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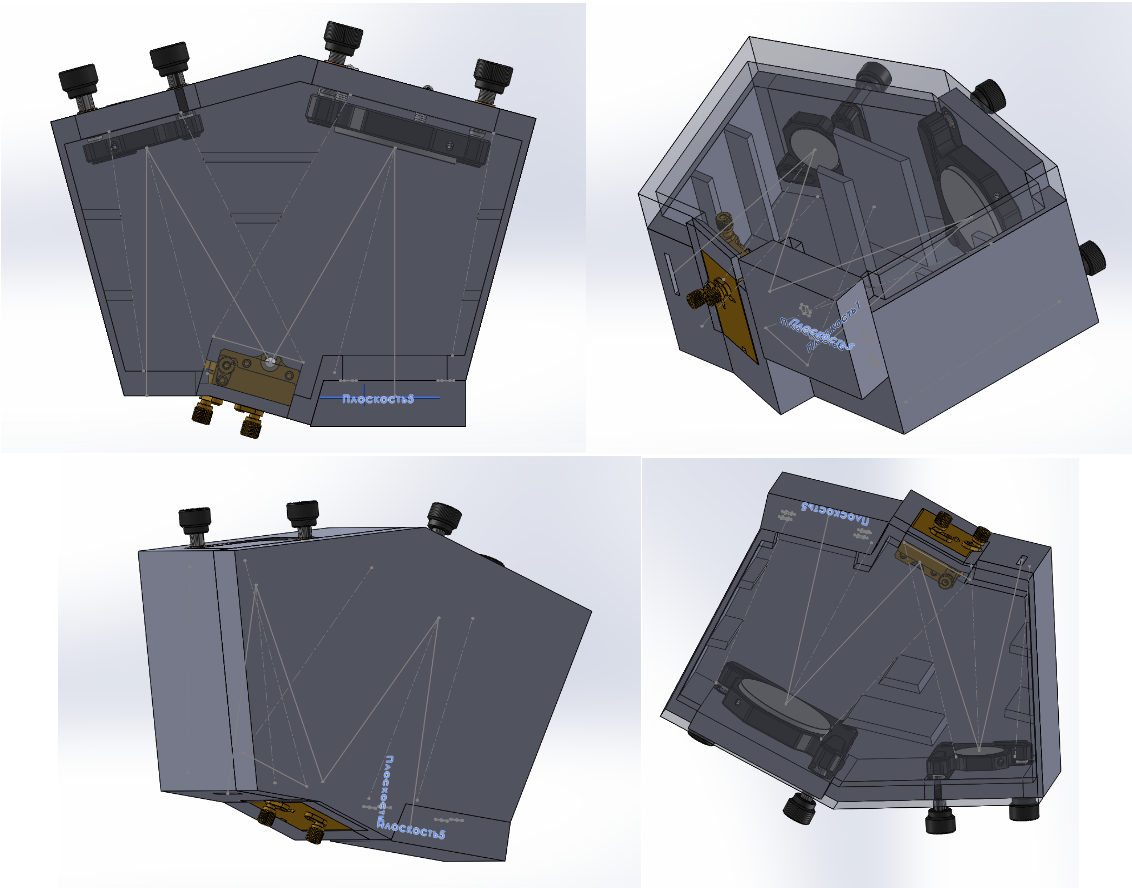
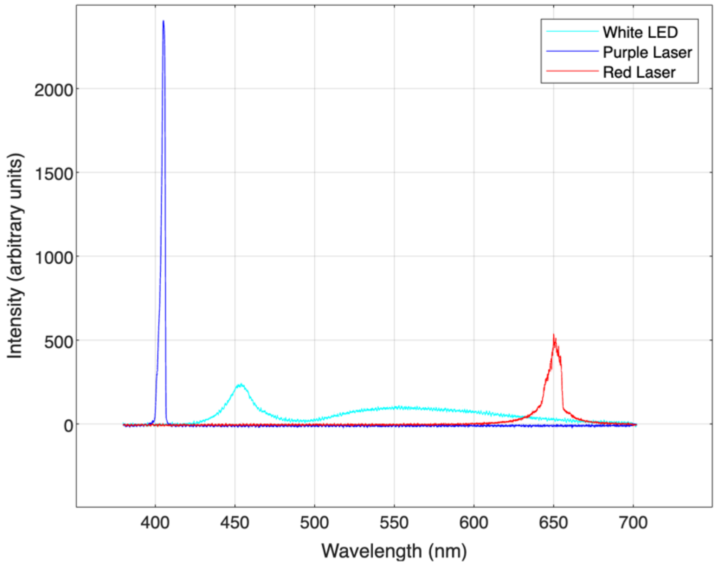
Insert an image of your CAD model here, and note any modifications or improvements made:



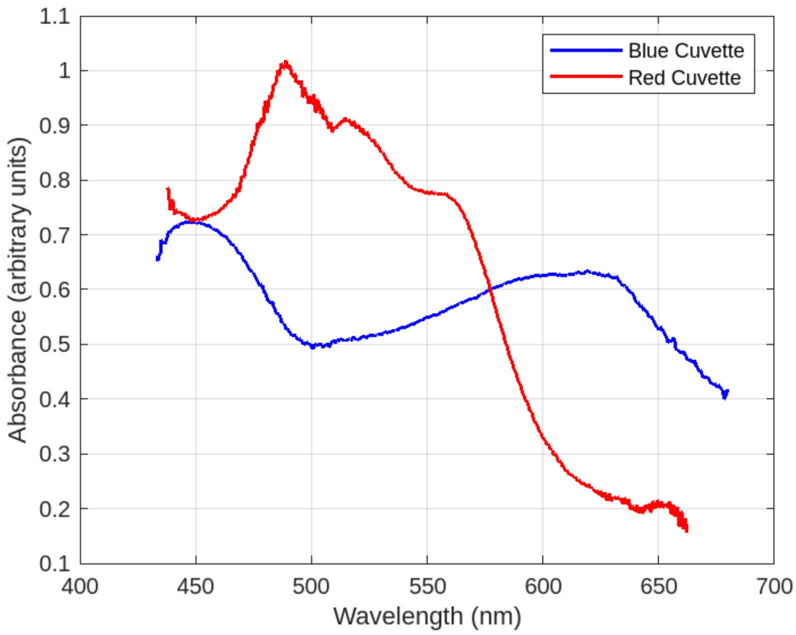
Proper enclosure was achieved for the spectrometer by adding a top lid, along with several external enclosures, to fully cover the spectrometer, including a separate enclosure for the CCD. Additionally, six light baffles were installed at various locations inside the spectrometer. This process involved first tracing the beam path from the slit to the CCD via the mirrors and the grating with adequate padding in a base sketch. Then, two baffles were in three different areas lying outside the traced boundaries. These can be seen in the figures above, particularly in Figure 1. The primary objective behind adding the baffles was to eliminate any additional light scattering that might occur inside the spectrometer. The decision to use two baffles in each location was made by balancing efficiency and minimizing the amount of material used for 3D printing.

Insert smoothed absorbance spectra of the red and blue dyes, with accurate wavelength axes here:



Unfortunately, due to an unforeseen issue, we were unable to save the data for all three of our laser calibrations, despite successfully saving every other spectrum. As a result, we had to rely on demo data for the calibration of only the red and purple lasers. Consequently, there is a notable disparity in intensity between the absorbances of the demo lasers and the White LED data we collected. We suspect that this difference is attributed to the relatively narrow slit size, which may have resulted in less light input compared to what was captured in the demo data spectra.

Insert unsmoothed spectra of the white LED and the three calibration lasers here, with accurate wavelength axes:



Here, we can clearly notice the difference between the absorbance curve calculated for the blue and red cuvettes even though demo-data was used for calibration.

Questions

1. **$\Theta_{incident}$ was set to 46.064deg previously, when you were constructing the CAD model. Derive this value using the grating equation $\mathbf{d}\left(\sin \boldsymbol{\theta}_{incident} + \sin \boldsymbol{\theta}_{reflected}\right) = \mathbf{m}\boldsymbol{\lambda}$. You will need to know the following information: the grating frequency is 900 line-pairs per millimeter, which means the period *d* is 1mm / 900 = 1.11 × 10^{-6}m. The angle between $\Theta_{incident}$ and $\Theta_{reflected}$ is 60deg, and you may assume that the spectrum's center wavelength is 532nm. The desired diffraction order *m* is 1. Don't forget that angles are measured from the *surface normal*, and $\Theta_{reflected}$ will be negative. As a hint, you may find the following useful: $\sin(x) + \sin(x - 60°) = \sqrt{3}\sin(x - 30°)$**

   We know the grating equation: $d\left(sin(\theta_{incident}) + sin(\theta_{reflected})\right) = m \cdot \lambda$

   We also know the following values:
   - $d = 1.11 \cdot 10^{-6} m$
   - $\mathrm{m} = 1$
   - $\theta_{\mathrm{reflected}} = \theta_{\mathrm{incident}} - 60°$
   - $\lambda = 532 \cdot 10^{-9} m$

   Plugging these values into the equation, we obtain:

   $$1.11 \cdot 10^{-6} m \cdot (sin(\theta_{incident}) + sin(\theta_{incident} - 60°)) = 532 \ \cdot 10^{-9} m$$

