DESIGN OF AN R.F. EXCITED HELIUM-NEON VISIBLE GAS LASER AND STUDY OF THE OPTIMAL CONDITIONS FOR GAS MIXTURES AND PRESSURES

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Design of a continuous wave helium-neon visible gas laser has been described. Brewster angle windows of fused quartz and external concave mirrors of B.S.C. glass have been used in the fabrication of resonant cavity. An RF oscillator having variable frequency in the range of 20-30 MHz and an out-put power of about 50 watts served as excitation source. Different mixture ratios of *He* and *Ne* have been tried and for each ratio power output was measured versus total pressure inside the discharge tube keeping cavity length constant. The optimum power output has been obtained for 5 : 1 mixture at 1·4 torr for a tube of length 55 cm and internal diameter 0·5 cm. Laser action at 1·153 μ has also been achieved.

After the discovery of first laser transition at visible wavelength (6328A°) in helium-neon by White & Rigden[1], interest of more and more workers has been increasing in this laser visualizing its utility in scientific, medical and industrial fields and also in military. Gas lasers have got distinct characteristics over solid state lasers *viz.* high monochromaticity, greater degree of coherence, less beam divergence and continuous operation. For using as an ideal source for different purposes this laser demanded much reduction in size, stability of frequency, greater power output and sufficiently longer life. Subsequently, a number of workers studied the optimization conditions for helium-neon visible gas laser. Gordon & White[2] used 1 to 15 mm inner diameter laser tubes operated by D.C. excitation source and for maximum gain obtained two relations—one between optimum discharge pressure and inner diameter of laser tube and the other between partial pressures of helium and neon.

$$P_{opt}\,(\text{torr}) \times D\,(\text{m.m.}) = 2{\cdot}9 \text{ to } 3{\cdot}6 \quad (2{\cdot}9 \text{ for lowest dia tube})$$

$$P_{He} = 5\,P_{Ne}$$

Field Jr.[3] made detailed study of different parameters of D.C. operated *He-Ne* gas laser. RF operated gas laser was first studied (for 2-7 mm dia tube) by Turner et al[4] who showed that the relations obtained by Gordon & White[2] are also applicable to RF excitation. Later, Mielenz & Nefflen[5] reinvestigated (for 3 mm and 5 mm dia tubes) the conditions for optimum gas mixtures and pressures for RF excited *He-Ne* visible laser and obtained some different results not agreeing to the relations of Gordon & White[2].

The author has designed and developed a *He-Ne* visible gas laser in this laboratory and studied the optimal conditions for gas mixtures and discharge pressures for one RF excited laser tube.

EXPERIMENTAL PROCEDURE

Resonant Cavity

Like microwave resonant cavities, for optical wavelengths also a high-gain low-loss resonant structure is required so that laser action may start by the gradual build up of electromagnetic field intensity upon multiple reflections. In the present gas laser, external mirrors near confocal cavity has been constructed using Brewster angle windows. Fig. 1 shows the complete experimental set-up.

For laser tube, a 55 cm long thick wall pyrex glass tube of 5 mm inner diameter was ground and lapped at Brewster angle (55° 24′ for fused quartz), the accuracy of Brewster angle and twist between the ground end faces maintained within 30′. The quartz flats have diameter 2·5 cm and thickness 3 mm and surface finish was maintained to better than $\lambda/8$ with a wedge less than 30″ of arc. These flats were sealed to the ends of the laser tube with a low vapour pressure epoxy resin.

The mirror substrates are plano-concave made out of B.S.C. optical quality glass and have radius of curvature 83 cm, diameter 2 cm and thickness 1 cm. For these also surface finish was maintained better than $\lambda/8$ to provide a good quality output beam. Tool was readily available in our optical workshop for generating 83 cm radius surface and hence mirrors were made of this radius of curvature and accordingly the

