ECE 185

HELIUM-NEON LASER

I. OBJECTIVES

To study the output characteristics of a He-Ne laser: maximum power output, power conversion efficiency, polarization, TEM mode structures, beam divergence, and longitudinal mode structures; to align several different laser resonator configurations and to determine cavity stability limits of those resonators.

II. REFERENCES

1) A. Yariv, Optical Electronics (3rd), Ch.4-5, Sec. 6.1-6.5 and 7.5.
4) "Scanning Spherical-Mirror Interferometers for the Analysis of Laser Mode Structures", Spectra Physics Laser Technical Bulletin No. 6. [References 3 and 4 are summarized in Appendices 1 and 2]

III. GENERAL BACKGROUND

A. HeNe Laser Physics

Ali Javan at Bell Laboratories developed the first c.w. He-Ne laser in 1960. Basically, an excited plasma, contained in a glass envelope, is formed from a helium and neon mixture (He: 1.0 mm-Hg; Ne: 0.1 mm-Hg) by applying either a DC or an AC electric field to the system. Electrons and ions, accelerated by the field, excite other atoms into higher levels by collisions (see Fig. 1).

For the 0.6238\(\mu\)m (red) laser line, electrons accelerated by the electric field collide with the helium atoms, exciting them to the 2\(^1\)S level. These atoms, upon collision, transfer their energy to the neon atoms. These neon atoms are then excited to the 3\(^S\) level, which is the upper energy level for population inversion. The transition between neon's 3\(^S\) and 2\(^P\) emits a photon for the lasing process. The lifetimes of the 3\(^S\) and 2\(^P\) states are 10\(^{-7}\)s and 10\(^{-8}\)s, respectively.

Important note is that the 1\(^S\) level has a long lifetime, and thus tends to collect atoms reaching it by radiative decay from the lower laser level 2\(^P\). To prevent these atoms from colliding with discharge electrons and sending them back to the 2\(^P\) level, the plasma tubes of He-Ne lasers are made small so that the electrons can relax back to the ground state by colliding with the tube walls.

B. Laser Cavity Physics

The 0.6328\(\mu\)m line has very low gain. As a result the laser cavity must be tailored to minimize losses. Brewster windows (see Fig. 2) are utilized at both ends of the laser tube to minimize reflection losses. As drawn in the figure, the Brewster windows will transmit vertically polarized light with no surface reflections. Consequently, the laser output will be polarized.

The mirrors that make up the laser cavity essentially form a reflecting waveguide, and hence are subject to the same stability criteria for a lens waveguide (see Yariv). Stability and losses are based on mirror placement (see Fig. 3) and a self-consistent solution to the Maxwell equations. The solutions to the Maxwell equations, given a combination of spherical mirrors, results in several...
eigenmodes (see Fig. 4). The TEM modes are the transverse electric and transverse magnetic modes that resonate in the cavity. The lowest order mode approximates a Gaussian profile, which will reproduce itself upon repeated mirror bounces; the higher order modes will do the same since they retain the common feature of a gaussian-spherical exponent as part of their transverse dependence.

Other laser lines (1.15µm and 3.39µm) are possible by using cavities with appropriately coated mirrors, and different Brewster window material, as windows made of glass or quartz absorb infrared radiation and will thus increase the lasing threshold for such wavelengths.

![Energy-level Diagram](image)

Fig. 1. HeNe laser energy levels. The dominant excitation paths for the red and infrared transitions are shown.

![Brewster Window Diagram](image)

Fig. 2. A Brewster window (θ = tan⁻¹ n; n=1.457 for quartz at λ = 0.6328µm).
Fig. 3. Cavity stability diagram. Shaded regions are unstable.

C. Ring-Cavity Structures

Typical laser cavities have two mirrors: a high reflector at one end, and a partially transmitting output coupler at the other. Inside those cavities, each photon travels in both directions by virtue of the facing mirrors. In some applications, however, photons are required to travel in one direction only, and this requirement is satisfied by a ring cavity, which has three or more mirrors. The result is two counter-propagating beams inside the cavity. Common ring cavity shapes are triangles (3 mirrors) and rectangles (4 mirrors).

