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Spectroscopic Study of a TEA CO_2 Laser of the CO_2/X, $X=H_2$; N_2/H_2 Type

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Abstract. The spectral output of a TEA CO_2 laser utilizing nonconventional CO_2/H_2 and $CO_2/N_2/H_2$ gas mixtures was analysed. A simultaneous multiline output in P-branch of the $00^01 \rightarrow 10^00$ transition was recorded. A domination of the P(18) line is typical for the first, and that of the P(20) line for the second gas mixture. The enhancement of the P(18) line intensity in spectra (different from P(20) line domination – $CO_2/N_2/H_2$ mixture) is explained primarily by a smaller contribution of the R(23) line gain ($01^11 \rightarrow 11^10$ CO_2 band), to P(20) line ($00^01 \rightarrow 10^00$ band). All measurements were conducted with a nondispersive optical cavity.

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During the last ten years considerable interest in the development of high output peak-power miniature TEA CO_2 lasers has emerged [1–13]. Such laser systems can be applied in different fields, e.g. for remote sensing of the atmosphere, spectroscopy, infrared photochemistry, optical pumping, rangefinding, marking, material processing, etc. In the last three listed applications, the lasers are typically operated with nondispersive cavity. The knowledge of the laser spectral output in this cases is often highly desirable.

The TEA CO_2 lasers which are utilized for any of the previous applications typically operate with conventional, ternary $CO_2/N_2/He$ or binary CO_2/He (seldom with CO_2/N_2) gas mixtures. The operation of the TEA CO_2 laser with nonconventional hydrogen (CO_2/X, $X=H_2$; N_2/H_2) mixtures is insufficiently described in the literature. The aim of this work is to give a contribution to the spectral study of a TEA CO_2 laser of the CO_2/X, $X=H_2$; N_2/H_2 type.

1. Experimental Apparatus

The construction of our TEA CO_2 laser has been described elsewhere [11, 13] and only minimum details will be given here for the sake of completeness. Our uv preionized TEA CO_2 laser follows the design of Howells et al. [5], and Norris and Smith [3].

The laser chamber was made of a block of perspex. Inside the chamber a pair of solid aluminum uniform-field electrodes profiled according to Chang [14] were placed. The electrodes define the discharge volume, 8 mm × 10 mm × 175 mm (14 cm^3). During the laser operation the gas flow at atmospheric pressure is maintained in the axial direction through the laser chamber at low flow rates. Close to the laser electrodes in the chamber the uv preionizer was situated. It consists of an array of five transverse spark gaps (2 mm spacing between the small pointed rods). Each preionizer spark gap was ballasted by several picofarads capacitance established between a pair of preionizer pins and a grounded plate [5].

The electric discharge circuit utilized in this laser has also been a version of the Howells et al. [5], and the Norris and Smith [3] circuits. (See [11] for more details concerning the discharge circuit.)

The laser cavity consists of a flat totally reflecting gold coated copper mirror and a 85% reflective germanium output coupler having 5 m radius of curvature. Cavity mirrors are seperated by 21 cm. Single transverse mode operation (TEM_{00}) was achieved by inserting a perspex diaphragm, with aperture of 0.7 cm diameter, within the cavity and near the output coupler.

Measurements of the laser output pulse energy were performed with a pyroelectric joulemeter (ED-200, Gen-Tec), while the pulse shape was monitored by a photon-drag detector (model 7410, Rofin Ltd.) and a Tektronix type 7704 oscilloscope. Also, the gas-flow rates were measured with appropriately calibrated flowmeters.

For the high-sensitivity measurements of the spectral composition of the laser radiation a modified CO_2 spectrum analyzer (model 16A, Optical Engineering) was used. It was converted into a spectrometer by inserting a single pyroelectric detector behind a 0.5 mm slit in the image plane. The detector was movable along a wavelength scale. The electric signal from the pyroelectric detector is led to a Tektronix type 466 oscilloscope. The radiation of the experimental TEA CO_2 laser before entering the CO_2 spectrum analyzer was focused by a plano-convex ZnSe lens (focal length of 25 cm).

The spectral composition of the experimental CO_2 laser of the CO_2/X, $X=H_2$; N_2/H_2 type was strongly dependent on the cavity alignment. Richardson [15] registered a similar behaviour for a TEA CO_2 laser of the CO_2/N_2 type. Consequently, all measurements of the spectral composition were conducted only for the given adjustment of the cavity.

