High Power Electric Discharge CO_2 Lasers†

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A discharge in high flow[1] gas has made possible extremely high power compact CO_2 laser, as compared with the power obtained from the conventional type with very low gas flow. An uniform and stable glow discharge in high flow gas is one of the most important factors in obtaining such high power. When an initially uniform electric power is deposited in a high flow gas where there is a non-uniformity of the velocity, the gas preferentially is heated in the zone where flow speed is lower from flow calorimatry consideration to cause non-uniform temperature distribution, and hence non-uniform electrical conductivity. This non-uniform conductivity leads to a constricted discharge, eventually to an arc. It is necessary not only to make the gas flow distribution as uniform as possible but also to disperse the heat locally concentrated in order to prevent such non-uniformity. The authors test-produced two types of high flow CO_2 laser, and some primary experimental data are shown in this paper. These laser systems consist of circulating pump, heat exchanger discharge tube, and gas mixtures of CO_2, N_2 and He.

In the first type of the laser, the directions of the laser beam, gas flow and discharge perpendicularly intersect each other. The electrode distance is about 3 cm and the maximum gas flow is about 30 m/sec. Under such conditions even without convective action it is comparatively easy to maintain discharge curtain-like over the range of about one meter between an anode and many copper cathodes having their own ballast resistor. The laser power is coupled out from Ge substrate and is nearly proportional to the gas flow rate.

Figure 1 shows the relationship between the discharge current, discharge voltage, and output power at the flow rate of 30 m/sec. The maximum power was about 1.6 KW with 10% efficiency at 11A, 1.5 KV and 30 torr.

Generally as the electrode distance becomes longer, it becomes more necessary to disperse heat

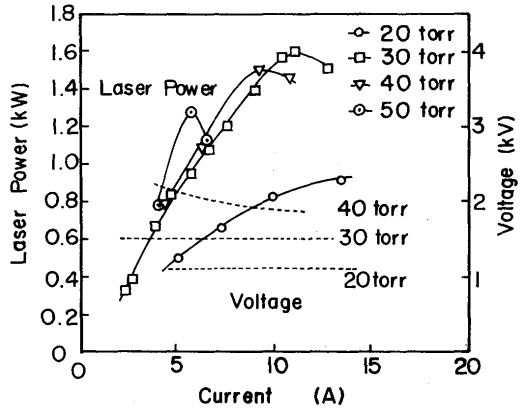

Fig. 1. Relationship between the current, voltage and the output power for the laser shown in Fig. 1 for various gas pressure. ($CO_2 : N_2 : He = 1 : 6 : 3$).

by convective action for the purpose of maintaining an uniform discharge. In the second type of the laser shown in **Fig. 2,** the directions of laser beam, gas flow and discharge are parallel with each other, the discharge cross section is comparatively small, and the electrode distance is long. The maximum gas flow in the discharge tube of 74 mm in diameter was 110 m/sec. The orifice type cathode was set at the upper stream in order to produce convection and consequently make the discharge uniform. A cylindrical tube was used for an anode at downstream. Both electrodes have the same internal diameter as laser tube. The laser power was taken out from the coupling hole of 20 mm in diameter. Various forms of the discharge tube were used and it was found that the

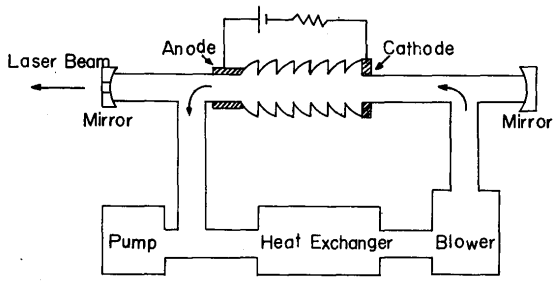

Fig. 2. Schematic diagram of high flow CO_2 laser.

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structure of modified tube shown in Fig. 2 was most effective for producing convection. In a straight discharge tube, the gas flow is inclined to be slower near the tube wall than around the center, and as the result the positive column is apt to concentrate on the low flow area, which causes non-uniform discharge. The convection effect at the orifice also weakens this tendency a little, but uniform discharge cannot be maintained any more under high electric input.

