PHGN 480 Laser Physics
Lab 4: HeNe resonator mode properties

Due Wednesday, 29 Oct 2015

For this lab, you will explore the properties of the working HeNe laser.

1. **Observation of higher-order modes:**

Realign your HeNe laser, starting with the output coupler close to the end window of the tube. Optimize the power. You next need to set up a CCD camera to observe the profiles of the output beams as the cavity alignment is changed. However you choose to set up your observation, be sure to leave room at the output end so that the output coupler can be brought out to a cavity length equal the radius of curvature of the mirror (assuming you have one flat and one curved mirror in your resonator. Two options for observing the laser mode: You can reflect the output beam off a surface to reduce the beam intensity, then direct the beam onto your CCD camera with a neutral density filter, but without the lens. Or you can put the beam onto a card, and use the CCD with its lens to make an image of the card on the camera. In either case, if the beam is small, you can use a negative lens to expand the beam.

a. For the initial cavity length (OC near the tube window, but with enough gap to allow insertion of an iris), record a picture of the output beam when the laser power is optimized. Comment on the azimuthal symmetry of the beam profile, and whether the beam seems to be an ideal Gaussian.

b. When the OC is misaligned, you should be able to see a higher-order or multimode (non-Gaussian) structure on the beam. Record some images of interesting mode shapes. A rectangular pattern of lobes indicates a Hermite-Gaussian mode, and typically indicates that there is something that is breaking the circular symmetry. A radial pattern (doughnut, ring shapes) correspond to Laguerre-Gaussian modes. You will see better modes later when you extend the cavity length, but see what you can find at this cavity length.

c. Place an iris near the Brewster window. Gradually closing the iris, align its transverse position so that it is perfectly centered on the laser beam. Show that you can use the partially-closed iris to discriminate against the higher-order spatial modes and force laser operation only on the Gaussian (TEM00) mode.

d. As you had done previously when you measured the output power vs cavity length, gradually move the OC back towards the hemispherical point (cavity length just less than the radius of curvature). Repeat the inspection of the modes with the mirror centered and slightly detuned. For a later test, you will want to be able to operate the laser in a multimode regime – ask the professor or a TA to verify that you can reach this condition.

2. Longitudinal mode measurements using the scanning Fabry-Perot:

For one of your cavity lengths (preferably on the long side of the range), collimate the output beam to approximately 4mm in diameter. For most of the devices, you will direct the collimated beam into the Fabry-Perot. For the Thorlabs device, you will use a 250mm focal length lens and direct the output beam into the scanning Fabry-Perot interferometer. Align the beam and the interferometer according to the instructions for the device.

a. Using the sawtooth driving waveform for the Fabry-Perot and the lowest sweep speed, you should see a pattern of spikes that repeats itself. The period of this pattern in frequency space is called the free spectral range (this varies with the device, it is 1.5GHz for the Thorlabs device). Measure the corresponding time on the scope to calibrate sweep time to MHz/division. Zoom in on one of the lines and measure the FWHM of a single peak. You may need to optimize the alignment to make sure the line is as narrow as the specification (Finesse is approximately 200, so it should be about 7.5MHz wide).

b. Measure the cavity length and calculate a prediction for the mode spacing in MHz ($\Delta\nu = c/2L$). Record the longitudinal mode spectrum for your laser, using the internal iris to ensure the laser is operating in a single transverse mode. Compare the measured mode spacing for your laser to your prediction.

c. Open the internal iris to allow the laser to operate with multiple transverse modes. The higher transverse modes have a slightly longer round trip time and therefore different mode spacing. See if you can observe new frequency components or at least a broadening in the longitudinal mode spectrum. Record an image of this lineshape.

d. Go back to TEM00 operation. Based on the envelope around the longitudinal modes, estimate the full width at half maximum for the gain of the lasing transition. The standard value given is 1.5GHz, which is the range of the scanning Fabry-Perot.

e. A window with parallel sides can be used to make a sub-cavity inside the laser that can be optimized to preferentially pass one of the longitudinal modes. The window acts like a Fabry-Perot interferometer of low finesse; used in this way the window is called an etalon. Mount an optical flat into a mirror mount and place it into the laser cavity near normal incidence. Restore lasing (this may require slight angle tuning of the window). Observe the longitudinal mode spectrum. angle-tune it to select one of the longitudinal modes. The mode spacing for the etalon is $\Delta\nu = c/2Ln\cos\theta$, where n is the refractive index of the window material (approximately 1.5), and θ is the internal angle of the ray inside the etalon. See if you can angle tune the etalon across two neighboring longitudinal modes. Estimate the angle over which you adjust the etalon and compare to what you would predict from the mode spacing calculation.

<u>3. Electronic detection of longitudinal modes:</u>

Suppose the laser is running with two longitudinal modes, then in the time domain, there should be a beat frequency at the difference between the two optical frequencies. A fast photodiode can observe this beat.

a. Align your laser for single transverse mode operation, and put the output onto the photodiode. Make sure the signal is not saturated – aim for about 100mV of signal, DC coupled. Switch to AC coupling, zoom in on the vertical scale, and see if you can detect fast noise on the output. Make a representative image of the trace.
b. Put the scope into FFT mode, where it will act like a spectrum analyzer. When the laser is operating with two or several longitudinal modes, you should see at least a spike at the longitudinal mode separation. You may also notice harmonics as well. Measure this frequency, and compare it to your calculated value (c/2L).
c. Try aligning for multimode operation and see if more peaks show up. The higher-order modes have a longitudinal mode separation that is affected by the mode index. Bonus points if you can identify different mode combinations from the measured frequencies.

Resources:
There is a huge amount of practical information on the website Sam's Laser FAQ:
http://www.repairfaq.org/sam/laserhen.htm#hentoo1