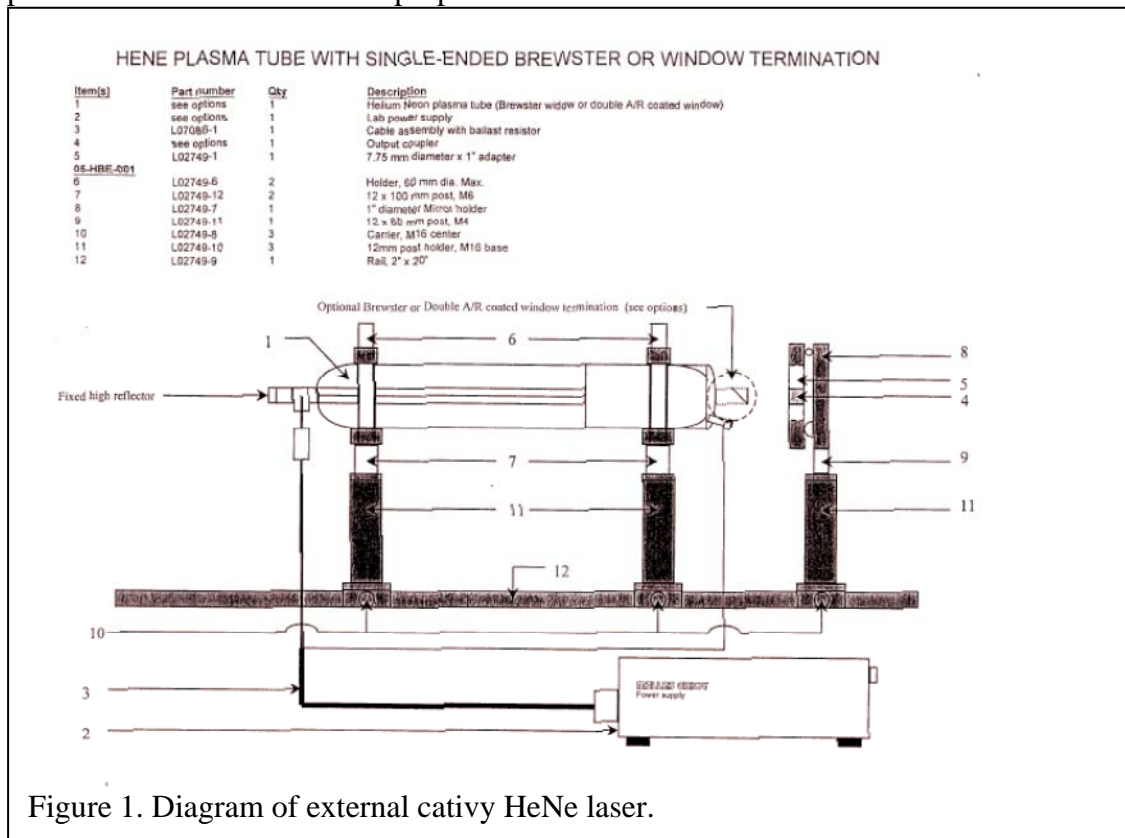


Experiment 5. Lasers and laser mode structure

1. Introduction

The laser is a very important optical tool that has found widespread use in science and industry, from high resolution, ultra-fast spectroscopy, to precise, high power welding. In this lab, we will explore how lasers work and examine some of the details that make different laser appropriate for different tasks.

Any laser starts with a gain medium. This gain medium, which can be solid, liquid, or gas, contains atoms or molecules with excited states that emit light over a range of wavelengths. The laser we will be exploring is the common Helium Neon laser, or HeNe. It is really the excited states of neon that are of interest. Neon is excited by an electrical discharge, which causes it to enter one of many high energy states. When the atom relaxes to a lower energy state, it emits light at several possible wavelengths. Neon emits at several wavelengths in the red, yellow, and green. For the gas to “lase”, a population inversion must be created, in which the gas contains more atoms in a specific high energy state relative to the low energy state. This is done by reflecting light of a specific wavelength back and forth across the gain medium using two mirrors, which causes stimulated emission of more radiation of the same wavelength. The region between the two mirrors is referred to as the laser cavity. This region is usually hidden from the users of a laser, but in our case we have an “external cavity”, which allows us to adjust the parameters that determine the properties of the laser beam.



