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Periodic-pulse, HF-excited CO_2 laser tuned in 1.5 GHz frequency band

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In this paper, the frequency-selective properties of planar resonators with a diffraction grating are considered. An improvement in selectivity as compared to that of resonators of a square cross-section discharge channel has been pointed out. Laser output power and the frequency tuning range of the transversal flow CO_2 laser depending on the operating mixture pressure haves been measured. Saturation power as well as small signal gain coefficient have been determined. The tuning in the 1.5 GHz range has been achieved for the peak power in the line centre of about 10 W.

1. Introduction

In order to select and tune the generation frequencies of molecular gas lasers, dispersive resonators are usually used, the losses of which depend on the wavelength and may be easily changed. A diffraction grating (DG) working in autocollimation regime is usually used as a selective element.

Both experiments and calculations showed [1], [2] that in traditional CO_2 lasers with open resonators, for which characteristic parameters are: Fresnel number $N \geqslant 1$, confocal parameters $0 < g < 1$ and resonator length $L \simeq 1$ m, the application of a diffraction grating of 150 lines/mm allows us to achieve the generation in a CO_2 molecule at all the fundamental wavelengths. Selectivity of such resonators appears to be sufficient for generation at a selected wavelength independently of the mutual position of the eigen-frequencies DG and the gain line. In this case, the change in a resonator length within a $\lambda/2$ interval causes no change in the CO_2 molecular transition line – the so-called steady selection regime is achieved. The continuous tuning band of the generation frequency is, in this case, maximal, being limited by the lower of the two parameters: the width of the amplification line and the free dispersion area. If a wide tuning band is desired, the resonator length is diminished (the free spectral range increases), while the gas pressure is increased (the line width increases). In accordance with the similarity rules, the product of the gas pressure and the discharge tube diameter is constant, [3], and therefore the discharge tube diameter is also diminished.

When diminishing the transversal sizes of the discharge channel a transition from the conventional lasers with open resonators to the waveguide lasers takes place, where a stationary radiation field structure is formed both by the mirrors and walls of the discharge channel. In such systems, the width of the amplification line is, as a rule, greater than in low pressure lasers with open resonators. At the same time, wide-band tuning of the generation frequencies becomes more difficult in practice. This is due to the decrease in transversal sizes of the laser beam incident on diffraction grating which results in a lowering of the resonator selectivity [4], [5]. An additional lowering of the selectivity degree is due to the interactions of different kinds of vibrations propagating in the waveguide [6], [7].

An improvement of the selectivity properties of the resonator may be achieved by exploiting the resonators either with an interferometer [8], [9] or a combination of different selective elements [10]–[12]. The price to be paid is the complexity of the resonator construction as well as the necessity of applying special stabilizing systems and frequency tuning by several feedback loops.

In this paper, we consider the application of planar lasers with a slit-shaped discharge channel.

2. Frequency selection of the planar waveguide laser with diffraction grating

An improvement of the DG resonator selectivity may be achieved because there are no side walls, while small height of the discharge channel slit allows us to operate at higher pressures. The selectivity of a resonator of planar geometry increases when the diffraction grating grooves are oriented perpendicularly to the slit. In this case, the beam reflected from the diffraction grating propagates in the dispersion plane parallel to the plane imaging the discharge channel. Therefore, the walls do not prevent the beam from propagating along the slit, while the increment in radiation losses, when mistuning from the autocollimation frequency occurs, is the same as in the open resonators of equal Fresnel number N. Besides, in this case, the walls of the discharge channel impose no restrictions on the number of working DG grooves which, additionally, allows us to improve the selectivity. This is illustrated in Fig. 1, where the dependence of the loss increment Δa on the $\Delta \nu$ for the CO_2 laser ($\lambda = 10.6$ μm) with a square waveguide (2×2 mm^2) and a diffraction grating (150 lines/mm, the blazing angle about 52°) located in the waveguide input [4] is shown (curve 1). In the same figure, an analogous dependence for the resonator of planar geometry [1] is also presented (curve 2). The width of the slit amounts to 2 mm. The resonator is composed of the DG and the mirror located close to the discharge channel at the distance of 10 cm from each other. For the aperture size along the slit equal to 2 mm the light spot size on DG is the same as in the quadratic waveguide and amounts to 2 mm/cos(52°) $\simeq$ 3.3 mm. Simultaneously, the selecting properties are improved due to lack of side walls. For example, at mistuning from the determined frequency by 5 GHz, the losses in the first case amount to 1%, while in the second – increase to 15%.

