⑥ Oscillating modes and stability of HeNe laser

A label on the polarized laser will indicate the plane or orientation of polarization of the output beam. For a random polarized He-Ne laser, a polarizer oriented at 45 degrees with respect to the plane of polarization would produce an output with respect to mode sweep that is similar to that of a linearly polarized laser, except that even with an ideal polarizer, the output power would be cut in half.

Now for some actual numbers: The Doppler-broadened gain curve for neon in a red (632.8 nm) He-Ne laser has a Full Width Half Maximum (FWHM, where the gain is at least half the peak value) on the order of 1.5 or 1.6 GHz. So, for a 500 mm long (high gain) tube with its mode spacing of about 300 MHz (similar to what is depicted above), 5 or 6 lines may be active simultaneously and oscillation will always be sustained (though there would be some variation in output power as various modes sweep by and compete for attention). However, for a little 10 cm tube, the mode spacing is about 1,500 MHz. If this laser were to be really unlucky (i.e., the distance between mirrors was exactly wrong) the cavity resonance might not fall in a portion of the gain curve with enough gain to even lase at all! Or, as the tube heats up and expands, the laser would go on and off. There are very few commercial He-Ne laser tubes that short. It is possible to widen the gain curve somewhat by using a mixture of neon isotopes (Ne20 and Ne22) rather than a single one since the location of their peak gain differ slightly. This would allow a smaller cavity to lase reliably and/or reduce amplitude variations from mode sweeping in all size He-Ne lasers. The actual lasing threshold will also determine the effective width of the neon gain curve over which lasing occurs, so it may be wider than the FWHM.

A high speed silicon photodiode and oscilloscope or RF spectrum analyzer can be used to view the frequencies associated with the longitudinal modes of a He-Ne laser. The clearest demonstration would be using a short tube where at most two longitudinal modes are active. This will result in a single difference frequency when both modes are lasing. A polarized tube is best as it forces both modes to have the same polarization as a photodiode will not detect the difference frequencies for orthogonally polarized modes. Adjacent longitudinal modes of random polarized tubes are almost always orthogonally polarized (for a 633 nm He-Ne at least). But, adding a polarizer at 45 degrees to the polarization axes can compensate for this with a slight loss in signal strength. Without a polarizer, the beat frequencies of a random polarized laser will tend to be at multiples of twice the mode spacing since only those modes with the same polarization orientation beat with each-other in the photodiode. (If measured very accurately, it will be seen that these frequencies will not generally be exactly at multiples of the mode spacing based on c/2L and will vary slightly during mode sweep. The is due to mode pulling or pushing effects, reserved for the advanced course!)

Passive stabilization (using a structure made of a combination of materials with a very low or net zero coefficient of thermal expansion or a temperature regulator) or active stabilization (using optical feedback and piezo or magnetic actuators to move the mirrors, or a heating element to control the length of the entire structure) can compensate for these effects. However, the added expense is only justified for high performance lab quality lasers or industrial applications like interferometric based precision measurement systems – you won't find these enhancements on the common cheap He-Ne tubes found in barcode scanners.

Thus, a typical HeNe laser is not monochromatic though the effective spectral line width is very narrow compared to common light sources. Additional effort is needed to produce a truly monochromatic source operating in a single longitudinal mode. One way to do this is to introduce another adjustable resonator called an etalon into the beam path inside the cavity. A typical etalon consists of a clear optical plate with parallel surfaces. Partial reflections from its two surfaces make it act as a weak Fabry-Perot resonator with a set of modes of its own. Then, only modes which have the same optical frequency in both resonators will produce enough gain to sustain laser output.

