

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.

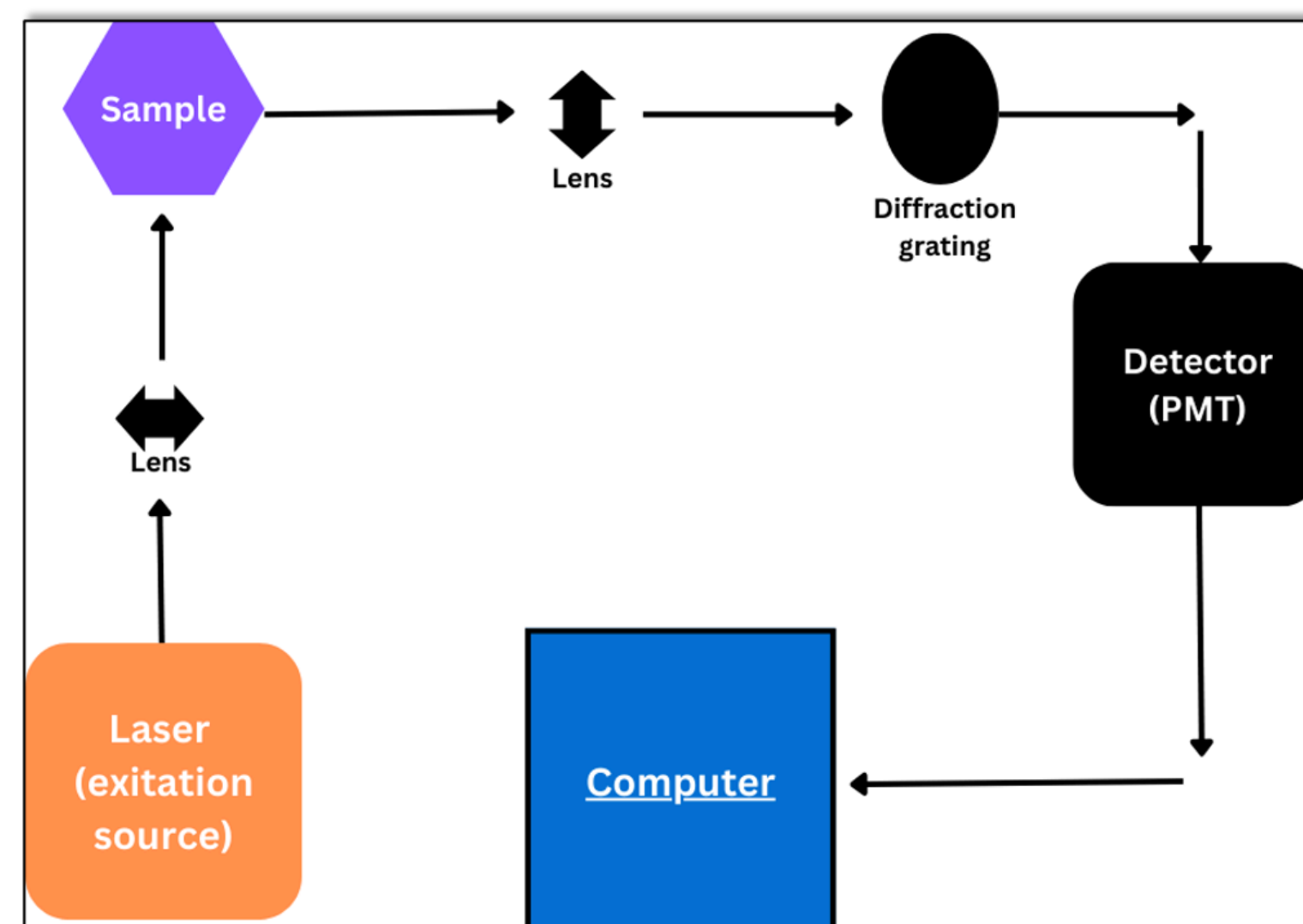
During the internship, I focused on learning and analyzing three key techniques:

- **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**.

