Design considerations and scaling laws for CO_2 lasers

The Class I CW CO_2 laser was the first CO_2 laser developed, and continues to be the most common. Figure 1 is a diagram of such a laser. Common characteristics of this CO_2 laser class include the following:

1. Water or oil cooling by use of a double-walled glass plasma tube.

2. Gas flow at a low rate (1-20 liters per minute, depending upon size and output of laser).

3. Dc excitation, coaxial with gas flow and laser beam.

4. Low-current operation (3-100 mA).

5. Gas pressures of 10 to 30 torr.

6. Tube diameters of 1.0-2.0 cm.

7. Available output powers up to about 50 W per meter of tube length.

The primary factor that limits output power of (class I) lasers is their inability to efficiently remove waste heat from the gas. Cooling is principally achieved by helium (He) collisions with tube walls. Air cooling of CO_2 laser tubes is possible, but this results in an elevated wall temperature and greatly reduces laser efficiency. Smaller CO_2 lasers and those used in research often employ water cooling. Industrial CO_2 lasers usually use recirculating oil and oil-to-water heat exchangers for better system stability and reduced maintenance. An increase of tube current beyond the recommended operating value results in more heat than can be effectively removed from the system in this manner. Increases in tube diameter also decrease cooling efficiency by increasing the path length necessary for (He) atoms to reach the walls from the center of the tube. Thus, the only effective method of increasing output power of this type of CO_2 laser is to extend the active length. For best results, this must also be accompanied by an increase in gas flow rate. In larger systems the gas is recirculated with a few percent being replaced on each cycle.

