Understanding Ultrafast Phenomena through Spectroscopy – Summer Internship Project

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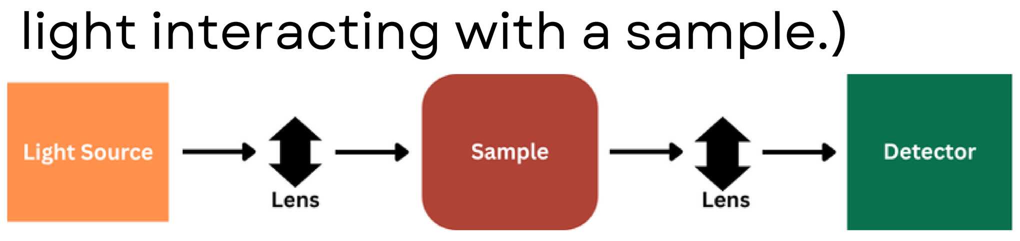
Introduction

Ultrafast spectroscopy helps scientists observe how **energy and electrons move** in materials right after light excitation – on the femtosecond scale (1 fs = 10^{-15} s). It reveals fast processes like **charge transfer, exciton dynamics**, and **energy relaxation** in molecular and nanostructured systems.

Despite progress, many ultrafast mechanisms remain unclear across different materials and wavelengths. Time-resolved methods like **emission** and **pump-probe** provide key insights into these hidden dynamics. During my internship, we used **femtosecond laser pulses** to study how samples absorb, emit, and transmit light over time. This knowledge is essential for developing better **optical devices, sensors**, and **energy materials**.

(Below is a simplified setup showing light interacting with a sample.)



Methodology

This research was based on data collected using a **Ti:Sapphire femtosecond laser amplifier**, which delivers ultrashort laser pulses for ultrafast spectroscopy experiments.

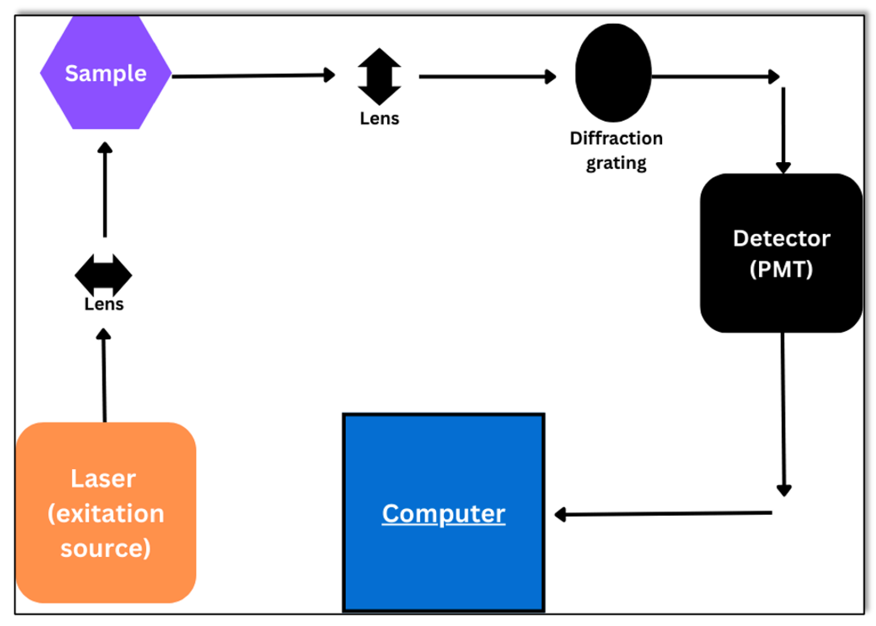
During the internship, I focused on learning and analyzing three key techniques:

- **Light Observation** – understanding how focused laser light interacts with a material sample.
- **Emission Spectroscopy** – analyzing the light emitted when excited molecules return to their ground state.
- **Pump-Probe Spectroscopy** – interpreting how delayed laser pulses reveal changes in absorption over femtosecond timescales.