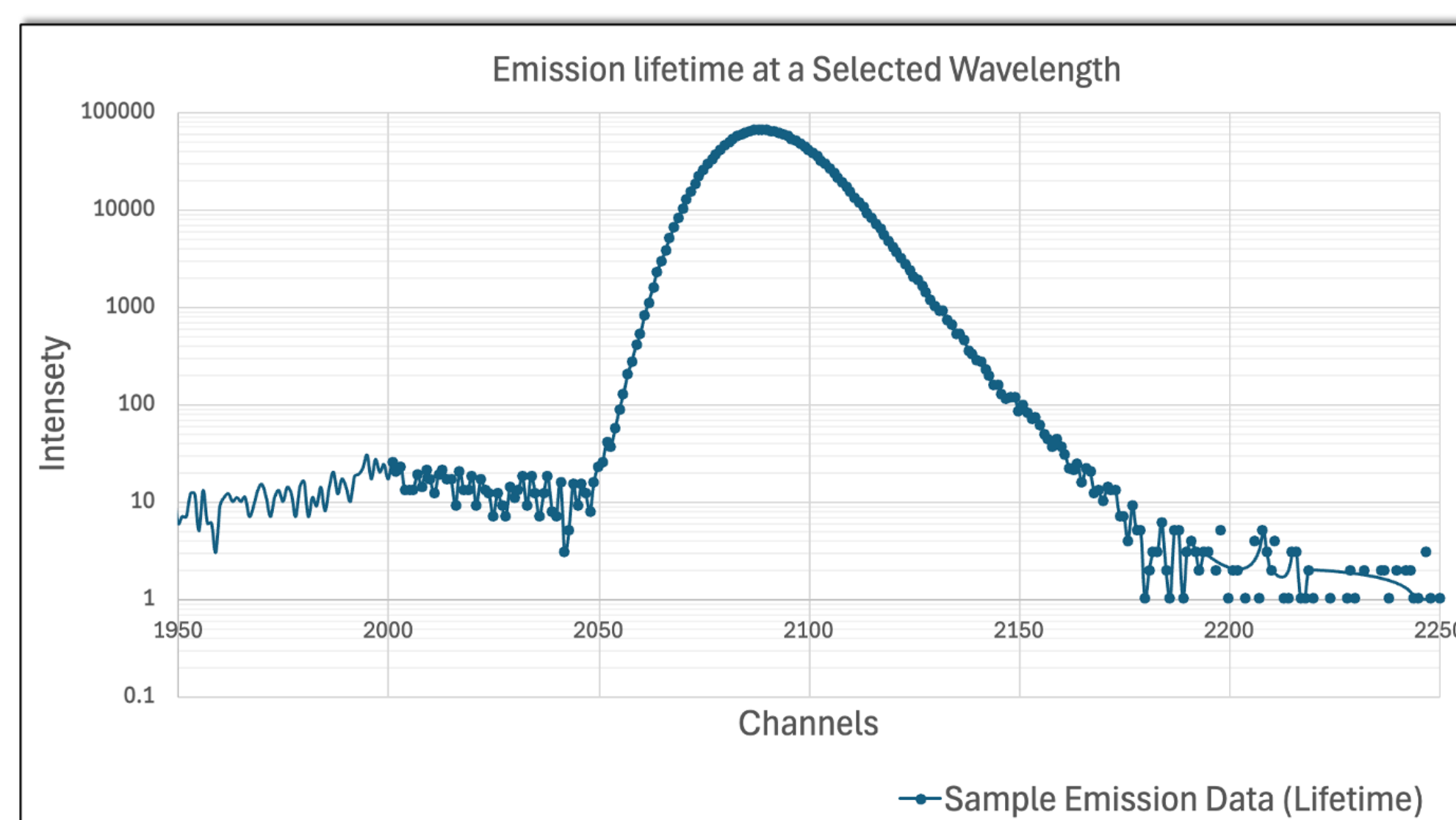
Results

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.