A four-mirror cavity is included in the lab as an exercise in cavity alignment. It uses three curved mirrors ($R = 75\text{cm}, 75\text{cm}, 200\text{cm}$) and one flat mirror ($R = \infty$).
Fig. 4. Hermite-Gaussian functions $u_l(\xi) = (\pi^{1/4}l^{1/2})^{-1/2} H_l(\xi)e^{-\xi^2/2}$ corresponding to higher order beam solutions

$$E_{l,m}(x,y,z) = E_0 \frac{\omega_x}{\omega(z)} H_l\left(\frac{\sqrt{2} x}{\omega(z)}\right) H_m\left(\frac{\sqrt{2} y}{\omega(z)}\right)$$

$$\times \exp\left[-\frac{x^2 + y^2}{\omega^2(z)} - \frac{ik(x^2 + y^2)}{2R(z)} - ikz + i(l + m + 1)\eta\right]$$

Curves are normalized to represent a fixed amount of total beam power in all modes

$$\int u_l^2(\xi)d\xi = 1$$

The solid curves are the functions $u_l(\xi)$ for $l = 0, 1, 2, 3, \text{and } 10$. The dashed curves are $u_l^2(\xi)$. 
APPENDIX 1. PROPERTIES OF LASER RESONATORS GIVING UNIPHASE WAVEFRONTS

I. INTRODUCTION

For best use of coherent light, minimum spot size is desired. This requires that (a) the wavefront of the output has the same phase across its entire surface, and that (b) the edge of the wavefront falls off slowly, rather than abruptly as if it has passed through an aperture.

![Fig. 1. Three basic transverse modes.](image)

The TEMoo mode in Fig. 1 satisfies the two conditions mentioned above, while the mode has two lobes and thus does not satisfy requirement (a). The TEM01* mode is a composite of two degenerate TEM01 modes, and its spot size is larger than that of the TEMoo mode (see reference 2 at the end of this appendix).

II. RESONATOR CONFIGURATIONS

For laser resonators, the only way for a uniphase wavefront to occur is to force all modes except for the lowest order mode TEMoo (which does not have any modes) to have high diffraction losses, so that they operate below threshold. To achieve this condition, the half-width of the lowest order mode should ideally equal the radius of the laser cavity mirrors. However, due to reasons such as dust particles located on the mirror which gives rise to different modal diffraction losses and can suppress lowest order mode operation, it is essential to design the laser with an adjustable mode diameter \(2\omega\) to laser aperture ratio. One way is by means of an adjustable mirror separation. In the following, several resonator configurations that can produce a uniphase wavefront will be described (see Fig. 2).

(A) Plane-parallel resonator

This was used in early demonstrations of gas lasers. However, due to diffractions around the edges which results in a 30° phase lag there, the output has a diverging wavefront. Also, the ratio of TEM01 diffraction loss to that of TEMoo is two, which is much smaller than that of other resonator configurations; this can easily lead to higher order mode operation if other imperfections exist. Furthermore, a plane-parallel resonator is extremely susceptible to high losses resulting from mirror misalignment, microphonic, and thermal effects. It is also extremely sensitive to the optical quality of the mirrors and Brewster windows. These resonators require mirrors parallel to within the order of one second of arc, and flatness to \(\lambda/100\). For these reasons, plane parallel resonators are rarely used.
Fig. 2. Resonator configurations giving uniphase wavefronts. The intra-cavity radiation pattern is also outlined.

(B) Large radius resonator
The mode dimension $c_0$ at the mirror surface is defined as the radius for which the electric field falls to $1/e$ of its maximum value. Boyd and Kogelnik (see references 3 and 4 at the end of this appendix) have calculated that for two equal mirrors with radius $b$ and separation $d$, $c_0$ is given by

$$\omega^4 = \left(\frac{\lambda}{\pi}\right)^2 \frac{b^2d}{2b-d} = \left(\frac{\lambda}{\pi}\right)^2 \frac{bd}{2} \quad (for \ b >> d) \tag{1}$$

Thus, $\omega$ is a very slowly varying function of $b$. Resonators with large radius mirrors can maximize the use of excited atoms in the cavity and thus potentially give high output power. Also, mirror alignment is not as critical as that in a plane-parallel resonator.