All results presented in this article are typically obtained for laser operation in the fundamental transverse mode (TEM_{00}). Also, all experimental values represent 20 pulse averages.

2. Experimental Results and Discussions

The typical spectral composition of the TEA CO_2 laser of the CO_2/H_2 as well as the $CO_2/N_2/H_2$ type in dependence of the CO_2 volumetric ratio is shown in Figs. 1 and 2, respectively. These spectroscopic studies were conducted under experimental conditions which are given in Table 1.

In all cases, (Figs. 1 and 2) simultaneous multiline laser outputs were obtained. Only the P-branch laser

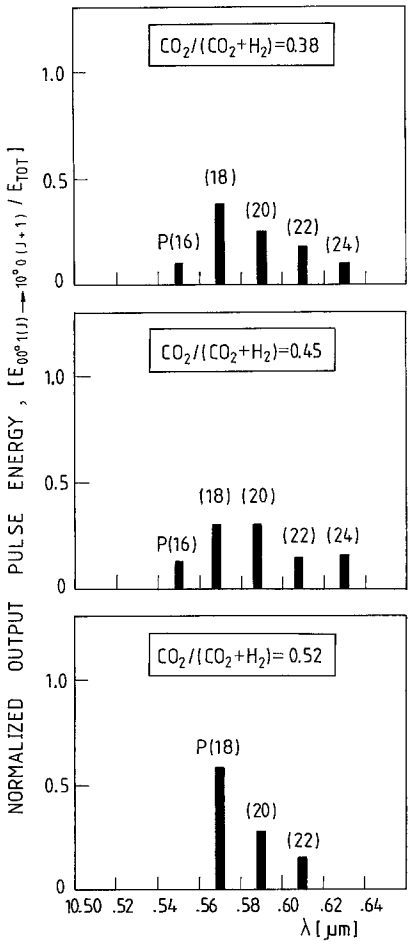

Fig. 1. Normalized distribution of TEA CO_2 laser (of the CO_2/H_2 type) output pulse energy versus vibration-rotational transitions for different gas mixtures content

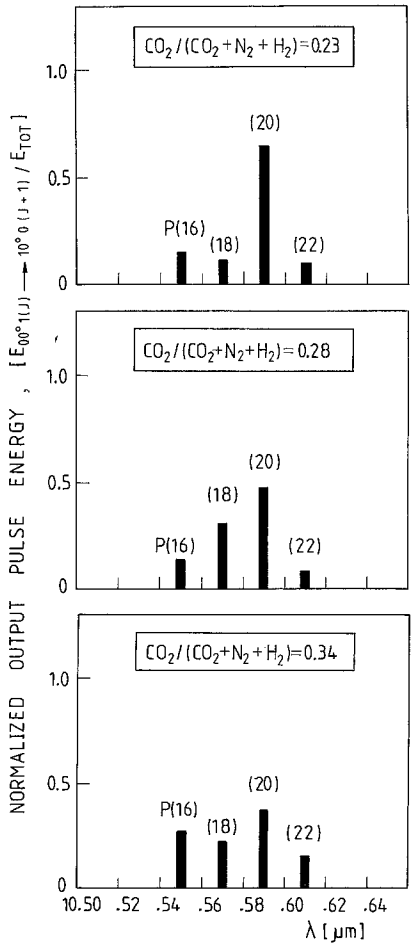

Fig. 2. Normalized distribution of TEA CO_2 laser (of the $CO_2/N_2/H_2$ type) output pulse energy versus vibration-rotational transitions for different gas mixture content

Table 1. The typical TEA CO_2 laser operational conditions during the spectral composition measurement

Gas mixture	CO_2/H_2	$CO_2/N_2/H_2$
CO_2 volumetric ratio	0.38–0.52 ($H_2=16\ cm^3 \cdot s^{-1}=const$)	0.23–0.34 ($H_2=16\ cm^3 \cdot s^{-1}=const$; $N_2=15$; 10 and 3 $cm^3 \cdot s^{-1}$, respectively, Fig. 2)
Maximum output pulse energy (TEM_{00} mode)	~6[a] mJ	~58[a] mJ
FWHM	90–60 ns	~70 ns – init. spike, (1.2 μs – the length of tail)
Input electric energy	245 $J \cdot l^{-1}$	245 $J \cdot l^{-1}$
Efficiency (η)	0.2%	1.7%
Laser cavity	Nondispersive	Nondispersive
Pulse rate repetition	1 Hz	1 Hz
Spectral output	(Simultaneous multiline operation in P-branch, $00^01 \rightarrow 10^00$ vibrational band)	

