CREOL, The College of Optics and Photonics

UNIVERSITY OF CENTRAL FLORIDA

Water Quality Spectroscopic Analysis

AUSTIN DZIEWIOR - PSE,
HEE-JUN JANG - PSE,
NIYAH LOWELL - EE,
& LAVINE VON - CPE

GROUP #3

Motivation

1. Industrial Spectrometers are expensive

   Most commercial spectrometers cost upwards of a thousands of dollars.

2. Water Quality is important to our health and well-being

   Freshwater algae or cyanobacteria are known to release cyanotoxins which in high doses are hazardous to humans.

   Chlorophyll is a useful protein to exploit its fluorescence capabilities in photosynthetic molecules.

(we have none)

Goals and Objectives

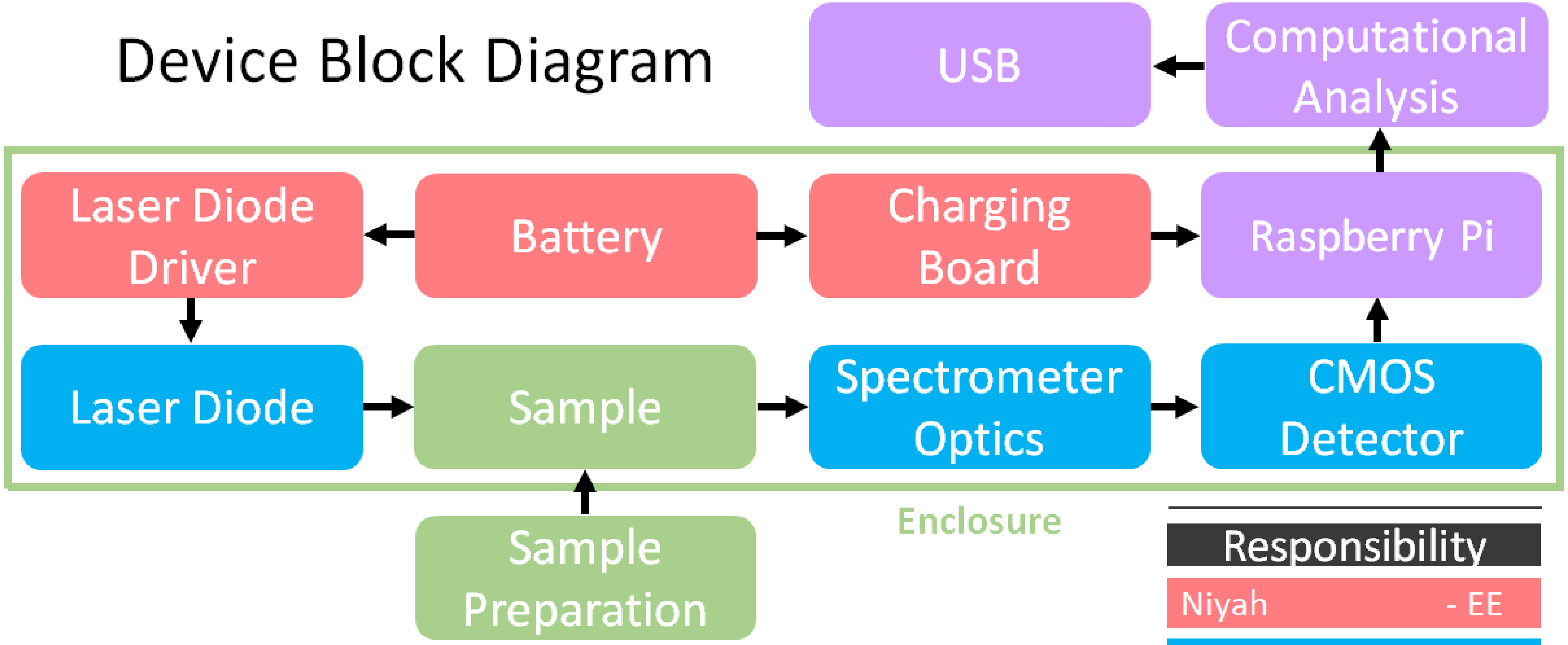
- Must be **cheap**, **lightweight** and **portable**.
- Measure the chlorophyll in a sample between 50 micrograms/liter and 50 milligrams/liter using fluorescence spectroscopy.
- Obtain a spectrum in the 600-750 nm range.

System Specifications

Parameter	Design Specification
Excitation Wavelength	409 nm
Spectral Range	600 – 750 nm
Resolution	2.2 nm
Target Concentration Detectable	50 micrograms/liter to 50 milligrams/liter
Sensor Type	CMOS 3280x2464 pixels
Input Voltage	12.7 V
Charge Time	1.5 hours
Discharge Time	Minimum 1 hour
Processing Time	Average of 30 seconds/sample
Dimensions	7.5x7.5x6"
Weight	4.7 lb
Output	Fluorescence Spectrum Intensity Profile CSV

