Methods to Improve Laser Calibration

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***Abstract*— A highly efficient mid-infrared semiconductor laser has many applications. However, in order to create such a laser and determine its effectivity at a given wavelength, one must insure that the wavelength read out given by the control box is the actual wavelength being emitted by the laser apparatus. This study analyzed manners in how to improve laser calibration between the wavelength read out provided by the control box and the actual wavelength of the laser beam being emitted by the laser apparatus. It is hypothesized that a piecewise curve results in a fit that is more accurate for newly acquired data after the calibration instead of a single fit as was true for the data before the new calibration. The comparison was carried out by obtaining data using a spectrometer and a spectrometer wavelength analysis system. Plots of the control box wavelength vs. the difference in the actual wavelength and the control box wavelength were created for before and after the calibration. These plots were then used to create models to approximate the data obtained, and a program was created to convert the control box wavelength to the actual wavelength and vice versa. The absolute error of the model for the new calibration is worse than the error of the model for the old calibration. However, the new model can be used for a larger range of wavelengths and has no significant error in the regions in which current experiments are running.**

***Index Terms*—laser, mid-infrared, semiconductor laser**

I. Introduction

A laser (Light Amplification by Stimulated Emission of Radiation) requires three parts to amplify light: a gain medium, a population inversion, and two mirrors [1],[2]. The gain medium is a material that can amplify light. One of the mirrors, called the output coupler, emits light. This light becomes amplified by reflecting between the output coupler and the second mirror [2]. Lasers have a monochromatic property, meaning the output light is a single wavelength which enables the beam to be more focused [1]. The light output in a laser can come in either a continuous wave or a pulsed beam. A pulsed beam may yield higher peak powers [2]. Mid-infrared lasers have important applications in chemical sensing, gas detection, security/surveillance, and the creation of a disease database [3]. Type II W lasers are named for the shape of their energy bond structure. They possess excellent electron confinement since the electrons cannot jump over barriers and do not tunnel. In type II W lasers, there is a strong wave function overlap so the transition between bands is more likely to occur [4].

The pump laser used in the lab to study mid-infrared semiconductor lasers can be set to produce light across a range of wavelengths, from the visible out beyond two micrometers. However, the calibration of the optical parametric oscillator used to generate these wavelengths may not always be as accurate. The wavelength of light produced by a laser can also be determined using a spectrometer. By determining the difference between the wavelength indicated by the controller and the wavelength determined by the spectrometer, the error can be determined and a program can be written to correct for the difference in the control box's wavelength from the actual wavelength of the beam. In particular, this experiment seeks to find a program that can adjust for the laser beam regions between 1824 nm and 1910 nm.

II. Procedure

A Fourier transform infrared spectrometer (Varian FTS) was used to determine the wavelength of the laser beam output. The output laser beam was analyzed using the program Varian Resolution Pro and AcqirisLive 2.0. The spectrometer was utilized to take a Stepscan Nanosecond TRS. A single scan was taken at a resolution of 8 cm^{-1} at a speed of 10 Hz using a potassium bromide beamsplitter. The input voltage was set at 200 mV/div with a delay of 177.2 microseconds. To begin the experiment, the laser was set to 1675.3 nm. This beam was analyzed by the spectrometer and the spectrum was saved. Then data was taken at intervals of approximately 5 nanometers from 1675.3 nanometers to 2349.4 nanometers on the control box. The intervals are not exactly 5 nm apart since manually the OPO can only be varied by a tenth of a nanometer in the visible range of light (from 400 nm-700 nm). Afterwards, the spectra were imported into Origin 7.5 so that the peaks could be found. This was done by fitting the spectrum using a Gaussian curve. Once the peak was determined, it was saved and labeled as the actual wavelength of the beam being put out by the OPO. A plot of the laser apparatus's beam wavelength versus the difference between the laser's wavelength and the spectrometer's wavelength was created (**Figure 1**). By studying **Figure 1**, it can be seen that there are three regions of interest: a linear region (laser wavelength less than 1824 nm), a bumpy region (laser wavelength greater than 1824 nm but less than 1910 nm), and an "S" shaped region (laser wavelength greater than 1910 nm). When compared to a previous attempt at calibration shown in **Figure 2**, it can be seen that the "bumpy" region from 1824 nm to 1910 nm did not exist in the previous calibration [5]. This variation in the profile resulted from an

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adjustment to the OPO and its controller during a realignment. Thus a new program must adjust for this region so that data may be reported for actual wavelengths rather than those indicated on the control box. The data in **Figure 2** can be

