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Generation of 13.9 μm radiation from CO_2 by cascade lasing or externally applied CO_2 laser

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Abstract. 13.9 μm radiation from the 10^00–01^10 transition can be obtained from a CO_2 laser by saturating the 00^01–10^00, 10.6 μm transition with an internally generated q-switched pulse or by the application of an external 10.6 μm pulse. Because of Fermi resonance between the symmetric stretch and the bending modes, decay of population from the 10^00 level is fast, and such lasers operate at low power and energies. A theoretical model was developed to study such lasers. The results of the calculations indicate that a large-aperture E-beam-sustained discharge is effective for excitation of the cryogenically cooled gain medium, which uses He rich mixture at low pressure. The system is scalable and capable of generating large powers and energies.

Keywords. CO_2 laser; Q-switching; generation of 14 μm radiation from CO_2; cascade lasing; E-beam-controlled discharge.

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1. Introduction

In a CO_2 laser medium, internal generation of a giant Q-switched pulse at 9.4 μm or 10.6 μm, can saturate the (00^01–02^00) or the (00^01–10^00) transition. In a cooled gas mixture, in which the thermal population of the (01^10) is negligible, inversion and lasing between the (02^00–01^10) levels at 16 μm and (10^00–01^10) at 14 μm is possible. Such sequential lasing is called cascade lasing and it generates a 10.6 μm pulse followed by a 14 μm pulse or a 9.4 μm pulse followed by a 16 μm pulse.

Cascade lasing in CO_2 was reported by Wexler *et al* [1]. They used an electrical discharge gas dynamic laser. In this scheme, N_2 and He were excited in a DC discharge, and accelerated in an array of supersonic nozzles to Mach 3. CO_2 addition took place in the supersonic nozzle. The expansion caused cooling of the gas mixture to -150°C. The optical cavity was transverse to the flow, and consisted of 5% hole coupling output mirror, and a high reflectivity rotating mirror. This laser exhibited cascade lasing in 10.6 μm and 14 μm transitions. If the 10.6 μm lasing was suppressed with the help of an intracavity BCl_3 cell, which absorbed at 10.6 μm, cascade lasing was obtained at 9.4 μm and 16 μm. Addition of a small percentage of H_2 with CO_2 improved the output energy for this gas dynamic laser, and the authors obtained 45 μJ/pulse at 14 μm and 170 μJ/pulse at 10.6 μm. CW cascade lasing with 0.6 W at 14 μm and 2.4 W at 10.6 μm was also demonstrated.

14 μm and 16 μm radiations can also be generated from the CO_2 laser, by using an external CO_2 laser operating at 9.4 μm or 10.6 μm, to saturate the (00^01–02^00) or the (00^01–10^00) transition. Kasner and Pleasance [2] used a conventional electrical discharge CO_2 laser, cooled it cryogenically, and optically pumped it with an external CO_2 laser to generate 14 μm and 16 μm radiations. The outputs were 15–20 μJ/pulse.

The basic limitation for obtaining 14 μm lasing from CO_2 is the Fermi resonance between the 10^00 and the 02^00 levels. Energy from the 10^00 level is siphoned away to the 02^00 and the 02^20 levels, by colliding with ground state CO_2 molecules. There is a subsequent fast transfer of energy within the bending mode and two 01^10 molecules are formed. This level is also the lower laser level for the 14 μm transition. This restricts the maximum CO_2 partial pressure in the mixture to a low value. The mixture must also be rich in He, as He is an efficient deactivator of the 01^10 level.

One must also cool the gas mixture to 120–200 K, so that the thermal population of the 01^10 level can be maintained at a low level. As already mentioned the rapid deactivation of the 10^00 level, and subsequent formation of the 01^10 molecules, compete with the lasing process. When the 10.6 μm pulse saturates the 00^01–10^00 transition, the population of the 10^00 level increases immediately. There is also an increase in the population of the 01^10 level, albeit with a delay. Thus the population inversion for the 14 μm laser is a transient one, and low-pressure operation and cryogenic cooling ensure an adequate time window for the growth of the 14 μm laser. We are using a mixture of CO_2, N_2, He in the ratio $1:1:40$ at 50 Torr. We are cooling the laser chamber to $-150°$C.