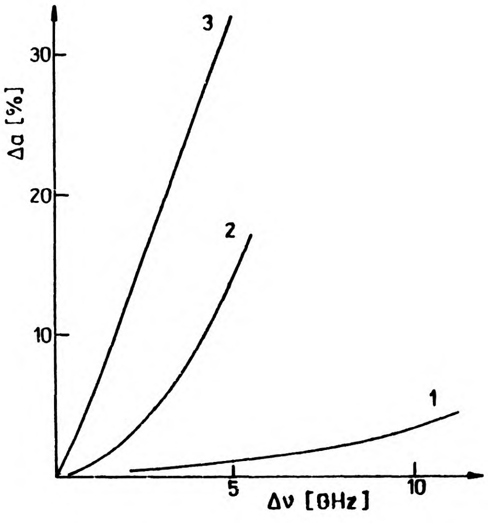

Fig. 1. Dependence of the radiation increment Δa on the mistuning frequency $\Delta\nu$ for different resonators: 1 – waveguide of square cross-section 2×2 mm^2, 2 – planar geometry of height 2 mm, aperture 2 mm, 3 – planar geometry of height 2 mm, aperture 9 mm

The frequency selectivity of the planar resonator may be increased by increasing the aperture along the slit. In particular, when using the 9 mm aperture, the size of the spot on DG amounts to 15 mm and selective losses for the above frequency mistuning amount to 35% (see curve 3, Fig. 1).

Due to its high selectivity, the resonator with planar waveguide allows us to select an arbitrary line from the spectrum of the CO_2 laser transition lines including the sequential lines. Moreover, in many cases the longitudinal mode selection of the resonator is possible since for the mistuning value of about 1 GHz being comparable with the line width in the waveguide CO_2 lasers, the increment in losses Δa amounts to 5%.

3. Experimental set-up

The examinations have been carried out in the set-up shown schematically in Fig. 2. The gas dosing-pumping systems as well as a high frequency generator controlled by a pulse generator were connected to the planar waveguide CO_2 laser, see Fig. 2.

The radiation of the CO_2 laser has been recorded by a fast HgCdTe detector connected to the oscilloscope. In order to identify the vibration-rotation transitions, the CO_2 spectrum analyser has been used. The saw-tooth voltage generator allowed us to shift along the optical axis the DG located on a piezoelement and by the same means to control the length of the resonator in two cases:i) keeping DG in a definite position, and ii) scanning with the repetition frequency up to 100 Hz. The saw-tooth voltage generator has been employed also to synchronize the oscilloscope. For the case when the length of the resonator is not scanned, the chopper is employed to interrupt the radiation (see Fig. 2).

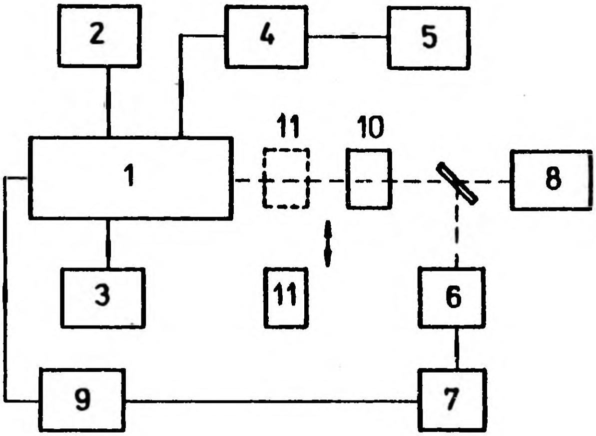

Fig. 2. Scheme of the experimental set-up: 1 – laser, 2 – vacuum pump, 3 – bottle filled with active gas mixture, 4 – rf power supply, 5 – pulse generator, 6 – fast HgCdTe photoresistor (300 K), 7 – storage oscilloscope, 8 – CO_2 spectrum analyser, 9 – saw-tooth voltage generator, 10 – chopper, 11 – laser power meter

For the case when the length of the resonator is not scanned, the chopper is employed to interrupt the radiation (see Fig. 2).

The discharge channel of the examined laser is composed of two uncooled polished copper plates of sizes 20 × 94 mm, distant 2 mm one from the other. These plates were also used as electrodes. The mirrors were located near the waveguide ends. One of the mirrors was the 150 lines/mm diffraction grating of the blaze angle 52° made of invar with the aluminium cover, while the other was a dielectric transmission mirror. The coefficient of reflection of DG amounted to 95% in the first order, while the output mirror transmission was about 5%.

