PlastiSense

Spectroscopy

Team 2: Aaron Achildiyev, Aidan Belanger, Victor Lam, Adrian Mora

Problem Statement

- Did you know microplastics have been found in our rainwater and you could be consuming five grams of microplastics a week -- the equivalent to a credit card?

- This has been linked to negative effects on fertility and increased occurrences of cell mutations and cancer.[1]

- Find out the abundance of microplastics in your water with PlastiSense, an optics-based microplastic sensing device!

[1] dalberg-advocacy-analysis_for-web.pdf
[2] Picture

Existing Solutions From Products on the Market

Manta Net [3]

Advantages:

- Easy to use
- Sample large volumes of water
- Produces large number of microplastics for further testing

Disadvantages:

- Expensive equipment
- Requires boat
- Time consuming
- Potential contamination

Fourier Transform Infrared

Advantages:

- Extensive spectral libraries

Disadvantages:

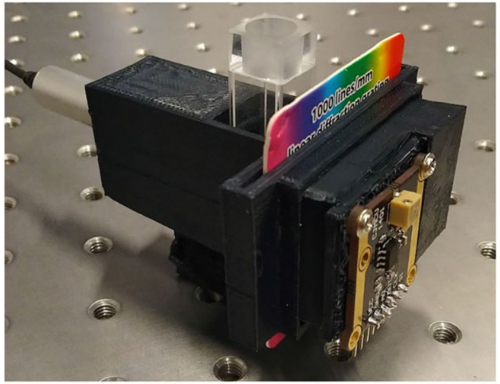
- Affected by particle thickness[4]
- Cannot detect smaller than 10-20um[4]
- Expensive scanning laser
- Requires Sonication of sample

[3] https://www.sciencedirect.com/science/article/pii/S0165993618305247

[4] https://link.springer.com/article/10.1007/s00216-015-8850-8

Existing Solutions: Raman Spectroscopy

- Existing solutions are pricey and are meant to be used in the lab setting
- DXR2 Raman Microscope (bottom right)
    - Can perform spectroscopy at multiple wavelengths for various solutions
    - Costs over $70k

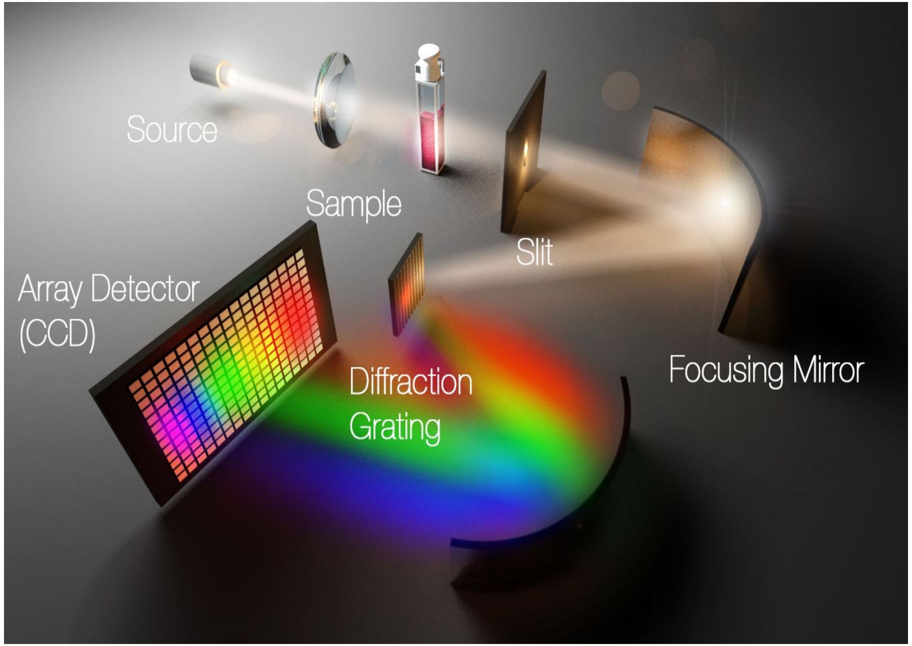


Thermo Scientific DXR2 Raman Microscope

[4] Science Daily

Our Product: PlastiSense with Comparisons Drawn

- Affordable (~$500)
- Utilizes Raman spectroscopy technology
- PlastiSense is specialized to detect Polyethylene
  - Polyethylene is the most prominent microplastic to be found in the environment (54.5% in study)[4]
- Portable and programmable



Goals

- Sense polyethylene with Raman spectroscopy
- Output readings of microplastic concentration in sample
- Create a compact optical chamber ready to integrate into a digital circuit
- Create waterproof enclosure for chamber and circuit for installing in rain barrel or large water containers

Specs

- Portable
  - Handheld (less than 1 sq ft)
  - Less than 20lbs
- Programmable (Duration of laser and sampling)
- Affordable (~$500)
- Application specific; detects polyethylene
- Measures concentration of polyethylene
- Water resistant

Testing Plan

1. Blend a polyethylene cup / bottle
2. Weigh sample of plastics and disperse in water
3. Measure intensity of the Raman response
4. Use intensity to calculate density of plastics
5. Compare plastic density sensed with Raman to actual density

