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Control of the Spectral Lines Intensity of Plasma Radiation in Visible Range by Acoustic Fields

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Abstract - The cathode region and the positive column one at DC discharge and acoustoplasma mode are considered. The spectrum and intensity of the lines of nitrogen and other components of the working mixture of a CO_2 laser are shown.

Dependence of the intensity of the certain spectral lines and the integral spectrum in the visible range (300 - 800 nm) on the frequency and on the modulation depth of the discharge current are obtained experimentally. The spectra of factory mixture of a CO_2 laser and a mixture of CO_2: N_2: He = 1: 1: 8 are compared.

Keywords: plasma radiation, acoustic fields, spectral lines, intensity

1. Introduction

When the current containing a constant and a sinusoidal modulated components generates in the discharge tube acoustic oscillations, the plasma passes from the undisturbed state in the new, disturbed state – acoustoplasma [1, 2]. Several studies have shown that the parameters of the acoustoplasma differ significantly from plasma parameters without acoustic interactions [1-5].

In this paper we consider the possibility of controlling the intensity of the optical radiation and the plasma radiation spectrum in the visible range (300 – 800 nm) by creating in a discharge tube acoustoplasma discharge mode.

2. Experimental setup

The experimental setup on which the studies were carried out was described in detail in paper [6]. For the spectra registration we used computer spectrograph OCEAN OPTICS PC2000 for the time-averaged spectra and modified spectrograph ISP-51 for instantaneous values [7]. Spectrograph modification ISP-51 was as follows: the standard spectrograph camera with focal length F = 270 mm was replaced by the one with focal length F = 150 mm. In focal plane of the spectrograph in place of a spectrum recording photographic plate, high sensitivity Web-camera without the lens was installed, allowing to record a part of the spectrum of the 4 mm large, turning this part of the spectrum on the entire display screen of the computer. Sometimes webcam with the standard lens is used. In this case the recordable length of the spectrum was in order of 8 mm. We used the spectra calibration obtained by webcam, on defined lines obtained using a spectrograph OCEAN OPTICS PC2000.

We used the factory laser discharge tube LG-23 [8]. The emission spectra of the laser laboratory mixture CO_2: N_2: He = 1: 1: 8 and the spectra of the individual components of the mixture are investigated. For comparison a commercial laser LG-23 with a factory filling mixture was used, in which besides carbon dioxide, nitrogen and helium were present as xenon and water vapor. The spectra were taken perpendicular to the discharge, i.e., a spectrum obtained by the cross-section of the cathode region of the discharge in the positive column.

To identify the spectral lines the table from [9] is used.

3. Results and discussion

As our experiments have shown, in the visible range the greatest contribution to the intensity of spectral lines gives nitrogen molecule N_2. It is known that each electronic level is transforming into a wide band due to the vibrational and rotational levels. Diagram of electronic and vibrational level of nitrogen molecule N_2 is presented in [10].

The lines of the first positive system (FPS) of nitrogen are observed in the positive column of a discharge of molecular nitrogen, and the most intense lines of the band FPS are in the yellow-green and red regions of the spectrum. The lines of the second positive system (SPS) are observed in the positive column of a discharge of molecular nitrogen and low pressure discharges. Lines of the first negative system (FNS) are characteristic for the molecular nitrogen ion (N_2^+).They was observed in a discharge at a very low pressure, in the case of an excess of helium and at a medium pressure are observed in the region of the cathode and a negative glow.

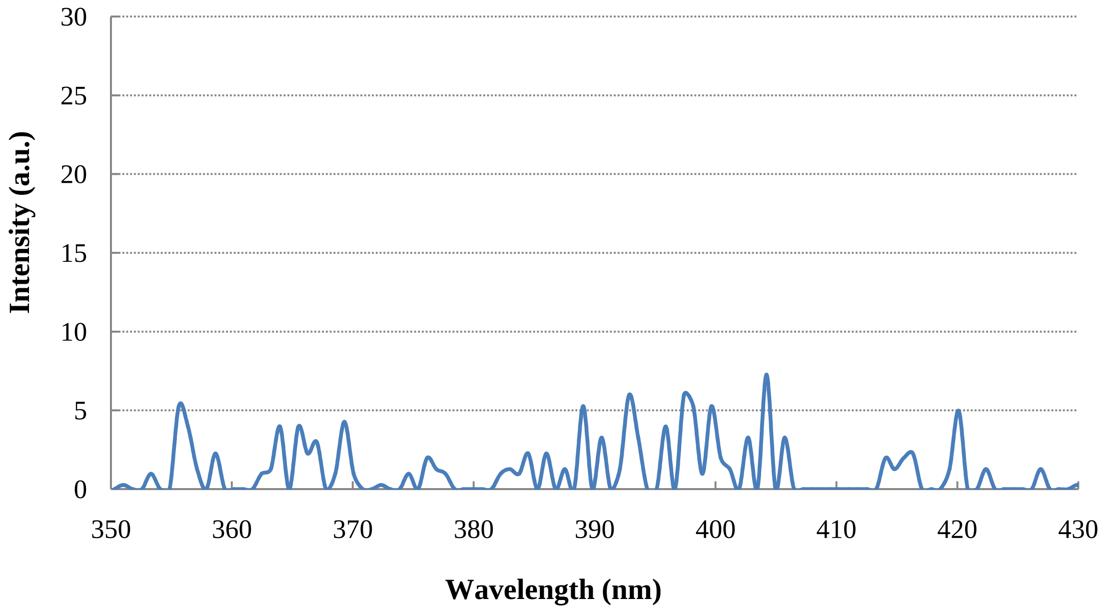
Population of the metastable level $A^3\Sigma_u^+$ is due to three mechanisms:

a) direct electronic impacts;
b) collisions of molecules of nitrogen;
c) transitions to this level from the upper levels.