2. The external cavity HeNe laser

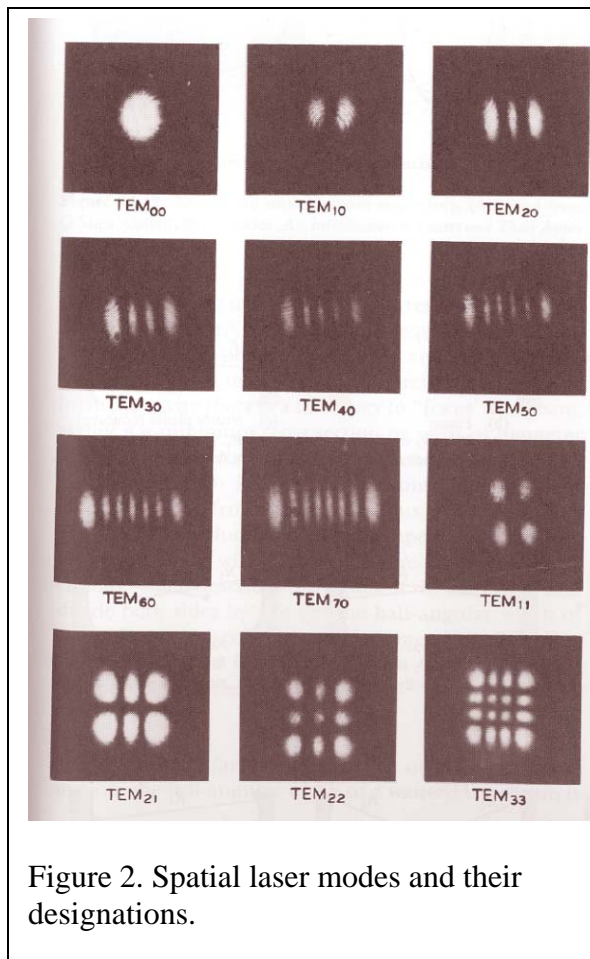
On the optical table in 26 Dana you will find our HeNe laser. The sealed laser tube (do not touch it!) contains an appropriate mixture of helium and neon. The back mirror seals one end of the tube, while at the other end there is a window at an angle. This angle is referred to as the Brewster angle, which allows only one polarization to pass through. Thus, the output will be polarized light at the various wavelengths emitted when neon is excited, which looks pink. Outside the laser tube there is a small mirror mounted on a post. This is the output coupler, which reflects 99% of the light at the desired wavelength, 633 nm. The setup is shown in Figure 1. Do not touch the electrodes on the laser tube! They are high voltage!

To turn on the laser tube, use the switch on the Melles Griot power supply. After a few seconds, the tube will begin to glow pink. Move the output coupler close to the Brewster window output of the laser tube.

Adjust the micrometers on the output coupler to achieve laser. This may take some time, but be patient and systematic. The effect when you see lasing will be very dramatic and cool.

3. Studying transverse lasing modes.

In addition to longitudinal modes that describe the wavelengths of the light being emitted from the laser, transverse modes are also possible. These modes are designated by the number of transverse nodal lines in the x and y directions. Examples of this are illustrated in Figure 2. Adjust the length of the optical cavity, the size of the pinhole diaphragm, and the angle of the output coupler (using the two micrometers on its mount) and explore modes that you see. List the modes that you see and under what conditions you see them. Can you remove some modes by closing the pinhole?



4. Using a scanning confocal interferometer to determine the cavity mode frequencies of lasers.

The confocal interferometer is a useful device for studying the frequency content of lasers because it has very high finesse (200 or greater). The finesse is very sensitive to the alignment of the input light relative to the interferometer and the mirror spacing. The interferometer must be operated with the mirrors very close to the confocal spacing in order to get high finesse. Mirror sets are specified by the free spectral range corresponding to the proper mirror spacing. The mirrors in our interferometer are designed to operate with 2 GHz FSR. The FSR serves as a scale factor for the horizontal axis - the output repeats itself every FSR scanned. The resolution of the interferometer is given by the FSR divided by its finesse, so we should have a resolution of 10 MHz.

The spacing of the mirrors can be changed using piezoelectric crystals (PZT) that change mirror spacing by a few wavelengths of light when a voltage is applied. The controller for the interferometer can apply a ramp voltage to the PZT to scan the interferometer. You can adjust the amplitude and frequency of the ramp. We will use this instrument to look at laser cavity modes. Please consult the SA^{Plus} user manual for instructions on how to control and display the data from the interferometer.

Laser cavity modes are determined by the cavity mirror spacing and curvatures. Modes are specified by a longitudinal mode number, which specifies the number of wavelengths that fit into one round trip at cavity center, and two transverse mode numbers that give the number of nodes in the two directions perpendicular to the cavity axis. These are the numbers shown in Figure 2. The longitudinal number is usually quite large, while the transverse numbers are usually less than 4. The transverse mode numbers can be reduced to zero by misalignment of the cavity or insertion of an aperture.

The frequency of a particular cavity mode depends on all three mode numbers. Changing the longitudinal mode number by one changes the frequency by

$$\Delta\nu_{\text{long}} = \frac{c}{2L} \quad (1)$$

The general case of transverse mode spacing is complex. The simplest case to consider is a symmetric cavity with identical mirrors. Changing either of the transverse mode numbers by 1 changes the frequency by

$$\Delta\nu_{\text{trans}} = \frac{c}{\pi L} \tan^{-1} \left(\frac{L}{2z_R} \right) \quad (2)$$

where

$$z_R = \frac{1}{2} \sqrt{L(2R - L)} \quad (3)$$

Our mirrors each have a radius of 45 cm.

