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High Pressure X-Ray Preionized TEMA-CO_2 Laser

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Abstract. The construction of a high-pressure (up to 20 atm) transversely excited CO_2 laser using transverse X-ray preionization is described. High pressure operation was found to be greatly improved in comparison to UV-preionized systems. Homogeneous discharges have been achieved in the pressure range 5–20 atm, yielding a specific laser output in the order of 35 J/l.

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Generation and amplification of short optical pulses in the picosecond range as well as continuous tunability over a complete vibrational band demands an overlap of rotational lines of a molecular laser. In the case of an atmospheric CO_2 laser, the bandwidth of a rotational line is only about 4 GHz, and there is no overlap. In that case it is not possible to generate or amplify subnanosecond pulses or to obtain continuous tunability.

The gain bandwidth of the CO_2 laser can be increased by increasing the pressure of the gain medium. The resulting pressure broadening is about 5 GHz/atm. Although from about 5 atm on, adjacent rotational lines start to overlap, it takes about 15 atm to obtain a continuous modulation-free gain spectrum. An additional advantage of these high operating pressures is that the saturation energy also increases, which offers the opportunity to extract extremely high output powers.

Operation of high-pressure CO_2 lasers in the self-sustained discharge regime demands a proper preionization technique to obtain a uniform glow discharge. The best known preionization techniques are UV preionization or electron-beam preionization. Both methods, however, have their own shortcomings. Those of UV preionization are mainly caused by the high absorption rate of UV radiation in (laser) gases. In a typical CO_2 laser, the effective range for UV preionization is limited to about 0.1 m atm [1]. Using a 300 keV e-beam increases this range only by a factor of two. Furthermore, UV preionization is hampered by an increased dissociation of the CO_2 molecules and, when dealing with a spark-source, by gas contamination. This decreases lifetime of sealed-off systems significantly. The main limitation of high pressure e-beam preionized or sustained systems is the window. Because the window has to be transparent for electrons of moderate energy (100–300 keV), thin metal foils are used. On the other hand, these foils have to be sufficiently strong (read thick) to separate the low pressure side (i.e., electron gun room) from the high pressure side (laser chamber).

This problem can be circumvented by X-ray preionization. Because of the high penetration depth of X-rays, relatively thick windows can be constructed. Medium-energy X-ray sources have been used successfully in several kinds of X-ray preionized lasers during the last few years [2–4]. So far, only a few TEMA-CO_2 lasers have been described [5, 6], with operating pressures up to 10 atm. This paper describes the results obtained with a 20 atm transversely excited CO_2 laser system, using X-ray preionization. The results demonstrate the proper operation at these high pressures.

1. Description of the Apparatus

The transverse X-ray preionized TEMA-CO_2 laser system is schematically shown in Fig. 1.

The X-ray source consists of a cold-cathode e-beam placed in a stainless steel vacuum chamber. The exit window is a 50 μm thick titanium foil which holds the vacuum (pressure range $1–9 \times 10^{-5}$ mbar). A second, 10 μm tantalium foil close to the cathode serves as

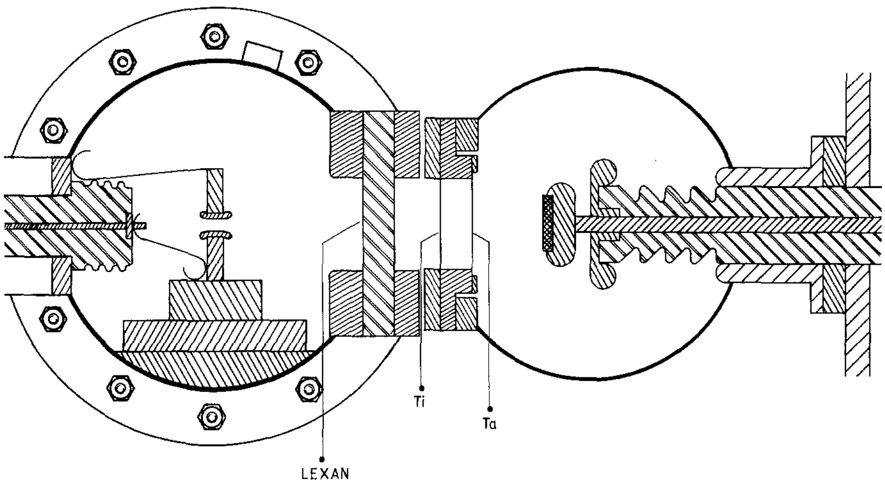

Fig. 1. Cross sectional view of TEMA-CO_2 laser and pulsed X-ray source

production foil for the X-rays and as anode for the e-beam. Electrons from the carbon felt cathode are accelerated towards the Ta anode in which they produce a bremsstrahlung spectrum. The anode area is 6×38 cm^2; the cathode-anode distance is 5 cm. The source is driven by a two stage Marx generator with a total capacitance of 20 nF and charging voltages between 30 and 45 kV.

Two uniform-field electrodes, as described by Ernst [7], are placed in a stainless-steel pressure vessel, closed by flanges with ZnSe Brewster windows on the inner side. The discharge volume is $0.8 \times 0.8 \times 30$ cm^3. The X-rays enter the laser chamber through a 20 mm thick rectangular Lexan window with the same dimensions as the exit foil of the X-ray source. We chose Lexan as window material because it is sufficiently strong to withold the high pressure and it has very little attenuation for the incoming X rays. The laser can also be operated with UV preionization instead of X-ray preionization. In that case we apply two spark-arrays which can be positioned at both sides of the electrodes at a distance of 25 mm from the axis. When using UV preionization, the electrodes are rotated through 90 degrees. The electrical power for the laser is provided by a 2–5 stage Marx generator; the capacitance is 1.2–8.4 nF per stage; charging voltages are in the range 15–100 kV per stage. The measured total circuit self-inductance is 0.9 μH indicating a rather slow discharge circuit. In case of UV preionization, we chose a fixed delay of a few tenths of a microsecond between the UV pulse and the main discharge.

