

INVESTIGATION OF He-Ne LASERS

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1. INTRODUCTION

To facilitate laser research at Chiao Tung, a laser plasma tube fabrication process using simple equipment has been developed. Consequently, tubes containing mixtures of He and Ne gases were made of different diameters and lengths, and their operation properties investigated.

In this paper, the fabrication process is described and some characteristics of He-Ne gas lasers pertaining to the relations between output power and reflecting mirrors, exciting current, etc., are presented.

2. FABRICATION PROCESS

Our special set up is shown in Fig. 1. The difficulty of such a simple set up is in accurate pressure measurement. The thermocouple gauges used usually have variable errors so large that any indication can be used only as a rough approximation. Ionization gauges are ineffective in the pressure range of several mm. Hg, and mercury gauges cannot be used because of the danger of contamination of the gas. To overcome such a difficulty, we developed a calibration process using the gas tube discharge current to measure the gas pressure directly.

The gas tube is made of precision bore pyrex glass tubing ranging from 1 mm to 5 mm I.D. Two Nonex bulbs are connected near the ends housing the anode in one and the cathode in the other. Oxide coated tungsten filaments are used.

The two extreme ends of the pyrex tubing are cut to a $55\frac{1}{2}$ degree angle (Brewster angle) with diamond saw and hand lapped to great precision. The Brewster angle windows, made of BSC-2 glass flat to one tenth of a wavelength, are cemented to the tube with Torr seal.

The assembled tube are then evacuated by liquid oxygen cooled sorption pump to 10^{-2} torr where the Vac Ion pump takes over. Use of mechanical pump and diffusion pump are to be avoided as the oil contamination even with good cold traps is annoying. During the process

of evacuation, the tube is baked to 150°C and when the pressure is lower than 10^{-4} torr, filament voltage is applied to degas the filament. A current of 10 amperes is passing through the getter for the purpose of degasing.

When the pressure reaches 10^{-8} torr, He and Ne gas mixture is induced into the tube to approximately 10^{-1} torr and high voltage applied. The discharge is kept for five minutes; then the power is turned off and the tube evacuated. The above process removes any possible contamination due to residues on the electrodes and the tube walls.

As the tube is evacuated again to 10^{-8} torr, a premixed gas mixture of 87.5% He; 12.5% Ne is induced into the tube and high voltage applied. The discharge current will be an indication of gas pressure through the calibration curve reproduced as Fig. 2. Such a calibration curve was prepared using identical gas tube and calibrated against the mercury gauges (the gas tube for calibration is not intended for lasing thus we donot worry about any possible contamination). When desired pressure of the gas mixture is obtained, bleeding valves are closed and getters flashed. The tube is then sealed off.