Population of the metastable level $A^3\Sigma_u^+$ from level $B^3\Pi_g$ occurs when FPS band lines radiate and is well studied in [11]. The processes ofexcitation and quenching of $B^3\Pi_g$ level involving metastable molecules and equalize each other, although they are not precisely inverse. Depopulation of the level $A^3\Sigma_u^+$ occurs either by radiation or by collisions on the wall of discharge channel, but mainly by transition to the metastable level of the excited vibrational level $N_2^*\{X^1\Sigma_g^+, \upsilon = 1\}$, the energy from which is transferred to the upper laser level of the CO_2 molecule [12].

Figure 1 shows the optical spectrum of the cathode region of the positive column of CO_2 laser plasma.

a)



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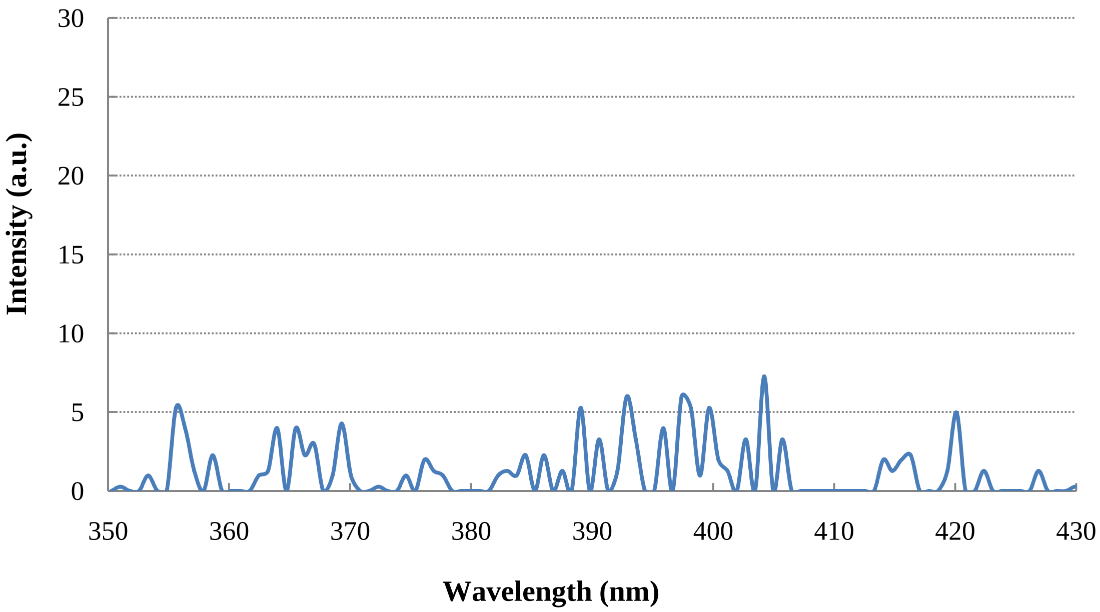
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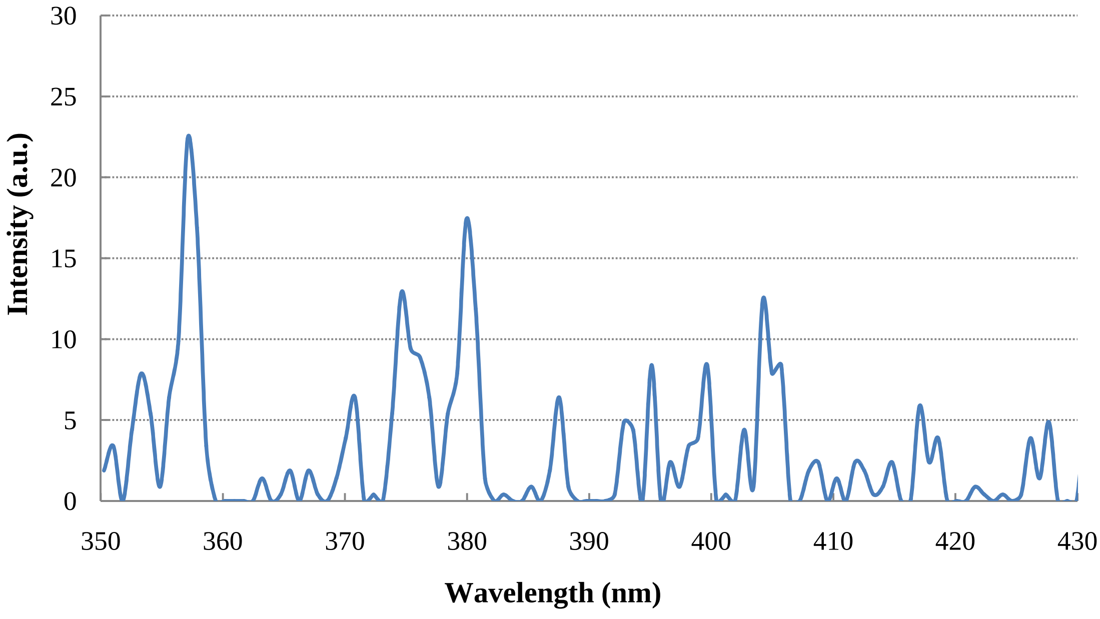
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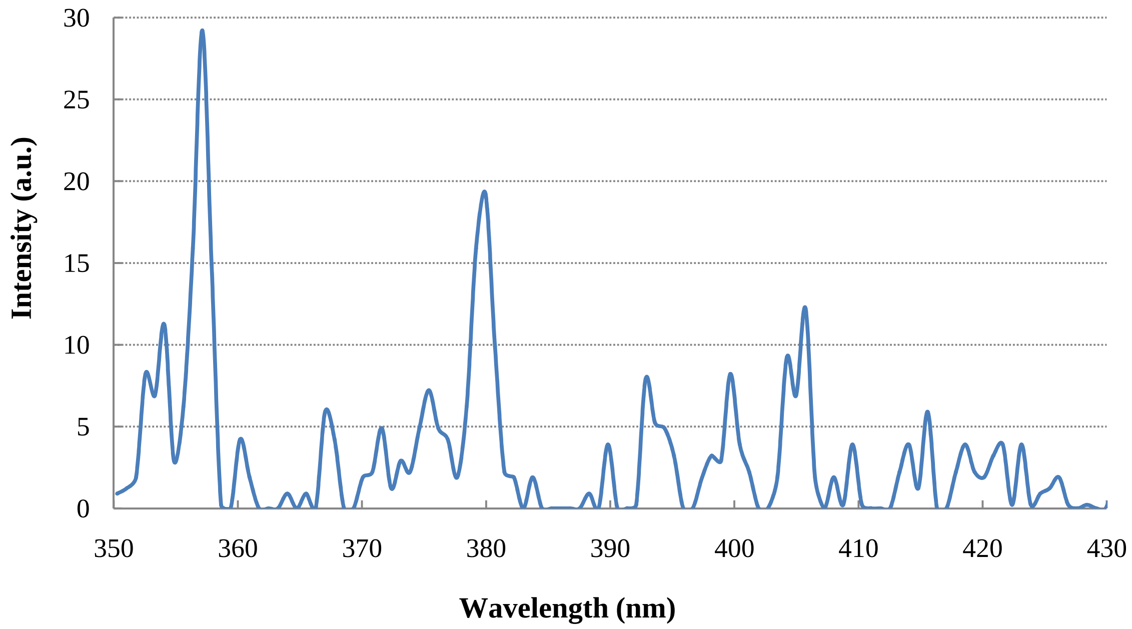