All the laser elements were located in a thin-wall metal cylinder 90 mm in diameter. In order to assure a uniform transversal flow of the laser mixture of a speed equal to about 20 m/s, sectioned jets were located on the walls of the waveguide. The radiation was directed through the BaF_2 window located behind the dielectric mirror between the vacuum part of the discharge chamber and the atmosphere. On the cylinder surface, some holes were made to supply the device with a HF current, while a glass window enabled visual observation of the discharge.

In order to excite the active gas mixture, a laboratory generator (operating at 81.36 MHz frequency) of cw power up to 1 kW for 50 Ω was used which was adapted also to operate in pulse regime of controlled pulse duration not less than 20 μs and the repetition frequency up to 25 kHz. A system of Γ type network of capacitance C and inductance L was used to match the power supply to the impedance of discharge channel. The parameters of matching elements were calculated after the chamber capacity had been measured as a function of frequency. The chosen inductance was $L = 30$ μH while the capacitance C was regulated within the interval 20 – 170 pF being dependent on the pressure of the mixture and the level of the input power.

4. Results of the experiment

The examinations were carried out for periodical pulse excitation of the gas active medium with the rf current. The pulse repetition frequency was changed from 500 Hz to 1.2 kHz. The pulse duration was within the 50–250 μs range. The average input power was between 30 W and 120 W. Typical time-dependence of the laser output power in a pulse is shown in Fig. 3. Its shape is characteristic of the pulse excitation [13]. Initially, a short peak of width of about 0.5 μs appears and then the level of the output power reaches *plateau* of the value equal to 1/3 of the maximum. After switching off the excitation the laser radiation disappears after about 25 μs. The maximum pressure at which the laser radiation was observed was 350 Tr. The dependence of the output power on the pressure in a quasi-stationary regime is presented in Fig. 4. The results of the examinations of the laser have been shown for the active mixture CO_2:N_2:He = 1:2:8. The frequency of the exciting pulses amounted to about 0.5 kHz and their duration was 200 μs. Optimal pressure

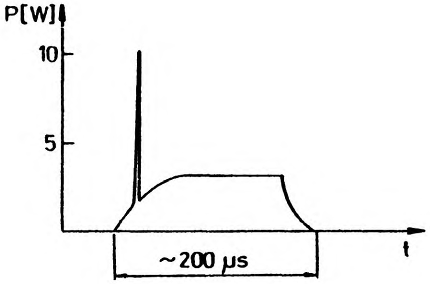

Fig. 3. Shape of the laser output pulse

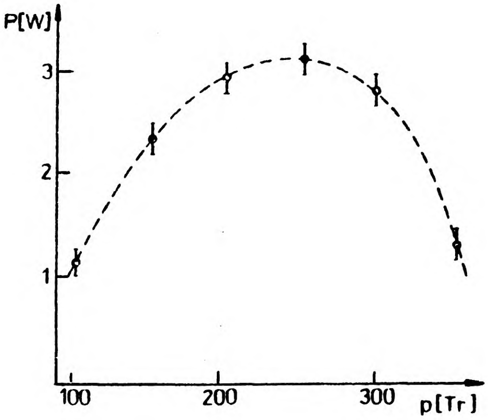

Fig. 4. Experimental dependence of the output laser power in the quasi-stationary regime on the gas pressure

due to the output power was 250 Tr for the average input discharge power of about 40 W. Under these conditions, the output power in the region of *plateau* was higher than 3 W, while its peak value amounted to 10 W.

A continuous frequency tuning was achieved by changing the resonator length and the regime of rigid selection of different vibration-rotation transitions has been realized. The dependence of the frequency tuning within the P20 line of 00^01-10^00 transition upon the pressure has been shown in Fig. 5, for the resonator parameters and the active mixture the same as those in Fig. 4.

