Company: GVSU Chemistry Department
Sponsor: Dr. George McBane

GVSU Advisor: Professor Karl Brakora

Measuring the Fluorescence of $[\mathrm{Ru(bpy)_3}]^{2+}$

Engineers: Jacob Cartwright, Ethan Lewis, Richard Critchlow, Hoan Lam, Andrew Kruse

Abstract

The fluorescence decay time of a material provides insight into a material's physical-chemical properties. This project will allow for the accurate measurement of fluorescence decay time of an aqueous solution of $[\mathrm{Ru(bpy)_3}]^{2+}$ at varying concentrations. This will be accomplished by placing a $[\mathrm{Ru(bpy)_3}]^{2+}$ solution in a standard cuvette.

The electrons of the $[\mathrm{Ru(bpy)_3}]^{2+}$ ions will then be excited by a light pulse producing photons with a wavelength of 450 nm. A 650nm optical filter and an avalanche photodiode (APD) will then be used to filter and collect the fluorescing photons. The current out of the ADP will be converted into a voltage waveform using a transimpedance amplifier. A series of voltage amplifiers and signal processing filters will be used to output a voltage waveform with an amplitude large enough to be measured on an oscilloscope.

Background

Measuring the fluorescent decay of $[\mathrm{Ru(bpy)_3}]^{2+}$ is difficult for two main reasons. The first is that the quick fall time of around ~450nm means that the excitation source must have a fall time significantly lower. It was determined that maximum fall time 100ns would be acceptable for the excitation source.

The second issue was finding a high-speed light sensor that could capture $[Ru(bpy)3]2+$ fluorescence decay while also creating an observable waveform. A high speed, low light, Avalanche Photodiode (APD) was selected. APD's are susceptible to both electric and light noise which needed to be considered in the system's design

$[\mathrm{Ru(bpy)_3}]^{2+}$ has an absorption and emission frequencies as seen in Figure 1. The absorption range shows how well $[\mathrm{Ru(bpy)_3}]^{2+}$ absorbs certain frequencies of light and the emission frequency shows what frequencies of light are emitted during the fluorescent decay. $[\mathrm{Ru(bpy)_3}]^{2+}$'s peak absorption is around 450 nm (blue) and it emits at a peak frequency of 625 nm (orange).

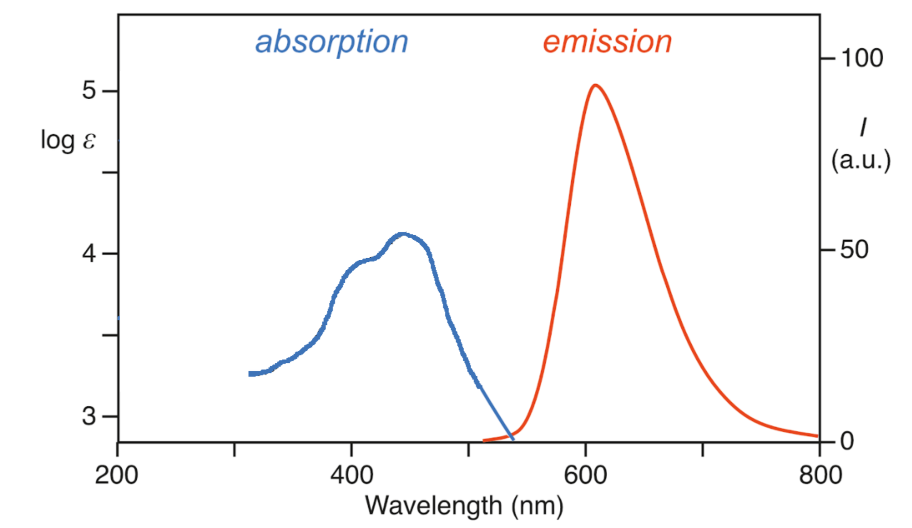

Figure 1. Absorption and Emission rates of $[\mathrm{Ru(bpy)_3}]^{2+}$

source: https://chem.libretexts.org

The Design

To create a usable device that could excite the $[\mathrm{Ru(bpy)_3}]^{2+}$ and collect a usable sample a three-stage system was built:

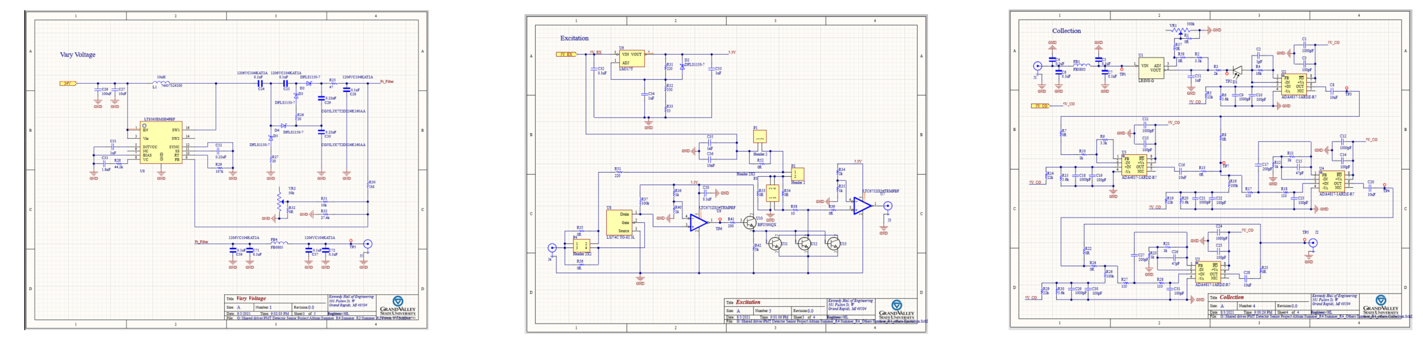

Figure 2. Power, Excitation, and Collection Design Schematics

1. Power Stage
   A power circuit was created that is separable from the main board. The power board provides both a 5V DC source and a high voltage DC source (196V) from a standard 120V AC wall outlet.

2. Excitation Stage
   An excitation circuit uses a function generator that triggers a focused blue LED to excite the $[\mathrm{Ru(bpy)_3}]^{2+}$. The circuit also uses quick RF transistors to ensure the LED fall time is under 100ns.

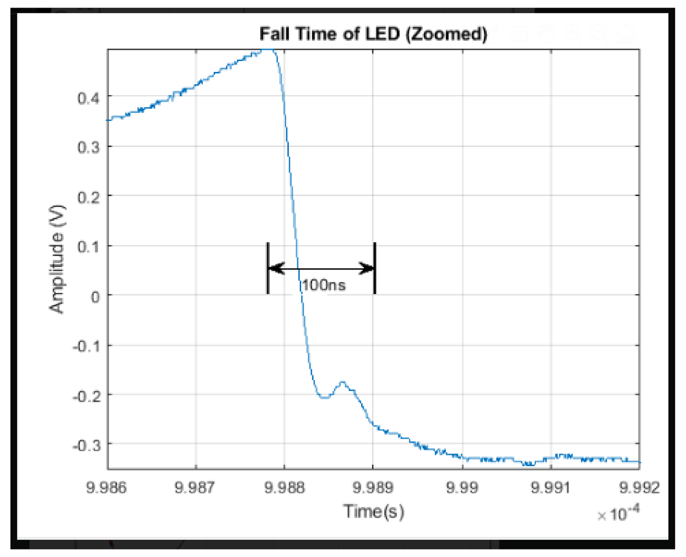

Figure 3.
Fall Time of Excitation Source (Blue LED)

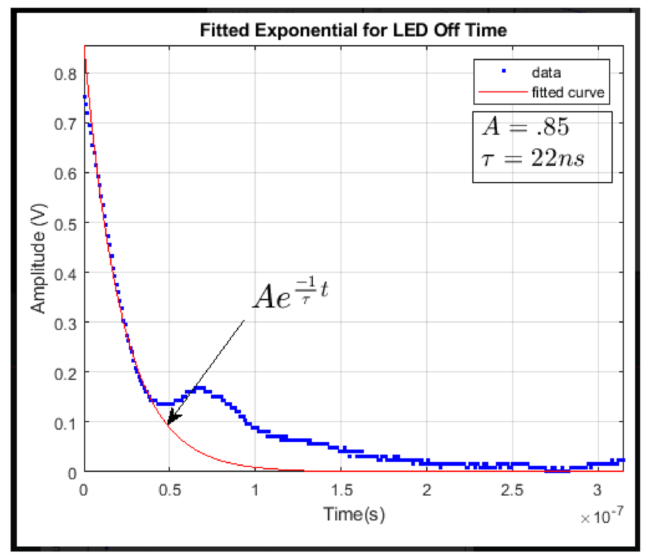

Figure 4.
Fitted Exponential showing a time constant of 22ns

3. Collection Stage
   The collection circuit uses an adjustable gain knob to adjust the voltage going to the APD. The APD converts the light from the $[\mathrm{Ru(bpy)_3}]^{2+}$ into a small (~10uA) current. A transimpedance amplifier followed by gain stages and signal filters are used to boost the signal above 100mV.

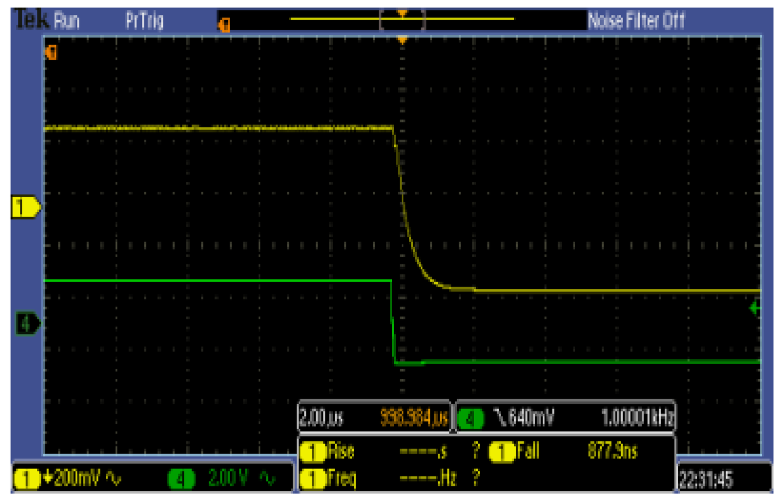

Figure 5.
Screen Capture of Final Output Signal

The Result

The final design is able to accurately measure the fluorescent decay time of the $[\mathrm{Ru(bpy)_3}]^{2+}$ at a concentration of 0.3 mM.

