INFLUENCE OF PARAMETERS OF THE ACOUSTOPLASMA MODE
ON THE OPTICAL EMISSION SPECTRUM OF THE MIXTURE
OF GAS DISCHARGE CO₂-LASER

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Abstract – The emission spectra in the visible range (0.3–0.8 μm) for radiation of plasma of a gas discharge CO₂-laser have been measured. Dependences of the intensity of spectral lines on the gas pressure and on the discharge parameters were obtained experimentally. It is shown that in acostoplasma mode conversion factor of electrical power into optical emission is up to 2–2.5 times higher than in the case of DC discharge only.

Keywords: acostoplasma, optical emission spectra, gas-discharge CO₂-laser.

1. Introduction

The current that contains constant and variable components generates acoustic oscillations in the discharge tube and the plasma passes from an unperturbed state in a new perturbed state calling acostoplasma. Acostoplasma parameters may differ significantly from the unperturbed plasma parameters [1-5]. In this paper the influence of acostoplasma mode of discharge tube on the intensity of radiation of plasma in the visible range is considered.

2. Experimental setup

The experiments were performed with a gas mixture of CO₂-laser (CO₂ : N₂ : He = 1 : 1 : 8) at pressures of 2–16 torr. A specially made water cooling discharge tube (Fig. 1) was used. The discharge gap length is 250 mm and the diameter of discharge channel is 5 mm. The cold electrodes are made from a NiCr alloy. By preliminary aging in low-pressure discharge Ni was cleaned from the surface layer of the electrodes. The temperature of electrodes was insufficient for diffusion of Ni from deep layers on the electrode surface.
Fig. 1. Diagram of the discharge tube: 1 - Glass flange; 2 - Electrode leads; 3 - Plastic ring water jacket; 4 - Water nozzle; 5 - Electrodes (anode and cathode); 6 - Water jacket cover; 7 - Cooling water; 8 - Discharge channel.

The diagram of experimental setup is presented in Fig. 2. The constant direct high voltage \( U_0 \) (1) was applied to the anode of the discharge tube (3). The discharge current, which contained the constant and variable components, was controlled by resistance (6). Radiation from the discharge tube through the fiber was fed to a computer spectrograph “Ocean Optics 2000PC” (4). Measurements were carried out in the spectral range of 0.3–0.8 \( \mu m \).

Milliamperemeter (2) measures the current \( I_{an} \), flowing into the discharge tube from the anode side and milliamperemeter (5) measures the variable component of the current \( I_{cat} \) (\(~\)) from the cathode side. Instantaneous values \( I_{an}(t) \) and \( I_{cat}(t) \) differ due to the change of charge inside the tube (3) during the period of modulation of the discharge current, i.e., \( I_{an}(t) \neq I_{cat}(t) \), but the average values of the currents are equal: \( <I_{an}> = <I_{cat}> = I_0 \) [6, 7]. Kilovoltmeter (7) measures the voltage on the discharge tube. To obtain instantaneous values of current and voltage, the signals from the milliamperemeter (2) and (5) and kilovoltmeter (7) were fed to an oscilloscope. The measuring complex is described in [8].

Fig. 2. Block diagram of the experimental setup: 1 – Regulated DC source of high voltage; 2 and 5 Milliamperemeters; 3 - Discharge tube; 4 - Spectrograph; 6 – Controlled resistance; 7 – Kilovoltmeter; 8 - Driving generator.
3. Results and discussion

Electric power consumed from the power source (1) is equal to

\[ W(\text{el})_{\text{consum}} = \frac{1}{T} \sum_{0}^{T} U(t) I_{\text{an}}(t), \]  

where \( I_{\text{an}}(t) \) is the instant value of the current during the modulation period \( T \).

Additional measurements show that the energy input into the discharge tube \( W(\text{el})_{\text{tub}} \) is \( \approx 50\% \) of \( W(\text{el})_{\text{consum}} \) (more precisely 46–52\%).

Fig.3 shows a comparison of the emission spectra of plasma of CO\(_2\)-laser at DC discharge – (blue line) and acoustoplasma discharge (red line). In both cases: the gas pressure in the tube is \( P_0 = 10 \) torr, the constant component of the discharge current \( I_0 = 17 \) mA, the modulation frequency \( f = 30 \) kHz and the modulation depth \( M = 1.2 \) (where \( M = I_\sim / I_0 \), \( I_\sim \) is the amplitude of the variable component of the discharge current).

![Fig.3. Comparison of the emission spectra of the CO\(_2\)-laser plasma; the blue line - DC discharge and red line - acoustoplasma mode. \( P_0 = 10 \) torr, \( I_0 = 17 \) mA, \( M = 1.2, f = 30 \) kHz.](image)

From Fig.3 it is seen that in acoustoplasma mode spectral line is 2 time higher than in the case of a DC discharge. Measured energy input into the tube in DC mode was \( W(\text{el})_{\text{DC}} = 64 \) W, in acoustoplasma mode \( W(\text{el})_{\text{AP}} = 42 \) W, i.e., in acoustoplasma mode energy input into the discharge was 1.5 times less.

