concentration of charged particles in gas discharges used both for continuously operating and for pulsed argon OQGs was carried out by us photographically, from the Stark broadening of the hydrogen lines H_α and H_β . In the case of a continuous-action OQG, hydrogen was added to the argon as an impurity, while in the pulsed OQG the natural hydrogen impurity was sufficient.

The contour of H_β in the discharge of a continuous-action OQG was studied with an STE-1 spectrograph crossed with a Fabry–Perot interferometer with mirror spacings of 1 and 2 mm. The argon pressure in the cold part of the discharge tube was 0.5 mm Hg. The experiments were carried out with two different capillary diameters and at currents of 8 and 10 A, usually used in operation of the OQG. The experimental conditions and results for the H_β lines are given in Table 1. As is seen from the table, the observed line widths are $\sim (43 \div 44) \cdot 10^{-2}$ Å. If one assumes that the observed width of H_β is due only to the Stark effect, then, according to Fig. 6 of ⁽²⁾, the concentration of charged particles will be of the order of 10^{14} cm⁻³. However, this is only an upper limit of the concentration. In reality, the observed line width

Table 1

Figure 1

Figure 1: Figure 1

Capillary length, mm	Internal capillary diameter, mm	Current, A	Current density, A/cm ²	Line	Width, 10 ⁻² Å:		Width, 10 ⁻² Å:		Atomic temperature, °K	Electron concentration, cm ⁻³
					observed	structural function	Doppler	Stark		
300	2.6	10	189	H_{β}	43	9	14	20	1650	$3.7 \cdot 10^{13}$
250	1.6	8	400	H_{β}	44	9	17	18	2350	$3.4 \cdot 10^{13}$

is composed of broadenings due to the instrumental function and the Doppler and Stark effects. For a rough estimate one may assume that the widths caused by these factors add. The results of such processing are also given in Table 1.

It is seen from the table that, in an argon discharge under regimes characteristic of the operation of a continuously acting ion argon OQG, the concentrations of charged particles are $\sim 3 \div 4 \cdot 10^{13} \text{ cm}^{-3}$. The gas temperature was determined from the Ar I 4259.361 and 4158.59 Å lines, whose contour, as our investigations showed, is purely Doppler.

The observed dependence of the gas temperature on the discharge-current density is given in Fig. 1. As is seen from the figure, the gas temperature is considerably higher than room temperature and increases with increasing current density, and this

means that the gas density in the capillary is not $\sim 10^{16} \text{ cm}^{-3}$ (corresponding to a pressure of 0.5 mm at room temperature), but an order of magnitude lower. This is due to the fact that the capillary of the gas-discharge tube is connected to larger volumes (the cathode and anode sections), where the gas temperature is much lower than in the capillary.

The ion temperature and its dependence on current density were determined from the ArII 4933.24 and ArII 4228.18 lines. The results obtained are shown in Fig. 1. The ion temperature is approximately 1.5 times higher than the atom temperature and increases with increasing current density. The spectra for determining the temperature from the Ar I and Ar II lines were photographed from the end of the capillary.

Fig. 1. Dependence of the temperature of atoms (1) and ions (2) in a direct-current discharge ($d = 1.6$ mm), determined from the Doppler broadening of the ArI and ArII lines, on the discharge current density. (The spectrum was photographed from the end of the capillary.)

Experiments to determine the concentration of charged particles in the discharge of a pulsed optical quantum generator were carried out with a quartz gas-discharge tube 95 cm long and with an inner diameter of 5 mm. The cathode was a heated oxide cathode used in TGI1-260/12 thyratrons. The experiments were carried out at a pressure of a He and Ar mixture (10 : 1) of $\sim 6 \cdot 10^{-2}$ mm. Power was supplied by a rectangular voltage pulse of 6-10 kV with a duration of 4 μ sec and a repetition rate of 40 Hz. The current was varied by means of ohmic resistors connected in series with the tube. The contours of the H_α and H_β lines were studied using an STE-1 spectrograph. The conditions under which the experiments were carried out and the results are given in Table 2.

The results were processed as follows. For a rough estimate, one may separate the Doppler and Stark widths from the experimental widths of H_α and H_β , taking into account that the Doppler width of these lines differs by a factor of 1.33 ($\lambda_\alpha/\lambda_\beta = 1.33$) and the Stark width by a factor of 10 (at a concentration $N_{el} = N_{ion} = 10^{15}$, the width of H_β is 9.4 times greater than the width of H_α , and the ratio tends to increase

Table 2

Resistor ohm	Current density, Current, A/cm ²			Instrumental function				Atom temp., °K	Electron conc., cm ⁻³
	A	A/cm ²	Line	Observed	Doppler	Stark			
0	160	820	H_α	77	36	36	5	6000	$2 \cdot 10^{13}$
0	160	820	H_β	123	33	27	63	6000	$2 \cdot 10^{13}$
25	110	560	H_α	68	36	29	3	4000	$1 \cdot 10^{13}$
25	110	560	H_β	95	33	22	40	4000	$1 \cdot 10^{13}$
50	75	400	H_α	59	36	22	1	2000	$8 \cdot 10^{12}$
50	75	400	H_β	56	33	16	7	2000	$8 \cdot 10^{12}$

with decreasing N_{el} , and therefore for the estimates we adopted $\delta\lambda_{St\beta}/\delta\lambda_{St\alpha} = 10$). Solving the equations

$$\delta\lambda_{exp\alpha} = \delta\lambda_{D\beta} \cdot 1.33 + \delta\lambda_{St\alpha} + \delta\lambda_{a\alpha},$$

$$\delta\lambda_{\text{exp}\beta} = \delta\lambda_{D\beta} + 10\delta\lambda_{\text{St}\alpha} + \delta\lambda_{a\beta}$$

($\delta\lambda_a$ is the instrumental function), we obtain $\delta\lambda_D$ and $\delta\lambda_{\text{St}}$. The Doppler width makes it possible to estimate the temperature of the atoms, and the Stark width the concentration of charged particles (²).

The results of such processing are also given in Table 2. It is seen from the table that, as the current density increases from 400 to 820 A/cm², the concentration of charged particles increases from $8 \cdot 10^{12}$ to $2 \cdot 10^{14}$ in 1 cm³, and the gas temperature from 2000 to 6000°K.

Thus, as a result of the work, N_{el} and T_g have been determined—two basic characteristics of gas discharges used in argon quantum generators operating both in pulsed and in continuous regimes. In addition to these characteristics, in order to clarify the question of the inversion mechanism in argon ion OQGs, it is necessary to know the electron temperature, the spectroscopic as well as the probe determination of which in our case is associated with great difficulties.

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Note: Figure translations are in progress. See original paper for figures.

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