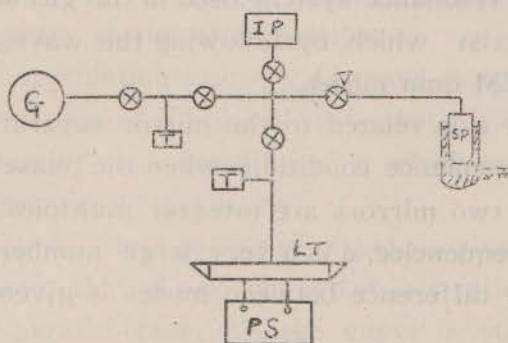


FIG 1. SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP

G: GAS RESERVOIR

T: THERMOCOUPLE GAUGE

V: VALVES

IP: ION PUMP

DW: DEWAR

LT: LASER TUBE

PS: POWER SUPPLY

SP: SORPTION PUMP

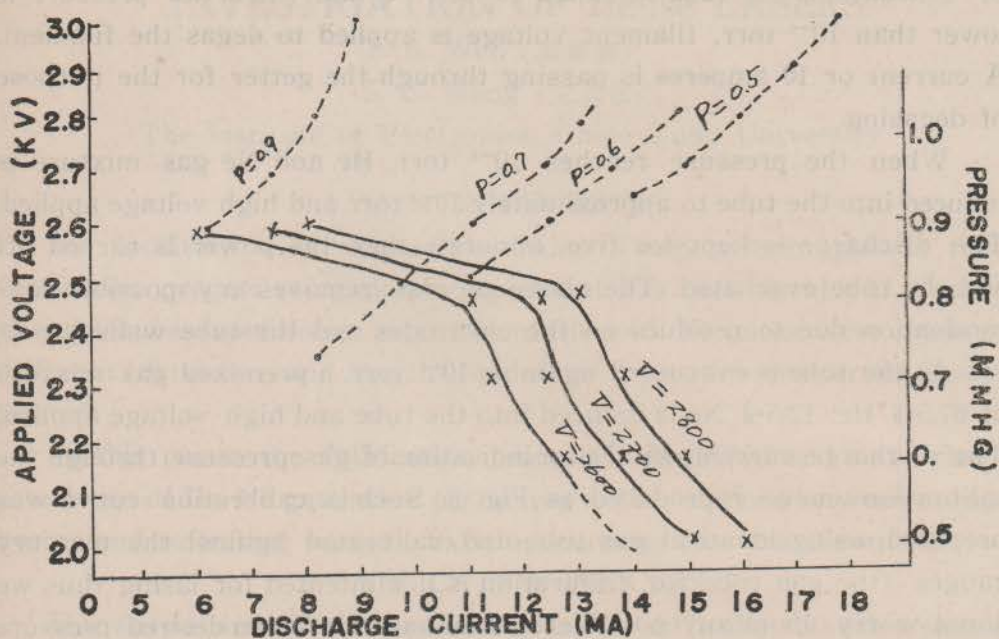


FIG. 2

3. MODE PATTERNS

In the two mirror resonance system used in the gas laser, a number of radiation patterns exist which, by following the waveguide practice, are designated as TEM qmn modes.

The mode number q is related to the mirror separation d and represents the possible resonance conditions when the phase shift through a round trip between two mirrors are integral multiples of 2π . Consequently, at optical frequencies, q is a very large number, in the order 10^6 , and the frequency difference between modes is given by

$$\Delta f = \frac{c}{2d}$$

where c is velocity of light.

Possible q numbers for a particular laser system are usually limited by the mirror reflection characteristics and the transition line width (including doppler broadening) of the active medium.

The transverse mode pattern in the x-y plane perpendicular to the laser axis z has the field amplitude distribution according to Boyd and

Gordon as

$$E_{mn} = E_0 H_m \left(\sqrt{2} \frac{x}{x_0} \right) H_n \left(\sqrt{2} \frac{y}{x_0} \right) \text{Exp.} \left(-\frac{x^2 + y^2}{x_0^2} \right)$$

where H_m and H_n are Hermite polynomials of order m and n , x_0 is a quantity known as spot size which is determined by the mirror geometry. The laser output, by the action of Brewster window, is linearly polarized and we can define the x direction as [the direction Parallel to the electric vector.

In a gas laser, the diffraction loss is a dominant factor in determining oscillation conditions. With higher numbers of m and n , the high fields near the edge of mirror make the diffraction losses so high that laser oscillations are impossible. So the laser transverse modes are usually limited to lower orders.

Some transverse mode patterns, obtained by slight misalignment of the mirrors, are shown in Fig. 3.

The discrimination between lower orders of transverse modes imposes a difficult problem. Fox and Li have shown that the curves of power loss against mirror geometry (expressed by the Fresnel number $N = a^2/d\lambda$ where a the aperture radius and d the mirror separation) for TEM_{00} , TEM_{10} , TEM_{20} etc have nearly the same curvature so that discrimination by mirror geometry is almost impossible.

A careful calculation later by Li using computer technique shown that the ratio of loss of TEM_{10} mode to that of TEM_{00} mode as related to Fresnel number is a function of g which is defined as $g = 1 - d/R$ where R is the mirror curvature.

A set of curves (loss ratio to Fresnel number), each for a constant value of g , shows that (1) no change of loss ratio with mirror aperture in the plane parallel case, (2) the curve is steepest for $g=0$ or the confocal case. For confocal case, the ratio is largest when N approaches 1. So for confocal configuration and large mirror aperture, TEM_{10} TEM_{20} modes may be discriminated.

To get higher order transverse modes, optimization of the system is necessary so that the gain will be sufficient to sustain higher order oscillations, Then the higher order modes will compete with the lower order ones and gain sufficient power to suppress the lower order modes.