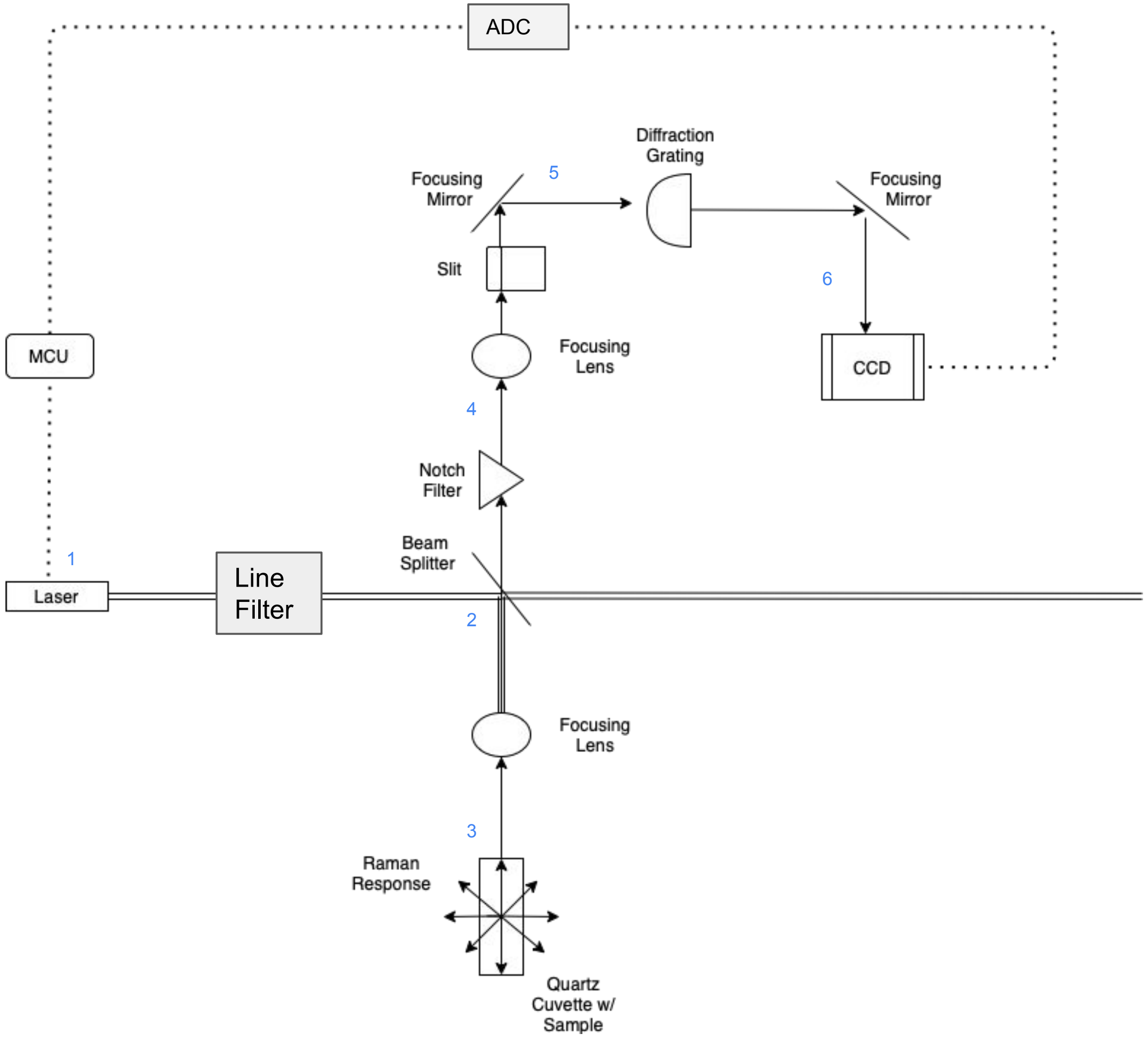
Justifiable, Quantitative Benchmarks

- Test by running system on various known samples
  - Take one sample then dilute it to get 5 samples of varying concentrations
  - 0 , 25, 50, 75, & 100mg/L
- Output concentration to user along with “hamming distance” of wavelength from expected Raman response

- Accurately identify concentration of microplastics with < 10% error
- Less than 3 minutes

Spectroscopy Setup

- Planning and mapping of Optical Path was done with the help of **Prof. Arbabi**
- The optical path is shown in numbered order
- The necessary training and certifications required for use of class 3 lasers in M5 have been acquired for all members.



Aaron Achildiyev

has completed the training

UMASS AMHERST

Laser Safety Training (On-line and Classroom Training)

Certification Date: 9/19/2021

Expiration Date: 9/19/2026

Environmental Health & Safety, University of Massachusetts at Amherst

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Victor Lam

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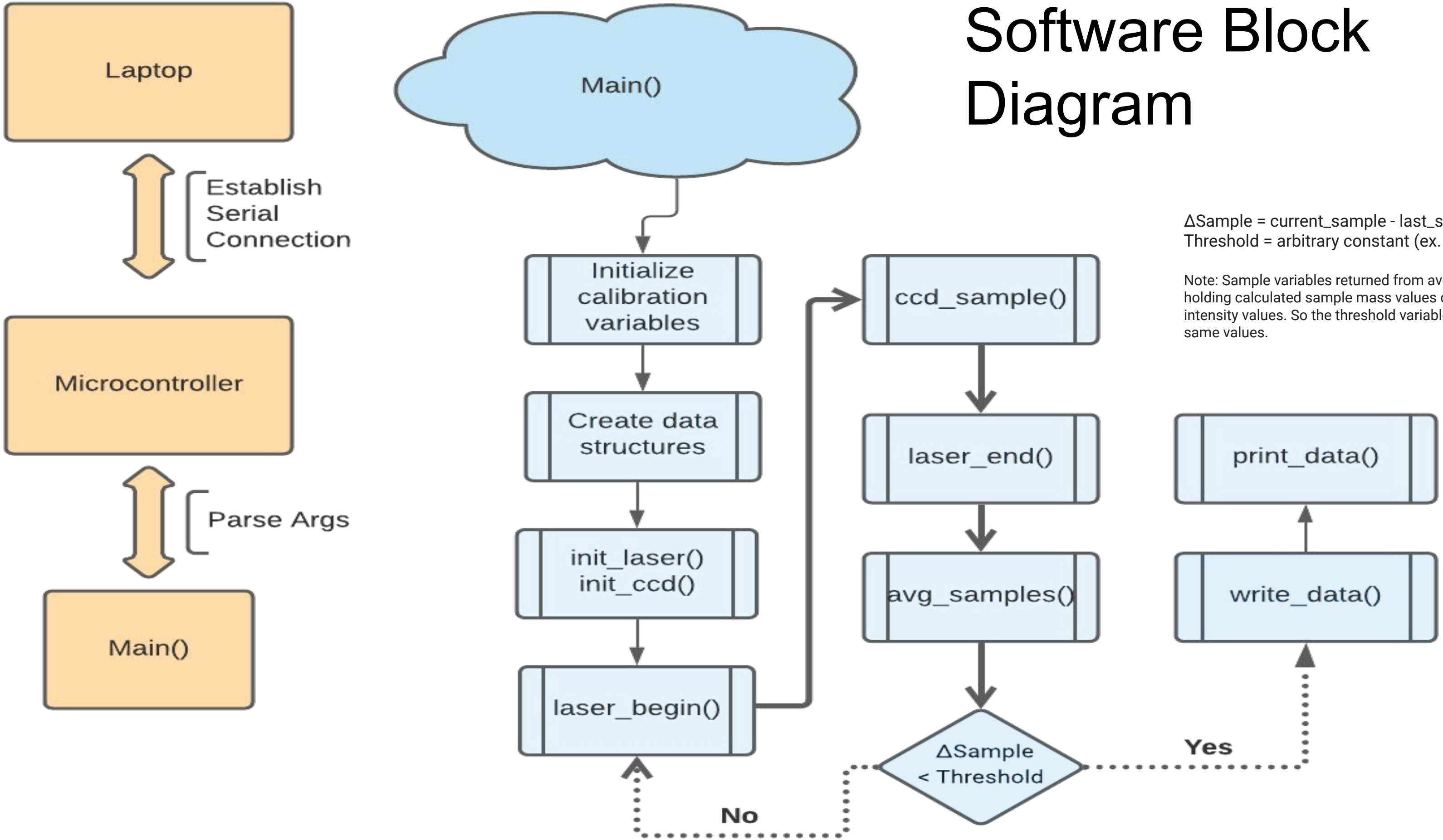
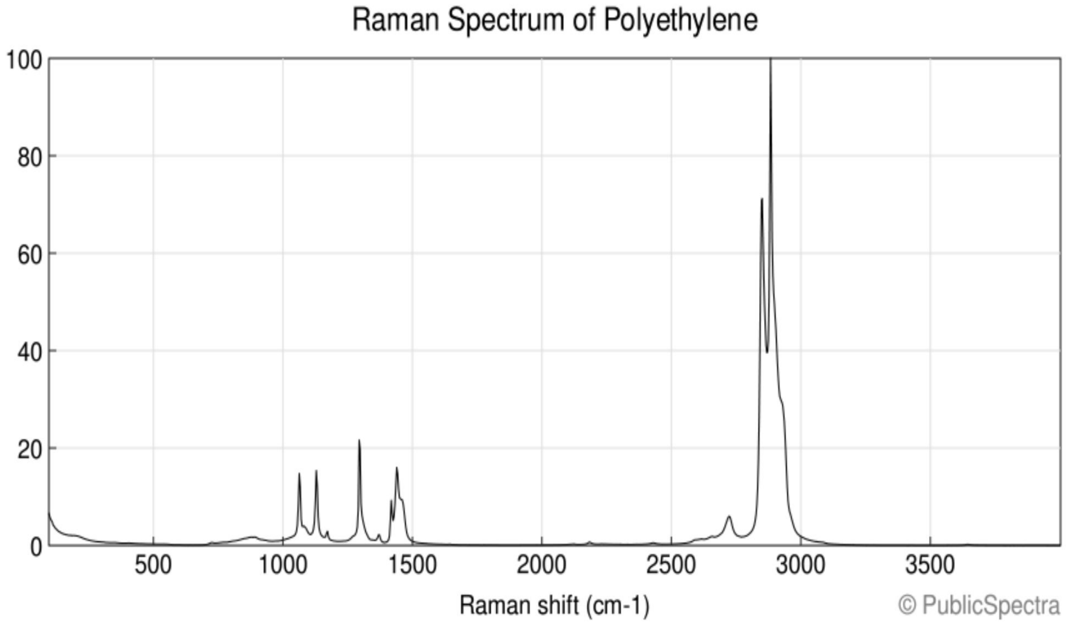
Software Block Diagram