(C) Confocal resonators
When $b = d$, the resonator becomes a confocal one. From equation (1), $\omega$ is given by

$$\omega = \frac{b\lambda}{\pi} \tag{2}$$
Thus for a given \( d \) (or \( b \)), this corresponds to the smallest \( \omega \). As a result, confocal resonators are used whenever the smallest plasma tube diameter is desired, e.g. for \( b = 1 \text{m} \), \( \lambda = 0.6328 \mu \text{m} \), \( 2\omega = 1 \text{mm} \), this gives a laser tube diameter of approximately 2mm.

When \( d \) is very close to \( b \), \( \omega \) varies very slowly with \( d \). One disadvantage for confocal resonators is that for two mirrors which have slightly different radii, say \( b_1 < b_2 \), then the resonator is stable only if \( d < b_1 \) or \( d > b_2 \). Thus in practice, \( d \) has to be adjustable.

(D) Spherical resonator
When \( 2b = d \), it is called a spherical resonator. From equation (1), \( \omega \) is very large at the mirror and it is focused down to a diffraction limited point at the center of the sphere. It resembles a hemispherical resonator (see F) except that mirror alignment is very critical in that the mirrors must be coaxial, and have radii of curvature that coincide to within diffraction limited dimensions.

(E) Concave-convex resonator
When \( d \approx b_1 + b_2 \) and \( b_1, b_2 \) are of opposite signs, the result is a concave-convex resonator. Mirror alignment is very critical for this configuration. Also, a geometry that makes good use of plasma volume does not provide much adjustability in mode dimension.

(F) Hemispherical resonator
In this configuration, a flat mirror is placed approximately at the center of curvature of a spherical mirror. Thus the mode has a large diameter at the spherical mirror, and it focuses to a diffraction limited point at the plane mirror. The output wavefronts from the two ends of the laser behave as if they came from the diffraction limited point at the flat mirror. For a spherical mirror radius \( b_1 \), and flat mirror radius \( b_2 = \infty \), \( \omega_1 \) and \( \omega_2 \) for the two mirror surfaces (see reference 4 at the end of this appendix) are

\[
\omega_1^4 = \left( \frac{\lambda}{\pi} \right)^2 \frac{b_1^2 d}{b_1 - d} \tag{3}
\]

\[
\omega_2^4 = \left( \frac{\lambda}{\pi} \right)^2 d(b_1 - d) \tag{4}
\]

loss. In practice, \( d \) is slightly less than \( b_1 \) so that a finite and reasonable value of \( \omega_1 \) is obtained which has a small diffraction loss. This allows mode dimension \( \omega \) to be chosen by small adjustments to \( d \). Another advantage of the hemispherical resonator is the relative ease of minor alignment with regard to parallelism. This is due to the fact that an angular misalignment of the flat mirror merely results in a smaller part of the spherical mirror forming a useful cavity, but it does not prevent the laser from oscillating on a smaller part of the spherical mirror. Thus in practice, the mirrors are first brought a little too close together so that \( \text{co}\{ \omega \} \) is relatively small. Once laser action is observed, perhaps with higher order modes present, the flat mirror is oriented slowly to give the lowest order mode; the mirrors are then pulled apart until uniphase operation is achieved. The disadvantage of this configuration is that the cone shaped mode intersects only part of the laser resonator volume, which results in smaller output power.
III. RESONATOR ALIGNMENT CHARACTERISTICS

The sensitivity to alignment variations of resonators can be deduced from the fact that the uniphase wavefront mode must lie symmetrically along the line joining the center of curvature of the two mirrors (Fig. 3).

\[ b_1 \theta = (b_1 + b_2 - d) \phi \]  

Therefore

\[ x = \frac{b_1(b_2 - d)\theta}{b_1 + b_2 - d} \]  \hspace{1cm}  
\[ y = \frac{b_1b_2\theta}{b_1 + b_2 - d} \]

The sensitivity is then defined as the smaller of the angles

\[ \theta' = \frac{\omega_1\theta}{x} \text{ or } \frac{\omega_2\theta}{y} \]

With equations (6), (7), and (8), we have the following summary:

A) Plane-parallel: \( \theta' = 0 \), alignment is critical.

B) Large radius (b \( \gg \) d): \( \theta' \approx 2\omega/b \), alignment is not as critical as in (A).

C) Confocal: \( x = 0, \ y = b\theta \), alignment is least sensitive among all the various configurations.