Overall Device Block Diagram

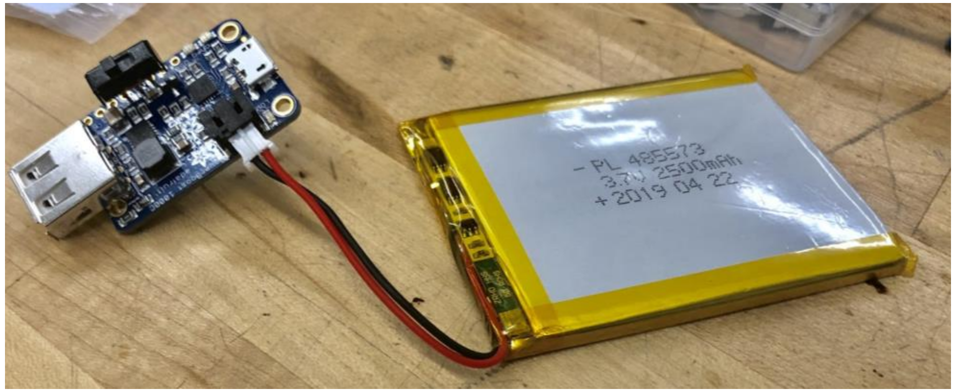
Device Block Diagram



Responsibility	
Niyah	- EE
Austin	- PSE
Hee-Jun	- PSE
Lavine	- CPE

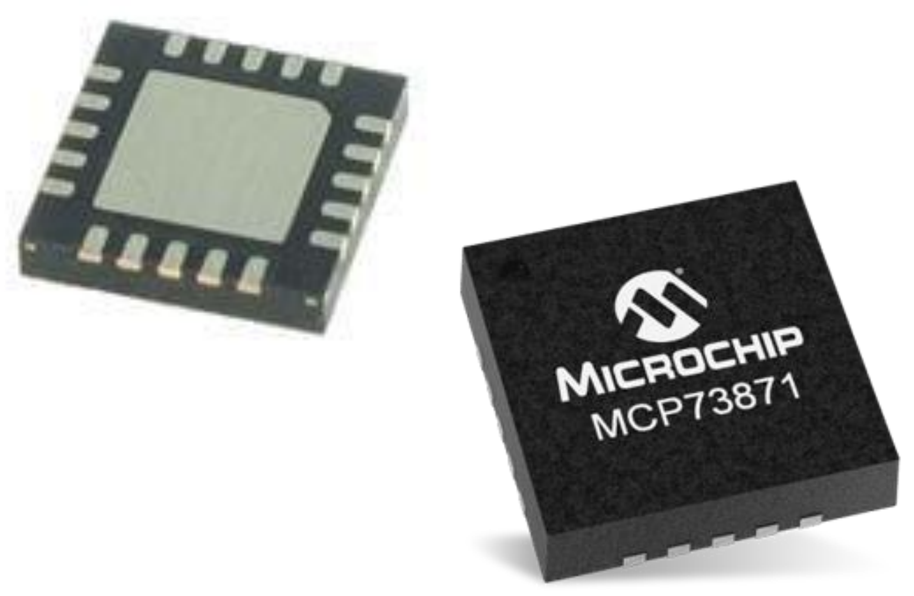
Power Supply

- Lithium Polymer
- 3.7V, 3000maH
- Small
- Light
- Low self-discharge
- Rechargeable
- Charging board

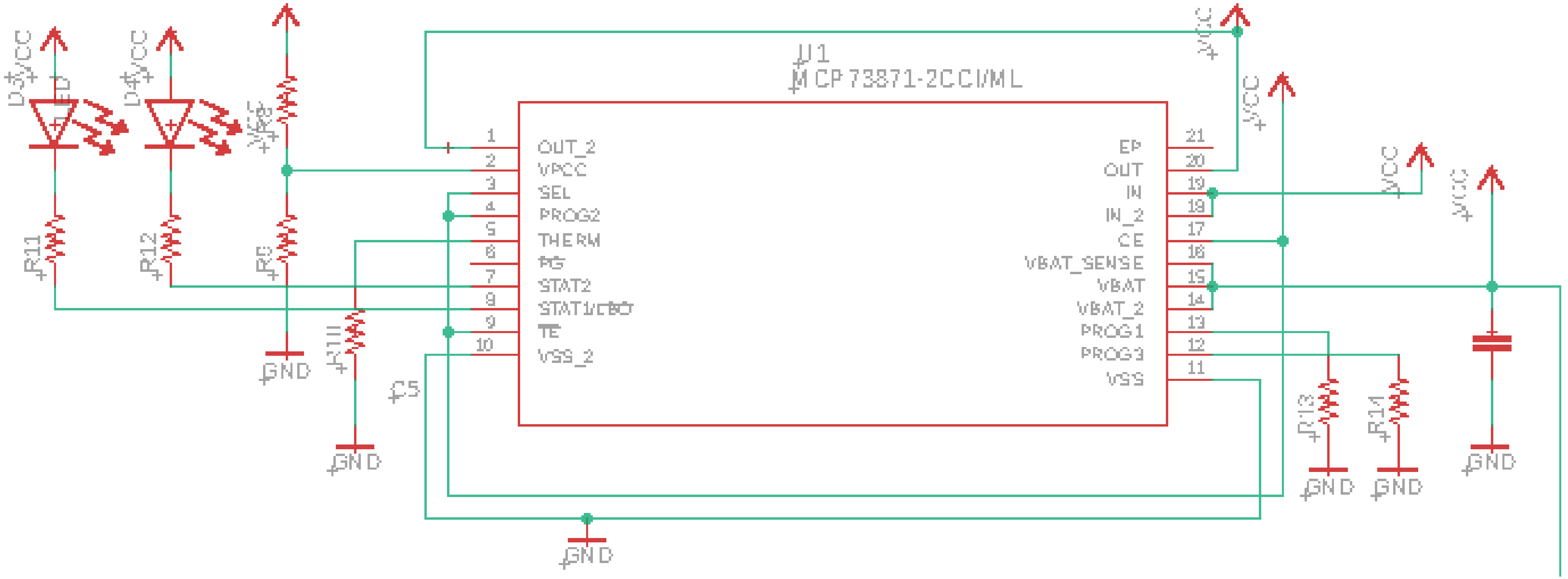


MPC73871

Manufacturer	Microchip
Function	Battery Management
Cost	$1.79
Voltage In	5V
Voltage Out	4.2V
Mounting Type	Surface mount