To observe these modes, you must set up the confocal interferometer to display the laser spectrum on the digital oscilloscope. First, you must have the laser light aligned and entering the interferometer. This will be the case when the input laser light is reflected back onto itself. The interferometer has a photodiode detector at its back, which is

connected to an amplifier. The output of the amplifier should be connected to channel 1 on the scope. For a given mirror spacing, you will observe a fixed intensity on the detector which depends on whether or not you are getting constructive or destructive interference. To generate the frequency spectrum of the laser light, the ramp generator must be turned on to generate a ramping voltage that repeats at a fixed frequency. The

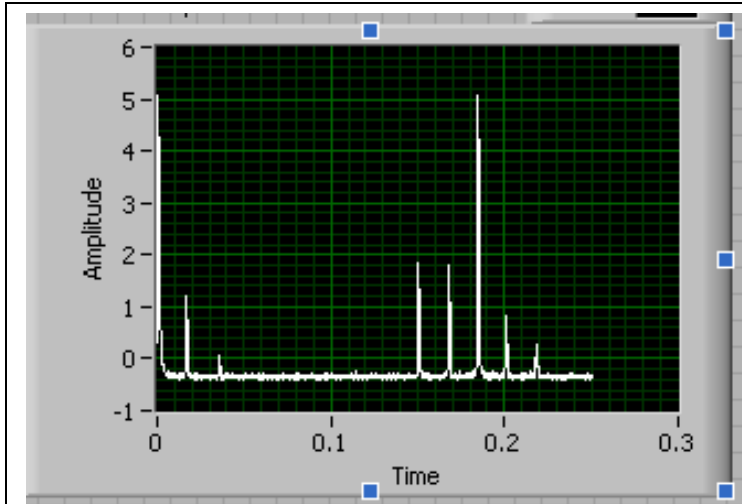


Figure 3. Example of output of interferometer when properly aligned. Note that the laser is operating in several modes under these conditions. Also, the signal is repeating every 0.18 s.

“blanking” output of the ramp generator outputs a square pulse for each ramp repeat. Connect this to channel 2 or the trigger to trigger your oscilloscope sweep. You should observe several peaks on the screen and these should repeat. Refer to the SA^{Plus} user manual for further instructions on how to resolve these narrow laser peaks.

When the setup is working, you should be able to identify different laser mode

structures. When the mirrors are adjusted so the laser is at its highest power, you will likely see many laser modes. Slowly adjust the mirrors away from optimum and watch the oscilloscope. You should be able to find a condition under which you can get a single laser peak, so the laser is operating in a single mode, both longitudinal and transverse.

5. Digital data acquisition using the GPIB interface

After you get the interferometer aligned and can observe a clean signal similar to that shown above, you should stop and figure out how to transfer data from the oscilloscope to the computer. Fortunately, our oscilloscopes are digital and we can directly transfer the digital data to the computer. You will now apply the skills that you learned in Experiment 1 to write a short data acquisition program using Labwindows. The data is transferred using a standard interface called the GPIB, or General Purpose Interface Bus. This is an old standard for talking to instruments with a computer and its protocol is well developed. Labwindows has a large collection of commands designed to send and receive commands over the GPIB. With many instruments, you would first look in the manual and learn the commands that must be sent to the instrument to tell it to send data or change settings. This can take a lot of work, but in some cases it is necessary.

Fortunately, the Tektronix TDS210 oscilloscope is a very common instrument and the GPIB commands have already been written into special programs for this oscilloscope, referred to as *drivers*. We have already downloaded the Tektronix TDS2xx drivers from the National Instruments web site and installed them in Labwindows. Write a simple program to read the waveform from the oscilloscope and display it on the front panel of your program. This will allow you to save some waveforms using “alt-print screen”. As you explore different laser modes, save some examples using this method and discuss the types of modes you see.

6. Analyzing the data and writing the report

The objective of this experiment is to observe different types of laser modes and quantify your observations. Set the laser mirrors so you are observing multiple transverse modes. Now look at the frequencies observed on the oscilloscope. Save this image and discuss it. Find conditions under which you observe only the TEM₀₀ transverse mode. What do you see on the oscilloscope? If you can observe only one peak, set the time scale so you can measure the width of the peak. Modify your Labwindows program to save your data to an excel file. Find the width of this peak. Is it a reasonable value? What is this width in Hz? What is the linewidth in nm? Use the fact that the center wavelength of the laser is 632.8 nm. Make a graph of this data with the x axis in units of Hz. Adjust the laser to lase in multiple modes. Extract your data and plot it in Excel. Measure the line spacing and explain it in terms of Eqs. 1-3 describing the cavity mode spacing. ***Do this for two cavity lengths.*** Are your results consistent with these equations?

Hint: You will need to use the fact that this interferometer has an FSR of 2 GHz to calculate the linewidth.