Total spectra power (area under the intensity lines \( W(\text{opt}) = 0.5 \sum_j \nu_j I_j \), where \( \nu_j \) is the optical frequency, \( I_j \) the corresponding intensity.

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In the case of DC $W_{\text{opt}}^{\text{DC}} = 9412$ a.u. (arbitrary units) and for acoustoplasma mode $W_{\text{opt}}^{\text{AP}} = 17128$ a.u., i.e., in the acoustoplasma mode the energy input is 1.5 times less, and the power of optical spectrum is 2 times more. Thus, for acoustoplasma mode, compared to unperturbed plasma with DC power the conversion factor $K$ of the pumping power into the optical power is increasing 3 times.

Fig. 4 shows the change in the intensity of spectral lines depending on the gas pressure in the discharge tube. Corresponding indices DC and AP refer, respectively, to discharge at DC and at acoustoplasma mode.
Fig. 4. Change of the intensity of the spectral lines depending on the gas pressure in the discharge tube.

For DC discharge: a) $P_0 = 2$ torr; $I_0 = 10$ mA; $W_{(el)}^{DC} = 27.5$ W; $W_{(opt)}^{DC} = 17051$ a.u.;
b) $P_0 = 4$ torr; $I_0 = 10$ mA; $W_{(el)}^{DC} = 29.8$ W; $W_{(opt)}^{DC} = 11874$ a.u.;
c) $P_0 = 8$ torr; $I_0 = 10$ mA; $W_{(el)}^{DC} = 37$ W; $W_{(opt)}^{DC} = 9777$ a.u.;
d) $P_0 = 16$ torr; $I_0 = 10$ mA; $W_{(el)}^{DC} = 56.7$ W; $W_{(opt)}^{DC} = 6667$ a.u.

For AP mode: e) $P_0 = 2$ torr; $I_0 = 17$ mA; $f = 30$ kHz; $M = 1.2$; $W_{(el)}^{DC} = 28.9$ W; $W_{(opt)}^{DC} = 30246$ a.u.;
f) $P_0 = 4$ torr; $I_0 = 17$ mA; $f = 30$ kHz; $M = 1.2$; $W_{(el)}^{DC} = 28.7$ W; $W_{(opt)}^{DC} = 24515$ a.u.;
g) $P_0 = 8$ torr; $I_0 = 17$ mA; $f = 30$ kHz; $M = 1.2$; $W_{(el)}^{DC} = 42.3$ W; $W_{(opt)}^{DC} = 24026$ a.u.;
h) $P_0 = 16$ torr; $I_0 = 17$ mA; $f = 30$ kHz; $M = 1.2$; $W_{(el)}^{DC} = 75.8$ W; $W_{(opt)}^{DC} = 23503$ a.u.
From the data given in the legend to Fig.4, the conversion factor $K$ of the pumping power (energy input into the discharge) into the optical power can be determinate by

$$K = \frac{W(\text{opt})}{W(\text{el})}. \quad (2)$$

Figure 5 shows the dependence of the conversion factor $K$ on the gas pressure in discharge tube for the data shown in Fig.4. The vertical axis is the conversion factor of electric power injected into the discharge in the optical power (in the visible range, in arbitrary units).

![Conversion factor $K$ of the electrical pumping power into optical power.](image)

Fig.5. Conversion factor $K$ of the electrical pumping power into optical power.
Blue line - DC discharge, red line - acoustoplasma mode.

From Fig.5 it is seen that in acoustoplasma mode the conversion factor $K$ increases 2-2.5 times in comparison with the discharge at DC. As expected, when the pressure in the discharge tube increases, the conversion factor $K$ is dropping, due to the increasing role of the excitation quenching due to collisions, but the ratio $K_{AP} / K_{DC}$ increases. From Fig.5 it is also seen that for the same values of $K$ in acoustoplasma mode the gas pressure is 3 times greater than at DC discharge. This increase in the operating pressure allows use it in various applications.

4. Conclusions

1. The spectral lines dependence on the pressure of gas mixture in the discharge tube was obtained experimentally.
2. It is experimentally obtained that in acoustoplasma mode the conversion factor of electrical pumping power into the optical radiation (0.3–0.8 μm) is up to 2–2.5 times higher than in the case of DC mode.
3. This ratio increases with increasing gas pressure.
4. For the same values of the conversion factor the gas pressure in the discharge tube for acoustoplasma mode is 3 times greater than for discharge on DC. This increase in the operating pressure can be used in various applications.

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References