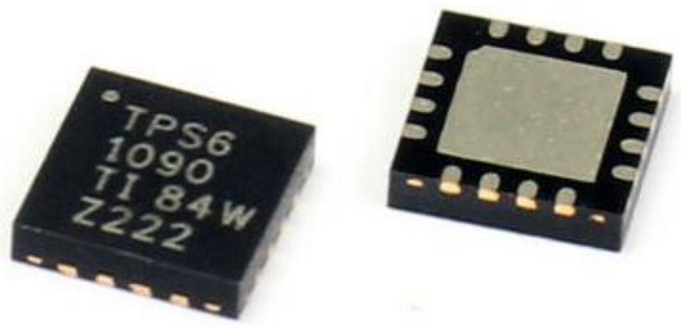


MPC73871 Connected

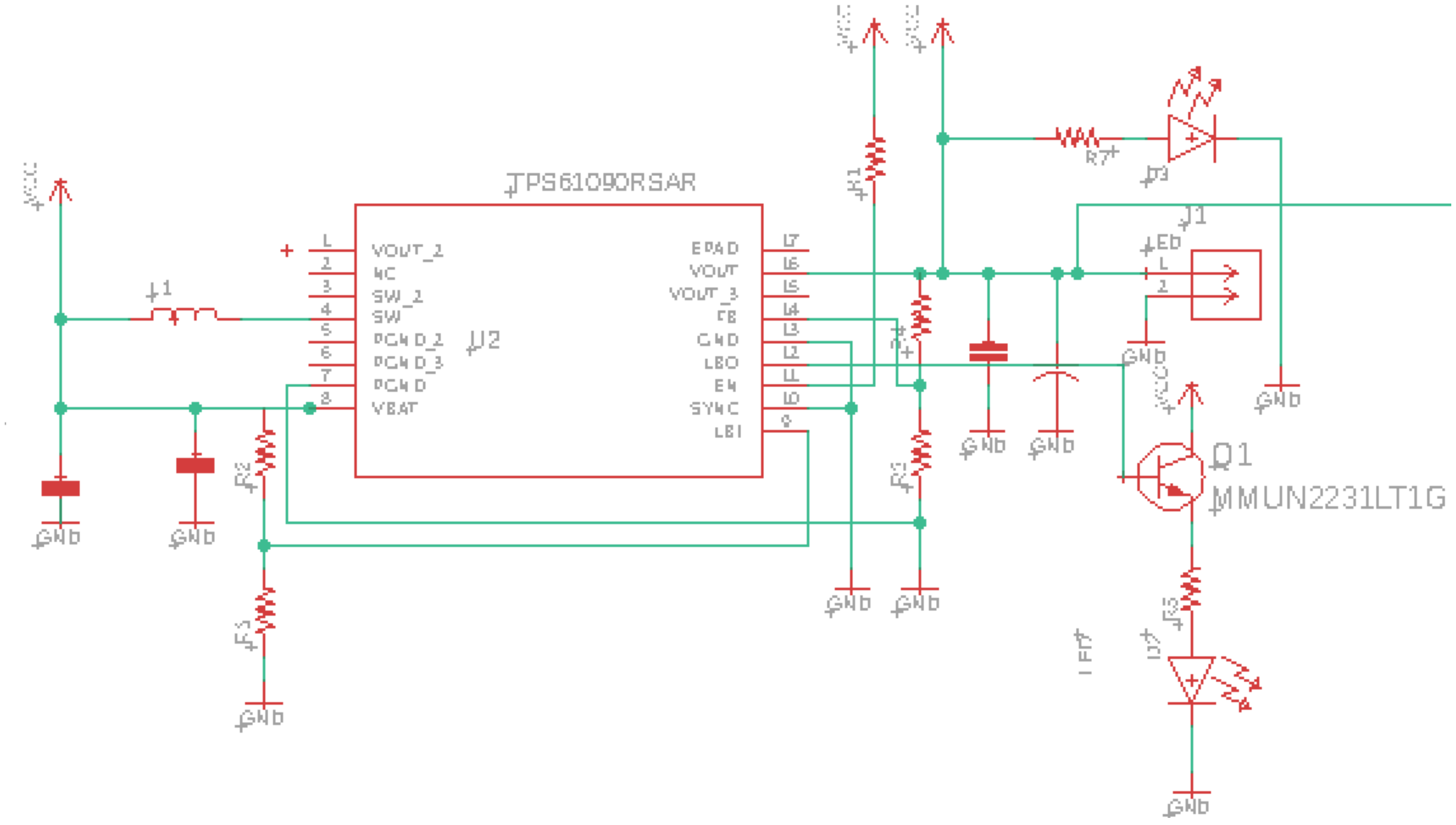


TPS6109RSAR

Manufacturer	Texas Instruments
Function	• Step Up Voltage Regulator
Cost	$2.41
Voltage In	1.8V-5.5V
Voltage Out	1.8V-5.5V
Mounting Type	Surface mount

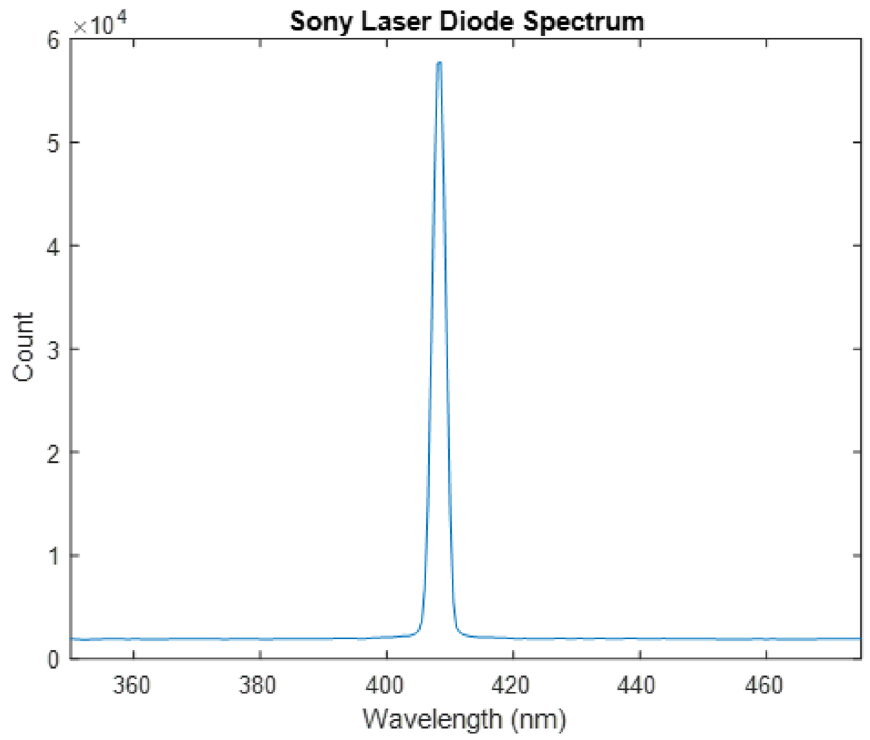


TPS6109RSAR Connected



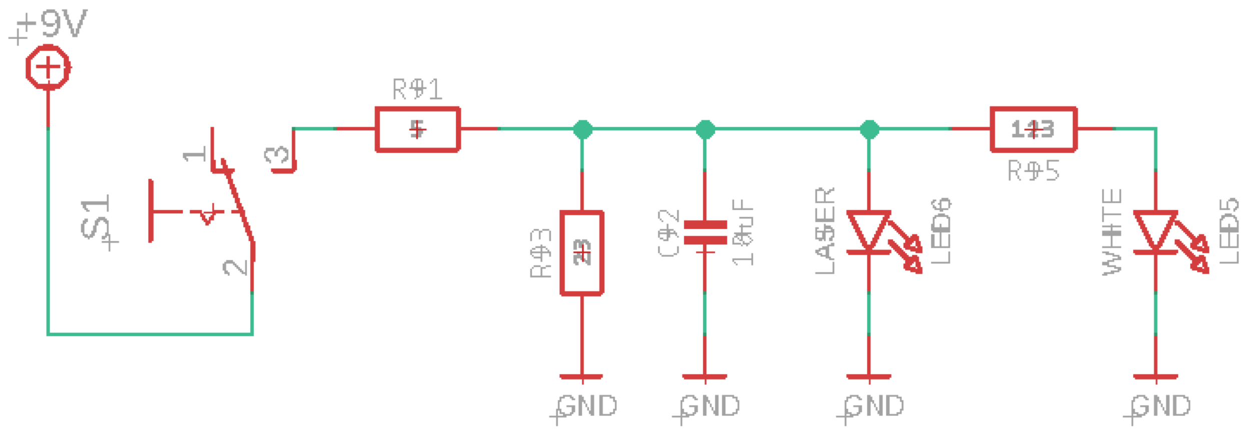
Laser Diode

- Sony SLD3232VF
- 405nm
- Operating voltage minimum: 5.3V
- Operating Current minimum: 50 mA