The longitudinal mode structure of an optional intra-cavity etalon might look like the following (not to scale):

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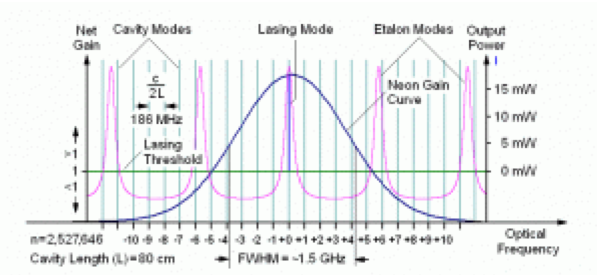
            |           632.8 nm
           I|    .        .        .
            |    |        |        |
            |    |        |        |
            |    |        |        |
```


```
             |             632.8 nm
             I|     .          .          .
             |     |          |          |
             |     |          |          |
             |     |          |          |
        _______|______|______________|______________|_______
          m=13,542   -1          +0          +1
```


Notice that since the distance between the two surfaces of the etalon is much less than the distance between the main mirrors, the peaks are much further apart (even more so than shown). (The etalon's index of refraction also gets involved here but that is just a detail.) By adjusting the angle of the etalon, its peaks will shift left or right (since the effective distance between its two surfaces changes) so that one spectral line can be selected to be coincident with a peak in the main gain function. This will result in single mode operation. The side peaks of the etalon (-1, +1 and beyond) will may coincide with weak peaks in the main gain function shown above but their combined amplitude (product) is insufficient to contribute to laser output.



Intracavity Etalon for Line Selection in a Single Mode HeNe Laser

Intracavity Etalon for Line Selection in a Single Mode He-Ne Laser

This example is based on the same 30 mW laser as in the diagram in the section: Longitudinal Modes of Operation. Adding an etalon inside the cavity introduces an additional loss function with peaks every GHz or so. (Note that such an etalon would be about 15 cm long, so the plasma tube for this laser needs to be short enough to allow for that much space between it and one of the mirrors, but that's just a detail!) Only where the product of the original net (round trip) gain and the etalon transmission is above one will the laser lase. For this example, there is only place where a cavity mode and etalon mode coincide – just to the left of centre of the neon gain curve peak. And, now that there is only a single mode oscillating, it will have an output power of over 15 mW, rather than the ~3 mW or less in each of several multiple modes. There is always some loss in adding an etalon, so the full 30+ mW originally present isn't usually possible, though the ~50 percent reduction in output power shown here may be excessive.

(From: Prof Harvey Rutt (h.rutt@ecs.soton.ac.uk).)

The standard, small He-Ne laser normally lases on only one transition, the well known red line at about 632.8 nm. The He-Ne gain curve is inhomogeneously Doppler-broadened with a gain bandwidth of around 1.5 GHz (at

632.8 nm). (The width of the Doppler-broadened gain curve depends on the lasing wavelength. At 3,391 nm, it is only about 310 MHz.) For a typical laser, say 30 cm long, the axial modes are separated by about 500 MHz. Typically, two or three axial modes are above threshold, in fact as the laser length drifts you typically get two modes (placed symmetrically about line centre) or three modes (one near centre, one either side) cyclically, and a slow periodic power drift results. Shorter lasers, less modes, more power variation unless stabilized. But it needs a huge He-Ne laser to get ten modes, and since they are closer of course they still only spread over the 1.5 GHz line width.

Most He-Ne lasers which do not contain a Brewster window or internal Brewster plate are randomly polarized; adjacent modes tend to be of alternating orthogonal polarizations. (Note that this is not necessarily true for He-Ne lasers operating at wavelengths other than 632.8 nm and/or can be overridden with a transverse magnetic field, see below.

Some frequency stabilized HeNe lasers are NOT single mode, but have two, and the stabilization acts to keep them symmetrical about line centre – i.e., both are half a mode spacing off line centre. A polariser will then split off one of them or a polarizing beamsplitter will separate the two.

(From: Sam.)

The party line is that adjacent modes in a He-Ne laser will be of orthogonal polarization. However, I've seen samples of small (e.g., 5 or 6 inch) random polarized tubes only supporting 2 active modes where this is not the case – they output a polarized beam that remains stable with warmup and in any case, applying a strong transverse magnetic field will override the natural polarization. So, it's not a strong effect. Only if everything inside the tube is reasonably symmetric, will the modes alternate. Modes may also remain one polarization as they move through part of the gain curve and then abruptly – and repeatably – flip polarization. But the majority of tubes are well behaved in this regard.