[a] In multimode operation, the TEA CO_2 laser of the CO_2/H_2 as well as $CO_2/N_2/H_2$ type (under optimum conditions) gives output pulse energy of 46 ($\eta=1\%$) and 214 mJ ($\eta=4.6\%$), respectively

emission (the $00^01 \rightarrow 10^00$ vibrational band) was registered. Typically in spectras (Fig. 1), the P(18) line is dominating. This is not in agreement with [15, 16], (where the P(20) line was dominant; conventional CO_2/N_2 gas mixture was used). Also, the variation of intensity of the individual laser lines between spectra (Fig. 1) were recorded. Parallely with Fig. 1 these variations of lines are shown and in Fig. 3.

On the contrary (of the CO_2/H_2 mixture), in the TEA CO_2 laser of the $CO_2/N_2/H_2$ type (Fig. 2), the P(20) line is dominating. This is in agreement with other observations [15–17], (where the conventional $CO_2/N_2/He$ gas mixture was employed). Also, the variation of intensity of the individual lines between spectra (Fig. 2) are established and parallely (with Fig. 2) are given in Fig. 4.

The role of hydrogen in the TEA CO_2 laser of the CO_2/X, $X=H_2$; N_2/H_2 type is in the following: (i) the hydrogen suppresses the CO_2 dissociation caused by electric discharge. (Relatively low flow rates of the gases make the laser almost sealed-off. In this case the previous effect shows high importance), (ii) the hydro-

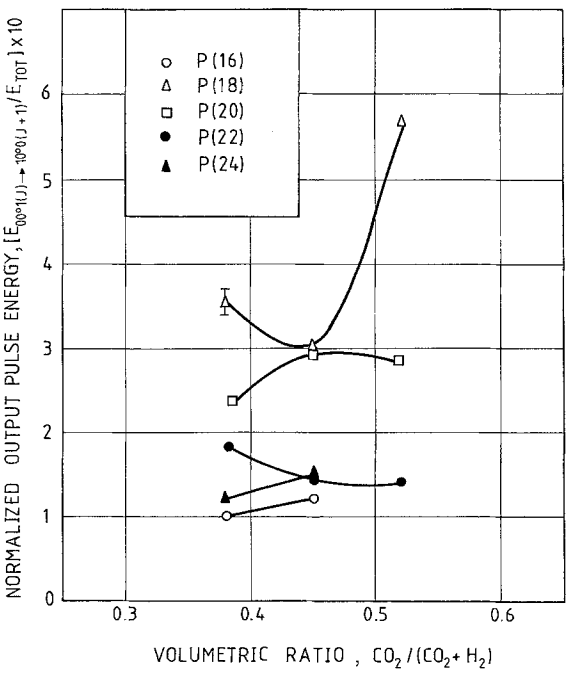

Fig. 3. Normalized TEA CO_2 laser (of the CO_2/H_2 type) energy per 00^01 $(J) \rightarrow 10^00$ $(J+1)$ transition in dependence of CO_2 volumetric ratio

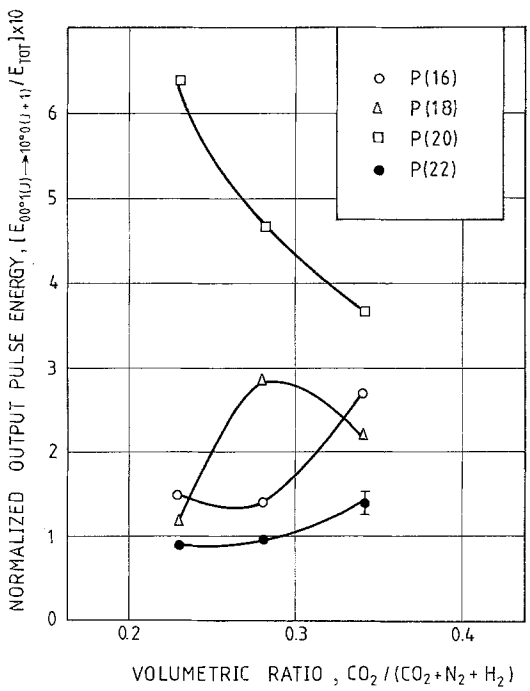

Fig. 4. Normalized TEA CO_2 laser (of the $CO_2/N_2/H_2$ type) energy per 00^01 $(J) \rightarrow 10^00$ $(J+1)$ transition in dependence of CO_2 volumetric ratio