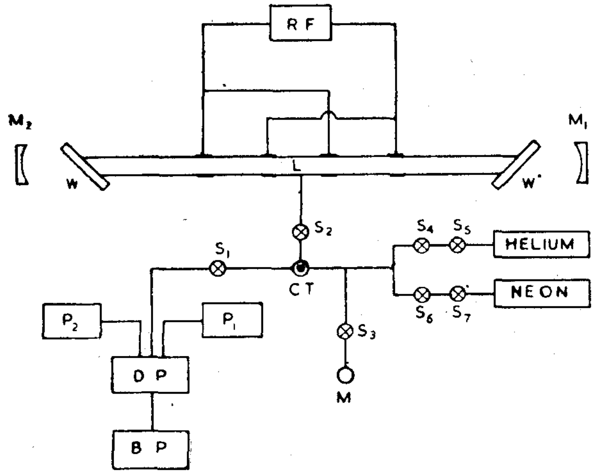

Fig. 1—Experimental set-up for *He-Ne* gas laser. (S_1...... S_7)=High vacuum stop cocks; CT=Cold trap of liquid N_2; M=Oil manometer; L=Laser tube; W=Brewster windows of fused quartz; M_1, M_2=Multilayer dielectric coated mirrors; RF=Radio frequency oscillator; DP=Oil diffusion pump; BP=Backing pump; P_1=Pirani gauge; P_2=Penning gauge.

length and dia of the laser tube were chosen for forming a near confocal resonant cavity, a detailed account of which is given by Garrett[6]. The mirrors have dielectric coating of 17 layers of $Zn\ S$ and $Mg\ F_2$ giving peak reflectivity for 6328A°. As there was no experimental device for measuring absolute reflectivity, the transmission of the mirror was measured on Carl Zeiss PMQ-II spectrometer which is ·4 per cent at ·633 μ.

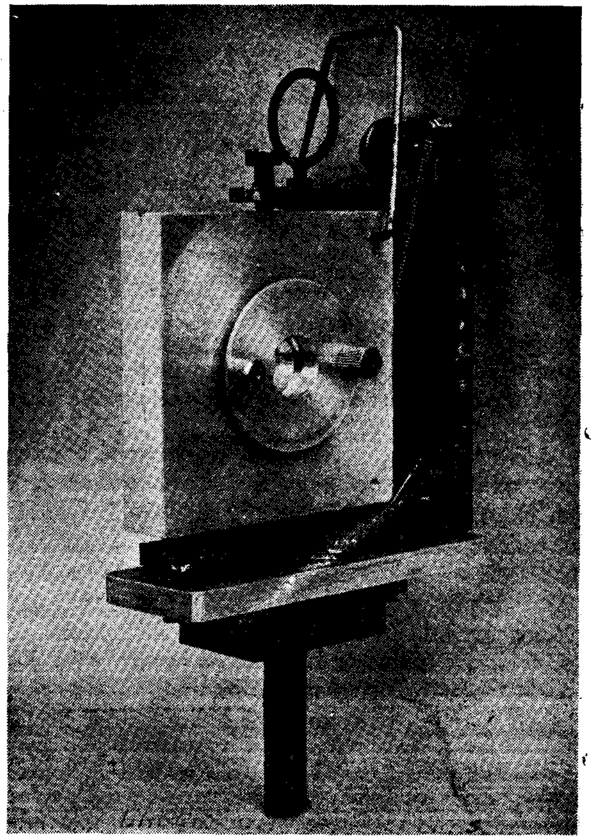

Fig. 2—Laser mirror mounts. These were specially fabricated to have spring loaded screws for finer adjustment of the tilt of the mirror.

Special type mirror mounts (Fig. 2) were designed and fabricated. These have got the spring loaded screws for fine adjustment of tilt of the mirror about two mutually perpendicular axes normal to the axis of the laser cavity.

Gas Filling System

For filling helium and neon gases a gas filling system was constructed as shown in Fig. 1. The system pressure was measured by means of Pirani and Penning gauges and the ultimate vacuum of the order of 10^{-6} mm of Hg was achieved using a liquid Nitrogen trap.

The degassing of the entire system was done for about 20 hours and the laser tube was baked at a temperature of 115°C. Other parts of the glass system were also warmed by running a mild Bunsen flame for quick removal of moisture and other absorbed vapours.

Excitation Source

For the excitation of discharge tube a radio frequency oscillator was fabricated (Fig. 3) having frequency 20 to 30 MHz and an output power of approximately 50 watts. About 10 electrodes of copper foils were wrapped around full length of the tube, each adjacent electrode being of opposite polarity.