D) Spherical: \( \theta' = \omega \delta / b^2 \), where \( \delta = (b_1 + b_2 - d) \) is small; alignment is critical.

E) Concave-convex: unless the negative mirror has a very small radius of curvature (thus resembling the confocal resonator), alignment is critical as in (D)
Hemispherical: if the flat mirror is tilted \( b_1 = \infty \), then

\[
\begin{align*}
x &= (b_2 - d) \theta \\
y &= b_2 \theta
\end{align*}
\] (10)

so the alignment is similar to that of a confocal resonator. If the spherical mirror is tilted \( b_2 = \infty \), then

\[
\begin{align*}
x &= b_1 \theta \\
y &= b_1 \theta
\end{align*}
\] (11)

and the entire mode is displaced parallel to the axis of the laser tube. To avoid this, the spherical mirror should be set up as part of a confocal resonator before inserting the flat mirror.

IV. REFERENCES


APPENDIX 2. SCANNING SPHERICAL MIRROR INTERFEROMETERS FOR THE
ANALYSIS OF LASER MODE STRUCTURES

I. INTRODUCTION

Scanning spherical-mirror interferometers (SSMI) are common tools for high resolution
analysis of laser mode structures. They can be used in conjunction with an r.f. spectrum analyzer
which displays the beat frequency (r.f.) between the laser oscillating modes (optical frequencies). In
laser mode studies, one has to distinguish between two types of laser modes: longitudinal modes are
associated with different modes of oscillation of the laser and are characterized by their oscillation
frequency; transverse modes are characterized by the field intensity distribution in a plane
perpendicular to the direction of propagation. Corresponding to a given transverse mode, there can
be a number of longitudinal modes having the same transverse field distribution. The SSMI are
useful in examining these laser mode structures. Among the various SSMI, the mode degenerate
interferometers, especially the confocal ones, are comparatively easy to use.

II. THE FABRY-PEROT INTERFEROMETER

SSMI belong to the general class of Fabry-Perot interferometers, which consist of two mirrors
placed parallel to each another with a separation d. The resonance condition for such an
interferometer is when the optical path between the mirrors is equal to an integral number (m) of half
wavelengths of the incident light. For normal incidence, the resonance condition is

\[ \nu_0 = \frac{mc}{2d} \]  

where \( \nu_0 \) is the frequency and \( c \) is the velocity of light. In general, the transmittance of the etalon
is given by

\[ \frac{I}{I_o} = \frac{1}{\left(1 + \frac{A}{T}\right)^2} \cdot \frac{1}{1 + \frac{4R}{(1-R)^2} \sin^2 \frac{2\pi \nu d}{c}} \]  

(2)

where \( I_o \) and \( I \) are the incident and transmitted beams, respectively; \( R \) and \( T \) are the mirror
reflectivity and transmissivity, and \( A \) is the dissipative loss of the mirrors. For \( R = 1 \), the
transmission fringes become very sharp, and in the vicinity of \( \nu_0 \) equation (2) can be written as

\[ \frac{I}{I_o} = \frac{1}{\left(1 + \frac{A}{T}\right)^2} \cdot \frac{1}{1 + \left[ \frac{4\pi d}{c(1-R)} \right]^2 (\nu - \nu_0)^2} \]  

(2a)

which is illustrated graphically in Fig. 1. Thus, the transmittance is Lorentzian near \( \nu_0 \) and has a
FWHM of

\[ \Delta \nu_b = \frac{c(1-R)}{2\pi d} \]  

(3)

This \( \Delta \nu_b \) is also called the instrumental bandwidth of the etalon.
Fig. 1. Transmittance of a Fabry-Perot etalon for various mirror reflectances. The dissipative loss of the mirrors is assumed to be 0.2%.

In addition, the difference in frequency between two transmission fringes is called the free spectral range (FSR = c/2d). The ratio of FSR to $\Delta v_b$ is called the finesse ($F = \pi/(1 - R)$). The ratio of $\Delta v_o$ to $\Delta v_b$ is called the resolving power, or $Q$ (quality factor) of the etalon.