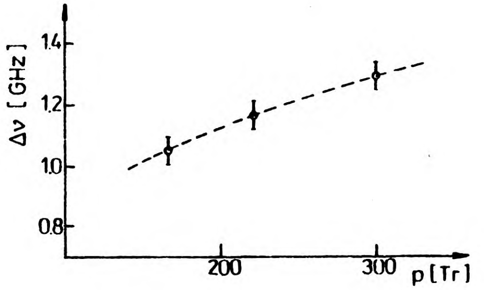

Fig. 5. Experimental dependence of the frequency tuning on the gas pressure

Under the experimental conditions the tuning range of the generated frequency was restricted by the overthreshold width of the excitation line. This allows one to determine the amplification factor in the centre of the line g_0 from the formula [14]

$$\Delta\nu = \alpha_p \left[\frac{g_0 L}{\ln (R_1 R_2)^{-1/2}} \right] \tag{1}$$

where: $\alpha_p = 5$ MHz/Tr – coefficient of collision broadening of a line (p – active gas mixture pressure),

R_1, R_2 – reflection coefficients of the transmission mirror and DG, respectively.

The dependence of the small signal gain coefficient g_0 on the pressure p is shown in Fig. 6. This dependence is consistent with the results of experiments presented in [16], where the tuning of the CO_2 laser in the range of 2 GHz for a similar resonator 75 cm long, and the gas flow speed being 20–30 m/s was examined. In the present work, the tuning was realized in the spectral interval consistent with the distance of the axial modes in the resonator equal to about 1.5 GHz.

When the output mirror of the transmission coefficient equal to about 5% was applied, the output power in the centre of the line amounted to 3 W, and for mistuning by ±0.75 GHz it dropped down to zero. Diminishing of the output mirror transmission to about 2% resulted in diminishing of the power in the centre of the line down to about 2 W, but at the limits of the tuning range (±0.75 GHz) the laser power exceeded the value of 0.3 W. This means that the overthreshold width of the amplification line is greater than the area of the free dispersion of the resonator.

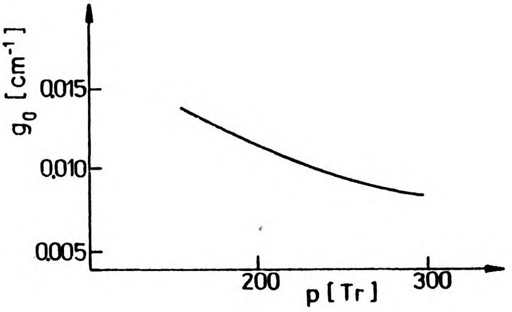

Fig. 6. Dependence of the small signal gain coefficient on the gas pressure

If the data concerning the resonator selectivity reported in Sect. 2 are taken into account, the possibility of frequency tuning in the range exceeding the intermode distances should be considered. This requires some other examinations.

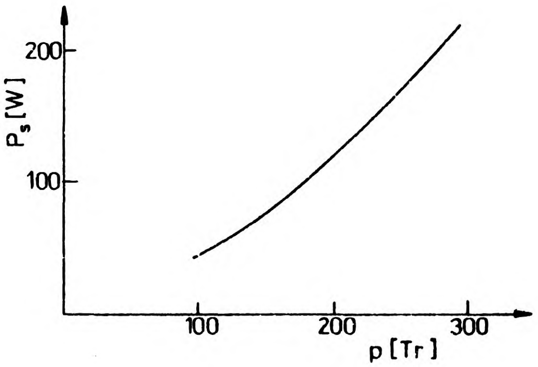

Fig. 7. Dependence of the saturation power on the gas pressure

The quantity W_s may be determined from the following expression relating the output power W with parameters of both the resonator and the active medium [17]

$$W = W_s \frac{(1-R_1)\sqrt{R_1}\left[g_0 L + \ln\sqrt{R_1 R_2}\right]}{\left(\sqrt{R_1}+\sqrt{R_2}\right)\left(1-\sqrt{R_1 R_2}\right)} \tag{2}$$

where: W_s – saturation power,
g_0 – small signal gain coefficients.

The dependence of the saturation power W_s upon the gas pressure p is shown in Fig. 7. It is of quadratic character $W = \sigma p^2$. The value σ computed from this dependence amounts to about 3 mW/Tr^2, and is shown in Fig. 7.

5. Conclusions

Both frequency and energy parameters of a planar transversal gas flow CO_2 laser were examined. It has been shown that for the DG grooves orientation perpendicular to the slit, the improvement of the selectivity is observed when compared to resonators exploiting capillars of square cross-section. The laser power as well as the range of continuous frequency tuning for different gas pressures were measured.

The dependence of saturation power and the small signal gain on the pressure has been determined for low signals.

The frequency tuning within the range of 1.5 GHz for the top power in the line centre of about 10 W has been realized.

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