- The final fall time measured by the system is ~450ns.
- The SNR of the final single shot signal is ~30dB.
- The fall time of the LED is less than 100ns.

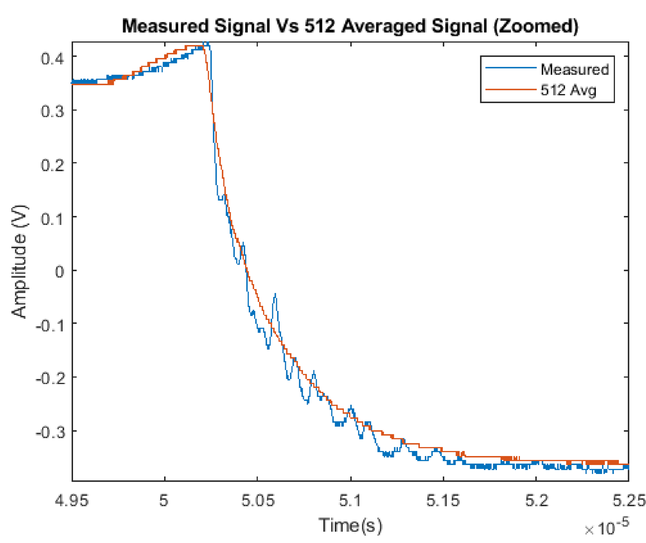

Figure 6. Single Shot vs 512 Shot Averaging.

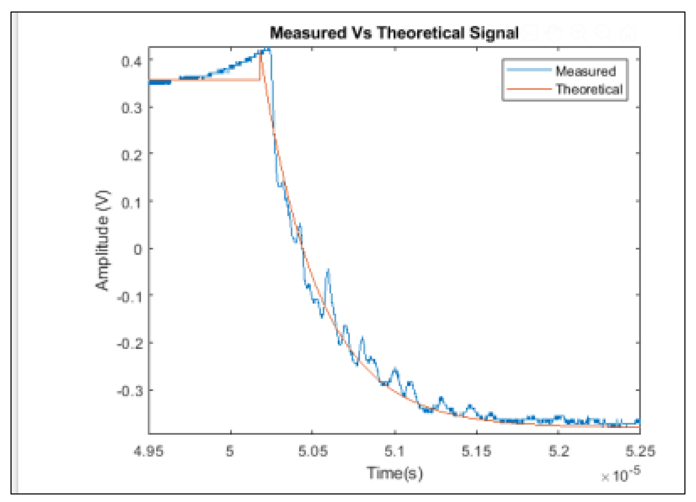

Figure 7. Single Shot Measured vs 450ns Fall Time

Purpose and Use

The GVSU Chemistry Department will use five of these systems in order to assist chemistry students' learning in a laboratory environment.

The product is set up so that it can be adapted in the future to measure other chemical solutions other than $[\mathrm{Ru(bpy)_3}]^{2+}$. Both the optical filter and the LED can be replaced depending on the absorption and emission frequencies of the chemical. Additionally, the function generator allows the LED to pulse slower for chemical solutions with longer fall times.

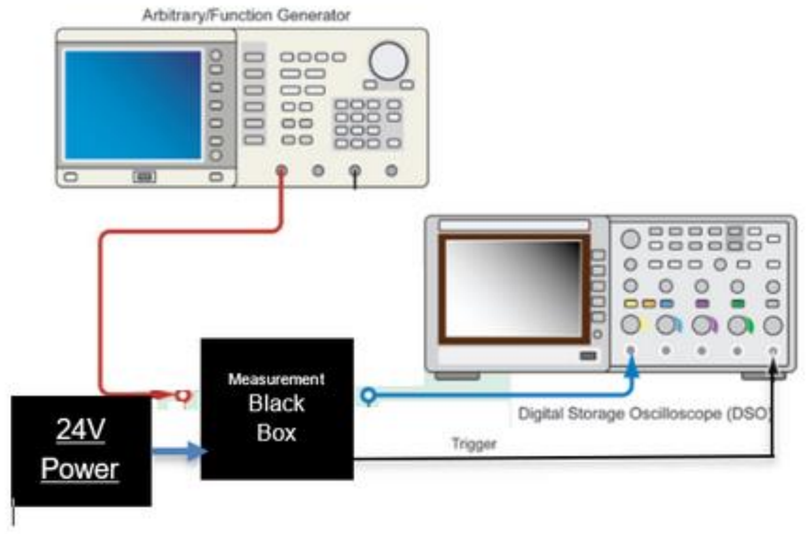

Figure 8. Laboratory Setup

Grand Valley State University