Figure 3 shows the limit of uniform discharge for various gas pressures in both straight and modified tubes. The maximum current of the modified tube is larger by 30～50% than that of the straight tube. The convection effect of the modified tube became larger with an increase in gas pressure.

The relationship between the discharge current and the laser power is shown in **Fig. 4,** where solid curves correspond to the modified tube, and a dotted

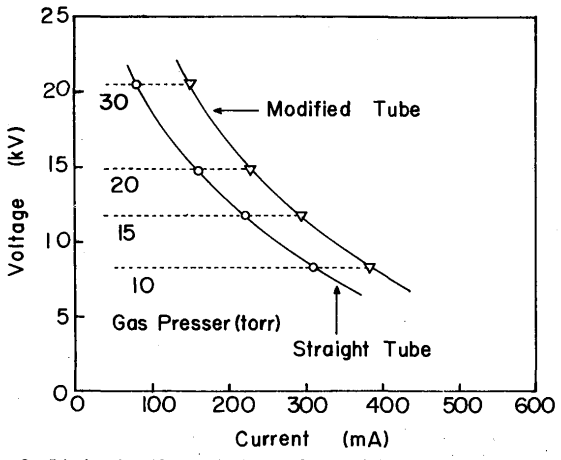

Fig. 3. Limit of uniform discharge for straight and modified tubes with discharge length of 75 cm.

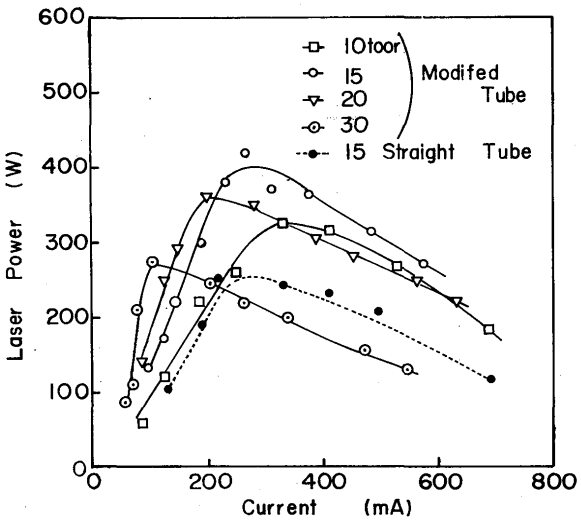

Fig. 4. Relationship between the current and the output power ($CO_2 : N_2 : He = 1 : 24 : 25$).

curve the straight tube. Comparing data for both tubes at 15 torr, the laser power of the modified tube is higher than that of the straight tube for each current value. The current of maximum laser power for each curve nearly coincides with the limit current shown in Fig. 3. The maximum power was about 420 W with the specific input power of about 4 KW /kg/sec, which was considerably lower than that shown in Fig. 1. This is because the internal diameter of orifice-type cathode is so large that the initial convection effect at upper stream is insufficient. Therefore it is assumed that input power can be enhanced by bending the discharge path and then by making the internal diameter small.

Photograph 1 shows an example of the cross section of bead welded by 1.5 KW beam obtained from the laser of the first type. The beam was focused through a concave spherical mirror with the radius of curvanture 310 mm with the incident angle to the mirror at about 5°. This apparatus emitted the laser beam with a comparatively large divergent angle, so that the beam was not concentrated well through the mirror used in this experiment, and deep penetration welding was observed, although not so obviously. However, the use of the optical system with short focal length increases the energy density, and thereby deep penetration welding may be achieved in much more obvious form.

Photo. 1. An example of weld bead of AISI 304 stainless steel, 0.8 mm in thickness. Laser power=1 KW, welding speed=1 m/min.

Reference

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A. E. Hill: Uniform Electrical Excitation of Large Volume High Pressure Near Sonic CO_2-N_2-He Flowstream, Appl. Phys. Letters, Vol. 18 (1971) No. 3.