The low-pressure operation severely restricts the output power and the energy of the laser. Large lasing volume is required to generate energy and power at useful levels. Electrical discharge is a convenient method for pumping of the laser medium. We had earlier worked on E-beam sustained discharges [3], and find this technique useful for the excitation of large aperture, low pressure, He-rich mixture employed for this laser. The advantages of E-beam-sustained discharges are explained below.

E-beam-sustained discharge provides a mode of operation, where the discharge E/N can be adjusted for optimum excitation of vibrational levels of CO_2 and N_2. Judd [4] calculated electron transport coefficients and vibrational excitation rates for CO_2, N_2 and He mixtures. For optimal vibrational excitation the average electron energy in the discharge should be between 1.5 and 2.5 eV. In He-rich mixtures, the average electron energy increases rapidly with E/N. Hence the discharge E/N must be restricted to a low value. This mode of operation is not possible with UV pre-ionized lasers. In UV pre-ionized discharges the value of E/N has to be high enough to enable multiplication of discharge electron density from a value of 10^6–10^7/cc to the final level of 10^{12}/cc. Unfortunately this E/N is not appropriate for vibrational excitation for the low-pressure He-rich mixtures employed in this laser.

2. Our scheme

We have developed a model to calculate vibrational excitation and lasing for the 13.9 μm laser. The model is a modified version of an earlier model developed by Chatterjee and Nath [5]. We present here our scheme and the important results of the theoretical analysis carried out by us.

We used a −200 kV, 2 μs, 1 kA E-beam, which entered the discharge region through a thin Al foil and screen cathode of area 10 cm × 100 cm. The current density provided by the beam was 330 mA/cm^2 in the discharge region. The main discharge volume was determined by the screen cathode and a profiled electrode as anode. The dimension of the discharge was 6 cm × 10 cm × 100 cm. The energy density deposited in the discharge was limited to 65 J/l-atm. This was done to restrict the discharge heating so that the average gas temperature remained within 200 K. The main discharge was energized by a 4.2 μF capacitor charged to 3.5 kV and provided 25 J to the discharge.

The electron beam was on for 2 μs. The discharge however persisted for 9.8 μs. After the discharge the medium was allowed to relax for 60 μs, so that the population of the 10^00 and the 01^10 levels excited during the discharge could attain values close to their thermal ones. The 00^01 level, however was continuously populated during this period by the excited N_2 molecules.

For the laser we used two schemes. One scheme used rotating mirror Q-switching. The cavity in this case was a semi-confocal cavity formed by a totally reflecting 5 m radius of curvature concave mirror, and a dichoric plane output coupler. This mirror had a reflectivity of 98% at 10.53 μm and 90% reflectivity at 13.9 μm. The plane mirror was at a distance of 2.5 m from the curved mirror. The curved mirror rotated at 400 Hz. Each mirror had a diameter of 5 cm.

The resonator optic axis can be defined as the line joining the pole of the concave mirror which is perpendicular to the plane mirror. When the curved mirror of 5 m radius of curvature rotated at 400 Hz, it caused the optic axis to traverse the flat mirror at a speed of ∼12.5 km/s, parallel to itself. For the 5 cm mirror the total reversal time was ∼4 μs. When the optic axis entered the edge of the mirror or left the edge of the mirror, the diffraction loss for the laser mode was the highest (50%). The diffraction loss was minimum (1%), when the optic axis went through the centres of both mirrors. The multimode beam that could grow in such a rotating cavity has a diameter of 15 mm on the plane mirror and 21 mm on the curved mirror. The lasing volume is ∼325 cc. The resulting cascade laser pulses at 10.53 μm and 13.9 μm are shown in figure 1. The energies are 7.1 mJ and 2.8 mJ respectively.