ΔSample = current_sample - last_sample
Threshold = arbitrary constant (ex. 0.1 or 0.01)

Note: Sample variables returned from avg_sample() holding calculated sample mass values or avg spectral intensity values. So the threshold variable will hold the same values.



How to Choose Laser Wavelength?



- For Polyethylene, the most intense Raman Shift happens at 2900 cm^{-1}
- Excitation Wavelength
  - 635 nm (red) -- good for low fluorescence
- Expected Raman Wavelength: 778 nm

Raman Spectrum of Polyethylene
Raman Shift Calculator

How Do We Know The Raman Wavelength is 778 nm?

635 nm = 4.72E14 Hz (Excitation Wavelength)

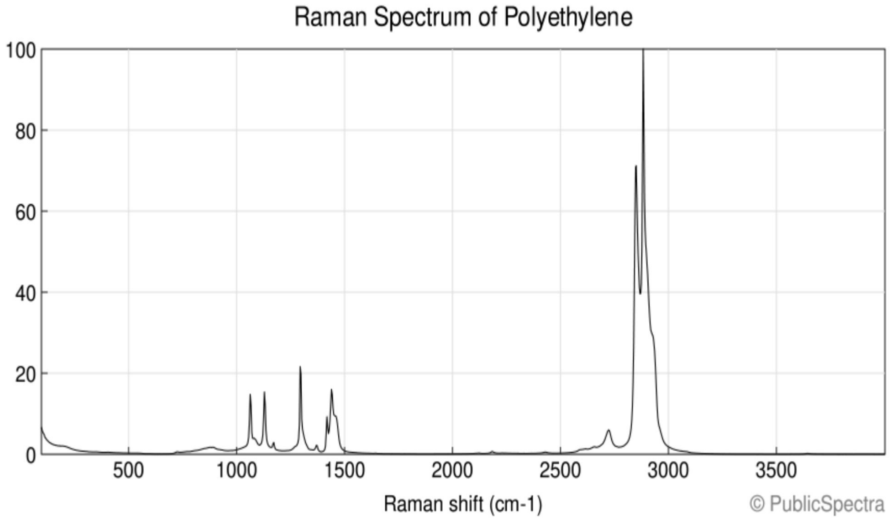
2900 cm^{-1} = 8.71E13 Hz (Raman Shift)

Take the difference: $f_1 - f_2 = f_3$

4.72E14 Hz - 8.71E13 Hz = 3.85E14 Hz

3.85E14 Hz = 778 nm

This means that we expect a Raman Signal at NIR!



Intensity vs. Fluorescence

- Laser with smaller wavelength = greater intensity of signal to be picked up by sensor
- However, the intensity is not at all accurate because of **fluorescence**
- Fluorescence is the emission of light by a substance that has absorbed electromagnetic radiation
- Much less fluorescence near infrared
- Fluorescence can effectively hide our Raman signal! Not good!