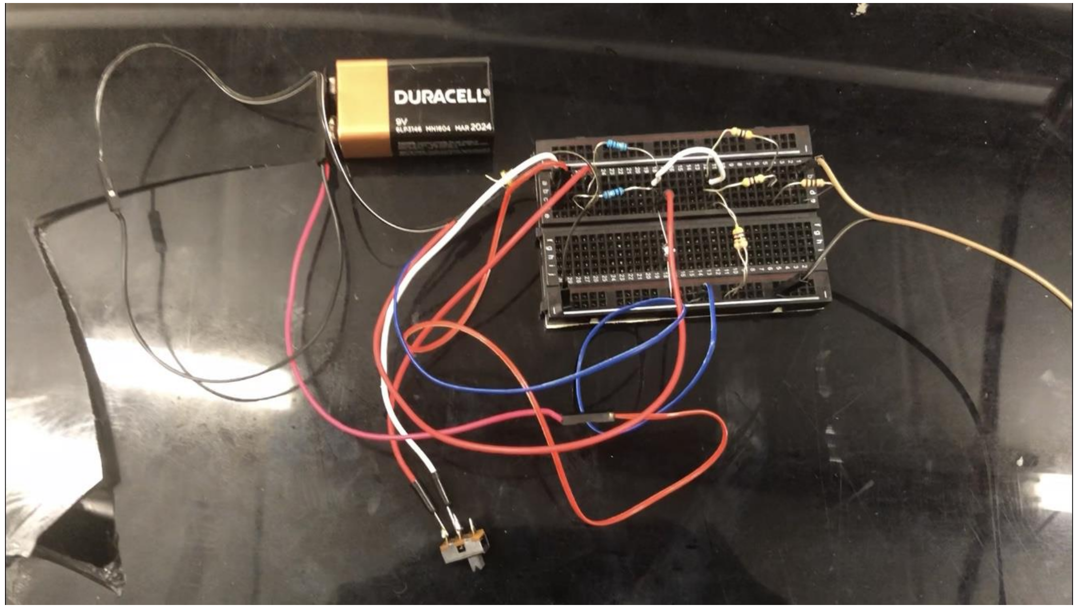
Laser Diode Driver Circuit

- Operating Current for LD 55mA
- Operating Voltage for LD 5.5V



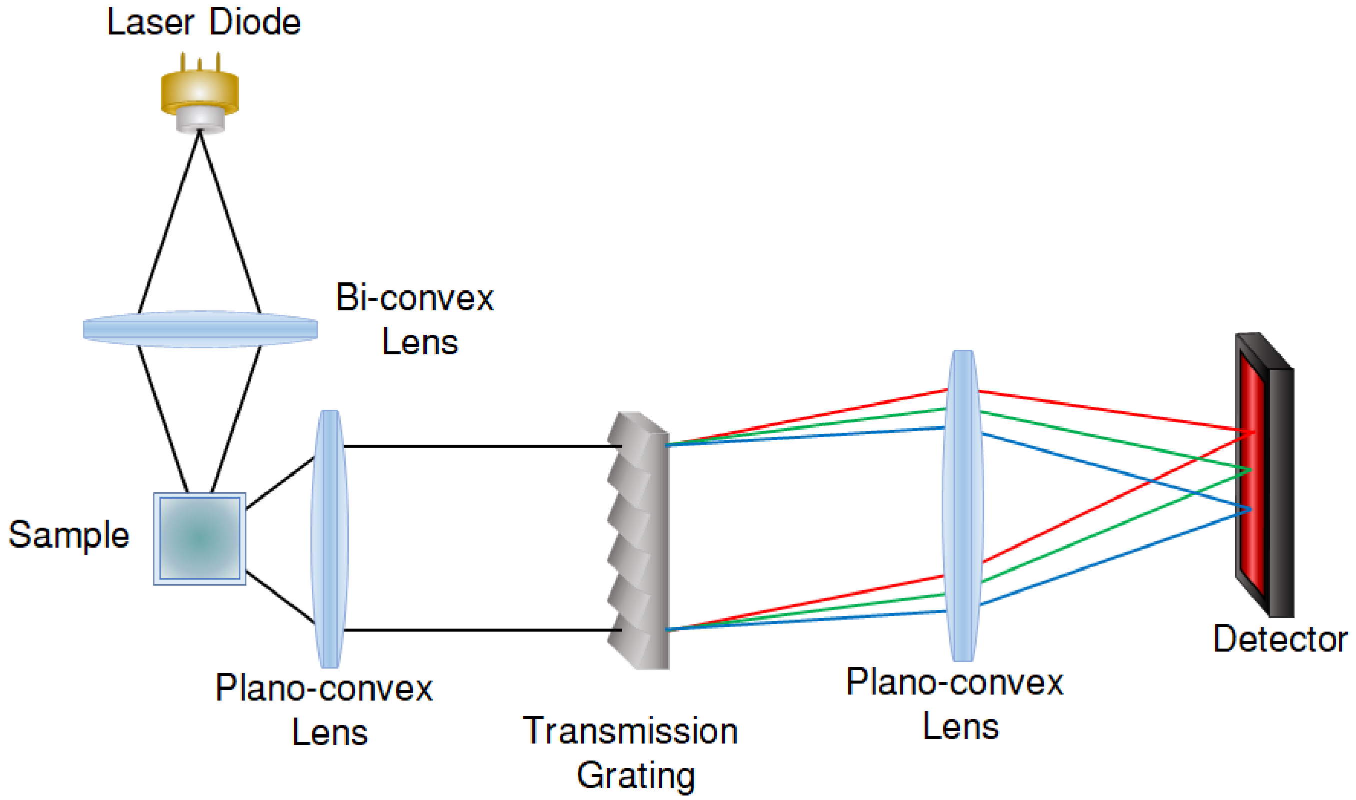
Laser Diode Driver Circuit

- Powered by 9V alkaline battery
- Includes indicator LED



Optical Layout

- Our layout is composed of a single lens to focus onto the sample and a telescope to collimate and focus unto our detector

