HANDBOOK
of
LASERS
with
Selected Data on Optical Technology

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POLYATOMIC MOLECULAR GAS LASERS

Notation for Polyatomic Molecular Gas Lasers

VIBRATIONAL STATE ENERGY (in cm\(^{-1}\)):

\[ G = G(I_1, v_1, v_2, \ldots, v_n) = \sum_{i=1}^{n} v_i + d_i/2 + \sum_{i=1}^{n} X_i f_i + d_2/2(v_2 + d_2/2) + \cdots \]

where \(v_i, d_i, X_i\) are quantum numbers for the \(n\) normal modes of vibration, \(v_i\) and \(X_i\) are the vibrational constants of the \(i\)th mode, and \(f_i\) and \(d_2\) are vibrational coupling constants between modes \(i\) and \(j\). For degenerate states, \(d_i\) is a degeneracy number and \(f_i\) is a quantum number associated with vibrational angular momentum. For nondegenerate states, \(d_i = 1\) and \(f_i = 0\). The vibrational state is denoted \((v_1, v_2, \ldots, v_n)\). For a triatomic molecule \(v_1, v_2, v_3\) are associated respectively with the symmetric stretching, bending, and asymmetric stretching modes. The degenerate bending states of a linear triatomic molecule, for example, are denoted \((v_1, v_2, v_3)\).

ROTATIONAL LEVEL ENERGY (in cm\(^{-1}\)):

\[ F_J = F(I, K) = E_J(J + 1) - D_J(J + 1)^2 + \cdots \]

as for diatomic molecules.

SYMMETRIC TOP MOLECULES:

\[ F_J = F(I, K) = F(I) + (A - B)K^2 \]

where \(A, B, D\) are rotational constants, and \(K\) is a quantum number \((0 \leq K \leq J)\) corresponding to a component of \(J\). There are \((2J + 1)\) rotational sublevels for each value of \(J\), but the \(K = -K\) sublevels are degenerate.

SPHERICAL TOP MOLECULES:

Same as for linear molecules.

ASYMMETRIC TOP MOLECULES:

\[ F_J = F(I, K_1, K_2) \]

As for symmetric top molecules, there are \((2J + 1)\) rotational sublevels for each value of \(J\), but these are now all different. The definition for \(F(I, K_1)\) is given by \(E_I = \frac{1}{2}K_1^2 + \cdots \frac{1}{2}K_2^2\) for symmetric top molecules, values of \(J, K_1\), and \(K_2\) are included. The vibrational band is denoted by \((v_1, v_2, \ldots, v_n, K)\). For a triatomic molecule \(v_1, v_2, v_3\) are associated respectively with the symmetric stretching, bending, and asymmetric stretching modes. The degenerate bending states of a linear triatomic molecule, for example, are denoted \((v_1, v_2, v_3)\).

Example of a Polyatomic Molecular Gas Laser: CO\(_2\)

Of all the molecular gas lasers, the CO\(_2\) laser is probably the most important both commercially and scientifically. The large gain coefficients, high levels of pulsed and continuous power, and high efficiencies obtainable in this laser have not been matched by other molecular systems. Moreover, the dependence of gain and output power on operating conditions are representative of most of the polyatomic molecular gas lasers.

An energy level diagram showing the best known 9.4 \(\mu\)m and 10.4 \(\mu\)m vibrational-rotational bands of CO\(_2\) is given in Figure 8-4. This diagram is typical of those for the linear triatomic molecular lasers, including CS\(_2\) and N\(_2\)O, and is similar to those for HCN and OCS. More complicated energy level schemes are encountered for the asymmetric top molecules (H\(_2\)O, H\(_2\)S and S\(_2\)O\(_3\)), as described above.

In the case of CO\(_2\), alternate rotational levels in each vibrational state are missing because of symmetry properties. The thermal distribution of rotational level population in the 9.4 \(\mu\)m vibrational state for two temperatures is given in Figure 8-5. The measured gain distribution in a typical CO\(_2\) amplifier is given in Figure 8-6 for the 10.4 \(\mu\)m, 90\(^\circ\)1-00\(^\circ\) band. The gain coefficient for the 1000 \(\mu\)m, 90\(^\circ\)1-00\(^\circ\) band is higher than that for the 9.4 \(\mu\)m, as described above for the diatomic molecular lasers. The roles of the N\(_2\) and He additives and detailed discussions of the various excitation mechanisms involved in CO\(_2\) lasers are treated extensively in the references listed in Section 8.3.1.

Figures 8-7 through 8-10 show the variation of gain in \(\frac{db}{dt}\) per meter with discharge current, wall
temperature, gas flow rate and CO₂ pressure, for CO₂ laser amplifiers. In Figure 8-7, the CO₂ flow rate is maintained constant at 150 cm³/min, and the discharge current is varied for several mixtures in tubes of either 12 mm or 37 mm bore. The effect of variation of wall temperature, which in turn affects gas temperature, on the gain of CO₂-He amplifier operating at optimum current is given in Figure 8-8. The dependence of the gain of several mixtures in 12 and 22 mm bore tubes on the flow rate of CO₂ is given in Figure 8-9. Gas mixtures and pressures are near optimum in each case. Figure 8-10 gives the dependence of gain on CO₂ pressure for several gas mixtures. The amplifier tube bore is 22 mm and the CO₂ flow rate is 100 cm³/min.

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**Fig. 8-6.** Gain distribution for individual vibrational-rotational transition in the P and R branches of the 00°1-00°0 band. Amplifier tube bore is 2.54 cm; gas mixture and flow velocity are: CO₂ (0.65 torr), N₂ (1.4 torr) and He (2.9 torr); v = 192 cm/sec. (Ref. 12)

**Fig. 8-7.** Gain versus discharge current for various flowing CO₂ gas media at optimum mixture ratios and a constant CO₂ flow rate of 150 cm³/min in 12 and 37 mm bore amplifier tubes. (Ref. 12)

**Fig. 8-8.** Effect of wall temperature on optimum gain of a CO₂-He laser amplifier. (Ref. 12)

**Fig. 8-9.** Effect of gas flow on gain of CO₂-N₂-He and CO₂-CD-He laser amplifiers in 12 and 22 mm bore tubes. Gas pressure and mixture ratio are near optimum in each case. (Ref. 12)

**Fig. 8-10.** Gain versus CO₂ pressure for various gas mixtures in a 22 mm bore amplifier tube. CO₂ flow rate is 100 cm³/min. (Ref. 12)