An ordinary Fabry-Perot is not useful in analyzing laser modes. A typical gas laser transition has a Doppler linewidth of a few gigahertz, and a mode spacing of a few tens of megahertz. This implies that the interferometer must have a FSR larger than the Doppler linewidth, and a $\Delta v_b$ smaller than the mode spacing. For gas lasers, this typically means a finesse of at least 100. However, the finesse of an ordinary Fabry-Perot is limited by the flatness and the apertures of the plane mirrors, and for small apertures, diffraction loss becomes significant.

### III. SPHERICAL-MIRROR INTERFEROMETERS

The diffraction effects of the Fabry-Perot etalon can be eliminated by using spherical, instead of plane, mirrors in the interferometer. However, the radius of curvature ($r$) must be greater than $d/2$. The spherical mirror also alleviates the constraint on surface figure, because only a small area of the mirror is used. One requirement of a general spherical-mirror interferometer is that it must be illuminated with a narrow, diffraction limited beam, i.e. the beam must be mode-matched with the interferometer for proper operation. The various resonant modes of such a cavity is given by

$$v_o = \frac{c}{2d} \left[ q + \frac{1}{\pi} (1 + m + n) \cos^{-1} \left( \frac{1 - d}{r} \right) \right]$$

(4)

where $q$ is an integer denoting longitudinal mode number, $m$ and $n$ are integers denoting transverse mode numbers. From equation (4), it can be seen that in order to have a large enough FSR, $m$ and $n$ must be fixed such that FSR = c/2d. In practice, the only transverse mode of the interferometer, which is convenient to excite is the TEM$_{00}$ mode. This single transverse mode requirement limits the use of a general spherical-mirror interferometer, as the laser itself may not operate in the TEM$_{00}$ mode. Moreover, an optical isolator must be used to avoid feedback of light from a well aligned interferometer into the laser.
IV. MODE-DEGENERATE INTERFEROMETERS

In contrast to the general spherical-mirror interferometer, the mode-degenerate interferometer does not need to be mode-matched to the incident laser beam. This results in several simplifications of its applications, namely:

1. The laser does not have to operate in a single transverse mode.
2. There is no spurious resonances due to mode-mismatching.
3. The interferometer need not be accurately aligned along the axis of the incident laser beam. This also allows the operation without an optical isolator as the light does not reflect back into the laser.

A mode-degenerate interferometer is a spherical-mirror interferometer whose transverse modes are degenerate in frequency. When the condition

\[ \cos^{-1}(1 - d/r) = \pi/l \]  

(where \( l \) is an integer) is satisfied, then the resonance condition in equation (4) becomes

\[ v_0 = c(q + 1 + m + n) / 2ld \]  

(6)

By increasing \((m-n)\) by \( l \), and decreasing \( q \) by 1, \( v_0 \) remains unchanged. Thus the interferometer will have \( l \) "sets" of degenerate transverse modes with equal mode spacing. It has an FSR of \( c/2ld \) and a finesse of \( \pi l/(1-R) \).

The best known mode-degenerate interferometer is the confocal one, with \( l = 2 \). It has "even symmetric" modes corresponding to \((m+n)\) even, and "odd symmetric" modes corresponding to \((m+n)\) odd. Mode-degenerate interferometers can also be analyzed in terms of geometric optics. For instance, equation (5) is equivalent to the condition that a ray launched in the cavity retraces its path after \( l \) complete travels of the cavity. A typical ray path for the confocal interferometer is shown in Fig. 2.

![Fig. 2. Ray paths in a confocal interferometer.](image)

The performance of mode-degenerate interferometers is limited by the mirror reflectivity, mirror surface figure, and spherical aberration. The reflectivity limitation is not serious as high reflectance (>0.998) has been achieved in practice giving a finesse greater than 750. In order to minimize the effect of surface figure of the mirrors, the laser beam diameter should be as small as possible (approximately that of the TEMoo mode of the interferometer). To avoid aberration, the beam should be close to the interferometer axis, so that the paraxial optics approximation applies.
V. STRUCTURE OF MODE-DEGENERATE INTERFEROMETERS

Fig. 3 shows a typical scanning confocal interferometer. It consists of two spherical mirrors, separated by a distance equal to their radius of curvature. The back surfaces of the mirrors are made such that the mirrors are self-collimating, so that a plane wavefront incident on the interferometer is transformed into a spherical wavefront with a radius of curvature that is matched to the transverse modes of the interferometer. The concave surfaces are coated with high reflectance dielectric films; the convex ones are coated with anti-reflection films to eliminate spurious resonances associated with the back surfaces. The mirrors are mounted in a cell whose spacing can be controlled (to within a few wavelengths) by a voltage applied to the piezoelectric spacer. For confocal interferometers, a scan of $\lambda/3$ in spacing corresponds to one FSR. An aperture is placed outside the entrance mirror to limit the diameter of the incident beam and hence reduce spherical aberration. The transmitted light is detected by a photodetector whose electrical output is viewed on an oscilloscope, as a function of the voltage applied to the piezoelectric spacer.

