October 09, 2010

Red fiber laser (2)

Continue work I started yesterday. Spectral measurements and wavelength variation as a function of temperature. In particular, to avoid instrument limitations, I will begin by calibrating against the linewidths of the various lasers in lab.

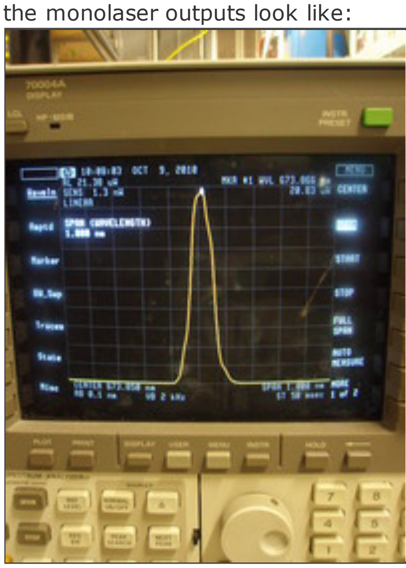
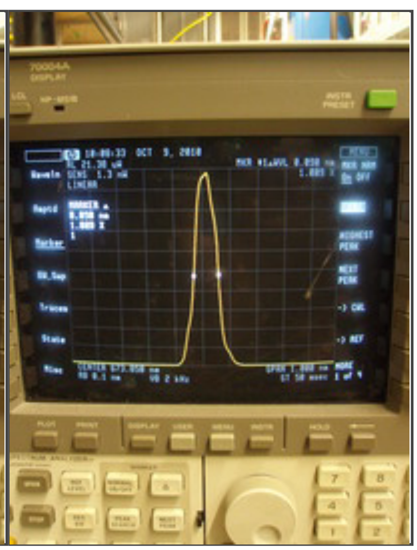
References:
-- Jarek's thesis, Chapter 4.
-- Diode (HL6714G) datasheet
-- Thorlabs pigtailed fiber (LPS-675-FC) datasheet

Aside:
-- I just realized that the degree signs seems to have some encoding problem. Sorry. (German keyboard has a degree sign as one of its main keys.)

I am suspicious that the HP70951A (large optical spectrum analyzer on cart) does not have the resolution to tell me what is going on. I will test this out two different ways.
1) I am going to use the small "AvaBench" spectrometer simultaneously,
2) I am going to test the various other lasers in lab for their linewidth.

Hmm. Two snafus with the first approach (1) of the second spectrometer.
1) The fiber input port is SMA, whereas I'm generally working with FC type connectors. So I have to prepare a hybrid SMA-FC fiber to make this work, but...
2) It's clearly lower resolution than the HP70951A, so the second analyzer of no real use to me. So, I won't bother with this spectrum analyzer. Actually, the manual states 1.2nm resolution, which is certainly not good enough.

Let me move on to trying to observe the ule-locked 674 linewidth with the HP analyzer. If things work the way they are advertised, then the ule-locked analyzer should have a linewidth that is much narrower than whatever the spectrum analyzer's resolution. So this ought to reveal the instrumentation limit. Yep, definite limitations by instrument. Here's how the monolaser outputs look like:



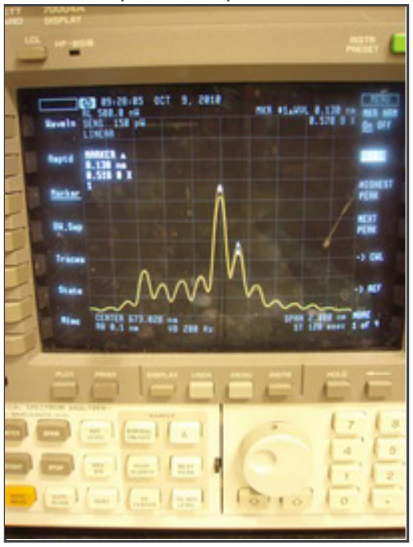
I find:
-- Center wavelength 673.85nm, c.f. 673.83955 by WS7(air wavelength)
-- FWHM of 0.1nm.
The FWHM resolution of ~0.1nm is to be compared with 0.08nm resolution advertised in the HP70951A datasheet. In the vicinity of 674nm, a FWHM in wavelength of 0.1nm implies frequency resolution of about ~60GHz... Oof! The fractional resolution of 0.1/674=1.5e-4 is commendable I suppose, but nowhere near the requisite resolution for atomic applications!