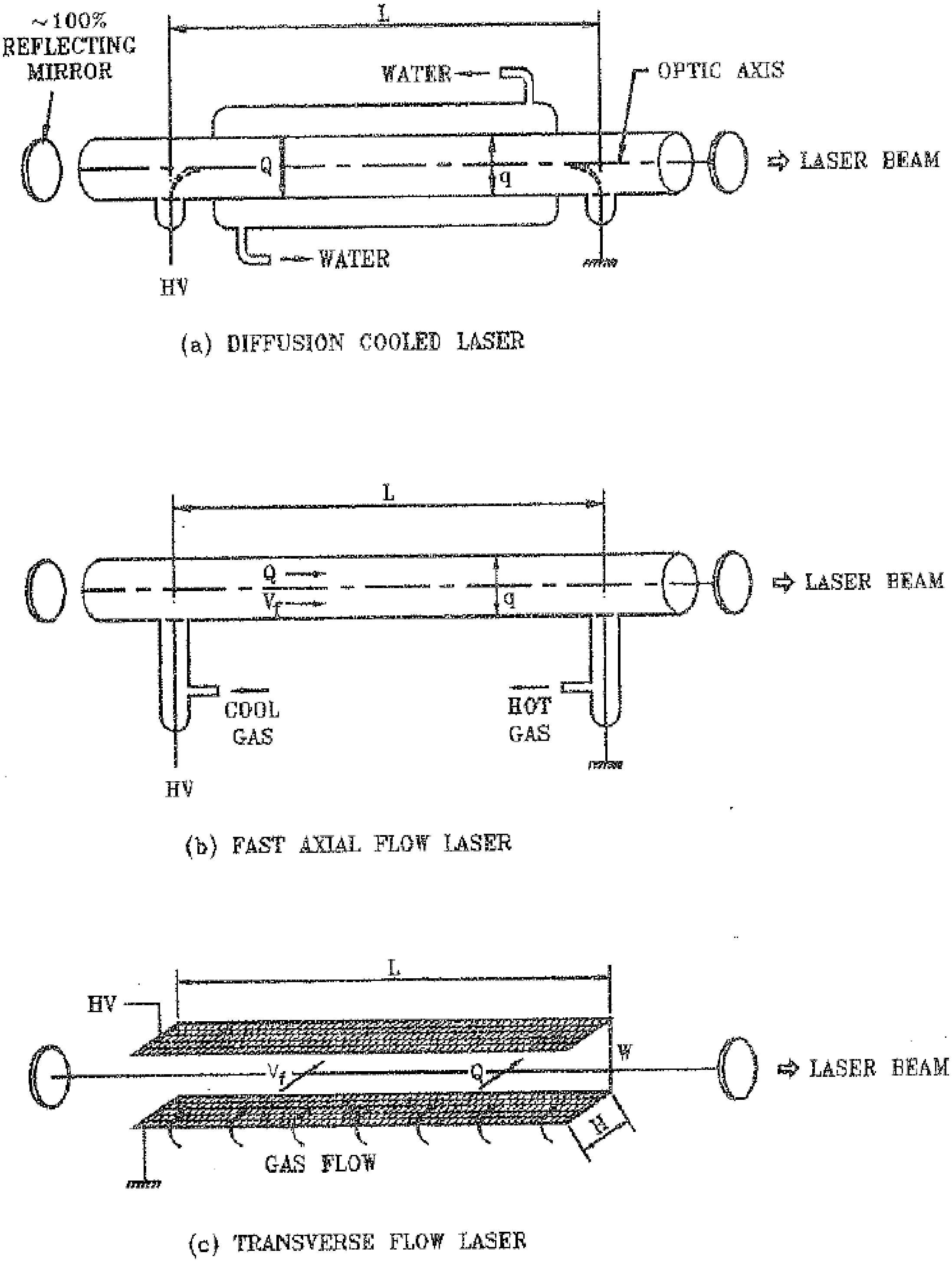

Figure 1. Schematic diagram of different types of CO_2 laser. Q: Heat flux, q: charged particle flux, V_f: gas flow velocity.

Laser power scaling in various types CO_2 lasers

The output power of a laser scales up with the input power. In a CO_2 laser, the input electrical power density is limited by two factors: first is the rise in laser gas temperature, optimum being, $\Delta T_{opt} = 200–250°C$. This limits the input power density P_{in} as the following:

$$P_{in} \le (1-\eta)^{-1} \cdot \rho \cdot C_p \cdot \Delta T_{opt}/t_c = P_c \quad \text{(say)}, \qquad (1)$$

where ρ and C_p are the density and the specific heat of the laser gas respectively, η is the electro-optic efficiency and t_c is the gas cooling time.

Second limiting factor for the input electrical power is the discharge instability, the most common being the ionization thermal instability. In order to avoid the discharge instability, the input power density should be [15]

$$P_{in} \le 1/A \cdot \rho \cdot C_p \cdot \Delta T/t_s = P_s \quad \text{(say)}, \qquad (2)$$

where A is a rate coefficient which is mainly determined by the slope of the dependence of the ionization rate on the discharge parameter E/p, and t_s is the characteristic decay time for any fluctuation in the electron density. The typical value of A is about 10 for the usual laser operating conditions. For efficient and reliable laser operation the input power density should be smaller than the above two limits determined by the cooling and the discharge stabilization processes.

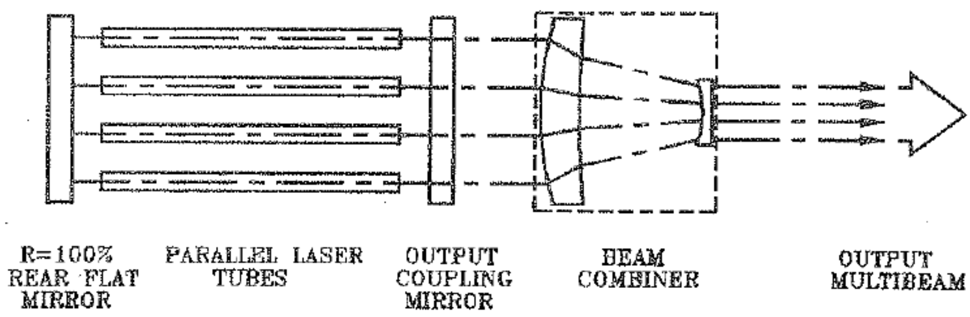

Figure 3. Schematic diagram of a multibeam laser.