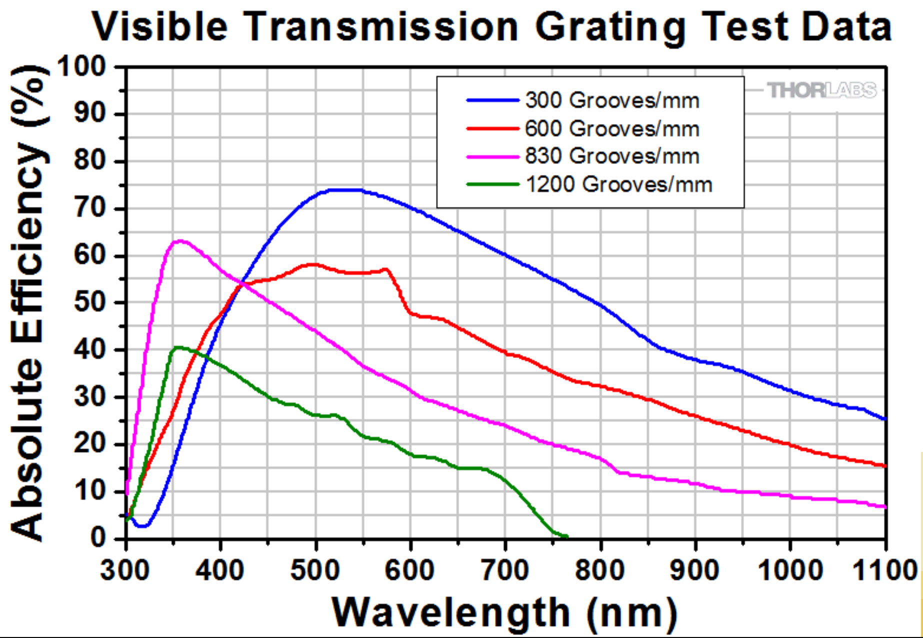


Lenses

- First Lens (focusing onto the sample)
  - Diameter: 20.0 mm
  - Focal Length: 20.0 mm
- Second Lens (collimating from the sample)
  - Diameter: 12.5 mm
  - Focal Length: 12.5 mm
- Third Lens (focusing onto the detector)
  - Diameter: 3.0 mm
  - Focal Length: 3.0 mm

Grating

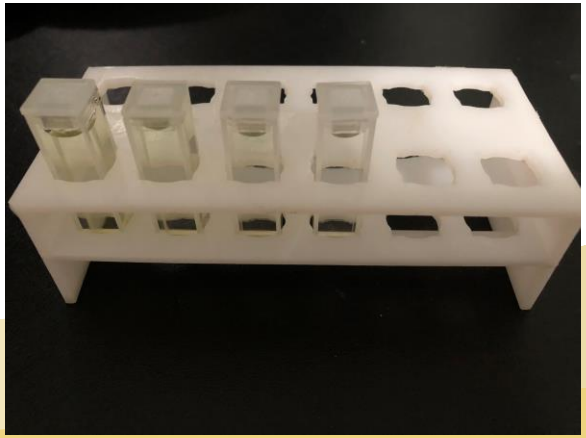
Grating	Diffraction Efficiency	Cost	Size	Compatibility
Ruled	60%-70%	$82.78	12.7mm x 12.7mm	Simpler optical setup
Holographic	45%-60%	$90.63	12.7 mm x 12.7mm	More intricate alignment



Taken from Thorlabs

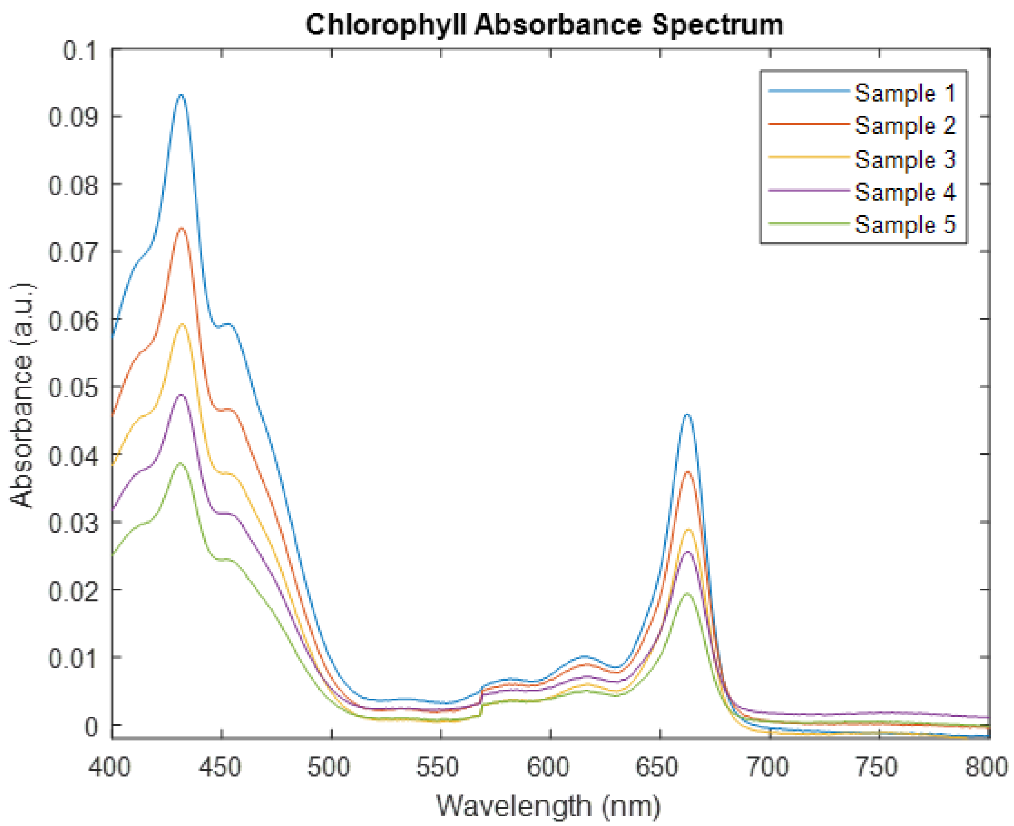
Sample

- Peak absorption at 430 nm
- Fluorescence peak at 655 nm
- Chlorophyll-a extracted from Anabaena, cyanobacteria culture
- All samples require to be diluted in acetone >99%
- Optical density (OD) must be less than 0.1 for accurate results
- Chlorophyll-a has a quantum yield of 0.2.



Sample

- Cary-500 spectrophotometer was used to detect the absorbance of the solution to determine the concentration
- Must use Beer's law to find the concentration with a known extinction coefficient at 662 nm



Complications

- Could not collect more data from spectrophotometer of different concentrations
- We required more data to match our fluorescence intensity to its matching optical density
- Our system does not tell the user the concentration of the chlorophyll inside the solution, but can still show the spectrum and the relative intensity

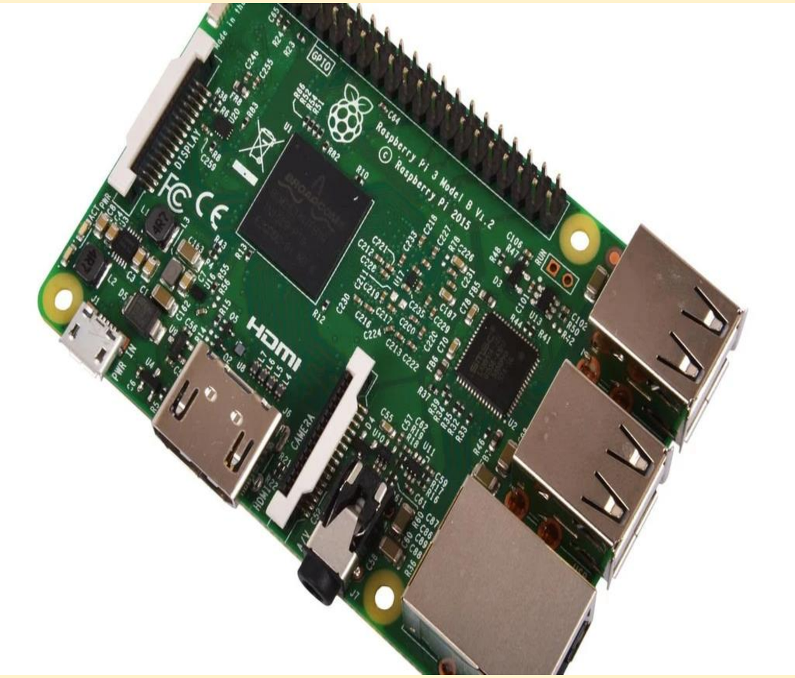
Sample Cuvette

Cuvette Material	Spectral Range	Optical Path Length	Price
Plastic	380-780 nm	10 mm	$22.77 for 100
Optical Glass	350-2000 nm	10 mm	$39.99 for 2
Quartz	190-2500 nm	10 mm	$49.95 for 2