Operation of the Laser

Prior to filling of helium and neon mixtures for laser action, flushing of the tube was done a number of times by filling and exciting neon only (at a pressure of about 2 torr) until discharge colour does not change even when operated for few hours. Now the tube is suitable for laser trial. It is found that after baking, flushing of the tube is very essential for longer life.

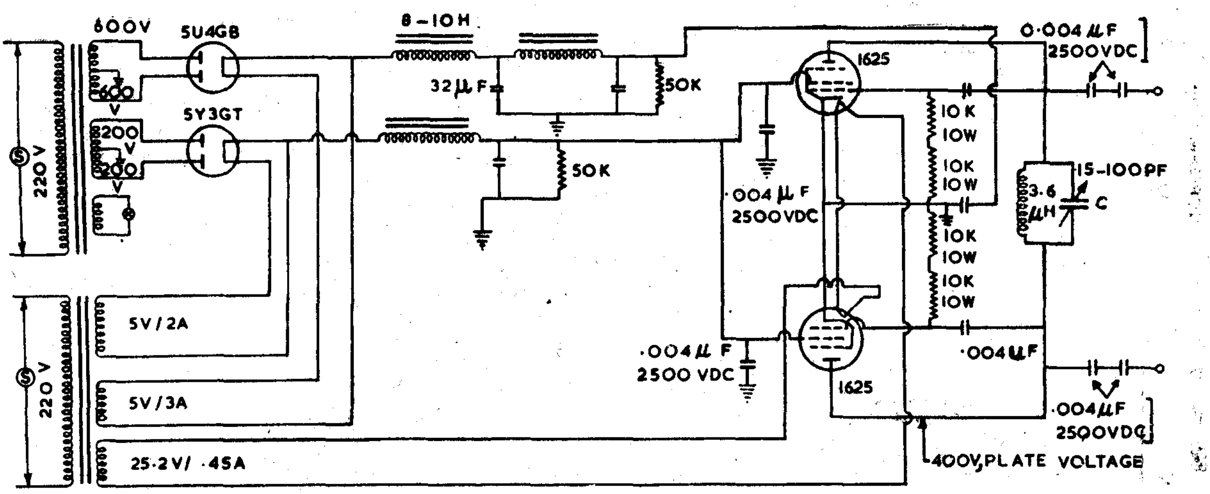

Fig. 3—Radio Frequency Oscillator.

The mirrors were placed 82 cm apart which is slightly less than the exact confocal cavity separation of 83 cm. In general, exact confocal cavity is always undesirable because of the reasons discussed by Boyd & Kogelnik[7] who concluded that the true confocal system is an optimal one with respect to diffraction losses. A small deviation from equal curvature of the two mirrors will, however, lead to a disproportionate increase in loss if the cavity is confocal. Normally the spacing of the mirror is kept less, rather than greater than the radius of curvature. This is desirable because (1) the mirror size (and therefore the required tube size) is smaller than at exact confocality (2) because the mode is less 'necked' and therefore uses a larger fraction of the atoms in the tube[6]. For the alignment of mirrors there are several methods now in practice[6,8]. In the present case it took hardly few minutes to align the whole cavity. After thorough evacuation helium and neon mixture was prepared in a definite ratio and introduced into the discharge tube. The oscillator was switched on and the frequency adjusted so that full tube gets excited. With the preliminary alignment it is observed that as soon as the discharge was excited for suitable mixture pressure, laser action started building up. Brightness of the laser beam was further improved by adjusting the mirrors and also by varying the frequency of the oscillator.

Different mixtures 20 : 1, 15 : 1, 11 : 1, 10 : 1, 9 : 1, 7 : 1, 5 : 1, 3 : 1, 2 : 1, 1 : 1 were tried and total pressure varied between 4 to 0·5 torr. The power output was measured by a flash integration system (International Light). The detector was placed at a distance of 1·5 m from the exit mirror.