Time-Resolved Spectroscopy

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

We measured either:

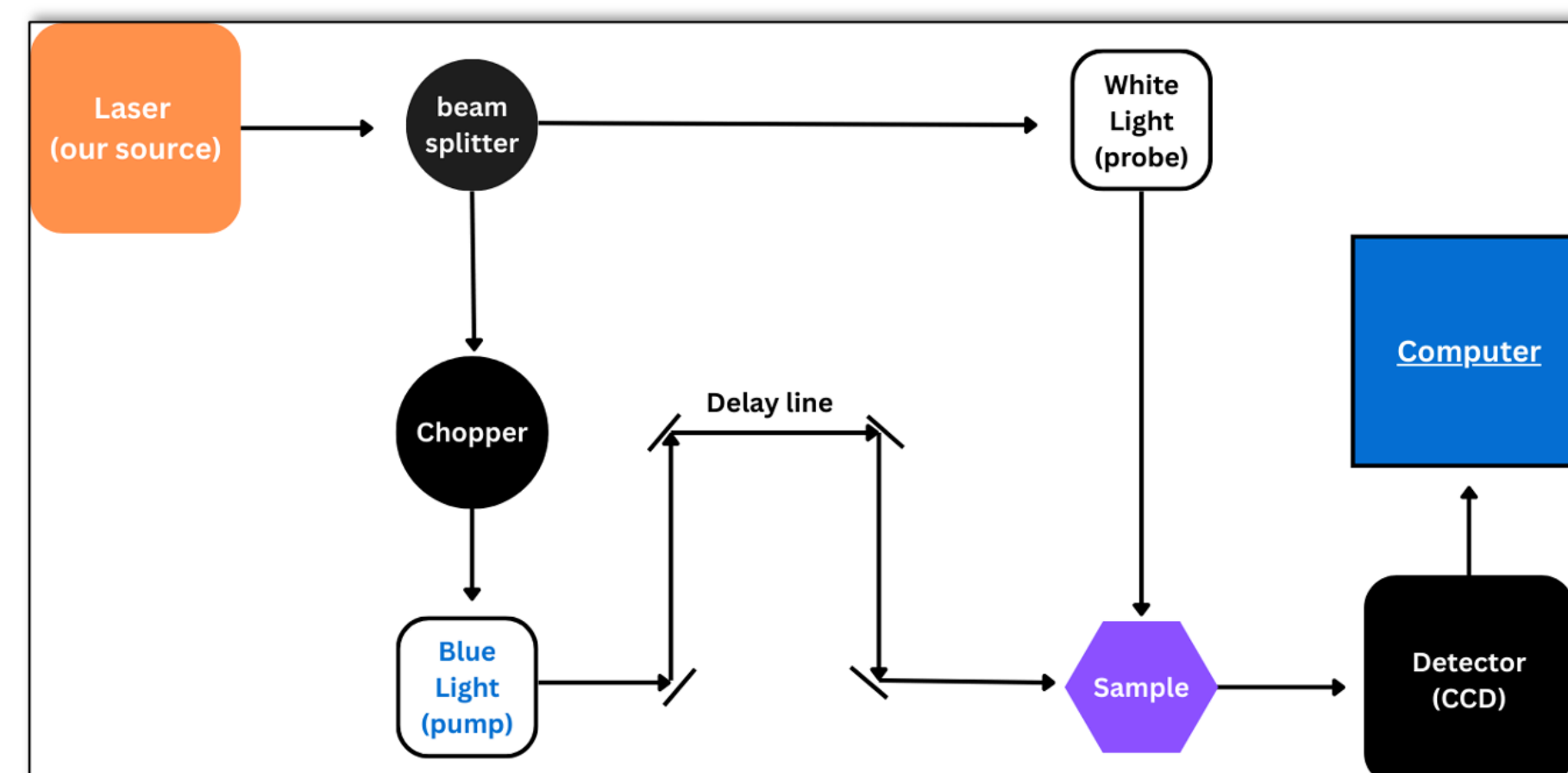
- **Emitted light** – in emission spectroscopy
- **Absorption dynamics** – in pump-probe spectroscopy