Fig. 1. The optical spectrum of the cathode region of the positive column CO_2 laser plasma series LG-23, P_0 = 10 torr, I_0 = 20 mA. a) factory mixture, DC; b) factory mixture, acoustoplasma discharge, f = 30 kHz, M = 1; c) laboratory mixture (CO_2: N_2: He = 1: 1: 8), DC; d) laboratory mixture (CO_2: N_2: He = 1: 1: 8), acoustoplasma discharge, f = 30 kHz, M = 1.

From Fig. 1 it is shown that the maximal difference in the spectra of the factory and laboratory working mixtures observed at 350 - 430 nm, where the spectral lines of **SPS** band of nitrogen are as follows: (350,05 nm, **Δv = -1, v_i-v_j = 2-3**; 353,67 nm, **Δv = -1, v_i-v_j = 1-2**; 357,69 nm, **Δv = -1, v_i-v_j = 0-1**; 364,17 nm, **Δv = -2, v_i-v_j = 4-6**; 367,19 nm, **Δv = -2, v_i-v_j = 3-5**; 371,05 nm, **Δv = -2, v_i-v_j = 2-4**; 375,54 nm, **Δv = -2, v_i-v_j = 1-3**; 380,49 nm, **Δv = -2, v_i-v_j = 0-2**; 385,79 nm, **Δv = -3, v_i-v_j = 4-7**; 389,46 nm, **Δv = -3, v_i-v_j = 3-6**; 394,30 nm, **Δv = -3, v_i-v_j = 2-5**; 399,84 nm, **Δv = -3, v_i-v_j = 1-4**); 405,94 nm, **Δv = -3, v_i-v_j = 0-3;** 409,48 nm, **Δv = -4, v_i-v_j = 4-8**; 414,18 nm, **Δv = -4, v_i-v_j = 3-7**; 420,05 nm, **Δv = -4, v_i-v_j = 2-6**; 426,97 nm, **Δv = -4, v_i-v_j = 1-5**; 434,36 nm, **Δv = -4, v_i-v_j = 0-4;** and for **FNS** (385,79 nm, **Δv = 0, v_i-v_j = 2-2**; 388,43 nm, **Δv = 0, v_i-v_j = 1-1**; 391,44 nm, **Δv = 0, v_i-v_j = 0-0**; 419,91 nm, **Δv = 0, v_i-v_j = 2-3**; 423,65 nm, **Δv = -1, v_i-v_j = 1-2**; 427,81 nm, **Δv = -1, v_i-v_j = 0–1**).

