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APERTURE COUPLING OF A CARBON DIOXIDE LASER EMPLOYING A NEAR-CONFOCAL OPTICAL RESONATOR

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OPTICAL RESONATOR

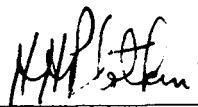John H. McElroy
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SUMMARY

Materials difficulties encountered at the 10.6 micron wavelength of the CO_2 laser often dictate that the laser output be obtained by aperture coupling through a hole in the output mirror. This document presents the results of measurements made on an aperture coupled carbon dioxide laser using a near-confocal optical resonator. The effects of coupling hole diameter and mirror spacing are related to laser multimode power output and mode structure. It is found that odd-symmetric modes dominate and, if a simple mode structure is required, with maximum axial power density, the diameter of the output coupling hole must be restricted.

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INTRODUCTION

The design of an optical resonator for use with the carbon dioxide laser poses problems unlike those encountered with lasers operating in the visible portion of the electromagnetic spectrum. Visible lasers, such as the helium-neon laser, employ multilayer dielectric coatings as highly efficient reflectors—as well as for partially transmitting surfaces to couple energy out of the laser cavity. Similar coatings for use at the 10.6 micron wavelength of the carbon dioxide laser have only recently begun to become available and are generally in an early state of development. At present, gold coatings are the most efficient reflectors for use at 10.6 microns. Unfortunately, partially transmitting gold films are an ineffective means of coupling energy out of the CO_2 laser. When the film is made thin enough to permit low absorption transmission of the infrared energy, the reflectance of the coating is too low to sustain laser oscillations. A gold coating thick enough to produce high reflectance absorbs too much of the energy passing through it to serve as an efficient output coupler.

Two techniques have been commonly employed to circumvent the problems mentioned above (see references 1 and 2). Both of these techniques involve aperture coupling of the output energy. In some cases, an uncoated disk is left in the center of a gold coating deposited on an infrared transmitting substrate. This technique has the disadvantage of requiring an efficiently transmitting substrate. Materials which pass 10.6 micron radiation well are frequently hygroscopic, mechanically weak, or intolerant of even slight thermal shocks. A second technique employed to couple energy from the CO_2 laser is simply to drill a hole through the center of one of the mirrors. This avoids the materials problems mentioned above. The second technique was employed in the experimental arrangement used to collect the data which are the subject of this document.

The purpose of this document is to report the results of measurements made on an aperture coupled CO_2 laser employing a near-confocal optical resonator. The effects of the diameter of the coupling hole upon the power output and mode structure are discussed for various mirror spacings both inside and outside the confocal dimension.

A theoretical analysis of the optical resonator studied in this experiment is not yet available. As of the date of this report, only two analyses of aperture-

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coupled optical resonators are available. An analysis of the plane-parallel optical resonator with equal diameter holes centered on both mirrors has been presented by Li and Zucker (see ref. 3). The symmetric cylindrical confocal resonator in the small Fresnel number case with apertures in both mirrors, has been the subject of an analysis by McCumber (see ref. 4).

The results presented in this document are in qualitative agreement with those predicted by McCumber, although the experimental arrangement employed only a single coupling aperture and involved, with some exceptions, larger Fresnel numbers. As was expected, the mode structure obtained with aperture coupling is, in general, very complex with the odd-symmetric modes strongly favored.

EXPERIMENTAL ARRANGEMENT

A dc-excited carbon dioxide laser (see Figure 1) employing a CO_2-N_2-He mixture in a flowing gas system was utilized for this study. The active plasma length in the laser tube is nominally 30.5 cm. Power outputs of 700 mw have been obtained from this laser, but it was operated at lower levels in this experiment. The laser consists of five major sections: laser tube, exciter, cooling system, gas flow system, and optical resonator.

The laser tube is nominally 35.5 cm long and has an inner diameter of approximately 13 mm. Barium fluoride windows are attached at the Brewster angle to both ends of the pyrex laser tube, with low vapor pressure epoxy. These windows, polished to five fringes flatness in the visible, were used because of their relatively low hygroscopicity and adequate transmission characteristics at 10.6 microns. The windows are approximately 6.5 mm thick and are mounted somewhat more than 2.5 cm from the discharge region to prevent erosion of their surfaces by the plasma. Connections for the gas flow system are provided with 10 mm diameter Kovar-to-Pyrex seals. The Kovar seals are also used as cold-cathode electrodes to excite the discharge.