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

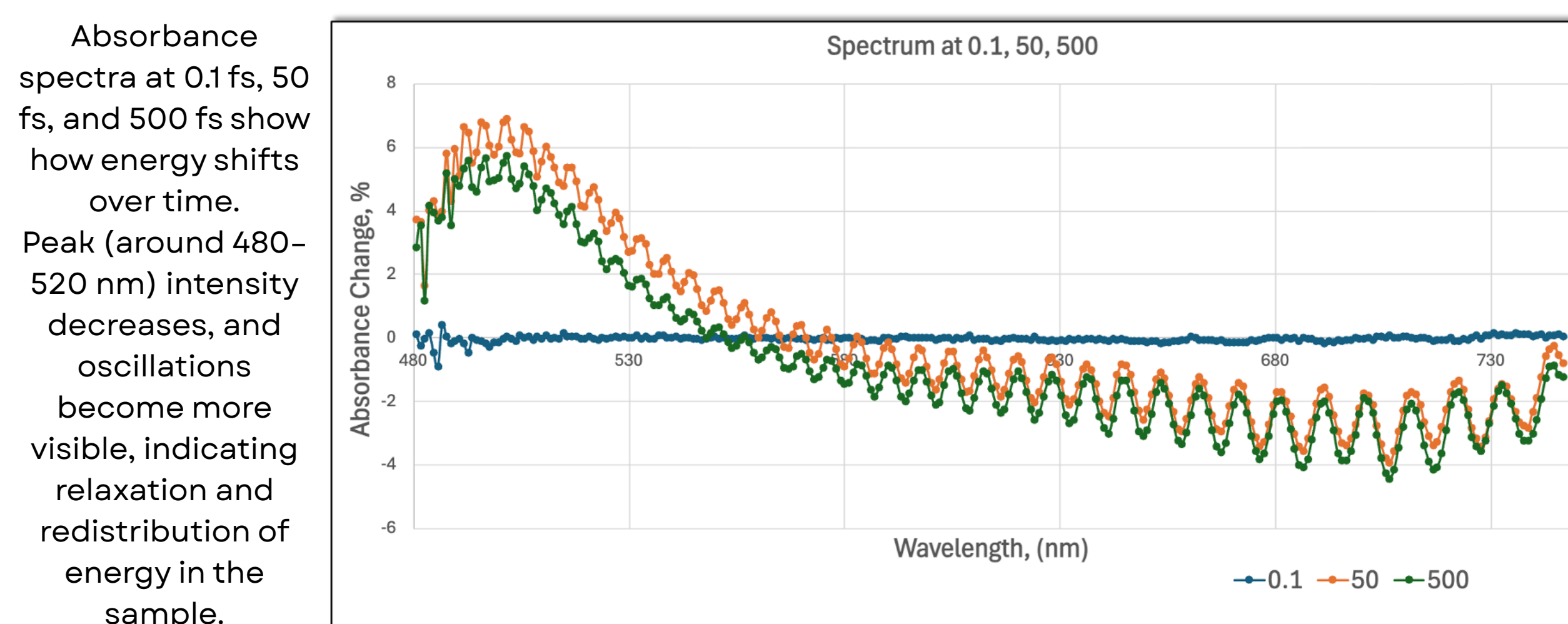
Where:

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

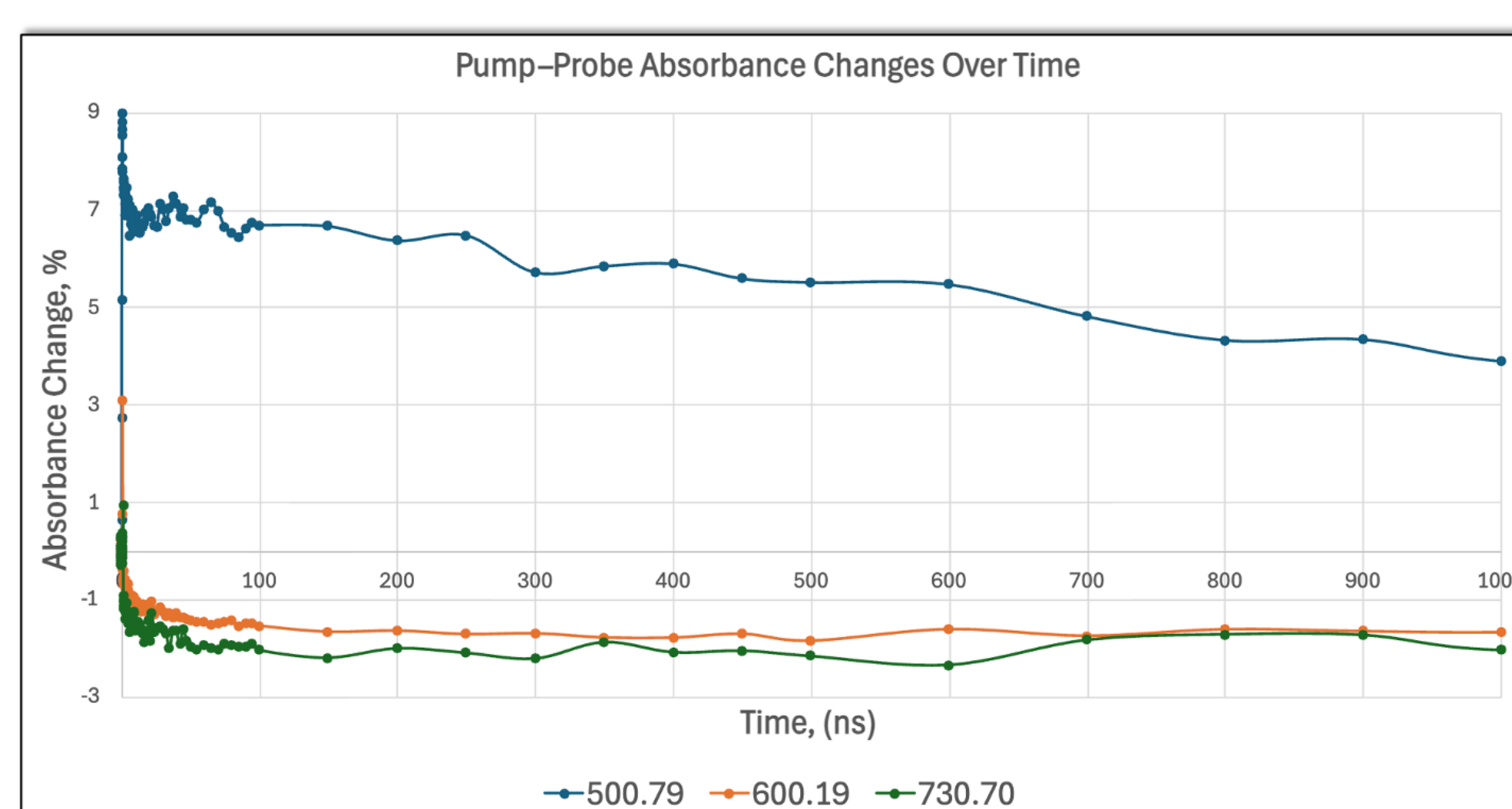
This allowed us to track **excited-state behavior, energy transfer**, and **relaxation processes** with femtosecond precision.



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



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.



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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