RESULTS

Curves showing variation of output power with respect to the total pressures for different mixture ratios are shown in Fig. 4. The maximum power output has been obtained for 5 : 1 ratio at a total pressure of 1·4 torr ($P_{opt} \times D = 7$. Mielenz[5] obtained values of this order for RF excited tubes) and then for 7 : 1 and 10 : 1 mixtures at pressures of 1·6 and 1·7 torr respectively. The laser action is obviously between the pressure range of 0·5 to 3·5 torr. For lower ratios 3 : 1, 2 : 1 and 1 : 1, laser action is observed but the intensity falls down. For higher ratios 11 : 1, 13 : 1, 15 : 1 and 20 : 1, the laser action builds up even at higher pressures but the power reduces considerably.

The power output of the present laser has been measured as 0·5 milliwatt approximately. The beam divergence has been found of the order of 0·8 milliradian. It may be pointed out that both mirrors being equally reflecting the total power output was divided on both sides. The author has not used one mirror perfectly opaque. Secondly to prevent the laser oscillation completion at 3·39 μ, which produces dominance effect in *He-Ne* 6328A° laser transition, no attempt was made, by using a Brewster prism for instance, to isolate[9] this wavelength. As in case of D.C. excitation, best output is expected to enhance by 50 per cent[10] if inhomogeneous weak magnetic field is applied, and by 25 per cent[11] if He^3 is used instead of He^4. The life of the present laser tube is about 100 hours. Efforts are being made to increase the power output and also the life of the laser tube. This laser is being used in aligning the Ruby Laser, testing of optical components and multilayer dielectric coated mirrors (for 6328A°) and also in holography.

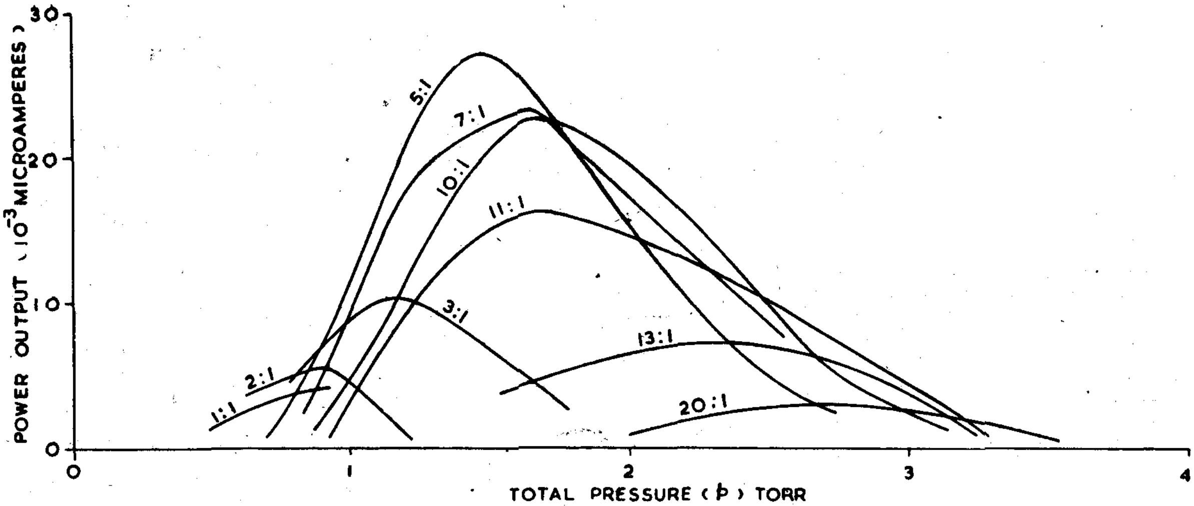

Fig. 4—Variation of laser power output *vs* total pressure for different mixture ratios in *He-Ne* gas laser (6328A°).

Laser Action at 1·153 μ

For lasing action at 1·153 μ experimental set-up similar to the one described for visible wavelength, has been used. The mirrors have been coated with 13 layers of ZnS and $Mg\ F_2$ to give peak reflectivity at 1·15 μ. Mixture of He and Ne in the ratios of 10 : 1 and 5 : 1 have been used at discharge pressures of 1 to 2 torr. To observe the laser beam visually an image converter tube has been used.

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