With the mirrors properly aligned, higher order modes are shown while slight misalignment gives only lowerest orders. Another way in gaining different mode patterns is by decreasing the exciting power, higher order modes by high excitation and lower order ones near the threshold as recorded by Ohi and Tako.

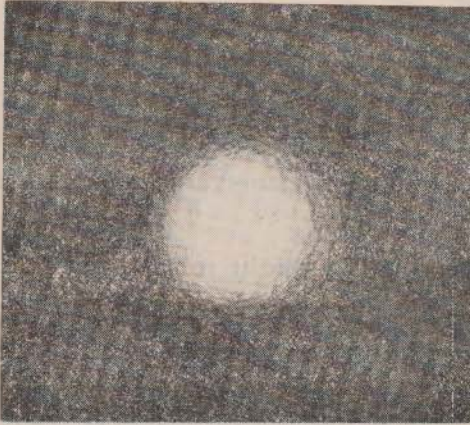
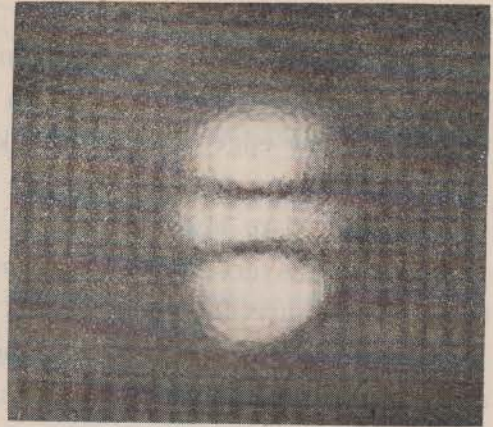
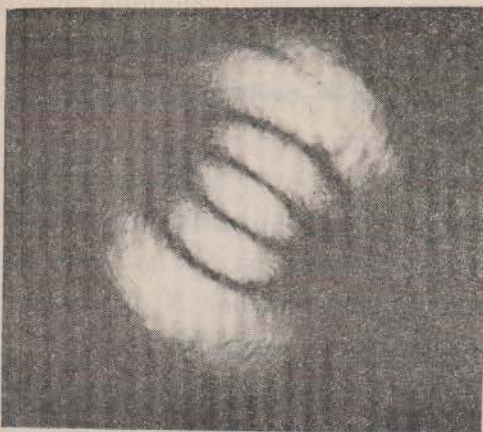
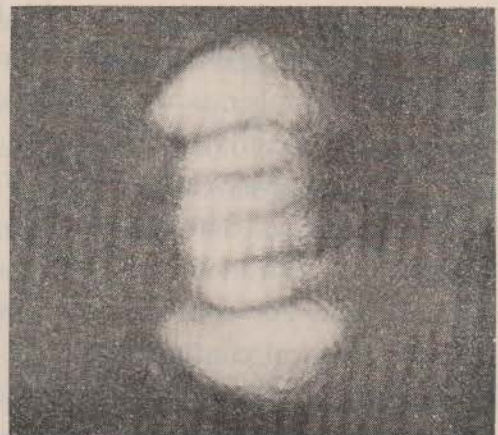