The laser exciter consists of a high-voltage dc power supply and a ballast resistor. Currents as high as 100 ma with voltages as high as 6 Kv have been used with this laser. In this experiment the power supply voltage was 4 Kv at a current of 25 ma. The ballast resistor is necessary because of the negative-resistance character of the gas discharge. A resistance of 28K ohms was used.

The cooling system for the laser consists of a slow flow of tap water around the cathode and through the water jacket surrounding the laser tube. Positive ion bombardment produces the heating of the cathode which led to the use of
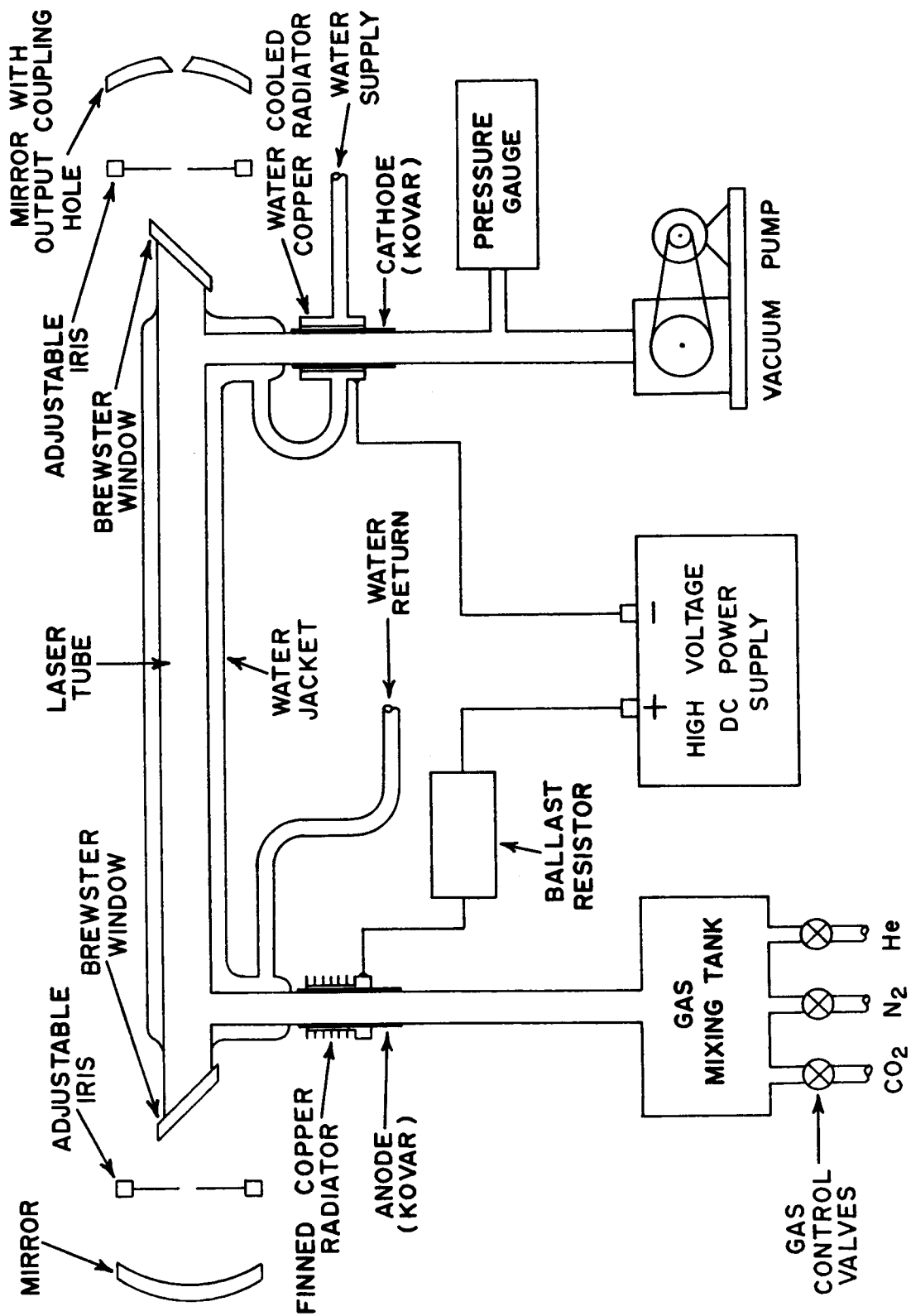
Figure 1. Experimental Carbon Dioxide Laser

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water cooling. A finned copper radiator, which also forms the electrical connection to the anode, provides sufficient cooling for the anode.