(The formula dl/l = df/f is very handy! For l=674nm, f=444.8THz.)

Hm. There goes my plan of familiarizing myself with linewidths of various things in lab. The typical linewidths are way below the resolution of such standard test equipment... A linewidth of 1MHz in the frequency domain seems like a large number... but considered as fractional accuracy, it implies ~10fm level of accuracy in wavelength! Wow! This is the need for FPs with large length (small FSR) and high finesse.

So, let me give up for the time being on trying to analyze the spectrum of the fiber laser and whatnot. Instead, I will investigate how the output wavelength varies as a function of temperature. According to the Wieman paper, over a range of 25Â°C~35Â°C, of a ~810nm diode, they observe about 3nm in wavelength shift and several mode hopping events. Let me see if I'm so "lucky".

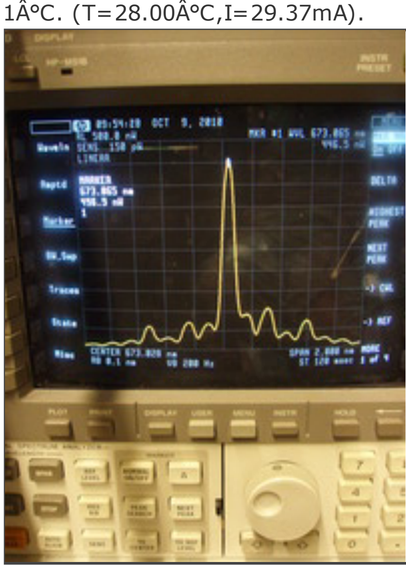
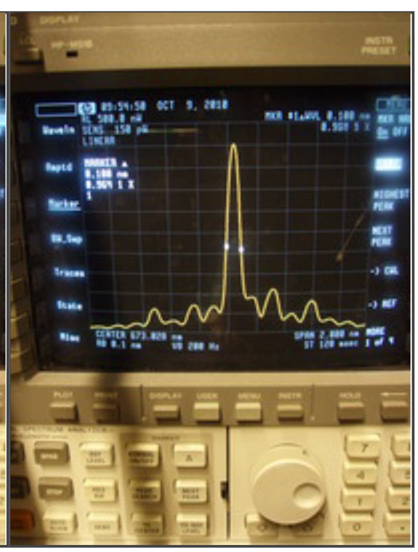
Aha, while doing this measurement, I noted the following. As remarked yesterday, I find that the diode has intensity fringes that are separated by ~0.1nm. Here's a current photograph of the spectrum:



Now, crunching the numbers on 0.13nm ("crunching the numbers" means dl/l = df/f) I find that the spacing in frequency is 87GHz. This is exactly in the order of the expected FSR from the diode cavity as given by Jarek's thesis. So, the fringes that I am observing are very likely to be the different longitudinal modes of the diode cavity, and the laser is emitting in all these longitudinal modes. The shape (i.e. the "amplitude modulation") of the various fringes then gives some indication of the laser gain curve as a function of wavelength. In fact, in tuning from 25Â°C-->27Â°C, I saw one fringe being favored for another fringe. So, I think that's the phenomenon of mode hopping. Hooray!

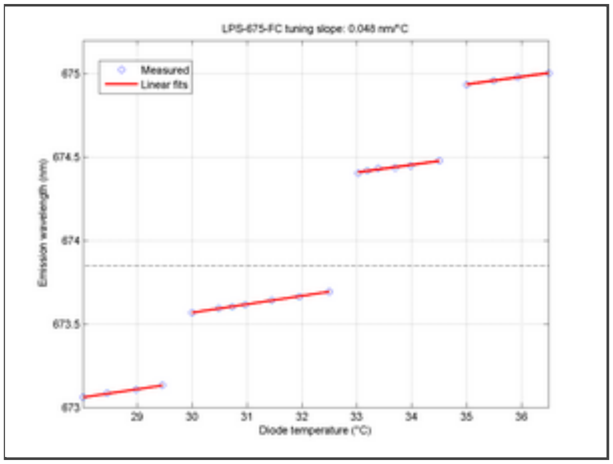
[The numbers used by Jarek for a "typical" diode are L~1mm, n~3 yielding FSR = c/(2*n*L) = 50GHz.]