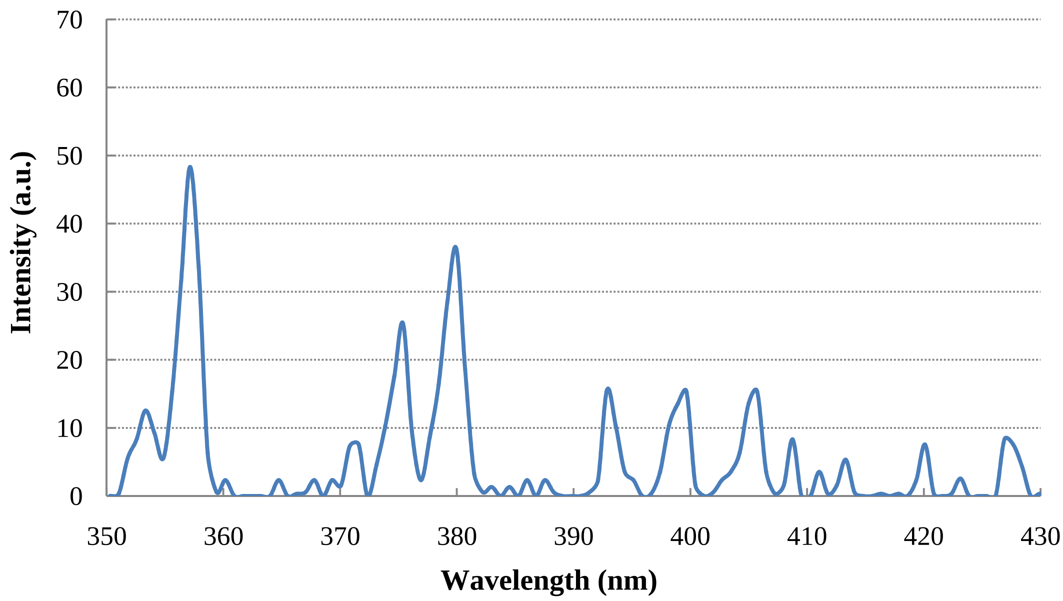
The difference in the spectra of the factory and laboratory laser mixtures is probably related to the fact that water molecules and xenon destroy the upper excited levels.

Identification of the spectral lines shows that the spectral lines characteristic to FNS band of molecular nitrogen ion N_2^+ are practically absent.

Thus, we can say that in the cathode region of the discharge of the working mixture of the CO_2-laser in the spectral region of FPS spectral lines 350 - 430 nm are mainly present, while the absence of characteristic lines of FNS band indicates that in the cathode region of the positive column concentration of molecular nitrogen ions (N_2^+) is small.

Experiments were performed in the frequency range of 0.1 - 50 kHz. On Fig. 2 the graphs of the intensity of the wavelength for three values of the current frequency modulation are presented, in which some spectral lines have the maximal intensity. As it is seen on the graphs, the each spectral line reaches maximum intensity at f = 15 kHz of modulation frequency of the discharge current.

a)



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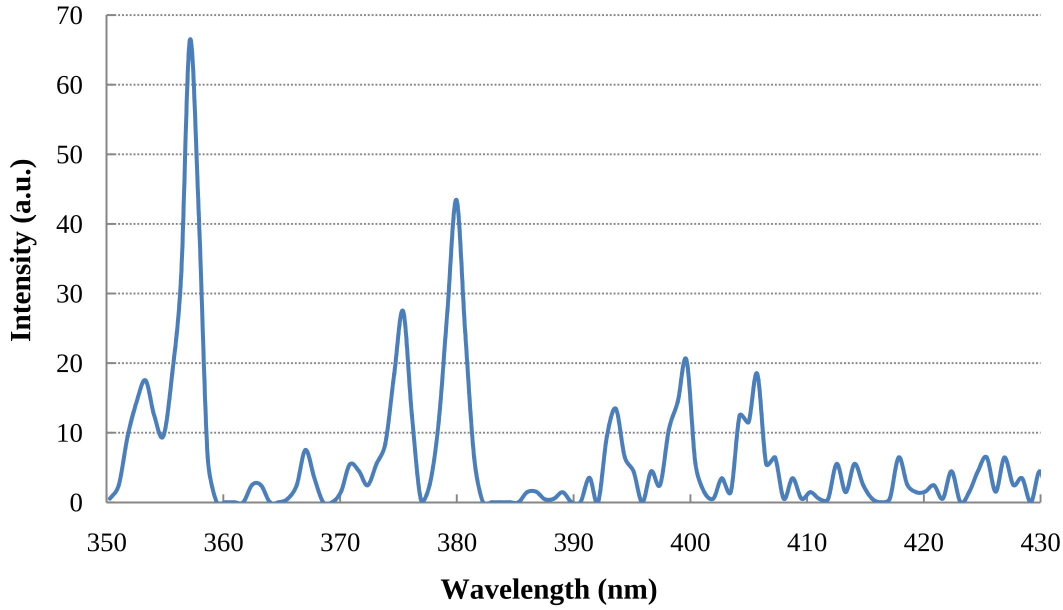