The gas flow system consists of a mechanical fore pump, mixing tank, leak rate valves, and gas supply. Standard commercial grade CO_2, N_2, and He have been found to be entirely satisfactory. For purposes of this experiment, a total gas pressure of 9 Torr, consisting of partial pressures of 1.0 Torr of CO_2, 1.5 Torr of N_2, and 6.5 Torr of He, was maintained.

The optical resonator is made up of two gold-coated spherical mirrors. The mirrors are mounted in precision gimbal suspensions and have equal radii of curvature (524 mm). The stress-relieved aluminum tooling plate which forms the laser base is slotted to permit adjustment of the mirror spacing. When the mirror mounts are centered in the slots, the mirror separation is 524 mm—the appropriate dimension for confocal operation. Each mirror can then be adjusted 10 mm to either side of the confocal position. To facilitate rapid realignment of the optical resonant cavity, the laser tube is attached to the base by a spring-loaded, hinged cradle which permits the laser tube to be rotated out of the cavity during alignment operations.

The mirrors are fabricated from 2" diameter by 1/2" thick quartz blanks and then gold coated. The output mirror has a tapered hole drilled through its center. A variety of output mirrors were fabricated. They provide coupling holes ranging from 1 to 7 mm in diameter in 1 mm steps. Calibrated iris diaphragms are mounted in front of each mirror. These permit the adjustment of the effective mirror diameter from 3 mm to 50 mm.

Power output measurements were made with a calibrated Eppley thermopile and a Coherent Radiation Laboratories laser power meter. Mode structure was observed with a thermally-quenched fluorescent screen (see ref. 5) and by scanning the mode patterns with a small aperture detector.

EXPERIMENTAL RESULTS

The effect of the diameter of the coupling hole upon the laser multimode power output and mode structure was studied for various mirror spacings. The results of the tests are shown in Figure 2.