Raspberry Pi V3

Purpose: The Pi will be used to process information gained from the sensor and convert it into a spectrum.

- The Pi was chosen because it has the ability to do image processing compared to the other options:
  - The MSP430, while cheaper cannot be used because its power is too low to produce high quality image processing.
  - The Arduino Uno, while a middle ground, has very little memory to do image processing.



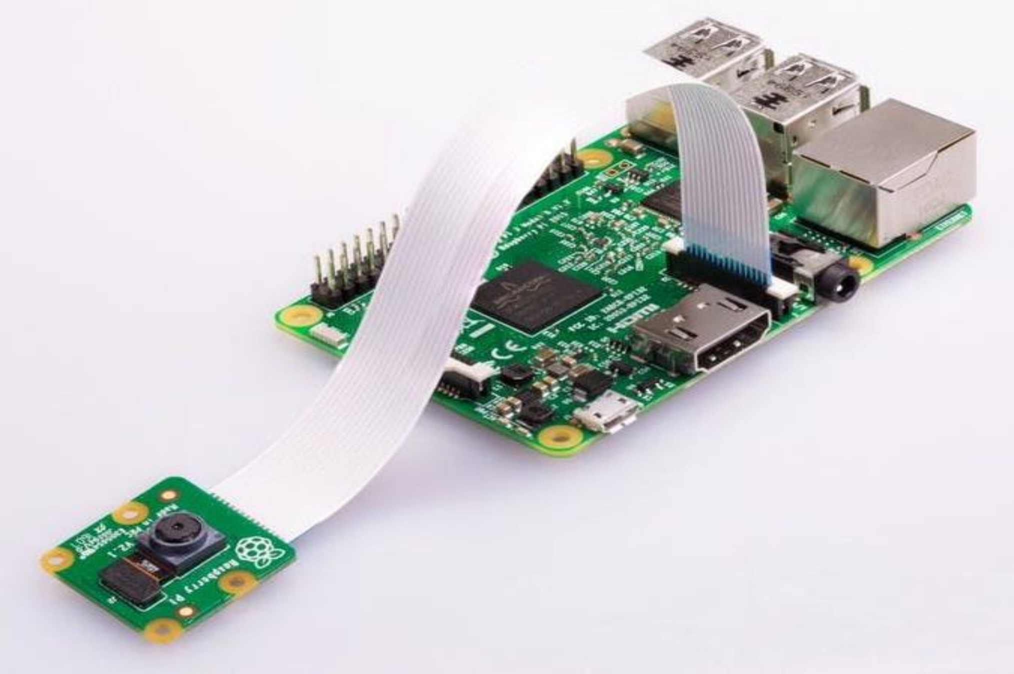
Development Kit	Cost ($)	RAM	Size	Weight
Raspberry Pi 3	30$	1 GB	4.9 x 3 x 1.3 in	2.4 ounces
Arduino Uno	22$	2 KB	68.6 x 53.4 mm	2.88 ounces
MSP430 G2	15$	512 B	6.3 x 6.1 x 1.7 in	4.8 ounces

Camera Module V2 for Raspberry Pi

Purpose: This will be the only detecting hardware to record the fluorescence signal from our cuvette.

- Detector size is large enough to record the whole area of the signal (3.7mm x 2.8mm)
- Quantum efficiency of this silicon-based detector is >80% for 663 nm

Originally, we wanted a monochromatic camera, but ultimately the Pi was chosen over it because of its ease of set up, cost, as well as the resources associated with the module.



Camera	Cost ($)	Bayer Pattern	Resolution
Camera Module V2	25$	BGGR	8 MP
MT9J001 camera	40$	Monochrome	10 MP

SanDisk Extreme Plus

Purpose: The SD card is used to contain the program to process the information recorded by the sensor. The SD card is chosen by the specific categories:

- SD card size (capacity) - The minimum card size needed to run the recommended software is 16GB
- SD card class - the cost of write speed is achieved at the cost of read speed and increased seek times
- We ended up only using 9 GB, so we can use a smaller SD card to reduce costs.

SD Card	Price	Capacity	Speed
SanDisk Ultra	8$	32 GB	Class 10
SanDisk Extreme	20$	64 GB	Class 10

Image Processing

- To find the spectrum of the sample, the intensity profile is needed to find its wavelength.
  - The program does this by looking at the intensity of each pixel.
- The camera takes in the raw bayer data of the sample and stores the results in a 2D array.
- IMX219 sensor's bayer data is organized in a BGGR pattern.
  - For calibration, we use blue and red.
  - For data analysis, we use just red.
- The tradeoff for using a color camera is that we have less pixels for the analysis when we want it to be as high as possible.

Sensor Calibration

- Sensor needs to be calibrated to identify which wavelength is on which pixel.
- 2 known input sources with given wavelengths are used as reference on the sensor.
- The program looks for the index of the maximum values of the red and blue arrays found in image processing.
- The difference between these indexes is divided by the difference between the two reference wavelengths to get the position of each pixel.

Data Analysis

Purpose: The program will receive an output from the sensor and translate it to a spectrum.

- The program prompts the user to take a picture both with the diode on and off to reduce noise.
- Based on the calibration discussed in last slide, the intensity of each pixel will be mapped to a wavelength.
- The intensities are then adjusted according to the Quantum Efficiency of each wavelength.

Output

- The intensity across the different wavelengths will be used to provide the full spectra of the fluorescence.
- From the results of the data analysis, the spectra is plotted using the matplotlib on the monitor.
- The .csv of the spectra is saved into a usb mounted onto the Pi.

