7: Resonator Length and Mode Hopping

Here are some additional comments that address the common fear of the novice laser enthusiast that the resonator length has to be stabilized to the nm or else the laser will blink off.

(Portions from: Steve Roberts.)

Flames expected, as I'm ignoring some of the physics and am trying to explain some of this based on what I observe, aligning and adjusting cavities on HeNe and argon ion lasers as part of repairing them. Anyone who only goes by the textbooks has missed out on the fun, obviously having never had to work on an external mirror resonator. It can be quite a education!

Due to the complex number of possible paths down the typical gain medium, you will see lasing as long as the mirrors are reasonably aligned. The cavity spacing is not always that critical and will change anyway as the mirror mounts are adjusted (there will always be some unavoidable translation even if only the angle is supposed to be changed). No, lasers don't really flash on and off in interferometric nulls as you translate the mirrors - they instead change lasing modes. They will find another workable path. You will in some cases see this as a change in intensity but it is more properly observed on a optical spectrum analyzer as a change in mode beating. Eventually you can translate them far apart enough that lasing ceases, but this is a function of your optics not the resonator expansion.

I have seen what you fear in some cases by adding a third mirror to a two mirror cavity with a low gain medium such as HeNe where the third mirror can be positioned in such a way to kill many possible modes. This usually occurs when I use a HeNe laser to align an argon laser's mirrors and the HeNe laser will flicker from back reflections. See the section: External Mirror Laser Cleaning and Alignment Techniques. But unless you have a extremely unstable resonator design, translation will just cause mode hopping, this becomes important on a frequency stabilized or mode locked laser if you have a precision lab application. Otherwise, most commercial lasers are not length stabilized in the least. There are equations and techniques for determining if you have a stable optical design - stable in this case meaning it will support lasing over a broad range of transverse and longitudinal modes. For examples see any text by A. E. Siegman or Koechner. If your library doesn't have any similar texts, find a book on microwave waveguides. It might aid you in visualizing what is going on.

Either an intracavity etalon or active stabilization systems are usually used on single frequency systems anyways, by either translating the mirror on piezos or by pulling on mirror supports with small electromagnets, or in the case of smaller units, heaters to change the cavity length on internal mirror tubes. An etalon is basically a precision flat glass plate in the lasing path between the mirrors, its length is changed by a oven and it acts as a mode filter.

Length stabilization to the 50 or 100 nm you might have expected to be needed would be gross overkill anyhow, and would be impossible to achieve in practice by stabilizing the resonator alone. Depending on the end use of the product, most lasers are simply built with a low expansion resonator of graphite composite or Invar, although in many products a simple aluminum block or L shape is used, a few rare cases use rods made of two different materials designed to compensate by one short high expansion rod moving the mirror mount in opposition to the main expansion. A small fraction of a millimeter is a more reasonable specification.

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

The basic idea, that the laser can only work at the frequencies where an integral number of half waves fit in the cavity, is perfectly correct. The separation between adjacent modes is just 1/(2*L) where L is the cavity length in cm. From this we get the separation in 'wavenumbers'. One wavenumber is 30 GHz, so in more usual units it is just 30 GHz/(2*L). Or, to make it easy, in a 50 cm long laser the modes are 300 MHz apart. That is not very far optically.

The laser operates by some molecule, gas, ion in a crystal, etc. making a transition between two levels. But those levels are not perfectly 'sharp'; we say they are 'broadened'. The reason can be many things:

- In a gas - Doppler (or temperature) broadening. The molecules move about randomly, and the light is Doppler shifted a random amount.
- Collision (pressure) broadening. Collisions either relax or dephase the state - i.e., 'mess it up' and broaden it!
- In a solid various things can happen, but for example in a glass different laser ions are in slightly different positions, and this causes them to have slightly different energies.

In any case no transition is *perfectly* sharp, the fact that it has a finite lifetime gives it a certain width, but this is not often the real limit, something else is usually more important.

These broadening mechanisms 'blur out' the line - we see optical gain over that *range* of frequencies, the gain bandwidth.

An example is carbon dioxide. The 'natural width' is very small, of order Hz. The Doppler width at 300 °K is about 70 MHz. The collision-broadened width increases about 7 MHz/Torr; so well below 10 Torr the width is Doppler-limited, ~70 MHz; above 10 Torr pressure broadened (e.g. ~700 MHz at 100 Torr).

If I take a typical HeNe laser it might 'blur' out over a GHz or so - **more** than that 300 MHz mode spacing - so there are *always* two or thee modes within the 'gain bandwidth' and it will always lase. For a glass laser there might be *thousands* of modes, because the glass gain is very wide indeed.

But there *are* cases that go the other way. For carbon dioxide, at low pressure, the line is Doppler-broadened and about 70 MHz wide, much **LESS** than that 300 MHz mode spacing. So short carbon dioxide lasers really do turn on and off as the cavity length changes, and you have to 'tune' the cavity length to get a mode inside the gain width. This mainly happens with short, gas lasers in the infrared.

For a *high pressure* CO2 laser at 760 Torr (1 atm), the line width is several GHz, much more than the mode spacing, so the effect disappears.