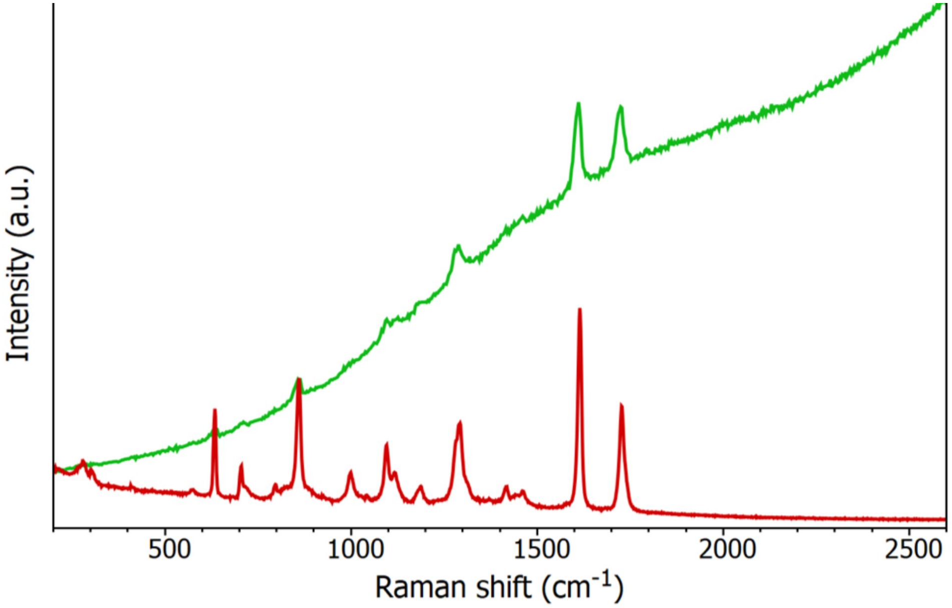
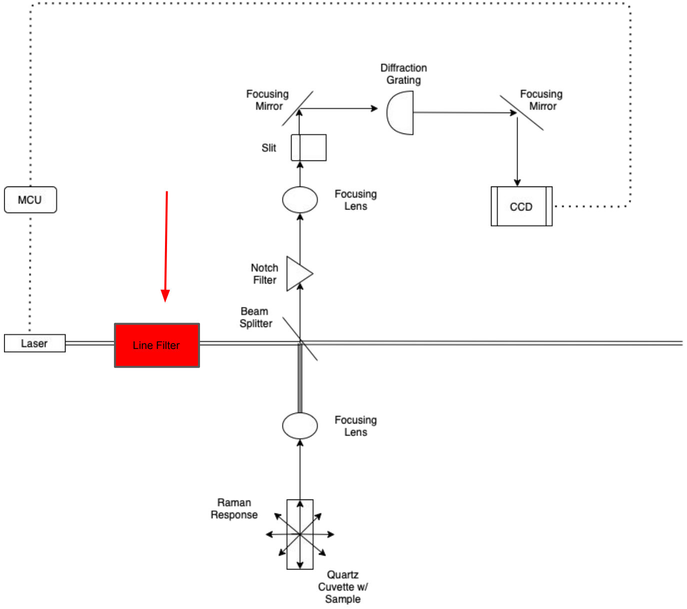
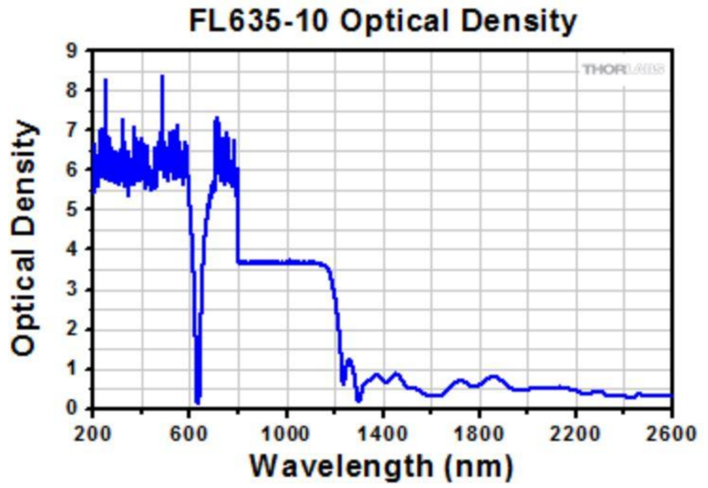


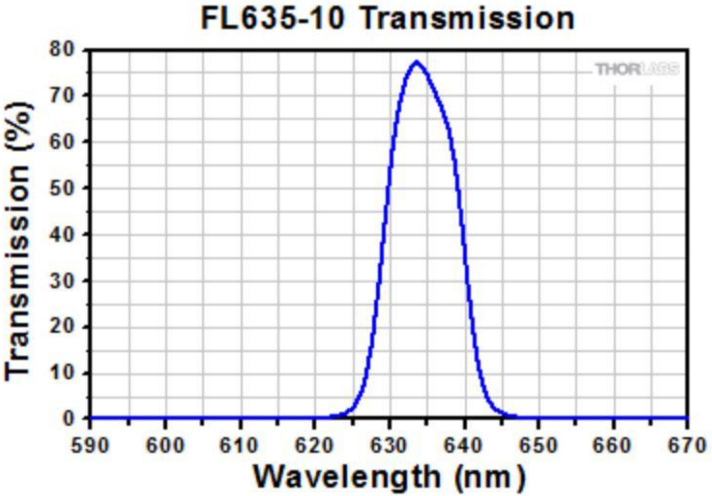
Figure 2: Nicotine patch spectra measured on the RM5 Raman Microscope with a 532 nm laser (green) and a 785 nm laser (red)

[Nicotine patch spectra]