Sometimes, the preference for a specific diode cavity longitudinal mode seems to be better. Compared to the fringe spectrum already shown above, I now have the following spectrum (same y-scale), where I increased the temperature by 1Â°C. (T=28.00Â°C,I=29.37mA).

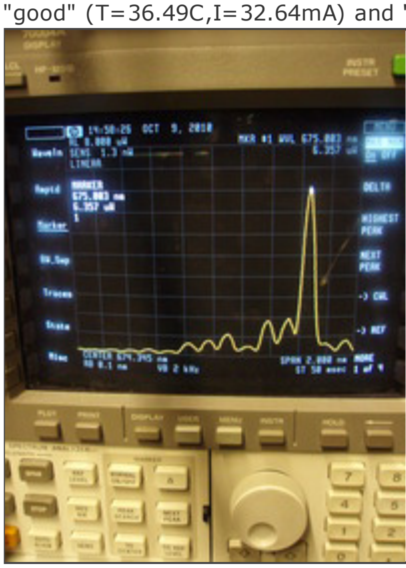
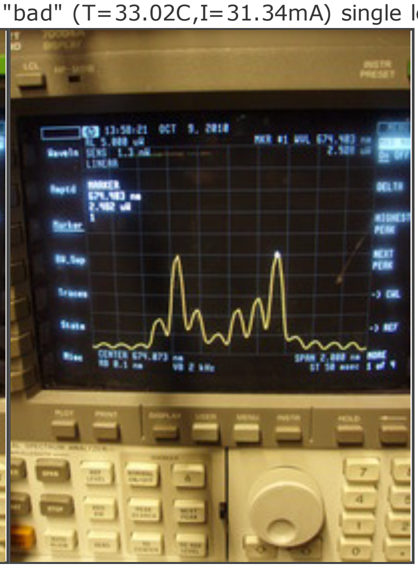



For this measurement, I also show the FWHM of the line of ~0.1nm, although this is an instrument limit.

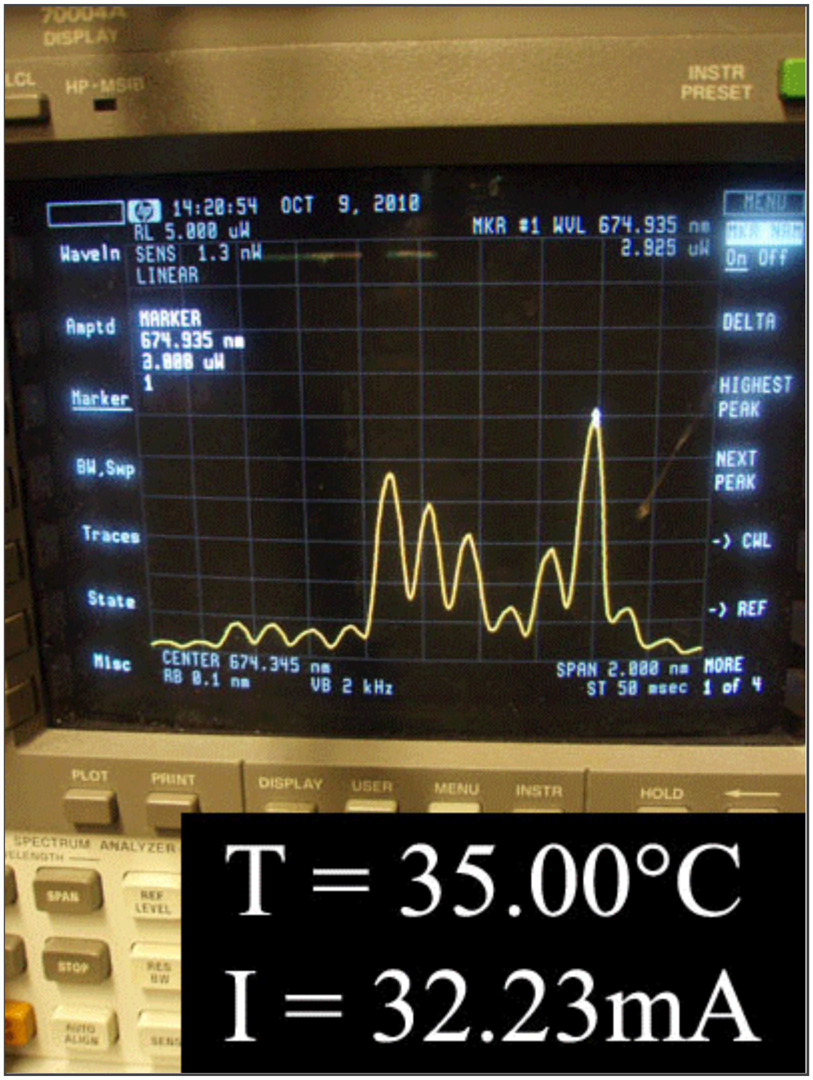
With this knowledge. I tabulate the wavelength variation as a function of temperature. This measurement took long because the camera battery is running low and I have to recharge it... Here's the result:



Remarks:
1) The wavelength dependence when the laser does not hop is about 0.05nm/C, which differs from Ike's coarser measurement of the dependence (0.12nm/C). However, the former is consistent with the Wieman review, stating "... in the AlGaAs devices the optical length of the cavity changes about +0.06nm/K".
2) I note the monolaser 674nm wavelength (as measured by HP70951A) with a dashed black line. Unfortunately, in this measurement, it appears that the needed wavelength lies within the tuning gap. The Vainio paper on injection locking seems to suggest that there is a "locking range" for injection locking of the slave, and it seems to be on the order of a ~1GHz, which translates to ~0.001nm. So, there is no point in the measured curve that is sufficiently close it seems.
3) Near modehopping events, the spectrum definitely seems to be lasing in many modes. Below, I show what I saw as "good" (T=36.49C,I=32.64mA) and "bad" (T=33.02C,I=31.34mA) single longitudinal mode spectra:

And here's a movie of the entire process, showing mode competition at particular diode temperatures. (Sometimes I move the x-axis.)

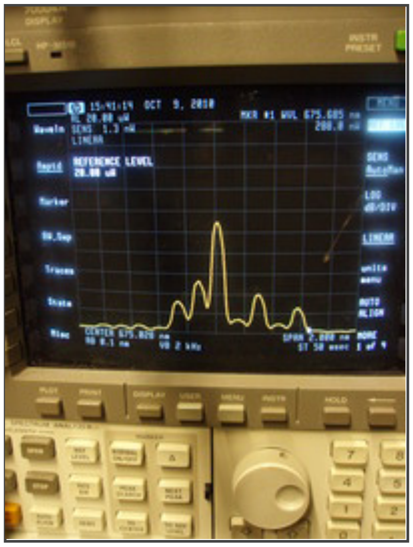


So, while there are definitely qualitative periods of "multimode" and "single mode" (longitudinal) operation, I am not impressed with the degree of selection of a single mode. I found an interesting passage from the Wieman review: "We might mention a few caveats about nominally single-mode lasers. First, they are not absolutely single mode in that there are small but readily observable amounts of power in numerous other modes that can occasionally be a problem. Second, a laser that has been sold as a single-mode laser will often not run in a single mode for all injection currents. The lasers will always be multimode for very low injection currents, but even at much higher currents there are often ranges of current and temperature where the laser will continue to operate in several modes."

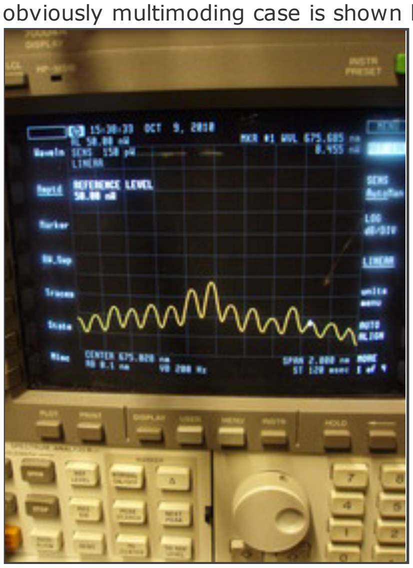
Interesting. Maybe my current is too low? However I currently have 660uW out of the fiber (550 after isolator; i.e. 83% transmission) of a nominally 2.5mW output laser (after pigtail fiber; the diode itself seems to be rated to 10mW). In my logs I've been recording both the temperature and current, and I've been using generally 30~33mA (more current going up in temp).