Instruments included **optical lenses, beam splitters, a spectrometer, CCD detector, chopper, and data analysis software.**

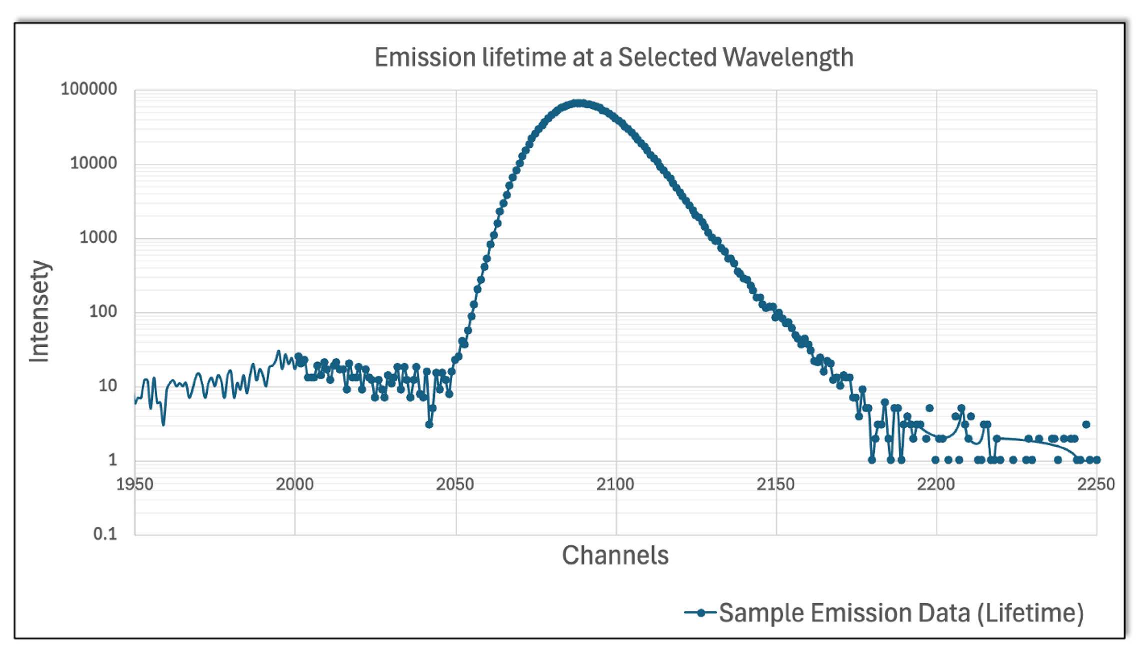
Results

Experimental Setups



Emission spectroscopy setup: laser excites sample, emitted light is analyzed by spectrometer and PMT detector.

Emission data showed a sharp peak followed by an exponential decay, revealing the **fluorescence lifetime** of the sample.



The graph shows a sharp emission peak followed by an exponential decay, representing the relaxation of excited electrons back to the ground state.

Time-Resolved Spectroscopy

Both experiments explored how **light interacts with the sample** right after excitation by a femtosecond laser.
We measured either:

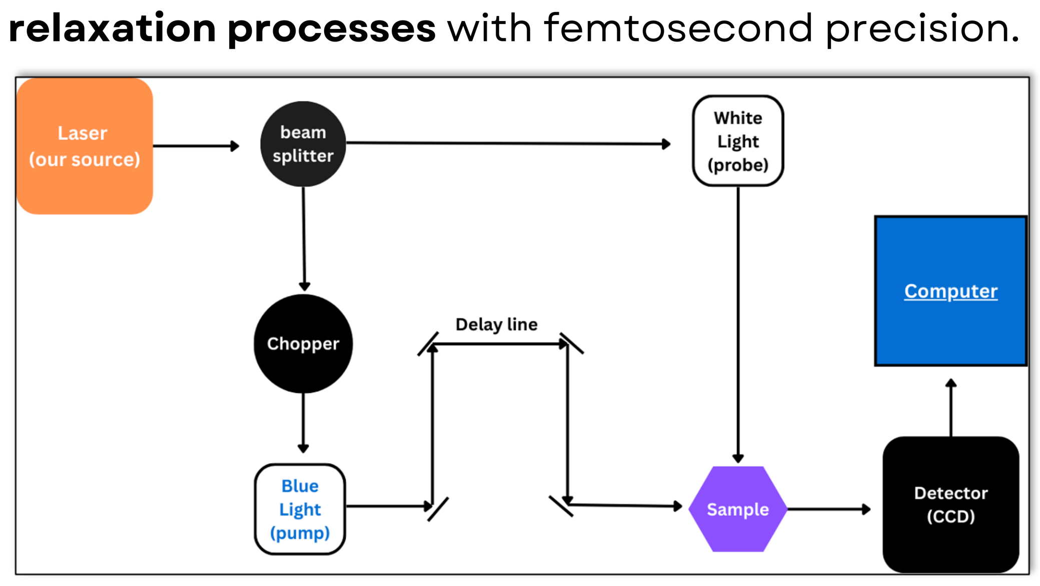
- **Emitted light** – in emission spectroscopy
- **Absorption dynamics** – in pump-probe spectroscopy