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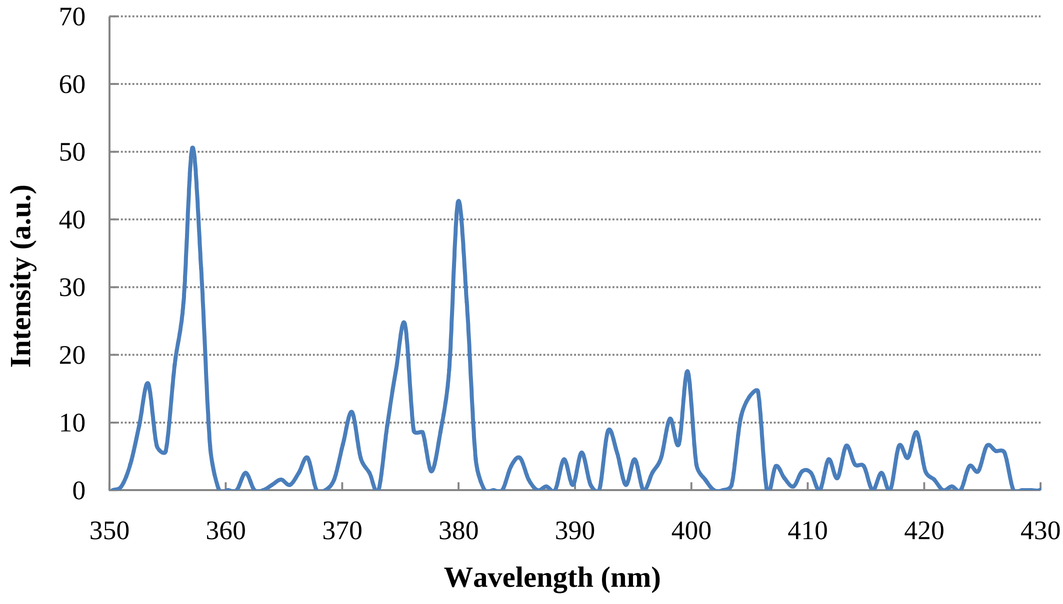


Fig. 2. Change of the intensity of the CO_2 laser mixture in the range of 350 - 430 nm when the current modulation frequency is changing: a) f = 10 kHz; b) f = 15 kHz; c) f = 20 kHz.

Wavelengths range on Fig. 2 is selected from 350 nm to 430 nm, which corresponds to the spectral band of the SPS of nitrogen. This choice is due to the fact that as our experiments show, in the visible range the greatest contribution to the intensity of the spectral lines gives the nitrogen molecule N_2.

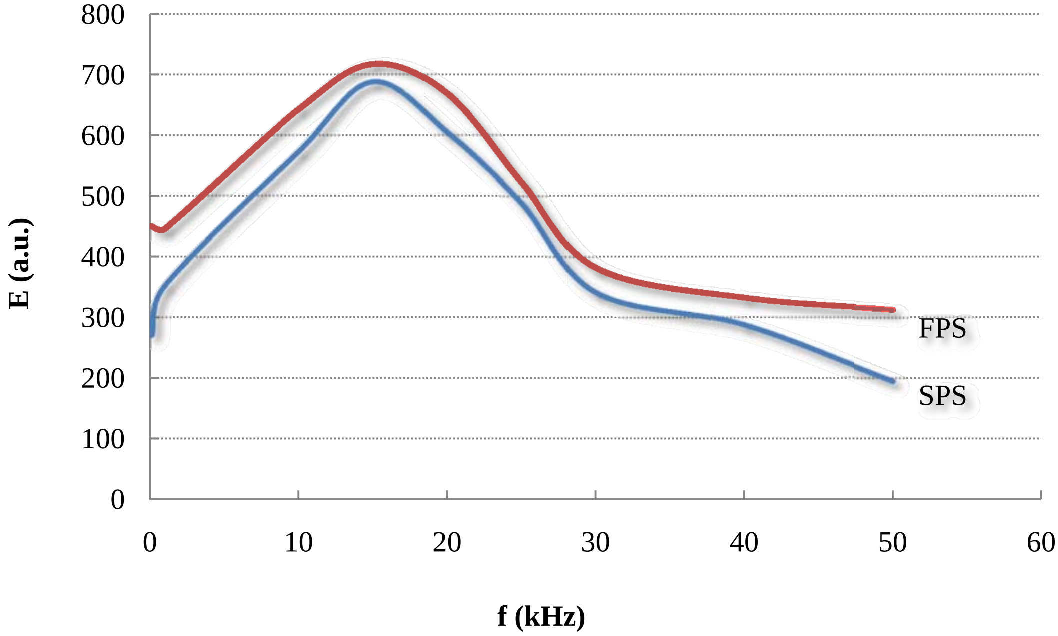


Fig. 3. Dependence of the energy emission in acoustoplasma mode for molecular nitrogen in the spectral bands of the SPS (350 - 430 nm) - blue line and FPS (570 - 690 nm) - red line on the frequency modulation of the discharge current.

From Fig. 3 it is shown that behaviour of the curves for the energy of FPS and SPS bandsis the same, except for the frequencies $f < 0,5$ kHz and $f > 40$ kHz.

The population of the upper level $B^3\Pi_g$ of the FPS spectral band depends mainly on radiation of the lines of SPS band from the level $C^3\Pi_u$ and on collisions. Therefore, the efficiency of population of the metastable level of nitrogen $A^3\Sigma_u^+$ depends largely on the population by direct electron impact and on the lines of the SPS band (and not from the FPS) and the intensity of the spectral lines of the SPS indicates the effectiveness of the population of a metastable level $A^3\Sigma_u^+$.

The intensity of FPS lines indicatesthe depopulation of the metastable level $A^3\Sigma_u^+$.