Let me investigate the spectrum change as I go up in diode current. I pushed up the current to 37.96mA, where the optical power after isolator is 1.50mW. This surely can't be "very low injection currents". I also don't know if the location of the tuning gaps can be modified by operating at a different diode current. So, there's a second motivation for changing the operating current.

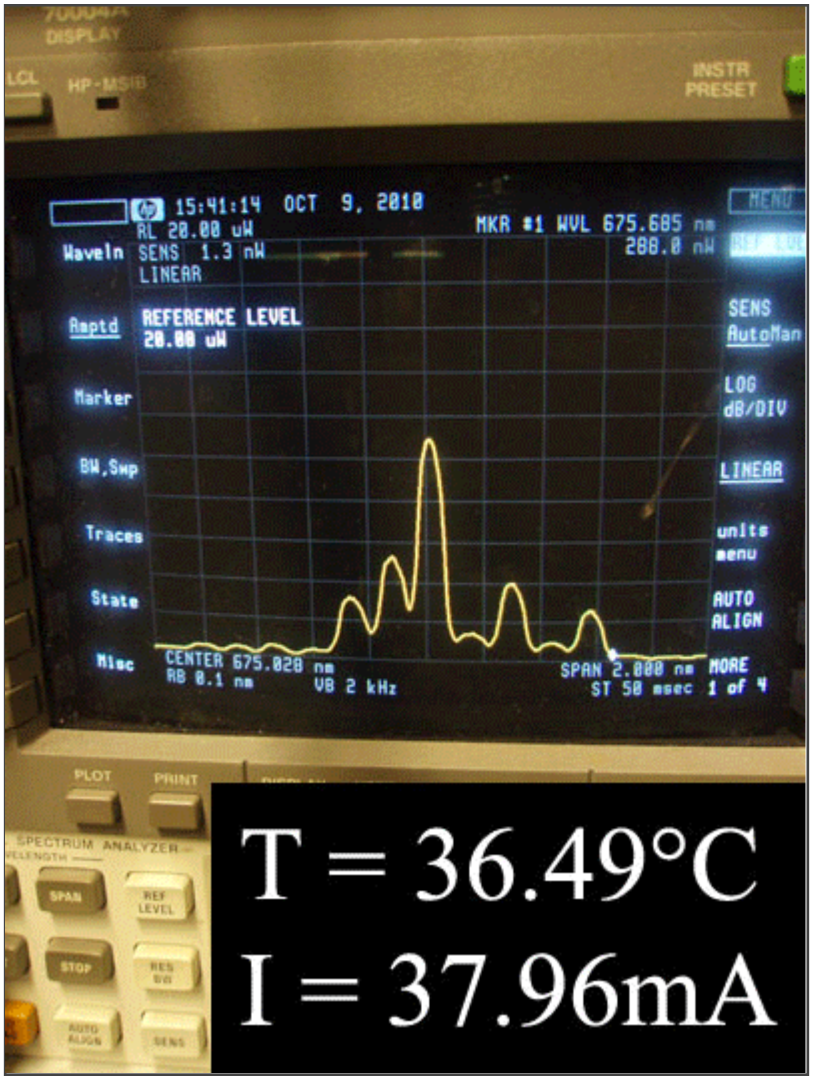
Welp. Increasing the diode power to 1.5mW doesn't necessarily do wonders for the "single-modedness" of the spectrum:



I tried to see if I could see the "very low current" multimode limit referred to by Wieman. I find that, to see such an effect, I have to go to a much, much lower current of 29.06mA, which corresponds to ~24uW after the isolator. Spectrum of this, obviously multimoding case is shown here:



And a movie again:



I will continue tomorrow with temp tuning behavior of the diode at 1.5mW output (after oi).

Posted by kimt at October 9, 2010 10:03 AM

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