PHYS 599 (Interim Report): stabilization of a Tunable Diode Laser

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Background The potential applications of color centers has become an important area of interest for researchers in photonics. In particular, single photon sources and quantum memories based on emitters such as Nitrogen Vacancy (NV) Silicon Vacancy centers in solid state platforms have the potential to be implemented more easily compared to other isolated quantum systems such as trapped ions. One method used to study the properties of the color centers is by photo luminescence excitation spectroscopy (PLE)[1], where a tunable diode laser is used to scan over the zero-phonon lines (direct transitions) while monitoring the phonon side band fluorescence. Once a line is selected, the line is monitored by setting the laser to a constant wavelength corresponding to the wavelength of the direct transition line. One of the problems we face in doing so is the stability of the scanning laser. The bandwidth of a zero phonon line depends on multiple factors including, the lifetime of the excited state of the color center, and spectral diffusion [2]. However for a high quality NV center, we expect linewidths of approximately 100 MHz [3]. However, the instability of the scanning lasers could be problematic if we are trying to monitor the zero phonon line by keeping a the wavelength of the laser constant with the corresponding wavelength of the line. The goal of the project is to stabilize the output from a tunable diode laser which will be used for performing spectroscopy on the resonances of NV/SiV vacancy centers in diamond at low temperature.

Set-up The external cavity tunable diode lasers functions by diffracting a beam of light from a laser diode source, splitting the beam into a spectrum of light with different wavelengths as shown in Fig 1. Recall that the angle at which light diffracts is dependent on the wavelength of the light. The appropriate wavelength of light is then selected by positioning an adjustable mirror at the correct angle with a DC motor and a piezo transducer. The adjustable mirror and the reflective coating on the laser diode acts as a cavity in which light resonates and gains intensity before escaping from the cavity.

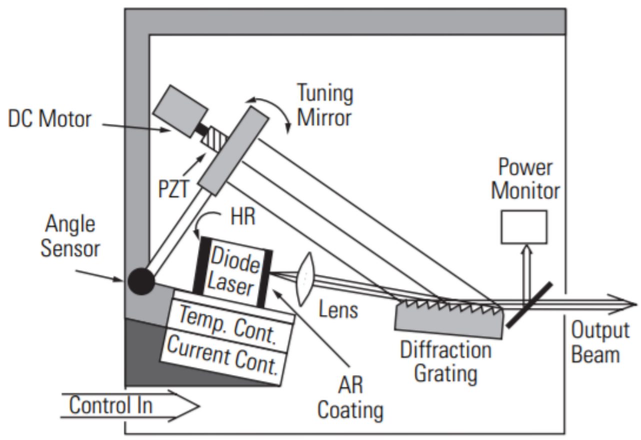

FIG. 1: User's guide: The Velocity Tunable Diode Laser, Model 6300-LN. Irvine: Newport Corperation [1969]

The laser used for scanning is a 6300 model, Newport velocity laser and it functions similarly as mentioned and the wavelength of its output is monitored with a wavemeter. The laser Scans from 632.5 nm to 637 nm. The long-term plan is to use this laser for low temperature spectroscopy of NV/SiV centers in diamond. As mentioned, the lasers used in most research is not stable enough for use. The wavelength of the laser tends to drift over long periods of time due to changes in temperature and current in the laser. Shorter fluctuations in the output wavelength also occur due to factors such as sudden changes in current and temperature.

Progress The focus of the project is primarily on developing software to stabilize the laser's output. So far, there are MATLAB scripts written by other members that prevents the output of the laser from drifting from its intended wavelength. The stabilization process works by reading in the current wavelength of the laser from the wavemeter and determines whether the output has drifted. The script then adjusts the wavelength of the laser by adjusting the applied voltage of the piezo transducer to slightly re-position the mirror in the laser module.

In table I, the target wavelength of light used was 636.17101 nm, and the target wavelength was 636.10815 nm in the stabilized test as shown in Table II. Table I and Table II compares the difference between the stabilized output and the normal output from the laser without any stabilization. The drift from the desired wavelength is apparent in Table I with an accumulated drift of 0.00214 nm over the course of the test without any stabilization applied to the system. Table II shows the results from the stabilization of the system using the MATLAB script. It works relatively well for long-term stabilization by keeping the wavelength within a range of$\pm 1 \times 10^{-4}$ nm from the desired wavelength. Note that the target wavelengths used for the stabilized and unstabilized tests were slightly different.