![Piezoelectric Spacer](Image)

Fig. 3. Scanning confocal interferometer.

It is important that the mirror separation be quite close to confocal. The tolerance on the mirror spacing depends on the length of the interferometer and its finesse. For very short, high finesse interferometers, the mirror spacing should be set to within a few wavelengths. In practice, the adjustment of length is quite easy to make. The mirror spacing should first be set so that it is approximately confocal; then by observing the mode structure of a laser on an oscilloscope, the final adjustment of the mirror spacing can be made to maximize the finesse of the interferometer. Once the separation of the interferometer mirrors is set, there is no need for further adjustment.

VI. USE OF SCANNING SPHERICAL-MIRROR INTERFEROMETERS

Two specific applications are considered here. (A) Usually by adjusting the laser mirrors, its output intensity profile can be changed. By focusing the laser beam into the scanning (mode-degenerate) spherical-mirror interferometer, the different transverse laser modes can be monitored, and the laser can be adjusted to operate in a single transverse mode. Fig. 4 shows the mode spectra for a helium-neon laser in double transverse mode, and single transverse mode operation. (B) The interferometers can be used to monitor phase-locking phenomena. Fig. 5 shows the output spectra of a single transverse mode argon ion laser in free running, and in self-phase-locking operation.
Fig. 4. (a) Output spectrum of a helium-neon laser operating simultaneously in two transverse modes, (b) Output spectrum of a helium-neon laser operating in a single transverse mode. The vertical sensitivity and horizontal dispersion are identical for both (a) and (b).

Fig. 5. (a) Output spectrum of a free-running argon ion laser, (b) Output spectrum of a self-phase-locked argon ion laser. The vertical sensitivity and horizontal dispersion are identical for both (a) and (b).
APPENDIX 3. TROPEL 240 SPECTRU ANALYZER.

I. DESCRIPTION

The Tropel model 240 spectrum analyzer is a high resolution confocal, or spherical, Fabry-Perot interferometer. The model 240 has relatively high reflectance dielectric mirrors, which, while retaining broadband coverage, give a compromise between high spectral resolution and high instrumental transmission at the center of the bandpass. The exact separation of the two mirrors has been made insensitive to reasonable room temperature variations by the use of thermal compensation in the interferometer assembly.

II. SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free spectral range (FSR)</td>
<td>1500MHz</td>
</tr>
<tr>
<td>Instrumental bandwidth ($\Delta\nu_b$)</td>
<td>75MHz</td>
</tr>
<tr>
<td>Spectral Resolving Power (Q)</td>
<td>$8 \times 10^7$</td>
</tr>
<tr>
<td>Finesse (F)</td>
<td>200</td>
</tr>
<tr>
<td>Peak instrumental transmission</td>
<td>20%-30%</td>
</tr>
</tbody>
</table>

III. General Use

For our purposes, the Tropel 240 will be used in the scanning mode.

When used in the scanning mode, a time-varying voltage is applied to the "scanning voltage" terminal. This causes the mirror separation to change through the action of a piezoelectric transducer, and this in turn varies the resonant frequency of the interferometer. The model 240 will scan over one free spectral range, or 1500MHz, with the application of 30-40 volts. If the time-varying voltage is made periodic, the resultant repetitive display of the spectrum, with a 1500MHz scan period, provides a convenient self-calibration of the frequency scale. Note that an increase in applied scan voltage produces a decrease in the resonant frequency of the interferometer. Fig. 2 illustrates a typical oscilloscope trace obtained when the model 240 is used in the scanning mode.
There are a few points to consider when using the model 240:

1) If the spectrum analyzer and laser beam are exactly co-linear, the spectrum of the laser may become; an erratic function of time due to optical feedback from the spectrum analyzer into the laser. This can be eliminated by a slight adjustment of the alignment, or by the insertion of a circular polarizer (linear polarizer plus 1/4-wave plate) between the laser and the spectrum analyzer. A relatively slow temporal variation of the spectrum of the laser is typical of many commercially available lasers and is due to thermal variations in the laser cavity length.