For pump-probe analysis, we calculated the **differential absorbance** using: $\Delta A = -\log(I/I_0)$

Where:

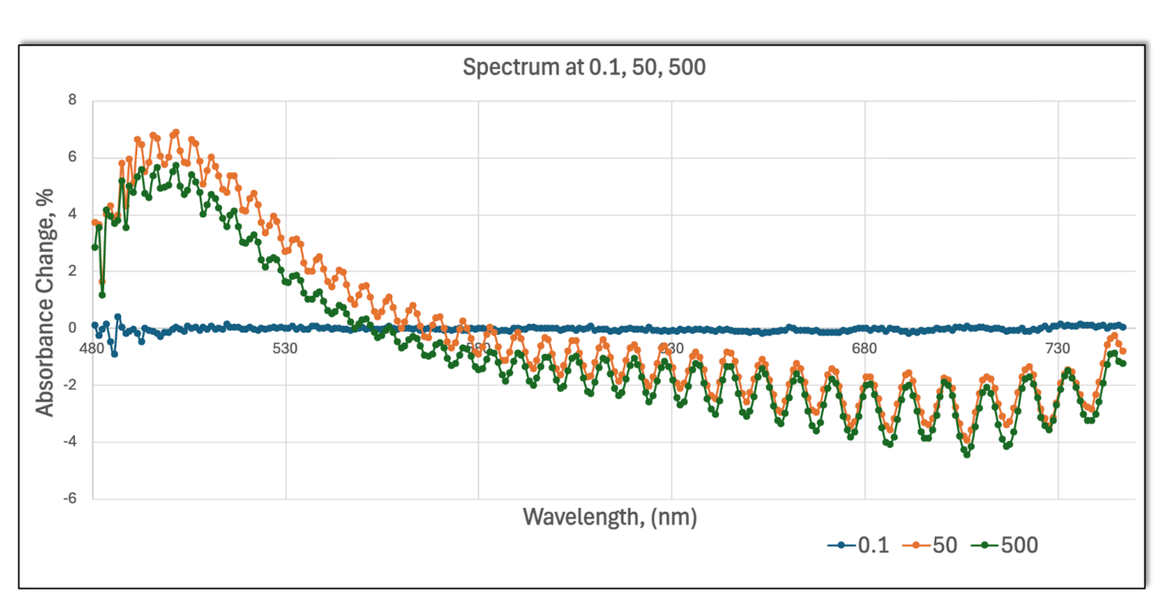
- I is the intensity of the probe with pump on
- I_0 is the intensity of the probe with pump off

This allowed us to track **excited-state behavior, energy transfer**, and **relaxation processes** with femtosecond precision.