First, the solid curves will be considered. These curves show the total multimode power radiated by the laser. They were obtained by measuring the total power radiated into a 25 mm aperture centered on the axis of the laser tube 30 cm from the coupling aperture. The lowest curve shows the results
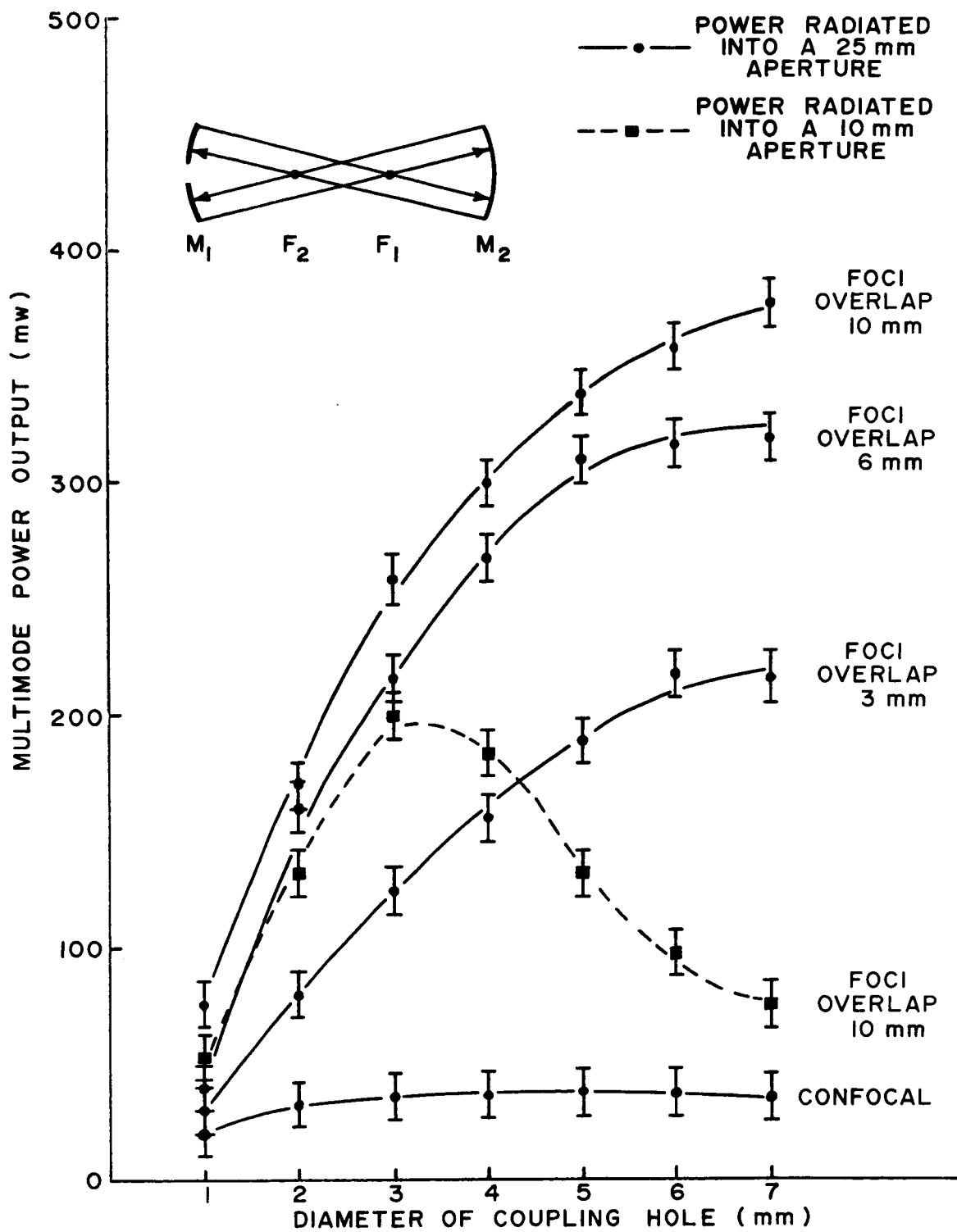
Figure 2. Multimode Laser Power Output as a Function of
Mirror Spacing and Coupling Aperture Diameter

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for the confocal case. The higher curves are the results obtained from progressively closer spacings of the mirrors. It is seen that overlapping and then increasing the overlap of the foci of the two spherical mirrors increases the multimode power output. It should be noted that the curves become closer together as the amount of overlap increases.

If any of the higher solid curves are examined, it is seen that increasing the diameter of the coupling hole produces an increase in the multimode power output. For apertures between 1 and 3 mm, the dominant mode was most frequently found to be the TEM_{10} mode. As the hole diameter was further increased, the mode structure became exceedingly complex. In general, semicircular and crescent-shaped mode patterns were almost invariably observed when the larger coupling hole diameters were used.

The dashed curve shows the effect of the hole diameter on the power contained in the center of the mode pattern. This curve was obtained by reducing the aperture into which the output power was measured to 10 mm. It can be seen that the power output nominally follows the previous curves for coupling apertures ranging from 1 to 3 mm in diameter. As the coupling aperture is further increased, however, less and less of the laser power output is contained in the center of the mode pattern.

The above results show that, while the total power output of an aperture-coupled laser may be increased by increasing the coupling aperture diameter, the larger coupling holes are not usable when simple mode patterns are required. They further show that, although the total power may increase, the power density, in terms of power per steradian, may decrease rapidly as the coupling aperture is increased.

When the mirror spacing is increased beyond the confocal distance, the laser operates in a high diffraction loss condition and the output power is generally low. This spacing may be regarded fundamentally as a very low-Q resonant condition. Qualitatively, it appears that numerous modes are competing in such a manner that none can produce a strong output.