Laser Line Filter

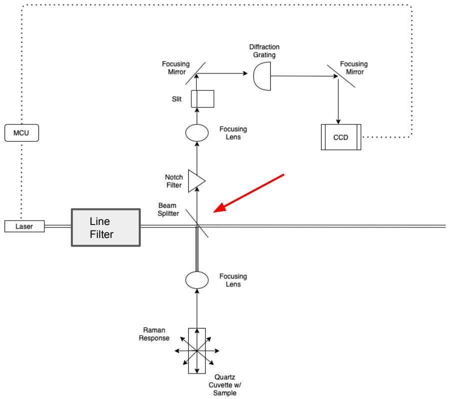




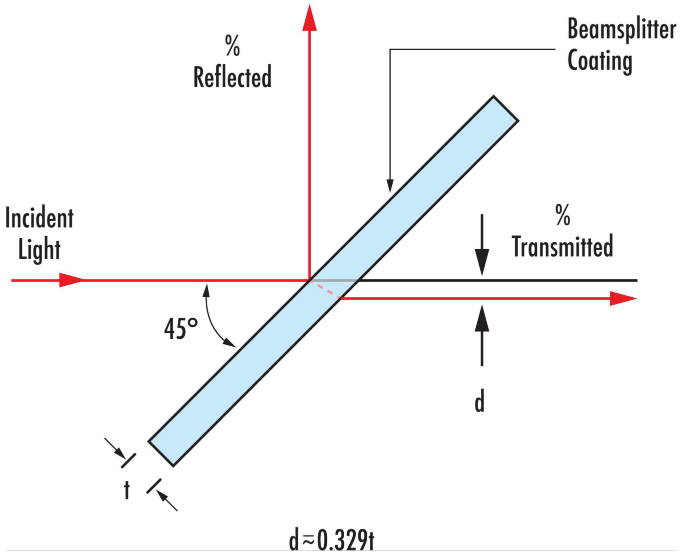


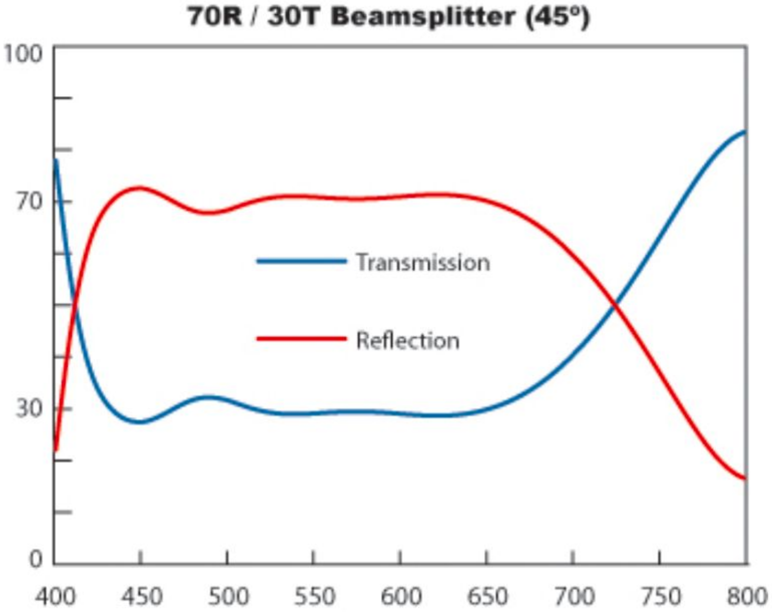
- Used to “clean” the spectrum of our excitation laser
- Good lasers with “clean” spectrums cost thousands of dollars

BeamSplitter



- 70R/30T Beamsplitter reflects 70% of our 635 nm laser towards the sample
- Transmits 70% of our ~770 nm Raman Wavelength



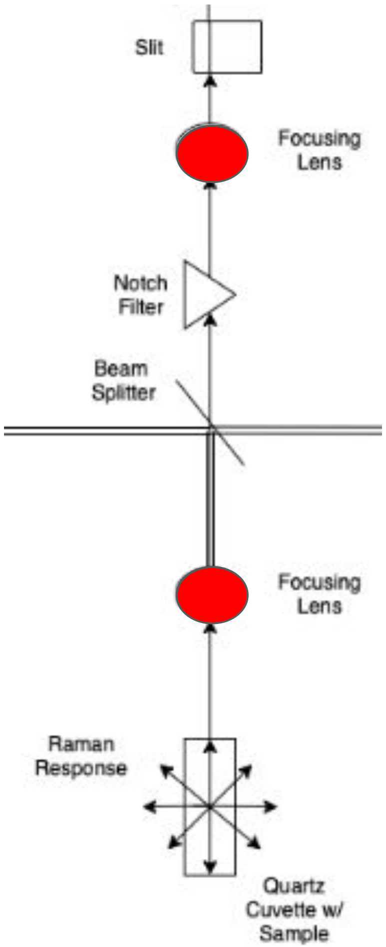


Focusing Lens

Used to magnify intensity of light to a single point.

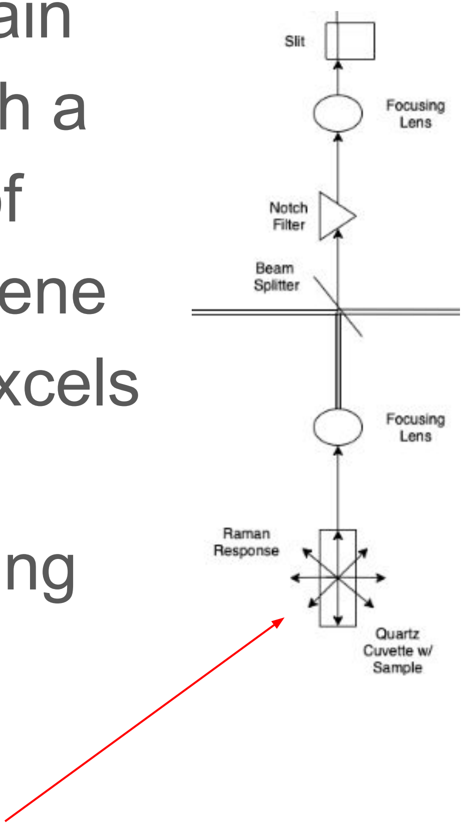
- Effectively reduces the diameter of the laser that hits the microplastic sample.

- 10x focus
- 7.1 mm working distance
- Achromatic



Quartz Cuvette

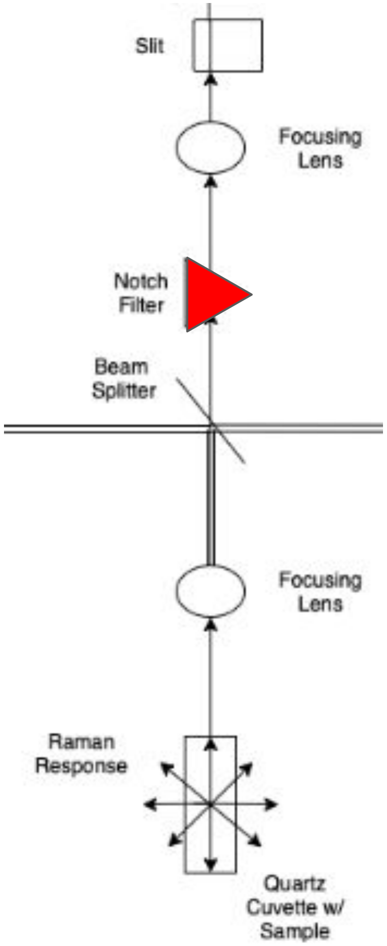
- Will contain water with a sample of polyethylene
- Quartz excels at transmitting light



Purpose of Notch Filter

Why?

- Optical filters are used to prevent the undesired (laser) light from reaching the spectrometer, or CCD sensor.
- If we do not include a notch filter, the undesired light can drown out the relatively weak Raman signal.
- Choose a notch filter that corresponds to our laser wavelength.