 TEM_{00}

 TEM_{02}

 TEM_{04}

 TEM_{05}

Fig. 3-A Some typical example of observed radiation patterns

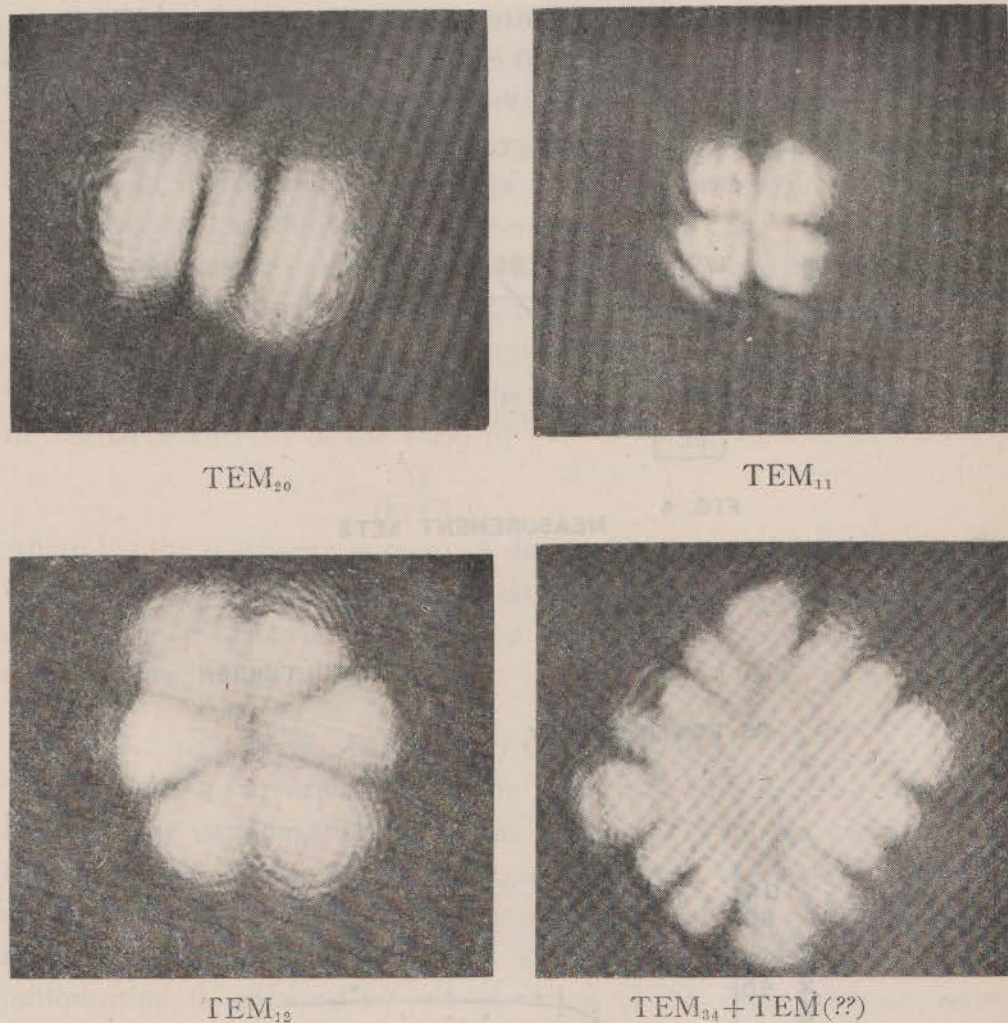


Fig. 3-B Some typical example of observed radiation patterns

4. EXCITATION AND OUTPUT POWER

The relation between the laser output and excitation power was measured in order to obtain an optimum operation condition. The experimental set up is shown in Fig. 4.

The resulting data is given in Fig. 5. In this experiment, photomultiplier anode current is used as an indication of the output power. Current due to the background light from the discharge tube was subtracted from the data and several beam splitters and a red filter are placed

before the photo tube serving as attenuator and noise filter. The laser set used has a cavity length of 45 cm with one plane mirror and one concave mirror of radius 2 meters. From the curve, the power increases with exciting current at first and gradually reaches saturation.

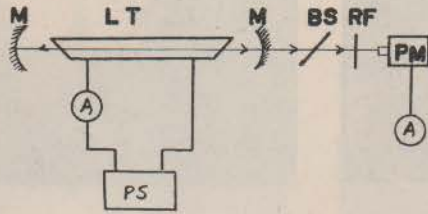


FIG. 4

MEASUREMENT SETS

- | | |
|------------------|---------------------|
| M: MIRRORS | BS: BEAM SPLITLER |
| A: AMMETER | RF: RED FILTER |
| LT: LASER TUBE | PM: PHOTOMULTIPLIER |
| PS: POWER SUPPLY | |