gen molecules relax 00^01, 10^00, as well as 01^10 levels of CO_2. (The relaxation of the 01^10 level (by H_2) is more efficient, so in this way the "bottleneck" in operation of the CO_2 laser is removed), and (iii) hydrogen probably causes the changes of the spectral composition of radiation of the TEA CO_2 laser.

The conclusions (i) and (ii) were considered in [18] while here we shall analyze only conclusion (iii).

Simultaneous multiline spectral output of the TEA CO_2 laser of the CO_2/X, $X=H_2$; N_2/H_2 type is unexpected (Figs. 1 and 2). Laser systems with a nondispersive cavity and with moderate gain operate typically on one wavelength, i.e. on P(20) lines, $\lambda=10.591$ μm. On the contrary, lasers with high gain [19], (as well as systems where an etalon [20, 21] or gas absorber [22] is located inside the cavity) can operate simultaneously on several wavelengths. Consideration of high-gain systems (applied to our laser) leads to the assumption that the buildup of the pulse is short [19] so that redistribution of the population among the rotational levels is minimum. This last fact mainly causes the multiline operation of the laser possible.

Also, the domination of the P(18) line, (Fig. 1, CO_2/H_2 gas mixture) different from P(20) line domination (Fig. 2, $CO_2/N_2/H_2$ mixture) is surprising. Again consideration of high-gain systems (applied to our laser) leads to the conclusion that the intensities of individual laser lines are almost independent of one another [19]. On the contrary, the theoretical and experimental studies of TEA CO_2 lasers which operate with conventional CO_2/N_2 and CO_2/N_2/He gas mixtures [16, 17, 23] show that the P(20) line is dominating. This disagreement is explained by the fact that the P(20) line ($00^01\rightarrow10^00$ band) possesses additional gain caused by the contribution of the R(23) line, ($01^11\rightarrow11^10$, "hot band") [16, 19, 22]. At the same time this contribution is strongly dependent on the gas temperature. From [24] it is well known that this contribution at higher gas temperature is higher (and vice versa). The nonconventional $CO_2/N_2/H_2$ (for given content, Fig. 2) as well as the conventional CO_2/N_2 and CO_2/N_2/He gas mixtures typically possess smaller thermal capacity in comparison with the CO_2/H_2 mixture. Therefore, the temperature rise (caused primarily by electrical discharge in the gas mixture) is considerable in the $CO_2/N_2/H_2$ as well as in the conventional mixtures. According to previous discussions the contribution of the R(23) line gain ($01^11\rightarrow11^10$ band), to the P(20) line ($00^01\rightarrow10^00$ band), (contrary to CO_2/H_2 mixture) will be higher for the $CO_2/N_2/H_2$ gas mixture. This latter fact probably causes the domination of the P(18) and P(20) lines in the CO_2/H_2 and $CO_2/N_2/H_2$ mixtures, respectively. One should have in mind that the R(23) and P(20) lines are separated by 48 MHz, and that their spectral widths are of the order of one GHz so that they overlap, as a rule, in the TEA CO_2 laser.

3. Conclusion

The spectral output in the P-branch (of the $00^01\rightarrow10^00$ CO_2 band) of a TEA CO_2 laser utilizing CO_2/H_2 and $CO_2/N_2/H_2$ gas mixtures was recorded. It was found that the first mixture yields a spectrum in which the P(18) line dominates, while in the second it is the P(20) line.

The domination of the P(18) line in spectra is primarily explained by a variable contribution to P(20) of the R(23) line gain of the $01^11\rightarrow11^10$ CO_2 band. This contribution is strongly dependent on the gas mixture temperature, which has to be smaller in the CO_2/H_2 mixture because of its higher thermal capacity.

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