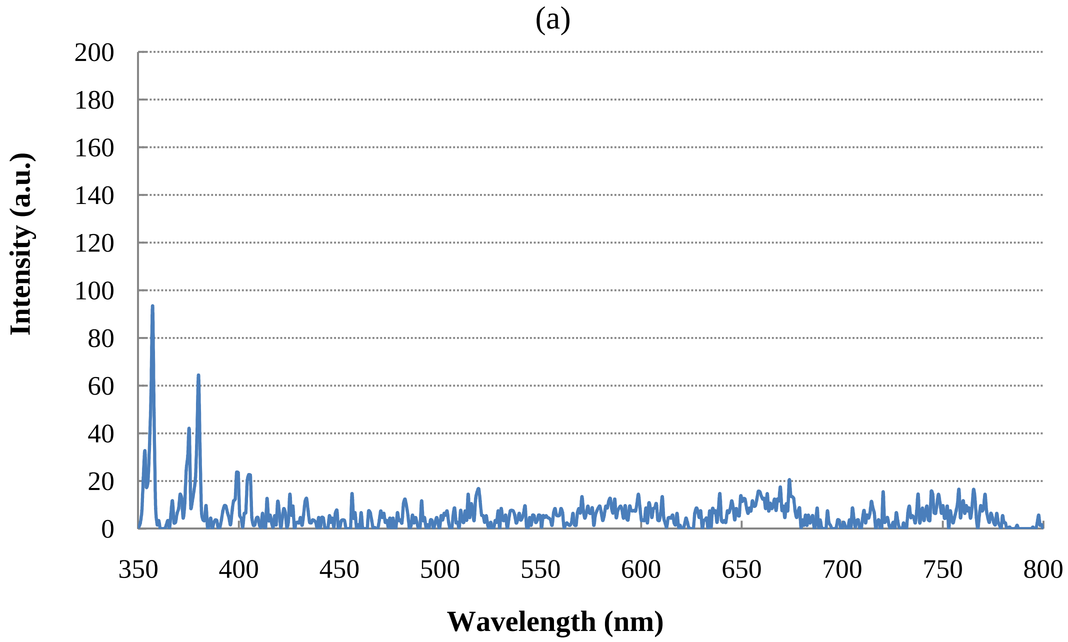
Therefore, the deviation in the behaviour of the spectra of FPS and SPS indicates that when the modulation frequency f <0,5 kHz and f > 40 kHz emission energy increase in band of FPS compared to the SPS band due to the increase of the SPS depopulation of metastable level $A^3\Sigma_u^+$.

Because dipole transitions of the diatomic molecule N_2 are forbidden, the depopulation of metastable levels can only occur due to collisions and we can assume that in acoustoplasma mode at frequencies f < 0,5 kHz and f > 40 kHz role of collisions increases. The frequency range f < 0,5 kHz corresponds to the range below the first longitudinal acoustic mode. The frequency range f > 40 kHz corresponds to the range of off-axis acoustic modes [13].Up to the frequencies 30 - 40 kHz, only a plane wave propagates in the discharge tube, and at higher frequencies off-axis modes that propagate.

Thus, Fig. 4 shows that depopulation of metastable level $A^3\Sigma_u^+$ at current modulation frequencies below the first longitudinal acoustic mode and higher than the first off-axis one exceeds$B^3\Pi_g$ level pumping by SPS band radiation and population by direct electron impact. In the area above the first longitudinal mode and lower than the first off-axis, when a plane wave propagates in the resonator formed by the discharge tube, depopulation of metastable level $A^3\Sigma_u^+$ approximately equal to pumping of the $B^3\Pi_g$ level by SPS band radiation and population by direct electron impact from the ground state.

The energy emission increase in the frequency modulation range of about 15 kHz indicates an increase in efficiency and the population of levels $C^3\Pi_u$ and $D^3\Sigma_u^+$ (fourth positive system), which is probably associated with transitions fromhigh levels. If it had been a collision, the probability of population a low level $A^3\Sigma_u^+$would be greater than the probability of a population of high levels $C^3\Pi_u$ and $D^3\Sigma_u^+$.