Notch Filter in Action

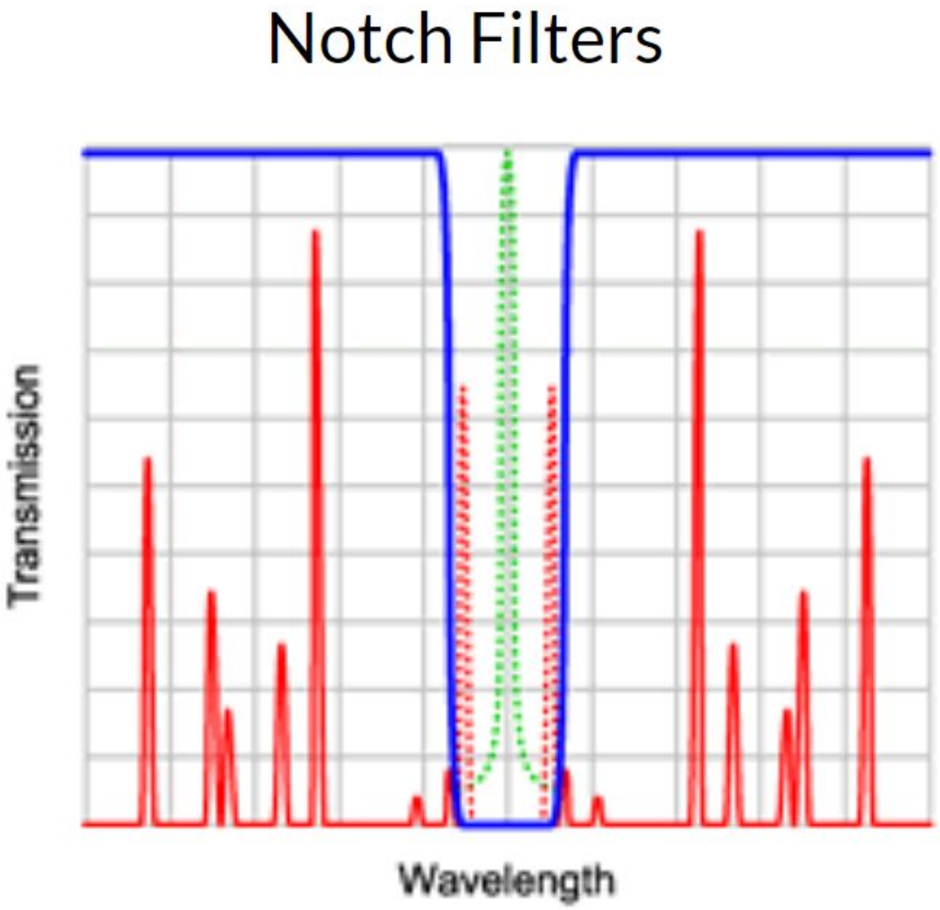
Green represents the excitation laser.

Blue represents the notch filter.

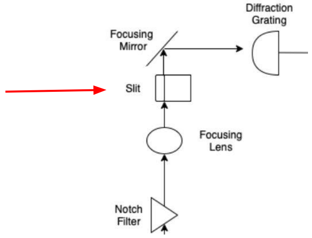
- Blocks the laser from transmitting to the sensor

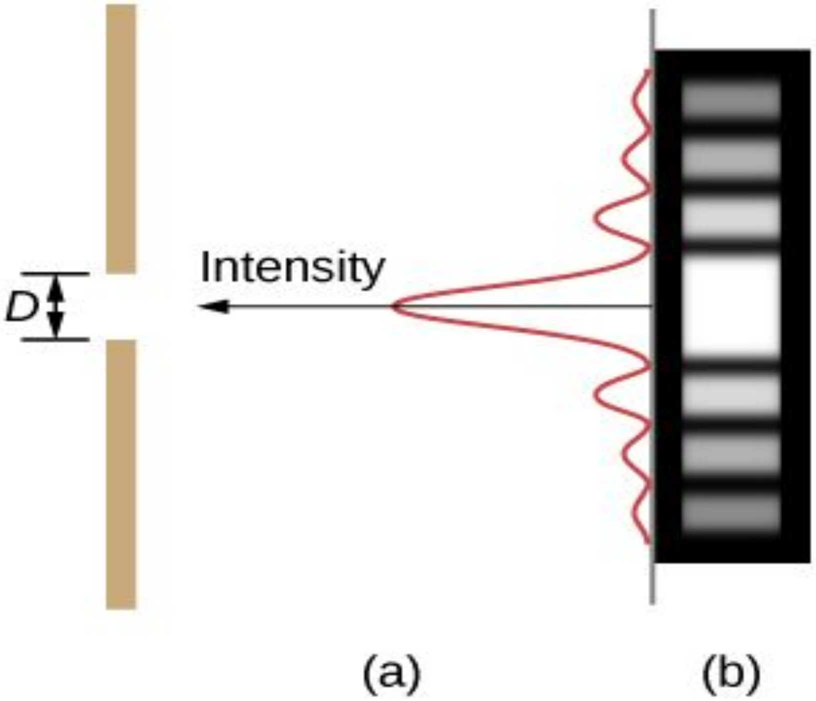
Red represents the potential Raman shifts

Notch Filter Transmission



What is a slit? Why is it useful?





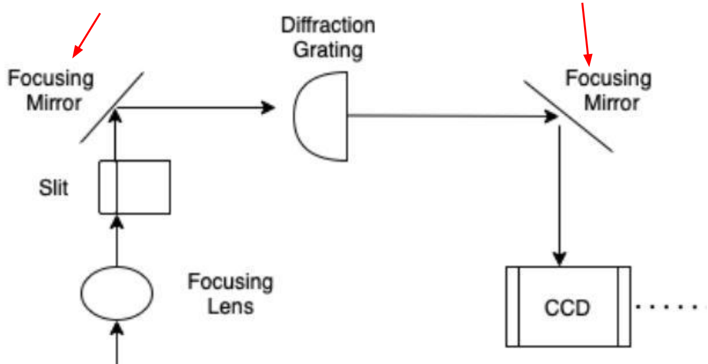
- The slit determines how much light the spectrometer (or CCD to be exact) will receive
- A slit with a larger width can:
  - **Pro**: Increase the optical power available for analysis
  - **Pro**: Reduce the time needed to acquire an accurate reading
  - **Con**: Increase the minimum difference in wavelength that can be resolved by the spectrometer
    - More difficult to differentiate colors and picture

Slit

Collimation/Dispersion Mirrors

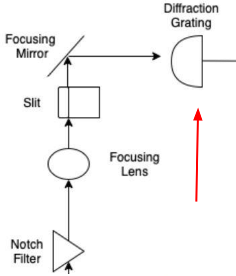
- Concave
- Aluminum
- f/1 speed
- 12mm focal length

These mirrors will be used to focus our light to the diffraction grating and then disperse the individual waveforms to the CCD.



Diffraction Grating

- The diffraction grating is in charge of dispersing the signal to the sensor
- Measured in grooves per mm (g/mm)
- The higher the groove density, the better the spectral resolution