We currently characterize the stability of the laser by plotting its output wavelength over a time interval. This

Elapsed Time (s)	Wavelength (nm)
0.010	636.16885
100	636.16920
500	636.16997
1000	636.17038
3700	636.17099

TABLE I: The wavelength of the unstabilized laser over an elapsed time. Target wavelength: 636.17101 nm

Elapsed Time (ms)	Wavelength (nm)
0.010	636.10820
100	636.10820
500	636.10814
1000	636.10812
3500	636.10815

TABLE II: The wavelength of the stabilized laser over an elapsed time. Target Wavelength: 636.10815 nm

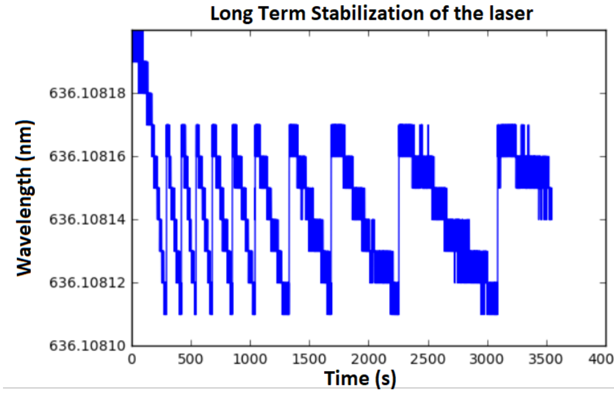

FIG. 2: Continuous plot showing the trend of the wavelength with the long-term stabilization

may not the most efficient way to characterize the stability of the system since some details may not be apparent with this technique. It will be beneficial to develop a new way to characterize the stability of our resulting system. That way, it would be easier to monitor our progress. At the moment, the existing code is being improved. The script can still be adapted so that it is more efficient, user-friendly, and the script can be integrated along with the GUI to allow the user to control the laser's properties such as wavelength of the output and the current through the laser diode.

Plans The short term goals, are to improve the scripts currently available for long term wavelength stabilization of the tunable diode laser. Referring to Fig 2, the existing program should be modified for more precise adjustments to the laser. Additional features can also be added to allow for simpler use. As of now, the code is limited to setting its target wavelength at the value of current wavelength of the laser is set at upon starting the code. The script can be implemented along with the existing GUI so that the stabilization process runs by default after setting a new wavelength by the user.

At the moment, the piezo voltage is incremented by 0.1% of its maximum voltage to make changes in the wavelength, so the process of locking on to the target wavelength could relatively slow depending on how big the difference between the target and the current wavelength is. This is evident in the first 250 seconds in Fig 2 We can adapt the program to increment by different percentages of the piezo's maximum voltage depending on the magnitude of the difference.

The wavelength of the laser also tends to have sudden variations within a shorter range of time. It may be necessary to somehow reduce the smaller fluctuations in wavelength of the laser. Stabilizing the smaller fluctuations is likely going to be software based, although the details of our approach is still unclear.

Challenges The ability to monitor the progress of our work is limited by how we characterize the stability of the system. We currently check the stability of the system by running the software and taking data from the wavemeter simultaneously over a period of time and plotting the output wavelength versus time. This method for checking the stability of the system is not the most efficient way to obtain details. This problem is evident in Fig 2, where the time span of the plot ranges up to $\sim$ 500 seconds to obtain meaningful results. Ideally, a new characterization method would shorten the amount of time needed to run the system. It is also difficult to characterize the short term fluctuations in the wavelength given our current method. This is evident in Fig 2 since it is difficult to observe the behaviour of the plot for shorter time ranges.

Another challenge that may arise is that some of the fluctuations are relatively short in time and it is likely something that we may need to account for. It is still unclear on whether stabilization using only software is quick enough to detect the fluctuations and make the necessary adjustments, so it is difficult to determine what the appropriate solution method is.

The stabilization of a tunable diode laser by software may be challenging when attempting to resolve smaller and quicker fluctuations in the wavelength. The ability for software to react to shifts in a signal and make adjustments is limited. We would most likely find the processing time of the computer to be longer than the time of the fluctuations themselves. The software would likely miss the fluctuations or make the wrong adjustments to the piezo. If a high performing stabilization technique is necessary, we may need to somehow implement other methods for stabilization.

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