The output energy in the above case is limited due to the high losses experienced by the laser mode due to mirror rotation. One can use stationary mirrors and inject the saturating pulse from outside as in ref. [2]. In this scheme we used an unstable resonator cavity comprising of a concave and a convex mirror. The convex mirror was totally reflecting. The concave mirror was transparent for the 10.53 μm laser and totally reflecting for the 13.9 μm radiation. The effective output coupling of the unstable resonator for the 13.9 μm radiation was 10%. The external 10.6 μm beam was injected through the concave mirror. The convex mirror had a diameter of 5 cm, and the lasing volume in this case was 1963 cc. If we inject a 2 J,

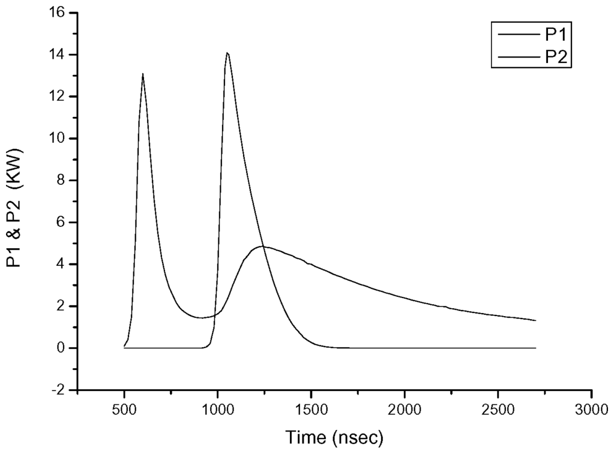

Figure 1. Output from rotating mirror Q-switch laser. The time is measured from the instant of q-switching. The first pulse is the 10.53 μm pulse and the second pulse is the 13.9 μm pulse.

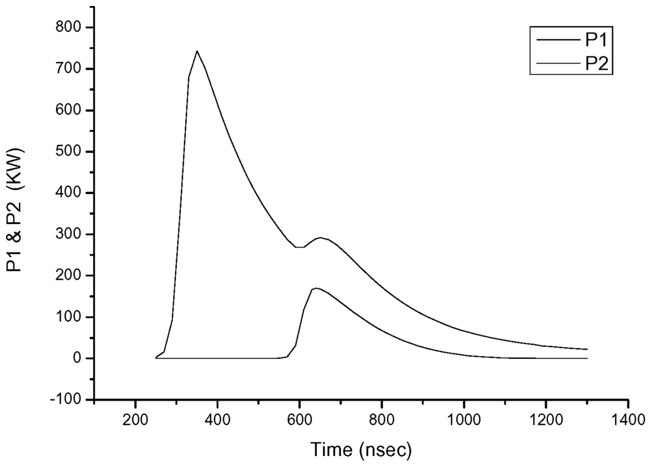

Figure 2. Output for the stationary mirror case. The larger pulse is a part of the injected 10.53 μm pulse and the smaller pulse is the 13.9 μm pulse.

10.53 μm CO_2 laser pulse (P 14 line of 10.6 μm band), the resulting 13.9 μm pulse has an energy of 32 mJ. Figure 2 shows the 10.53 μm and the 13.9 μm pulses at the output.

3. Conclusion

We have presented the results of a theoretical calculations which points out the feasibility of generating high-energy 13.9 μm pulses in a practicable scheme. With suitable modifications it should be possible to generate 16 μm pulses with tens of millijoules of energy, from such a system.

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References

[1] R L Wexler, T J Mannucia and R W Wayant, *Appl. Phys. Lett.* **31**, 730 (1977)
[2] W H Kasner and L D Pleasance, *Appl. Phys. Lett.* **31**, 22 (1977)
[3] V P Singal, R Vijayan, B S Narayan, D J Biswas and U Nundy, *Infrared Phys. Tech.* **41**, 69 (2003)
[4] O P Judd, *J. Appl. Phys.* **45**, 4572 (1974)
[5] U K Chatterjee and A K Nath, *J. Appl. Phys.* **53**, 4610 (1982)