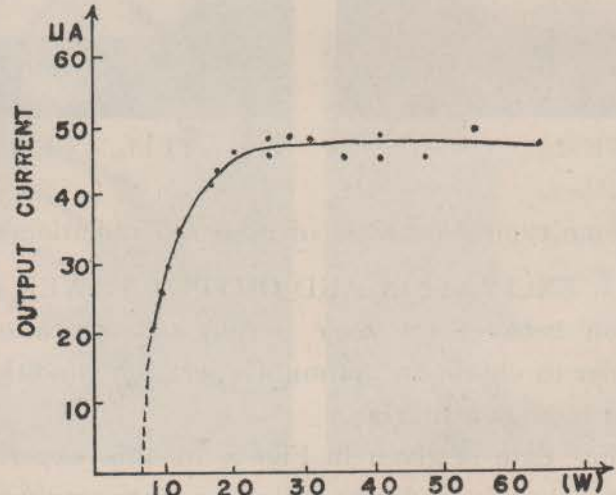


FIG 5

In our D C discharge arrangement with thermoionic emission cathode, there is no glow discharge near the cathode but an arc forms there. The voltage current relation is in the region of so called anomalous glow discharge where large current change results with relatively small voltage changes. In the operation range, the exciting power may be considered as proportional to the square of the current.

The population densities of Ne 3S₂ and He 2S can be measured by the 6328 Å emission line of the plasma tube without lasing. From the gaseous electronics theory (for example, see Loeb: Basic processes of Gaseous Electronics), one expects the population density of He 2S related to discharge current in the form of

$$N_{2s} = \frac{AI}{B+CI}$$

where I is the discharge current, A due to direct electron impact, B due to diffusion loss and C due to excitation transfer loss. From the above equation, it explains the saturation effect of the excitation current-output power curve.

5. SELECTION OF MIRRORS

In selecting mirrors for a certain laser tube with length L and inside radius c, the consideration should be given to (1) mirror separation be larger than L, (2) the spot size anywhere within the tube be less than c, (3) fulfill the stability conditions imposed, and (4) sufficient mirror aperture to reduce diffraction loss. With the above conditions fulfilled, optimization is obtained by consideration of the mode volume which determines the gain of the medium.

The confocal resonator (mirror separation equal to mirror curvature) has been analyzed in great detail by various workers. The following equations from Boyd and Gordon relate the wavefront radius and spot size to longitudinal distance along the laser axis.

$$x_0 = \sqrt{\frac{b}{k} \left[1 + \left(\frac{2z}{b} \right)^2 \right]}$$

$$r = \frac{b}{2} \left[\frac{1 + \left(\frac{2z}{b} \right)^2}{\frac{2z}{b}} \right]$$

$$k = \frac{2\pi}{\lambda}$$

refer to Fig. 6:

b = mirror separation (equal to mirror radius of curvature for confocal case)

x_0 = spot size defined as the transverse distance when the exponential term in the electric field equation reduced to e^{-1} (see section 3)

r = radius of curvature of the constant phase plane or wave front.

Those equations can be also applied to mirrors in nonconfocal case by situating the mirrors at appropriate places where the wave front coincides with the mirror surface.

To use the equations for nonconfocal case, we eliminate z from the two equations and get:

$$x_0 = \sqrt{\frac{b}{k} \left(1 + \left(\frac{r \pm \sqrt{r^2 - b^2}}{b} \right) \right)}$$

from the second equation, rearranging:

$$z = \frac{r \pm \sqrt{r^2 - b^2}}{2}$$

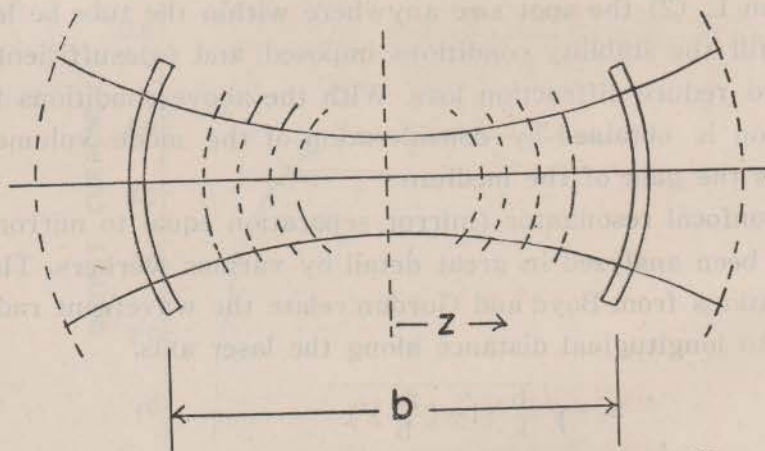


FIG. 6 CONFOCAL RESONATOR

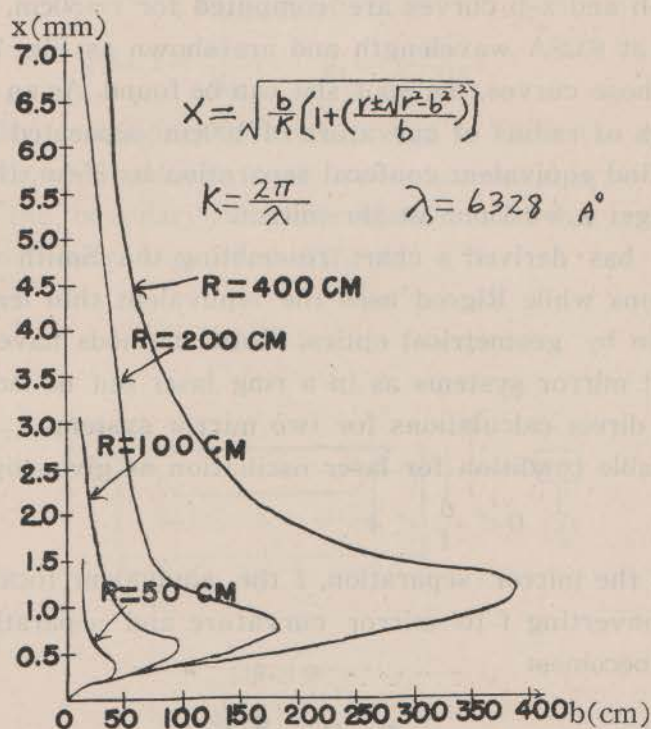


FIG. 7

$$z = \frac{r \pm \sqrt{r^2 - b^2}}{2} \text{ CM}$$

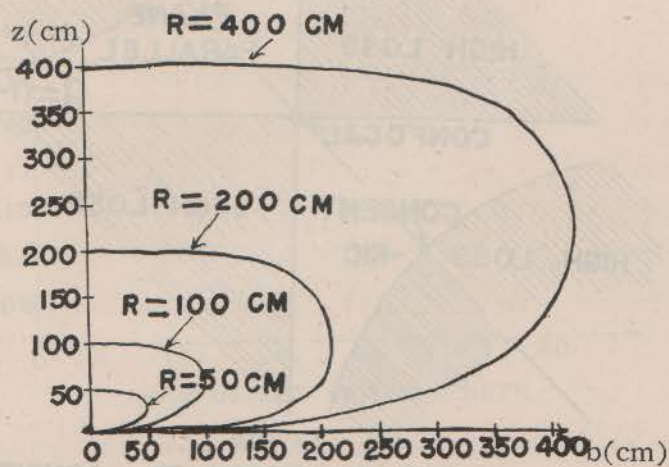


FIG. 8

The x-b and z-b curves are computed for $r=50\text{cm}$, 100cm , 200cm and 400cm at $6328\text{\AA}$ wavelength and are shown as Fig. 7 and Fig. 8.

From those curves, the spot size can be found. As an example: with two mirrors of radius of curvature of 100cm separated by 50cm , from Fig. 8, we find equivalent confocal separation $b=85\text{cm}$, then transfer to Fig. 7, we get $x_0=0.65\text{mm}$ at the mirror.

Collins has derived a chart resembling the Smith chart to solve the equations while Rigrod used the equivalent thin lenses and found the solution by geometrical optics. Both methods have much use for complicated mirror systems as in a ring laser but no advantages over the simple direct calculations for two mirror systems.

The stable condition for laser oscillation as given by Pierce:

$$0 < \frac{d}{f} < 4$$

where d is the mirror separation, f the equivalent focal length of the system. Converting f to mirror curvature and separation, the stable condition becomes:

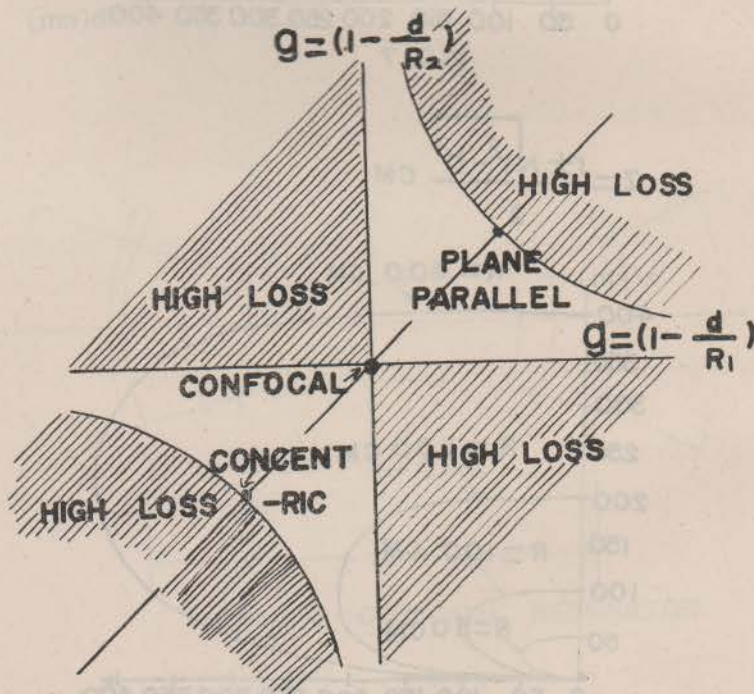


FIG. 9 STABILITY CONDITION

$$1 \geq g_1, g_2 \geq 0$$

$$g_1 = \left(1 - \frac{d}{R_1}\right) \quad g_2 = \left(1 - \frac{d}{R_2}\right)$$

The stability condition is plotted in Fig. 9. From the diagram, the plane parallel ($g=1$), confocal ($g=0$) and concentric ($g=-1$) configurations are at the boundary of stable operation so that critical alignments made such operations very difficult.

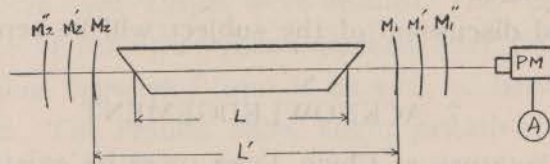


FIG. 10

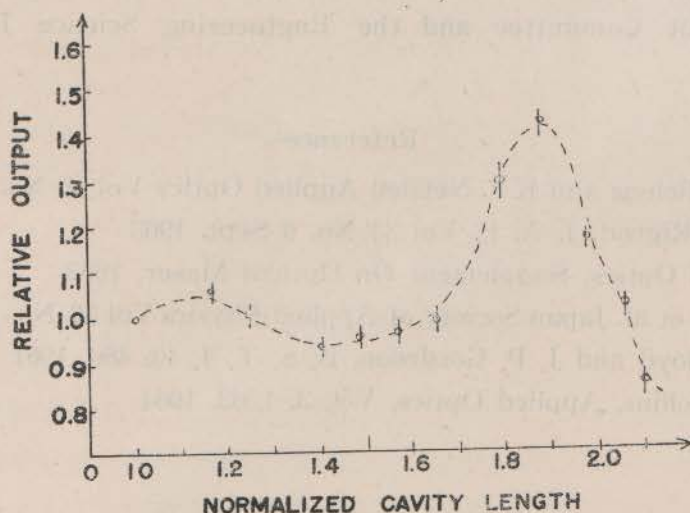


FIG. 11

6. OUTPUT POWER TO CAVITY LENGTH

The discussions concerning mirror separation as related to output power are usually with the assumption that the active medium fills the whole space between mirrors, i. e. the laser tube length approximates the mirror separation. In our experiments, we use laser tube of fixed length and displace the mirrors as shown in Fig. 10 and the results plotted in Fig. 11.

In Fig. 11, the mirror separation is normalized by tube length and the output is also normalized by the output at minimum mirror separation or cavity length.

More detailed discussion of the subject will be reported later.

7. ACKNOWLEDGEMENT

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References.

1. K. D. Mielenz and K.F. Nefflen Applied Optics Vol. 4. No. 5. May 1965
2. W. W. Rigrod. J. A. P. Vol 34 No. 9 Sept. 1963
3. Applied Optics, Supplement On Optical Maser. 1962
4. T Taxo et al. Japan Society of Applied Physics Vol 32 No. 7. July 1963.
5. G. D. Boyd and J. P. Gordrdon, B. S. T. J. 40, 489, 1961
6. S. A. Collins, Applied Optics, Vol. 3, 1263, 1964