The time delay between the X-ray pulse and the main discharge can be varied electronically. It is observed that a delay of 2 μs provides a proper operation over the complete region of experimental parameters.

The optical cavity is formed by a gold coated aluminium total reflector with a radius of curvature of 3 m and a 50% Ge outcoupler with a curvature of 2.5 m. The cavity length was 1.30 m. It should be noted that the cavity was not optimized with respect to mirror parameters. The output measurements are mainly meant to demonstrate the characteristics of the system and do not describe the optimum performance.

2. Experimental Results

Some initial experiments have been performed using UV preionization to determine the conditions for obtaining a stable, homogeneous and arc-free discharge. For three typical CO_2 laser gas mixtures, we measured the maximum operating pressure and the reduced electric field E/p. The results are listed in Table 1.

After these experiments the setup has been altered to utilize X-ray preionization. The experiments demonstrate clearly the superiority of X-ray preionization over UV preionization. It was possible to obtain uniform discharges at pressures up to 20 atm in the $CO_2:N_2:He = 1:1:10$ and $1:1:7$ mixtures. So far the only limitation to the pressure is imposed by the mechanical strength of the laser chamber and the ZnSe Brewster windows. The $1:1:4$ mixture has been

Table 1. Maximum operating pressure and reduced electric field strength for various gas mixtures using UV preionization

$CO_2:N_2:He$	p_{max} [atm]	E/p [kV/cm atm]
1:1:4	5	10.6
1:1:7	7	7.6
1:1:10	11	6.7

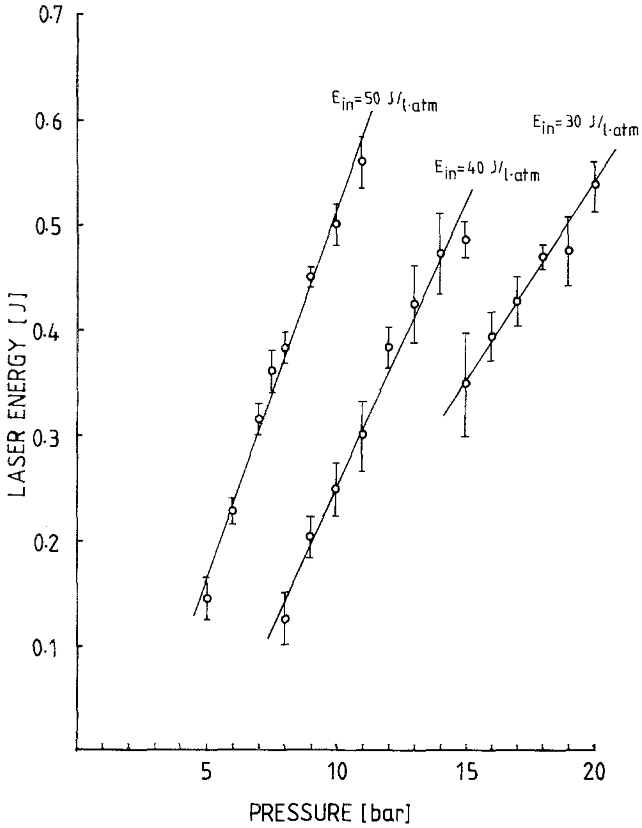

Fig. 2. Laser output energies for three different specific input energies as a function of the total pressure. $CO_2:N_2:He = 1:1:10$

operated up to 10 atm. At this pressure, the discharge became unstable and showed streamers. No further attempt has been made to stabilize the discharge again in order to increase the operating pressure for this mixture.

Figure 2 shows the output characteristic for the configuration described above, using a mixture of $CO_2:N_2:He=1:1:10$ at various pressures. In the case of an input energy density of 50 J/l atm we used 3 stages in the Marx generator with a capacitance of 7.2 nF/stage. The series of 40 J/l atm and 30 J/l atm input energy density are obtained using 4 stages with a total capacitance of 1.2 nF.

From measurements of the peak-current in the main discharge as a function of the applied voltage over the laser electrodes, we found the normalized break-down field E_B/p to be 8.0 ± 0.4 kV/cm atm for the 1:1:10 mixture which is significantly lower than the estimated value of 11 kV/cm atm in case of UV preionization. This effect (the normalized break-down field being lower when using X-ray preionization) has also been reported by Dyer [6]. From our experimental parameters we calculated the degree of ionization in the laser chamber induced by the X-ray pulse. We found an electron number density $n_e = 1.5 \times 10^8\ \mathrm{cm}^{-3}$ at a pressure of 20 atm (1:1:10).

Comparison of the results obtained with the X-ray preionized system and the UV-preionized system (same laser electrodes, 2 stage Marx generator for laser excitation, 9 nF/stage, total circuit self-inductance of 0.3 μH) shows the following major differences:

i) laser breakdown voltage in the UV-preionized system is remarkably higher,

ii) maximum permissible input energy density is roughly a factor of two higher for the UV system (up to 120 J/l atm at 7 atmosphere)

iii) the laser efficiency is roughly 40% higher for the X-ray preionized system ($\eta_{UV} \approx 3.5\%$; $\eta_{X\text{-ray}} \approx 5\%$).

Note that no attempt has been made to optimize the system for maximum efficiency. Furthermore, the efficiency has been calculated directly from the energy stored in the Marx generator. No correction has been made for an impedance mismatch in the coupling between the generator and the laser.

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