   Applying the given trigonometry property, we simply the equation to:

   $$\sqrt{3} \cdot sin(x - 30°) = \frac{266}{555}$$

   After further simplification, we get:

   $$x - 30° = arcsin(0.2767120) = 16.06406°$$

   Thus,

   $$x = 30° + 16.06406° \ = 46.0.6406°$$

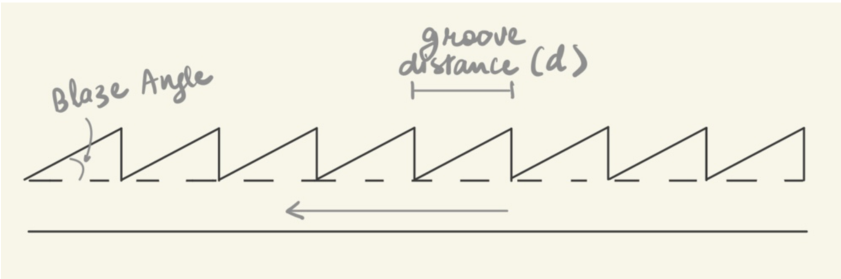
2. **Why is 532nm a good wavelength to define the grating angle?**
   When converting the positions to the wavelength using the calibration curve obtained from the laser, we determine that the range of wavelength spectra is between 350nm and 700nm. The 532nm wavelength is ideal for defining the grating angle as it falls in the center of the wavelength spectra range, ensuring optimal distribution of the spectra. Defining the grating angle at a wavelength lower than 532nm may result in some of the lower wavelength light not being captured on the CCD. Conversely, if the grating angle is defined above 532nm, higher wavelength light captured by the CCD might be trimmed.

3. **What purpose does the entrance slit have? What will happen if it is too narrow? Or too wide?**
   The entrance slit is positioned at the focus of the first curved mirror, which serves to collimate the light onto the diffraction grating. The grating then directs the light to the larger curved mirror, which, in turn, directs light of the same wavelength to a specific spot on the CCD. If the entrance slit is too wide and allows a larger column of light to enter, there will be an overlap in the spectra obtained on the CCD that cannot be differentiated.

The width of the slit is a crucial parameter to control as it effectively determines the resolution. A narrow slit allows the larger curved mirror to direct the light more sharply into a narrower space on the CCD. Conversely, if the width is too great, a blurry signal might be obtained.

Additionally, the width of the slit controls the intensity. A larger opening allows more light to enter, resulting in a higher intensity. Conversely, for a smaller width, the intensity integration window might need to be increased to capture a sufficient number of photons.

4. **What does the term 'blaze angle' signify? Draw a diagram of the grating at very high magnification, and explain what the arrow on the grating signifies.**



The diffraction grating surface contains small blazes across its surface to selectively disperse light of different wavelengths. The angle between each blaze and the horizontal surface is known as the blaze angle. This angle is adjusted to optimize the grating efficiency for light of a specific wavelength – the blaze wavelength. Light with wavelengths larger or smaller than the blaze wavelength is dispersed with lower intensity. Therefore, tuning the blaze angle is crucial in a spectrometer. The arrow indicates the direction of the blaze. If an individual blaze is considered as a right-angle triangle, then the direction of the arrow points toward the tip where the hypotenuse touches the base, while the direction away from the arrow points toward the tip where the perpendicular touches the base.

5. **What value should be used for R1, the series resistor for the white LED? Resistors are not available in arbitrary values; they have a range of standard values. Which should be used and why?**

We know the equation to calculate the value of resistor R1 (as given in the handbook):

$$R_1 = \frac{V_s - V_f}{I_f}$$

By plugging in the values for the source voltage, forward voltage, and the forward current, we obtain:

$$R_1 = \frac{(5 - 3.2)V}{20 \cdot 10^3 A} = 90\ \Omega$$

If we're unable to obtain a 90-ohm resistor, than multiple resistors can be combined in series (if resistors of smaller resistances are available) or in parallel (if resistors of larger resistances are available).

6. **Why is the absorbance at either edge of the spectrum particularly noisy? How might you overcome this difficulty were you designing a real spectrometer?**
   Since the intensity values are maximum between 300 to 700nm, the signal-to-noise ratio within this range is quite high, resulting in a smooth absorbance curve during calculation. Towards the edges, however, due to the lower intensity of light captured by the CCD, the signal-to-noise ratio in the absorbance ratio decreases, leading to high-frequency fluctuations. Coating the inside of the spectrometer black can reduce noise and minimize unwanted reflections. Additionally, extending the duration for light capture can increase intensity intake, which may generally improve the entire spectrum and help smooth the edges. Device recalibration might also be beneficial.

7. **How could you use this spectrometer to measure the fluorescence spectrum of a cuvette full of dye? What extra equipment would be needed?**
   The fluorescence spectrum of a cuvette filled with dye can be easily measured by making a slight modification to the light holder module, specifically the LED holder. By adjusting the LED holder to hold the cuvette perpendicular to the direction of light propagation and submerged to a sufficient depth, we can ensure accurate measurements. Using an LED, we can then capture the entire fluorescence or absorbance spectrum.

   In this setup, with minimal alterations, the LED is directed across the cuvette, and the resulting diffraction signals are recorded on the CCD. These signals are then processed and converted into a comprehensive fluorescence spectrum.

If there were any difficulties or problems during the experiment (such as equipment not working), note them here:

We were unable to save the intensities of lasers while conducting the experiments. For the same reason our calibration might not be completely precise.