On Fig. 4 the emission spectra of pure gases CO_2, He, N_2 at the DC at acoustoplasma mode are shown. Gas pressure is always P_0 = 10 torr, and the modulation depth of the discharge current is M = 1.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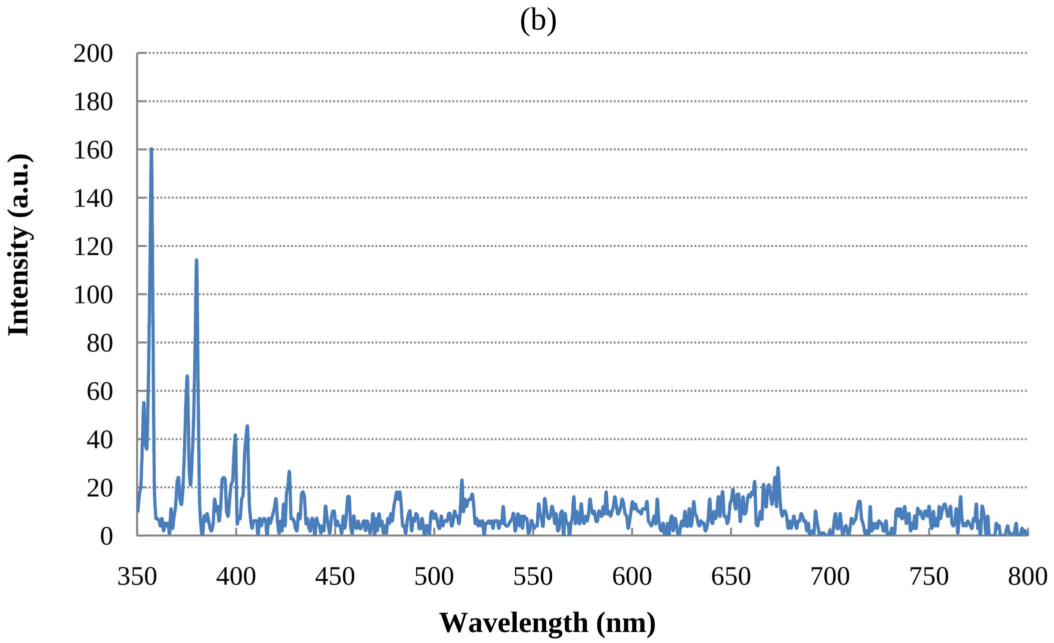
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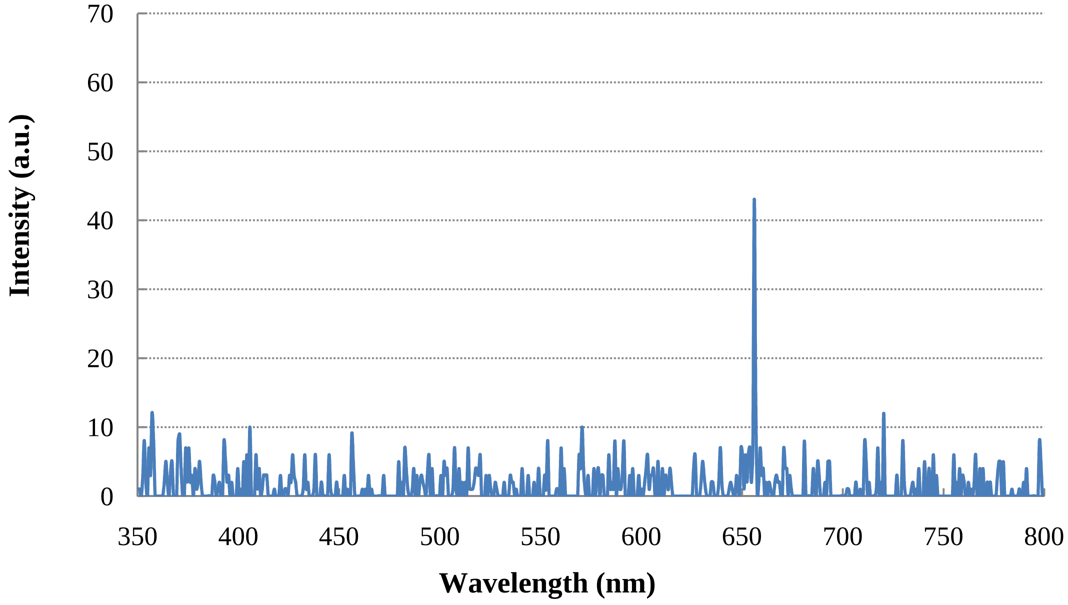
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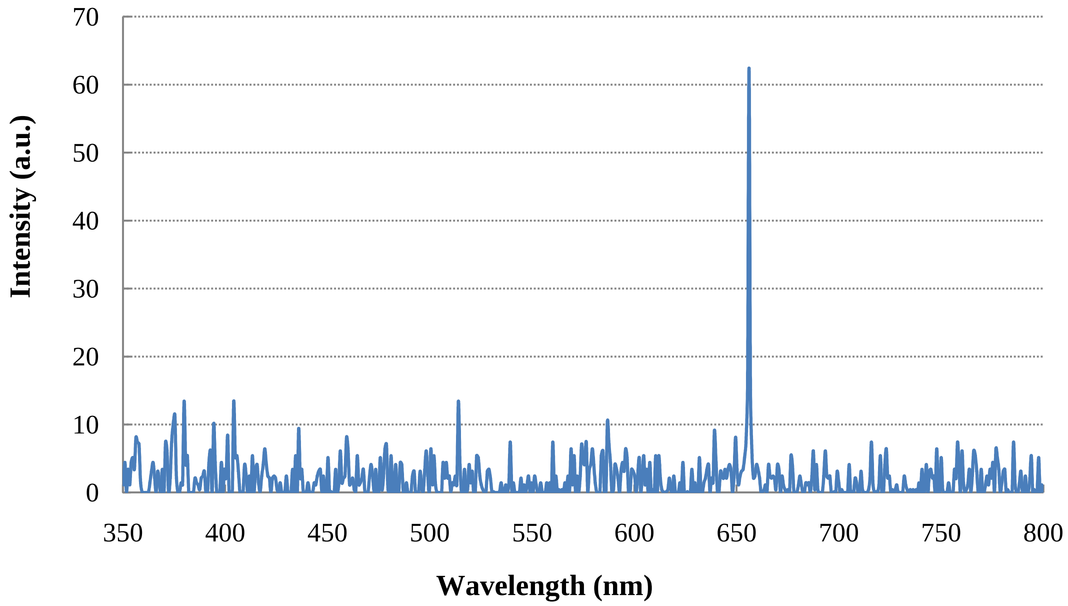
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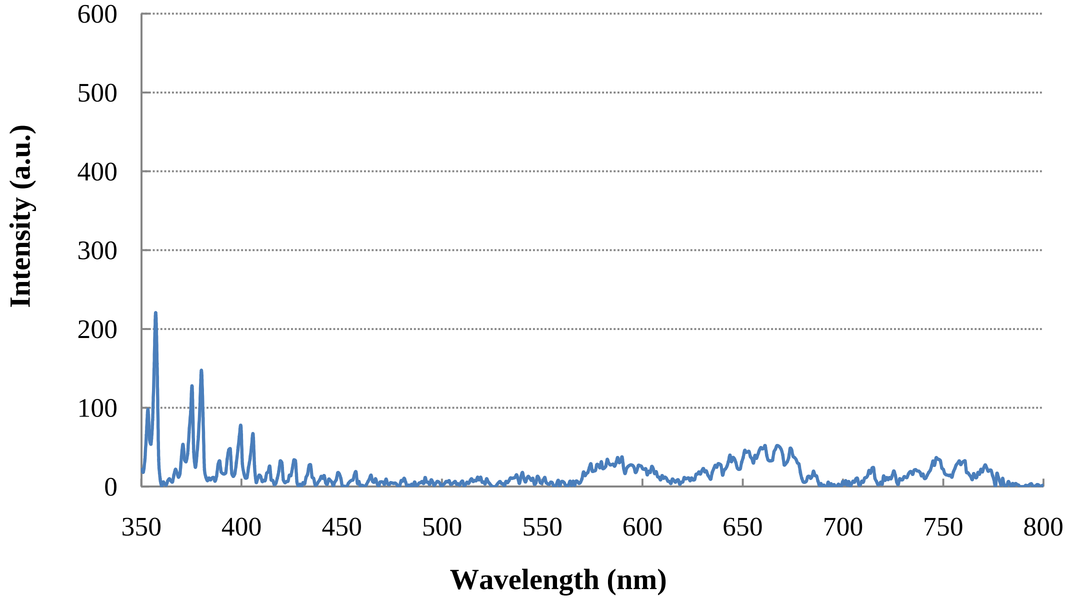

