21: Mode Competition in Short HeNe Lasers

If you haven't been wondering why some of the output power plots are so strange, you should be. :)

The primary reason that the output power in any give longitudinal mode doesn't vary in a nice smooth (Gaussian) manner is due to mode competition. If not for mode competition, the gain would not saturate and be the same for all modes. Everyone would thus trace out the envelope of the neon gain curve. However, since the lasing modes are actually competing for a limited resource – the atoms in the upper lasing state – whenever there are more than one mode present, they have to be nice and share. This is most dramatic when only 2 or 3 modes are present since each one has a large fraction of the total output power. With those, the shapes of the envelopes of the polarized output power curves can be decidedly non-Gaussian. And for Zeeman-split lasers, downright weird. But once the various regions are understood – where there are 1, 2, 3, or more modes competing – then the resulting shapes make more sense:

1 mode: The output power will change smoothly during mode sweep roughly following the profile of the Gaussian neon gain curve (minus the lasing threshold). The only way a real laser could be single mode throughout mode sweep would be either for the cavity to be around 10 cm or less (in which case lasing may cease entirely for a part of mode sweep) or for there to be an additional means of forcing SLM operation (such as an etalon inside the cavity). But slightly longer tubes will operate with a Single mode over a portion of mode sweep with 2 modes for the remainder.

Plot of Mode Sweep of Typical 1 mW Random Polarized HeNe Laser Tube shows the appearance for a Melles Griot 05-LHR-007, the shortest modern laser tube I'm aware of. Over approximately 50 percent of the mode sweep cycle, it is pure single mode with power sharing during the remainder.

2 modes: When a second mode appears, it will start eating into the power of the first mode. Where the modes are balanced on either side of the neon gain curve, their power will be equal. Between these 2 points, they will share power. The total output power may remain relatively constant or increase slightly when equal (usually up to around 20 percent). Tubes with a cavity length of 12 to 16 cm will operate with 1 or 2 modes.

3 modes: When a third mode appears, it will start eating into the power of the other two. The relative and total power will depend on their location on the neon gain curve and is at the very least, not intuitively predictable. :) Tubes with a cavity length of 20 to 25 cm will operate with 2 or 3 modes during mode sweep.

Plot of Mode Sweep of Typical 3 mW Random Polarized HeNe Laser Tube shows the appearance for a Spectra-Physics 088 (same as the Melles Griot 05-LHR-088) used in the SP-117/A/B/C and Melles Griot 05-STP-901 stabilized lasers. It is similar a common barcode scanner tube. At the peaks of the polarized modes (minimum for total power), there are 2 modes. Where the polarized modes cross, there are 3 modes. The overall shape of the mode sweep depends on many factors including the exact length of the cavity which determines where it switches from 2 to 3 modes.

4 or more modes: The same general rules apply, but since the contribution of each mode is smaller, the effects of mode competition are also smaller and more difficult to see and interpret.