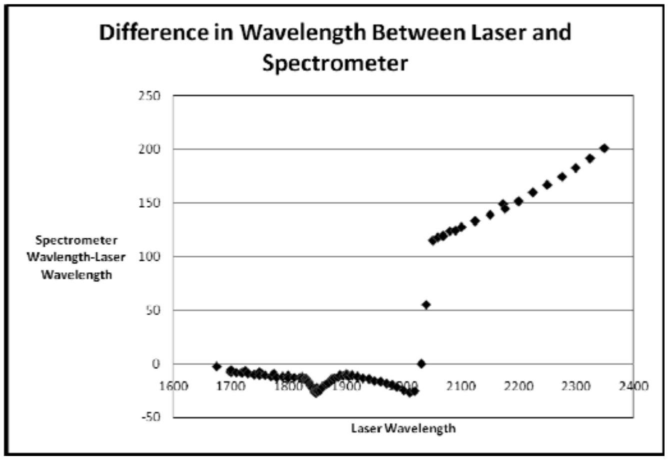

Fig. 1. Difference in wavelength between the laser (control box) and the spectrometer. This data was newly acquired after a recalibration of the laser apparatus.

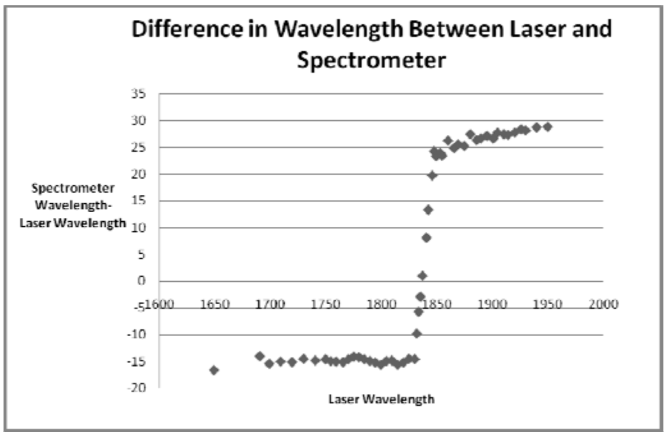

Fig. 2. Difference in wavelength between the laser (control box) and the spectrometer. This data was acquired before a recalibration of the laser apparatus[5].

modeled by **Equation 1** where m_1 and b_1 are the slope and y-intercept, respectively, of the linear region to the left of the jump and m_2 and b_2 are the slope and y-intercept, respectively, of the linear region to the right of the jump [6]. C is merely a constant that results in the best fit and λ is the wavelength at which the center of the step function is located. A hyperbolic tangent was used to accurately mimic the step function behavior.

$$(1)\ \lambda_{spectrometer}-\lambda_{control}=[m_1\lambda_{control}+b_1]\ [H(\lambda-\lambda_{control})]+[m_2\lambda_{control}+b_2][H(\lambda_{control}-\lambda)] \text{ where } H(\lambda_{control}-\lambda)=1/2\{1+\tanh[c(\lambda_{control}-\lambda)]\} \text{ and } m_1=-0.00041,\ m_2=0.04077,\ b_1=-14.30586,\ b_2=-50.47482,\ c=0.13766, \text{ and } \lambda=1838.65995$$

However, **Equation 1** is not an accurate representation of the data shown in **Figure 1**. For **Figure 1**, it was determined that the best method to create a program to model the data was to determine individual equations to fit each of the three regions piecewise. Using Origin 7.5, the data from the laser beam's wavelength for the region less than 1824 versus the difference between the control box's wavelength and the spectrometer's wavelength was plotted and a line of best fit was determined (**Equation 2**). Programs created in LabView control the control box wavelength and converts between the actual wavelength and the wavelength displayed on the control box and vice versa. The existing programs were modified to fit the new data. Since two programs have to be written, one for the conversion from the control box to the spectrometer and one from the spectrometer to the control box, a second plot was made for the spectrometer's wavelength vs. the difference between the control box's wavelength and the spectrometer's wavelength and a line of best fit also determined (**Equation 3**).

$$(2)\ \lambda_{spectrometer}-\lambda_{control}=90.46548-0.05704\lambda_{control}=\Delta$$

$$(3)\ \lambda_{spectrometer}-\lambda_{control}=107.64399-0.0673\lambda_{spectrometer}=\Delta$$

Then the data from the control box's wavelength for the region between 1824 nm and 1910 nm were plotted in Matlab and centered to prevent the program from trying to fit data with polynomials with large exponential powers since these exponential powers cannot be interpreted by the LabView program and create errors. A second plot was created where the x-axis contained the values from the spectrometer. The equations for these plots were as follows:

$$(4)\ \lambda_{spectrometer}-\lambda_{control}=-1.4634z^6+4.279z^5+1.0122z^4-13.026z^3+9.136z^2+9.9315z-23.224=\Delta \text{ where } z=(\lambda_{control}-1857.1)/23.623$$

$$(5)\ \lambda_{spectrometer}-\lambda_{control}=-9.4003z^{10}+54829z^9-93.418z^8-16.915z^7-181.4z^6-100.52z^5-80.139z^4+61.406z^3+10.927z^2-0.87939z-21.265=\Delta \text{ where } z=(\lambda_{control}-1839.1)/26.646$$