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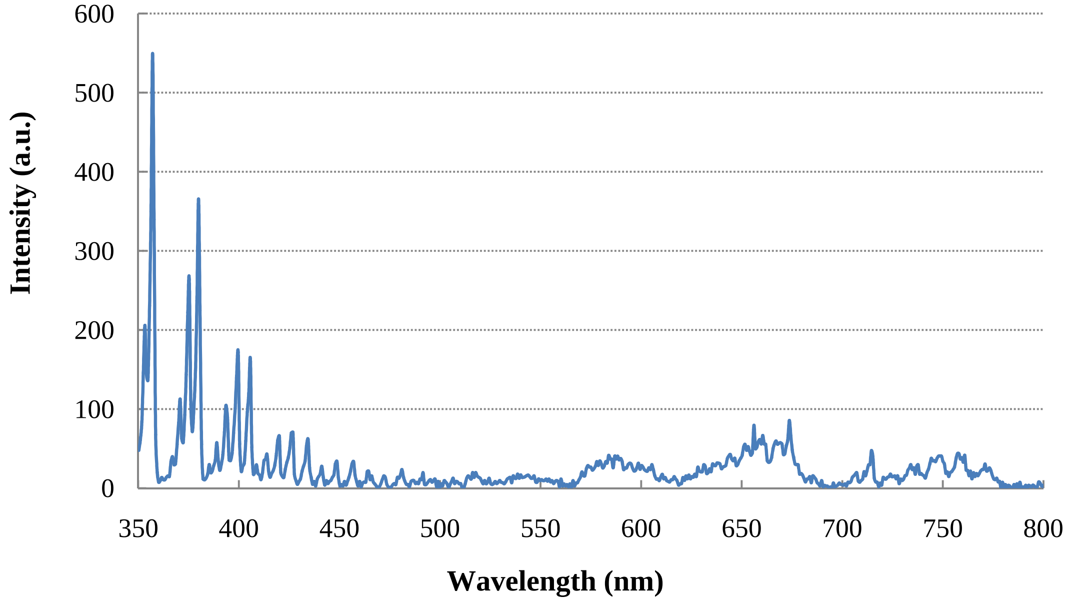

Fig. 4. Emission spectra of pure gases CO_2, N_2, He at DC discharge (DC) and acoustoplasma mode (AP). Gas pressure is P_0 = 10 torr, and the modulation depth of the discharge current is M = 1. a) CO_2, DC, I_0 = 20 mA, W = 74 W; b) CO_2, AP, f = 20 kHz, I_0 = 15 mA, W = 31,5 W; c) He, DC, I_0 = 20 mA, W = 49,4 W; d) He, AP, f = 20 kHz, I_0 = 14 mA, W = 29,4 W; e) N_2, DC, I_0 = 23 mA, W = 85,6 W; f) N_2, AP, f = 25 kHz, I_0 = 16,4 mA, W = 40,8 W.

The graphs on Fig. 4 show that the intensity of the spectral lines for pure CO_2 and He are significantly less than for N_2. It is also clear that the intensity of spectral lines of the individual components of the chosen laser mixture in acoustoplasma mode higher than the discharge at DC.

4. Conclusions

1. The optical spectra in the visible range (300 - 800 nm) of laser factory mixture of the serial laser LG-23 and laboratory laser mixture CO_2: N_2: He = 1: 1: 8 at DC discharge and at acoustoplasma mode are compared. The difference in the spectra of the factory and laboratory laser mixtures probably related to the fact that water molecules and xenon destroy the upper excited levels.
2. It is experimentally shown that at acoustoplasma mode the intensity of spectral lines for the laser mixture and for individual components of the mixture is much higher than at DC discharge.
3. It is also experimentally shown that in acoustoplasma mode emission energy (the total for the entire band) for FPS and SPS bands behaves the same way in the current frequency range of 0,5 – 40 kHz. The deviation in the behaviour of the spectra of FPS and the SPS in the modulation frequencies f < 0,5 kHz and f > 40 kHz due to increased depopulation of metastable level $A^3\Sigma_u^+$.
4. Identification of spectral lines of nitrogen in the bands of the SPS and the FNS is made, and as it was experimentally found it is the molecular nitrogen that gives the greatest contribution to the intensity of spectral lines of the CO_2 laser mixtures.

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