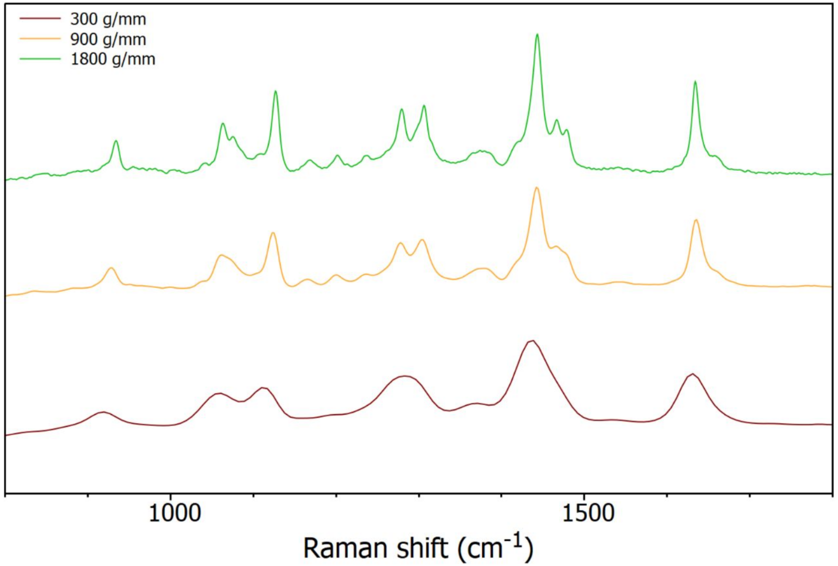
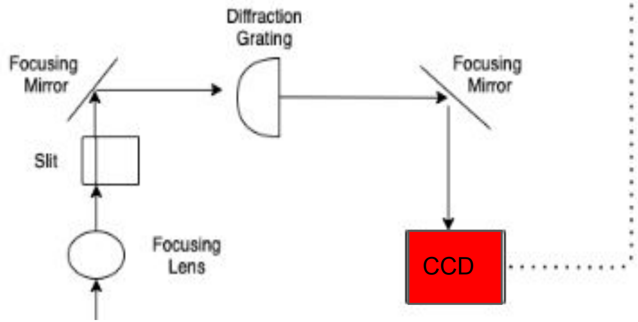


Figure 2: Raman spectra taken on the RM5 Raman Microscope of nylon-6 with a 532 nm laser and three different diffraction gratings

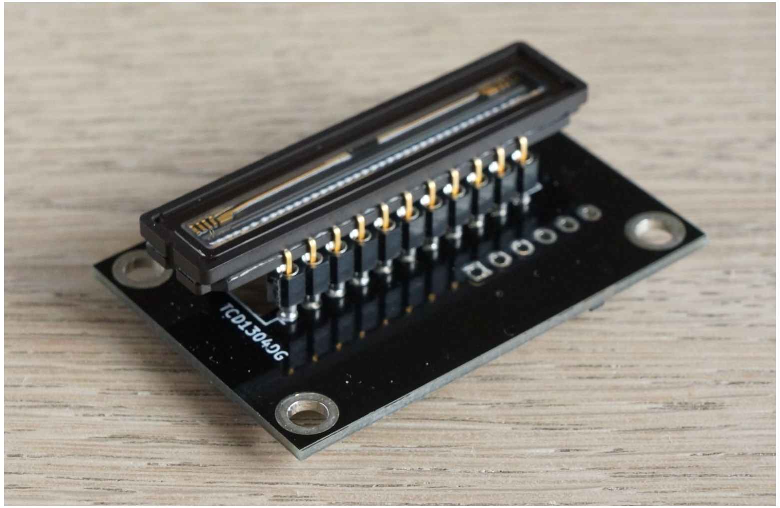
[Diffraction Grating]

Charge Coupled Detector (CCD)

- Highly sensitive photon detector (camera); more sensitive than a photodiode making it great for capturing the low sensitivity raman response
- Linear (one dimension) image sensing; 3694 spectral elements for the TCD1304AP
- With precise alignment the diffracted raman response will cover the CCD pixel range.



TCD1304AP



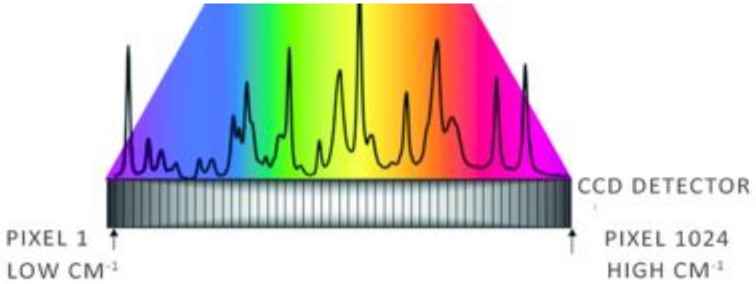
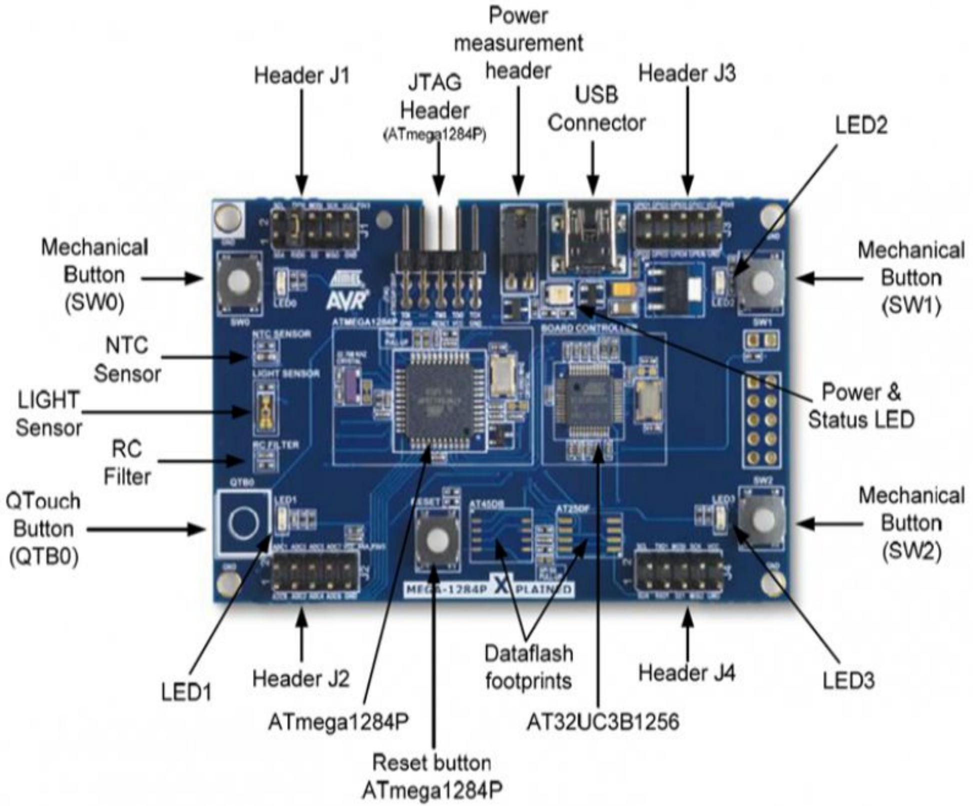