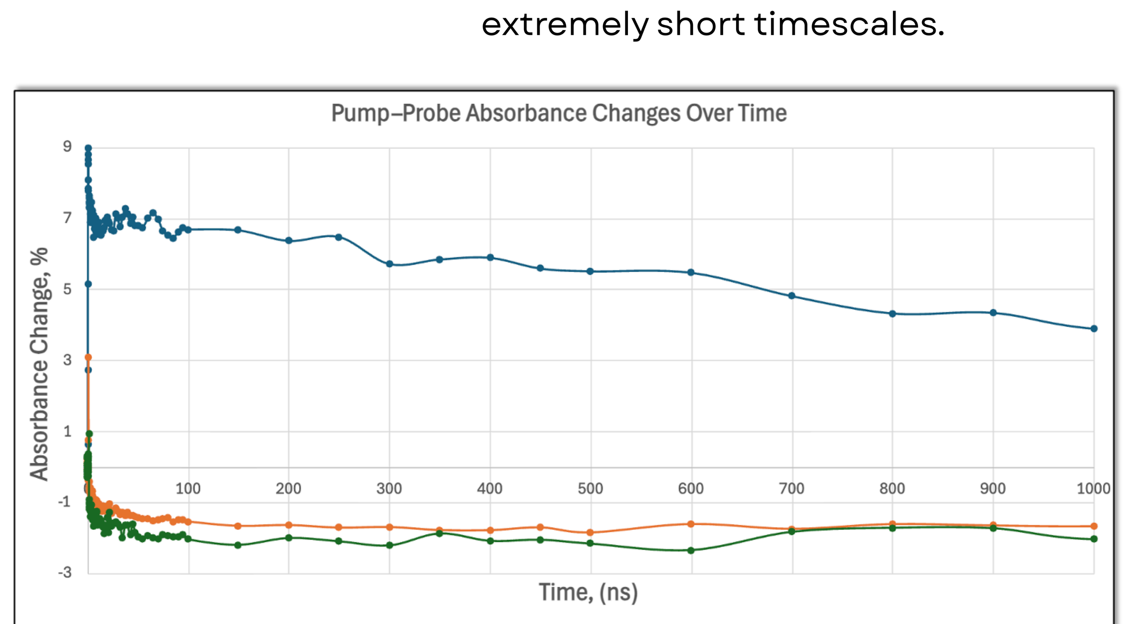


Pump-probe setup: a delayed white-light probe tracks absorption changes after excitation by a femtosecond laser pulse.

Absorbance spectra at 0.1 fs, 50 fs, and 500 fs show how energy shifts over time. Peak (around 480–520 nm) intensity decreases, and oscillations become more visible, indicating relaxation and redistribution of energy in the sample.



Pump-probe analysis revealed **absorbance changes at specific wavelengths**, with strong response near **500.79 nm**, moderate at **600.19 nm**, and minimal at **730.70 nm.** These results highlight how ultrafast spectroscopy tracks excited-state dynamics on extremely short timescales.



This graph shows the time-resolved change in absorbance (ΔA) at three different wavelengths: 500.79 nm, 600.18 nm and 730.70 nm.

Discussion

This project explored how light interacts with materials on ultrafast time scales using femtosecond laser pulses.

Emission spectroscopy showed a strong signal near **500.79 nm**, likely related to an **exciton transition**, while weaker signals from **600–730 nm** served as background. Pump-probe measurements revealed **absorption changes over time**, helping us track how excited states relax after laser excitation.

These results demonstrate how **ultrafast spectroscopy** allows us to study molecular and electronic behavior in real time – beyond the reach of conventional techniques.

Such methods are essential for research in **solar energy, quantum materials**, and **next-generation sensors.**

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References

1. "Research." *Gedik Lab – MIT Department of Physics*, Massachusetts Institute of Technology, https://web.mit.edu/gediklab/research.html.
2. "The Beer-Lambert Law." *LibreTexts*, https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Spectroscopy/Electronic_Spectroscopy/Electronic_Spectroscopy_Basics/The_Beer-Lambert_Law.
3. "Hydrogen Spectrum." *Priyam Study Centre*, https://www.priyamstudycentre.com/2019/02/hydrogen-spectrum.html.
4. Boulesbaa, Abdelkrim. "Home." *CSUN Ultrafast Spectroscopy Lab*, California State University, Northridge, https://www.csun.edu/~aboulesbaa/index.html.
5. "Pump–Probe Spectroscopy." *Encyclopedia of Analytical Chemistry*, Wiley, https://analyticalsciencejournals.onlinelibrary.wiley.com/doi/book/10.1002/9780470027318.
6. M+, S. "Ultrafast Spectroscopy – Explained." *YouTube*, uploaded by ScienceABC, 17 Mar. 2020, https://youtu.be/zuUvQN8KXOk.
7. Chemical Force. "Pump Probe Spectroscopy – Explained Simply." *YouTube*, uploaded by Chemical Force, 4 Jan. 2023, https://youtu.be/Vy71bJJ9EnU.
8. Explained Chemistry. "Photoluminescence and Emission." *YouTube*, uploaded by Explained Chemistry, 10 June 2022, https://youtu.be/p40n-xo2lT8.