2) Once a high resolution display is obtained on the scope, the user should experiment to find out the angle through which the alignment can be varied without seriously affecting the instrumental bandwidth. In general, the final alignment is accomplished by observing the displayed spectrum while touching up the alignment adjustment screws to maximize the amplitude of the display, and to minimize the linewidth of each observed longitudinal mode.

3) Whenever possible, use a collimated beam with a small beam diameter (on the order of 1-2mm). This will provide the maximum signal and minimum instrumental bandwidth, while at the same time will allow maximum alignment tolerance.

4) Scan rates greater than a 200Hz should be avoided because the scan becomes nonlinear at high frequencies. Moreover, the silicon photo diode cannot resolve pulses shorter than a few microseconds, since zero reverse bias voltage is applied to the detector in the model 240. For continuous scans, a sinusoidal scanning voltage should be used to prevent damage to the piezoelectric transducers. In practice, a scanning voltage of around 35Vp-p at 100Hz is recommended for obtaining an initial display on the scope.
QUALITY CONTROL

SPECTRUM ANALYZER SPEC. SHEET

S.O. # 23245

SET #

MODEL # 240-2B

WAVELENGTH RANGE 5500Å-6500Å

WAVELENGTH PEAK 6000Å

WAVELENGTH TESTED AT 6328Å

FREE SPECTRAL RANGE FSR = 6cm 1.5 GHz

BANDWIDTH AT THE 50% POINTS BW = 0.028 7 MHz

FINESSE TOTAL FT = FSR/BW = .214
EXPERIMENTAL PART

In this Lab you will use a 25.5cm HeNe plasma discharge tube that has a brewster window on one end, and a R = 300cm output coupler on the other. Approximately 11W of electrical power is supplied to the discharge tube. A high reflecting mirror with R=60cm (reflector) can be placed at distance d away from the output coupler to complete a laser cavity.

1. Align two-mirror cavity for lasing action.  
   Alignment procedure:  
   - Be sure the plasma tube power supply is off.  
   - Adjust the height of the alignment laser, discharge tube, and reflector. Light from the alignment laser must pass through the brewster window and hit the reflector.  
   - Adjust discharge tube horizontally so that the beam reflected from output coupler is centered on the iris.  
   - Adjust the reflector so that the reflected beam coincides with the incident beam. You should see a blinking spot at the face of brewster window. (This blink shows the interference effect by two beams.)  
   - Turn on the power to the plasma tube. If there is no laser action, fine tune the reflector.  
   - Use power meter to maximize the output power.  

2. Fine tune the laser cavity to achieve maximum output power. Calculate total conversion efficiency.  

3. Determine output polarization using a polarizer.  

4. Change the laser cavity distance d by moving the high reflector. Fine tune the reflector mirror to get maximum output power. (You should perform this step individually.)  

5. Plot the output power as function of laser cavity distance.  

6. Use a CCD video system to monitor the light leakage from the reflector end of the laser. Tune the reflector mirror to obtain the TEM00 mode with maximum possible power before it transforms into a higher order mode.  

7. Measure the beam size at two different locations along the optical axis and calculate the beam divergence:  
   - Adjust optical attenuator and camera exposure time to avoid image saturation.  
   - Capture the image of beam spot and save as bmp-file.  
   - Move CCD-camera at some distance and capture the second image.  
   - Using MatLab perform a cross-section of beam spot, making sure the highest intensity peak is included.  
   - Determine the beam diameter on the FWHM level; pixel size is 7.5µm.  
   - Repeat calculation for the second beam spot and determine the beam divergence.  

8. Repeat (7) for the TEM01 mode and one other higher order mode.
9. Using the spectrum analyzer (scanning Fabry-Perot interferometer; see Appendix 3), obtain the mode spacing and sketch the longitudinal mode structure. Be sure the laser is kept as stable as possible, since vibrations will generate a jittery signal and measurement will be difficult. Measure the cavity length (carefully) and estimate the plasma index (recall effective plasma tube length is 25.5cm).