Methane Detection in the Near Infrared

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The purpose of my research is to help detect methane in agriculture as methane is extremely harmful to the ozone layer. In order to do so, I am working to developing a laser. By using a laser, methane detection will turn into a much more streamlined process. I am using an Extended Cavity Laser Diode (ECLD) specifically due to the high tunability of the laser and the narrow line width associated with the output. While working on this project, I have learned about how lasers work and how to build one. This experience will be useful to me in the future because it has given me practical skills in the field of optics. In addition to learning about hardware, I also learned how to process the data I will receive from the laser. In doing so, I have learned about signal processing and I have learned more about coding. I can easily apply the knowledge of signal processing in the fields of optics and electrical engineering. The experience I have gained in coding will be beneficial in any form of research or engineering I will do in the future.

The ECLD laser design consists of a laser diode that is in a DC circuit with a power source and resistor. The laser diode out puts a narrow band of frequencies. The first laser cavity occurs within the diode housing. This cavity narrows the band of frequencies further and creates a weak laser. This housing consists of a partially reflective window that is placed a distance of one to two millimeters away. This window is adjusted with a spring and threading until it in a distance that optimizes feedback. After the light is output from the housing of the diode, it will travel a distance of about fifteen centimeters. At the end of the path is a diffraction grating. This grating will reflect the laser light at various angles depending on its wavelength. The grating is placed on an adjustable stage such that the preferred wavelength can be reflected back into the diode in order to further narrow the possible frequencies. This is the extended cavity referred to in the name. The grating will also reflect some of the light upward and this light will hit a mirror and be output from the laser system. For small adjustments in the diffraction grating, a PZT is used. The PZT uses the Piezo effect in order expand or contract when a current is running through it. The benefit of high tunability stems from the ease of adjustment for the diffraction grating's angle and distance.

When we measure the laser, we measure the output in terms of power in the time domain. Once we get this, we take the Fourier transform of the output in order to put the data in the frequency domain. The transformed data will have a sharp spike of power in the frequency domain around the center wavelength. In addition to this sharp spike, there will be local maximums and minimums due to Doppler broadening and other modes of the laser. When detecting a gas, such as methane, the power output will be lowered at certain frequencies. When observed in the frequency domain, it is possible to see which frequencies have the greatest decrease in power output. By creating a laser with maximums around the frequencies where methane has the greatest absorption, it becomes possible to detect the amount of methane present within a sample of gas. Within our data, in addition to the sharp spikes, there will be some noise. This noise will come from the temperature of the gas particles and the pressure of the gas particles. More noise will also appear if the laser is not properly focused. This will result in many smaller spikes rather than one large central spike in the frequency domain.

During this semester, I replaced the damaged PZT. The old PZT had been damaged when the wired sheared off from the circuit. To repair this, I soldered a new PZT circuit and improved on the previous design by using wire that can be removed when making repairs or adjustments to the circuits. I also replaced the diffraction grating. The old diffraction grating was scratched and was unable to properly reflect light. Upon replacing the grating, the laser became able to properly create feedback. After both of the parts were replaced, I also coupled the laser to some fiber optic cable and measured the output using the optical spectrum analyzer (OSA). The OSA allowed me to see the power output in the frequency and adjust the laser according to further optimize the frequencies. In order to understand how the laser worked, I learned about the Maxwell equations and the Fresnel equations. In addition to repairing hardware, I also worked to develop code to help process data that will be collected from the data. When coding, I started by creating a program that will take the data points and create a model. The program I created will model the data to a Voigt distribution. A Voigt distribution is convolution of a Lorentzian distribution and a Gaussian distribution. A Lorentzian distribution is used to model pressure broadening and the Gaussian distribution is used to model pressure broadening. Both types of broadening are present within the data we will observe from our laser and as such we use the Voigt distribution to account for both types of broadening. The second program I created will take the Fourier transform of our data. When detecting gasses, it is easiest to see the effects of absorption in the frequency domain and as a result, it is important to be able to move our data into the frequency domain. In order to write this program, I learned about the FFT, which is a numerical method for taking the Fourier transform, and the Fourier transform itself.

In the future, I will start taking measurements of methane samples with the laser and eventually, I will use the laser to test the amount of methane within samples of gas similar to the makeup of our atmosphere. To process this data, I will use the code I developed.