Software Enhancements

Additional features were planned for implementation, but could not make it due to lack of time:

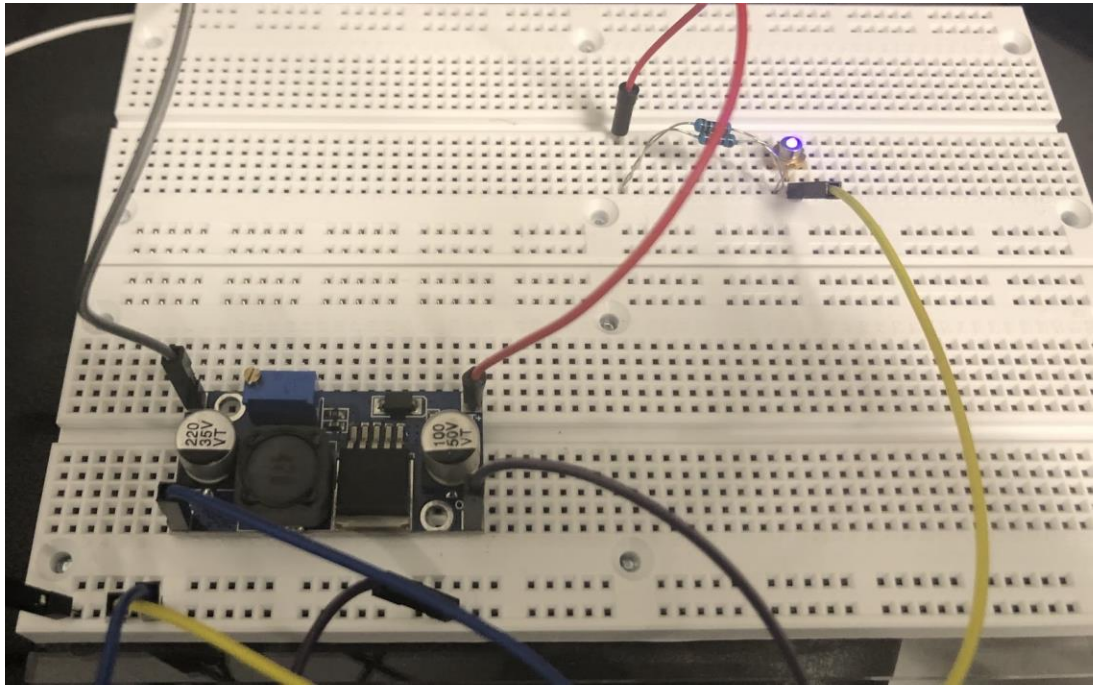
1. A user-interface for the user to easily use the device.
    - Focus was to get the image process and analysis working.
    - Difficulty with display.
2. Unable to display concentration due to lack of a baseline.
3. Ability to turn on diode via software.
    - Workaround was to prompt the user to turn on the diode.

Enclosure

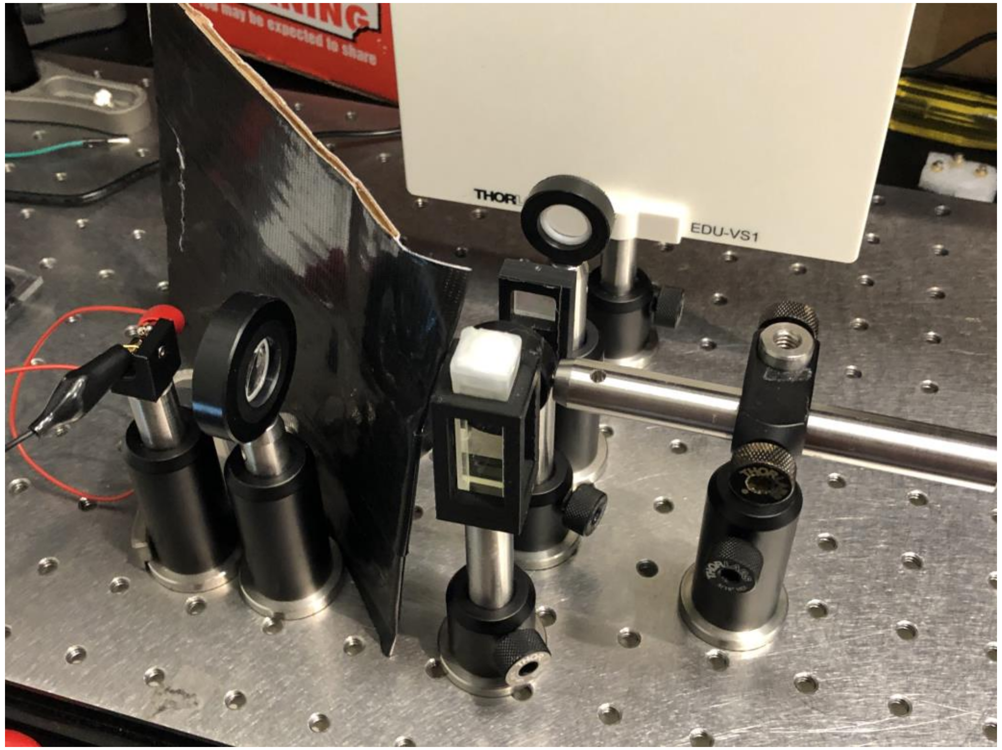
- We have chosen to construct our housing out of acrylic, being the most cost effective material.
- Base of the spectrometer is an optical breadboard; 7.5"x7.5"x5.75"

Materials	Aluminum 7075	Acrylic	Copper	Wax
Prone to Defects	Little	Moderate	High	Moderate
Dimensions	10"x5"x5"	2"x6"x6"	1.25"x11"x1.25"	3"x3"x7"
Cost	~$174.14	~$68.12 (4)	~$159.99	~$21.95

Prototyping

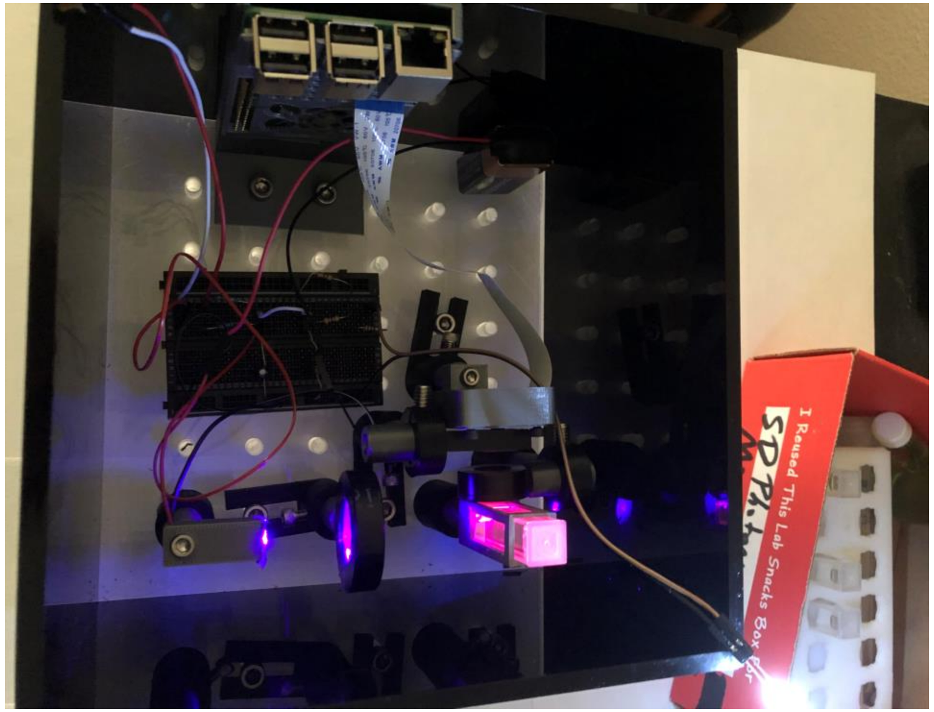


Driver Circuit Prototype



Spectrometer Prototype

Final Design



Safety Precautions

- Photonics
  - Asdfgvhbnjk
- Electrical
  - Goggles when soldering
  - Laser diode eye safety