Fig 30: CCD Detector

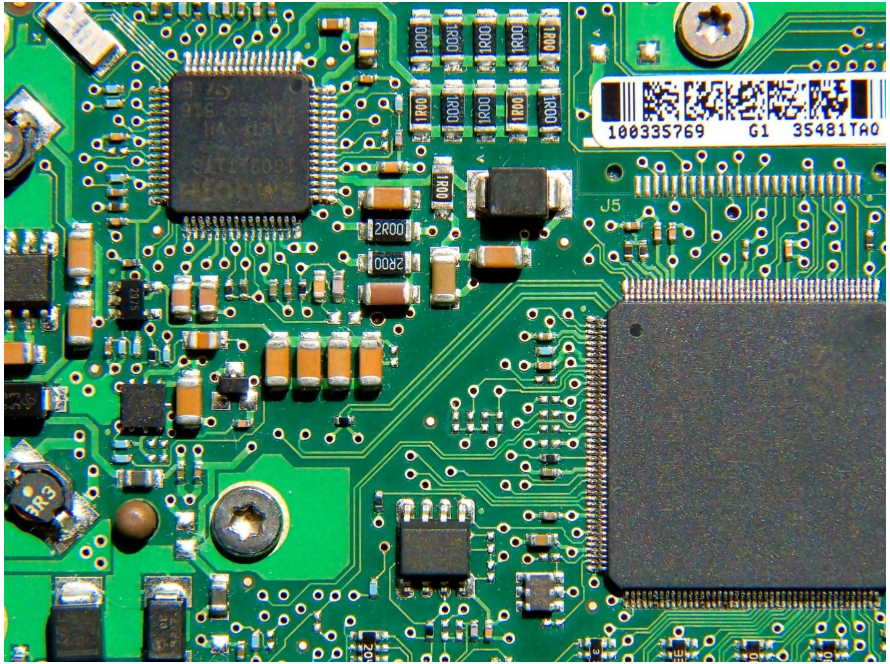
CCD Image Spectrum Image

Microcontroller - MDR

- USB Connector allows for serial connection to board from laptop
- Controls the flow of the optical sensing, interfacing with both the laser and CCD
- Provides the necessary computational capabilities to analyze sample data
- AVROSP Bootloader allows for external programming of board (Arduino firmware for example)
- 16KB Memory allows for the required RAM to capture the full CCD pixel array

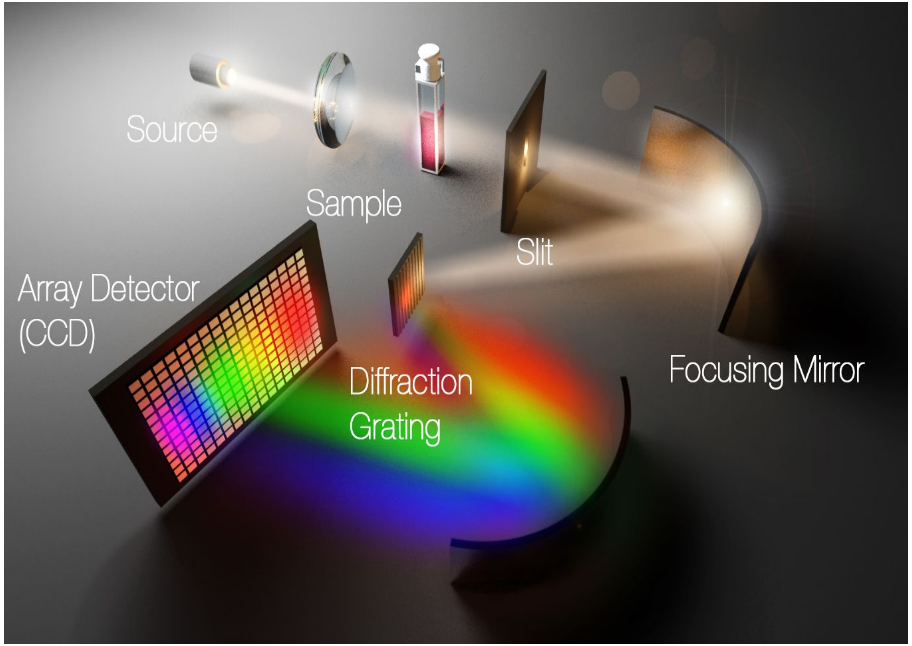


PCB



- Sensing the Raman response
- House CCD sensor, ADC, microcontroller
- Read data from CCD
- Transmit Data to user via Bluetooth

MDR Deliverables: System



- Complete optical chamber, built around a development board
- Physical spectrometer linked to user interface via serial monitor to display results of the laser detection
- Workbench ready breadboard solution

MDR Deliverables: Testing

- Mix 10 samples of distilled water with 1 mg to 10 mg of blended polyethylene
- Run system on these samples and compare results against actual known quantities of plastic
- Test system on other types of plastics and in muddy water to get false positive rate

Team Member Responsibilities

Aaron:

Team Coordinator

Optical Design Lead

Aidan:

PCB Design Lead

Victor:

Lead Software Developer

Adrian:

Hardware Specialist

Projected Expenditures

Component	Item	Units	Cost/Unit	Total
635nm laser	Laser Diode	1	$0.00	$0.00
Laser Line Filter	Optical Bandpass Filter	1	$70.00	$70.00
Focusing Lens	Achromatic Focusing Lens 7.1mm Working Distance	2	$18.98	$36.96
Quartz Cuvette	Quartz Cuvette - Amazon	1	$21.94	$21.94
Notch Filter	632.8nm, 12.5mm Diameter, OD 4.0 Notch Filter	1	$245.00	$245.00
Slit	Diaphragm with 4 Double Slits of Different Spacings	1	$22.19	$22.19
Diffraction Grating	Diffraction Grating, 1000 lines/mm	1	$1.80	$1.80
CCD/Photodiode	FDS100 - Si Photodiode	1	$14.94	$14.94
MCU	ATMega1284P-PU	1	$7.26	$7.26
Dev Board	ATMEGA1284P-XPLD	1	$0.00	$0.00
PCB	Custom PCB	3	$25.00	$75.00
Focusing Mirrors	Concave Focusing Mirror	2	$36.50	$73
			Total Sum:	$568.09

Gantt Chart

	Task	Start Date	End Date	Team Members
Hardware				
	Print Mounts	10/04/21	10/08/21	AB & AM
	Setup Laser, lenses and mirrors	10/06/21	11/05/21	Whole Team
	Test with samples and calibrate	11/02/21	11/15/21	AA & AB
	Make enclosure	11/16/21	11/19/21	VL & AA
	Test system within enclosure	11/22/21	11/26/21	Whole Team
Software				
	Interface with external ADC	10/18/21	10/27/21	AM & VL
	Calibration and Signal Manipulation	10/26/21	11/15/21	AM & VL

Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F
10/04/21-10/08/21	10/11/21-10/15/21	10/18/21-10/22/21	10/25/21-10/29/21	11/01/21-11/05/21	11/08/21-11/12/21	11/15/21-11/19/21	11/22/21-11/26/21

https://docs.google.com/spreadsheets/d/1OHg3hsFPrn7y8HzGHCxtCrHnbmyyK7mWF9AoY363IB4/edit#gid=0

Questions?

Thanks for your time!