Support for this view is given in Figure 3. With the foci spaced 10 mm apart (not overlapping), an iris diaphragm was introduced into the laser cavity. Basically similar results were obtained irrespective of which end of the laser in which the iris was inserted. Figure 3 shows the results obtained when the iris was placed in front of the mirror with the coupling hole. It can be seen that a strong enhancement of the power output occurs when the iris diameter is slightly larger than the coupling hole diameter. The simpler mode pattern observed at the higher power level seems to indicate that the effect of the iris is
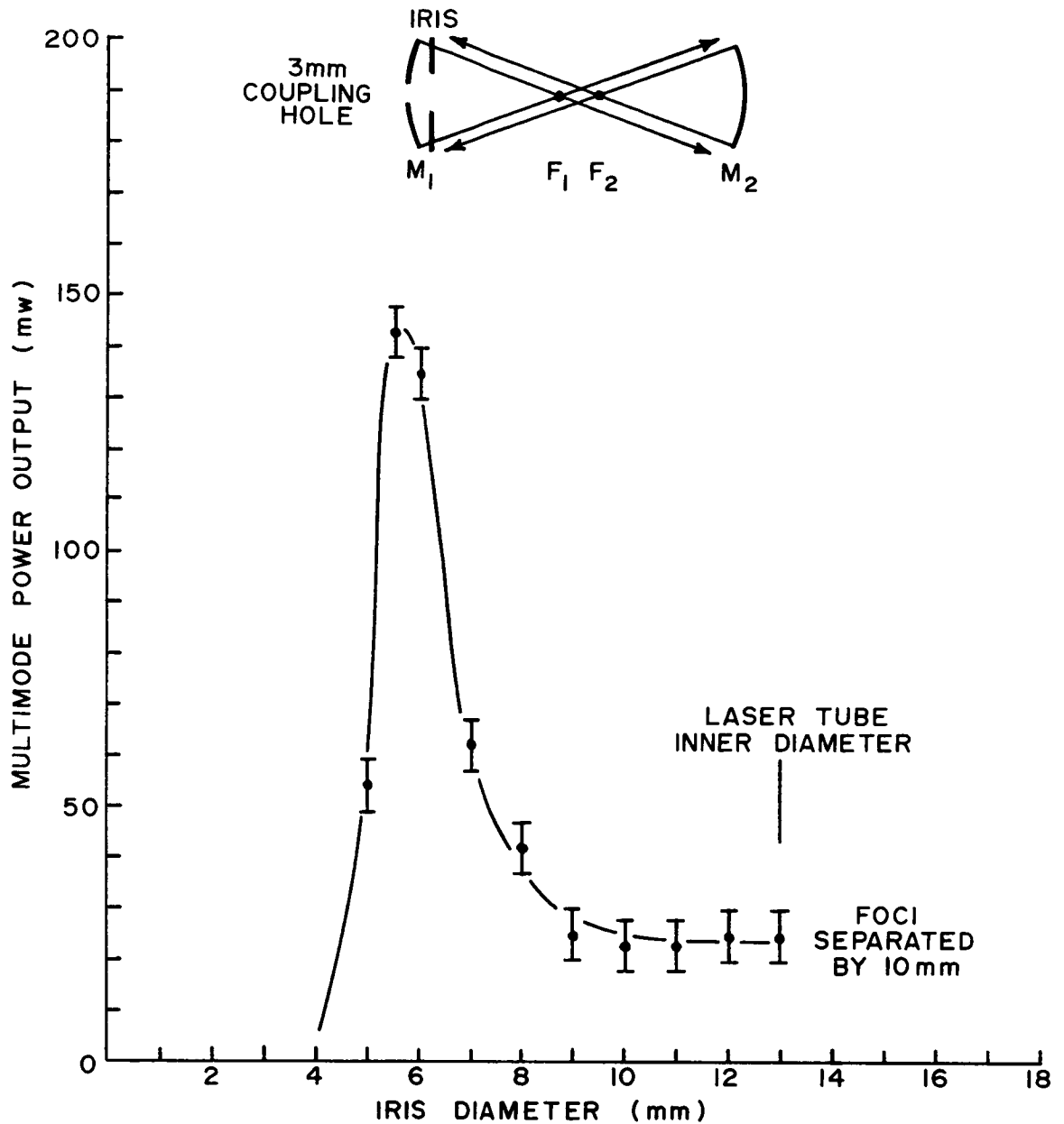
Figure 3. Power Enhancement with an Iris Diaphragm in Laser Cavity

to prevent a number of transverse modes from oscillating and, therefore, through the reduction of mode competition, permit strong oscillations in the remaining modes.

The same enhancement of the output power was noted for all spacings of the mirrors outside the confocal distance. A far less pronounced enhancement was also observed at near-confocal spacings.

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ACKNOWLEDGEMENTS

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