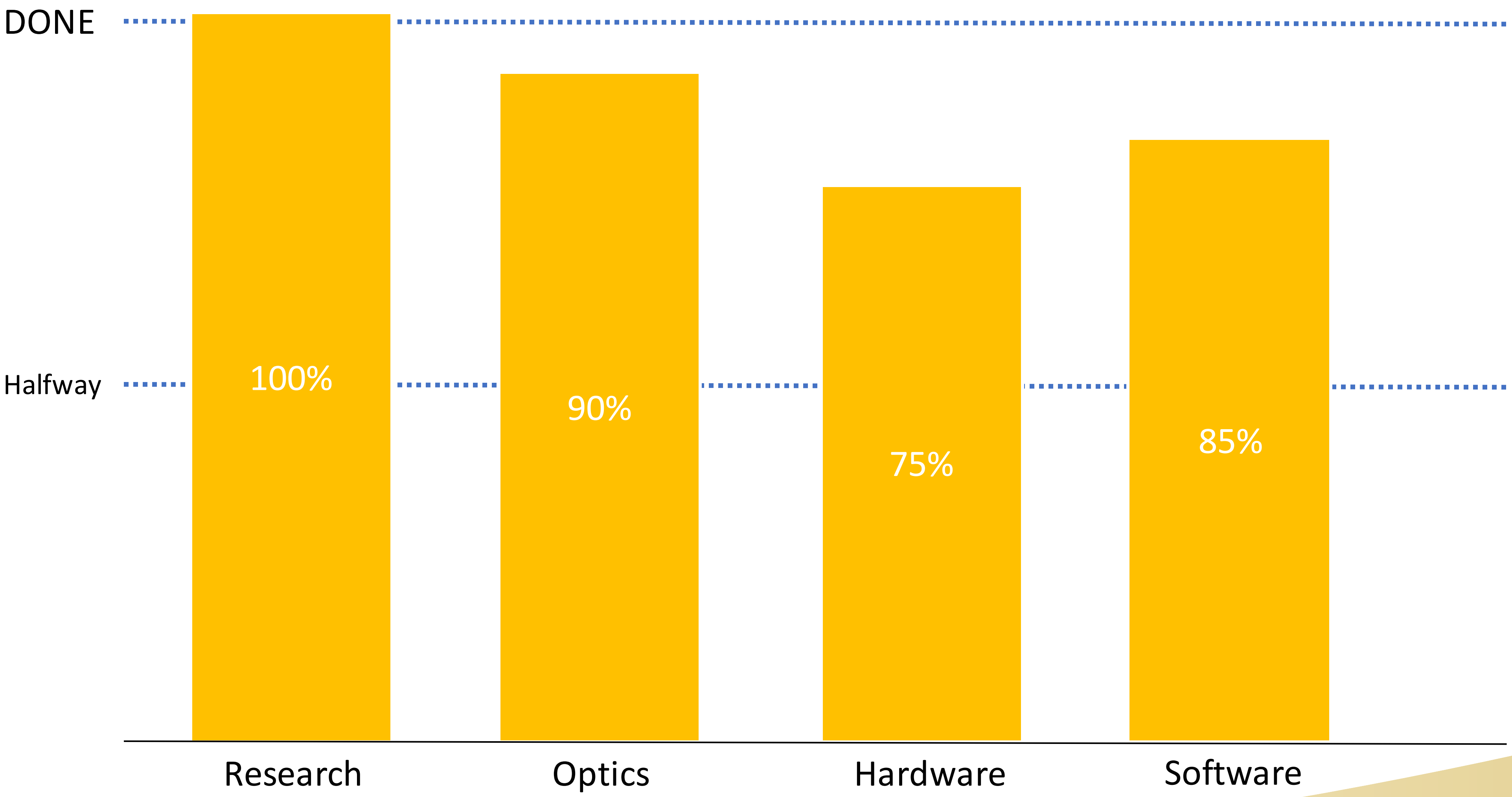
Individual Responsibilities

Responsibility	Primary	Secondary(s)
Power Supply	Niyah Lowell (EE)	
PCB	Niyah Lowell (EE)	
Laser Source	NiyahLowell (EE)	Hee-Jun Jang (PSE)
Sample	Hee-Jun Jang (PSE)	Austin Dziewior (PSE)
Sensor	Lavine Von (PSE)	Hee-Jun Jang (PSE)
Spectrometer	Austin Dziewior (PSE)	Hee-Jun Jang (PSE)
Casing	Hee-Jun Jang (PSE)	Austin Dziewior (PSE)
Raspberry Pi	Lavine Von (PSE)	Niyah Lowell (EE)
User Interface	Lavine Von (CPE)	
Computational Analysis	Lavine Von (CPE)	Austin Dziewior (PSE)
Spectrum/Data	Austin Dziewior(PSE)	Lavine Von (PSE)

Budget

Item	Supplier	Unit Price	Units	Cost
Rechargable Battery	Amazon	$7	2	$14
Boosters	Amazon	$2.40	5	$12
Charging Board	Adafruit	$20	2	$40
Laser Diode (Pack of 5)	Sony	$11.99	1	$11.99
Biconvex Lens f=20 mm	EdmundOptics	$25.50	1	$25.50
Planoconvex Lens f=12.5 mm	EdmundOptics	$42.00	1	$42.00
Planoconvex Lens f=75 mm	EdmundOptics	$26.00	1	$26.00
Transmission Grating	ThorLabs	$82.78	1	$82.78
Glass Cuvette (Pack of 2)	Science Outlet	$39.99	1	$39.99
Cyanobacteria Culture	California	$8.50	1	$8.50
Raspberry Pi 3	Amazon	$50	2	$100
MicroSD Card	Best Buy	$13	1	$13
Raspberry Pi Camera Module V2	Amazon	$28	1	$28
Total				$443.76

Progress


DONE
Halfway
100%
90%
75%
85%
Research
Optics
Hardware
Software

Questions?