Since the third region, the "S" region is similar to the data shown in **Figure 2**, the model equation was kept the same with adjustments to the constants so that the new equation (**Equation 6**) fit the new data when the laser beam wavelength is plotted on the x-axis. This method also works when the spectrometer wavelength is plotted on the x-axis creating **Equation 7**.

$$(6)\ \lambda_{spectrometer}-\lambda_{control}=[m_1\lambda_{control}+b_1][H(\lambda-\lambda_{control})]+[m_2\lambda_{control}+b_2][H(\lambda_{control}-\lambda)]=\Delta \text{ where } H(\lambda_{control}-\lambda)=1/2\{1+\tanh[c(\lambda_{control}-\lambda)]\} \text{ and } m_1=-0.14374,\ m_2=0.26968,\ b_1=264.19082,\ b_2=-438.04348,\ c=0.11854, \text{ and } \lambda=2037.26163$$

$$(7)\ \lambda_{spectrometer}-\lambda_{control}=[m_1\lambda_{spectrometer}+b_1][H(\lambda-\lambda_{spectrometer})]+[m_2\lambda_{spectrometer}+b_2][H(\lambda_{spectrometer}-\lambda)]=\Delta \text{ where } H(\lambda_{spectrometer}-\lambda)=1/2\{1+\tanh[c(\lambda_{spectrometer}-\lambda)]\}$$

and m_1=-0.22043, m_2=0.20754, b_1=408.28824, b_2=-333.00301, c=0.01683, and λ=2063.56 [6]

After the equations for each region were determined, a program was written in LabView using these fits to convert the control box wavelength to the spectrometer wavelength (Program 1) and vice versa (Program 2). **Equation 8** is the basic equation that guides the programs. Each program calculates a delta value using one of Equations 2-7.

$$(8)\ \lambda_{spectrometer}=\lambda_{control}+\Delta$$

In Program 1, the program determines whether the input laser beam wavelength is greater than 1910, if this is true, the program calculates a delta value according to **Equation 6** and adds this value to the input laser beam wavelength to determine the spectrometer wavelength. If the input wavelength is less than 1910, the program determines whether the input is greater than 1824. If this is true, the program calculates a delta value using **Equation 4** and adds this value to the input wavelength to determine the spectrometer wavelength. If the input wavelength is less than 1824, the program calculates a delta value using **Equation 2** and adds this to the input wavelength to obtain a spectrometer wavelength. In Program 2, the program determines whether the input laser beam wavelength is greater than 1895, if this is true, the program calculates a delta value according to **Equation 7** and adds this value to the input laser beam wavelength to determine the spectrometer wavelength. If the input wavelength is less than 1895, the program determines whether the input is greater than 1807. If this is true, the program calculates a delta value using **Equation 5** and adds this value to the input wavelength to determine the spectrometer wavelength. If the input wavelength is less than 1807, the program calculates a delta value using **Equation 3** and adds this to the input wavelength to obtain a spectrometer wavelength.

III. Results

For the initial data obtained, Program 1(control box wavelength converts to spectrometer wavelength) the percent error is less than 0.16. The wavelength is off by about 2 nanometers at 1830.1 nm and 1847.6 nm. In comparison, for the data acquired for the new program, the overall maximum error does not exceed 0.3%. Most regions are much lower than this; however, regions that approach 0.3% are the regions less than 1700.7 nm, 2030 nm-2051 nm, 2176 nm-2200 nm, and around 2349 nm which are out in the tails of the data gathered and not in the primary pump wavelength of interest for current optical pumping experiments in the laboratory.

For Program 2, the initial data has no significant region of large error. Overall the error is less than 0.1%. For the final data obtained, the percent error is less than 0.23%. However, in some locations the wavelength is off by at least 2 nanometers and at 1807 the program is off by 137 nm. This is at the interface between fitting regions so improvements must be made to match the fits across these regions. The fit for the bump works very well (most regions are less than a nanometer off) until the 1970 nm-2178 nm range where the errors go up to 5 nm off from the actual value.

IV. Conclusion

The new programs are an improvement over the old programs since the new programs are able to handle a wider range of wavelengths and are designed to model the latest control box calibration. The new programs account for the dip in the data in the laser wavelength range of 1824 nm to 1910 nm that previously did not occur in the old laser calibration data. However, the absolute error margins were better in the old calibration programs. The error margin of the new programs can be improved by obtaining more data in the regions where the program has a large error margin to determine if the error was a result of the spectrometer reading. Obtaining more data can also fill in regions where there are large margins of no data so that new equations can be more accurately modeled due to additional data points.

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