Ultrasensitive volumetric imaging through optical coherence tomography

Ritika Garg[1], Ethan McFarlin[2], Maxwell Adolphson[3]
[1] Saratoga High School [2] Thomas B. Doherty High School [3] University of Colorado, Boulder | B.A. Candidate

Acknowledgements
Shu-Wei Huang, Ph.D.
Kathryn Penzkover, Ph.D.

1 Purpose

Laser imaging is a technique used widely by medical professionals to obtain **cross-sectional** images below the surface of a tissue. By measuring the **intereference patterns** produced by coherent light waves, **high-resolution** images can be generated in vivo with virtually no prior **preparation** of a sample.

2 Background

Out of all imaging techniques, optical coherence tomography **(OCT)**, confocal microscopy, and multi-photon microscopy **(MPM)** stand out for their unique **sectioning capabilities.**

Optical Coherence Tomography (OCT)	Multi Photon Microscopy (MPM)	Confocal Microscopy
• Ultrahigh detection sensitivity	• Unsurpassed imaging depth	• Clear examination of thick specimens
• Ultrafast imaging speed	• Submicron-level spatial resolution	• Improved signal to noise ratio
• Limited penetration depth	• Can induce tissue damage	• Reduced imaging depth/speed

3 Objective

A **proof-of-principle** OCT configuration that maximizes imaging resolution capabilities will be constructed. This system will lay the **groundworks** for the development of a future CU imaging modality that **couples** the fast **imaging speed** of OCT with the unsurpassed **imaging depth** of MPM.

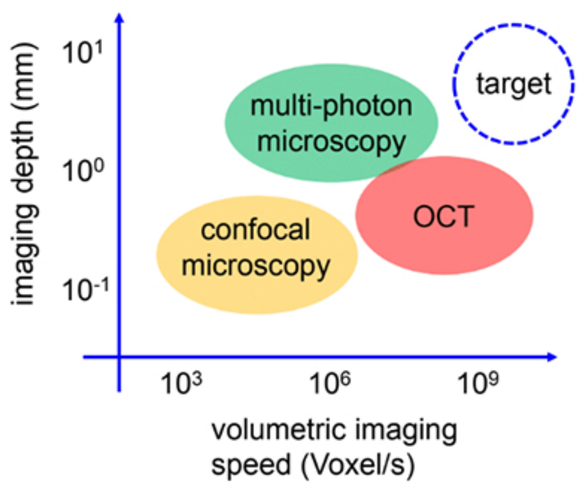

Fig. 1. compares **existing** laser imaging techniques with the **target** OCT system.

4 Engineering Goals

(1) **Align** optical componets under **OCT model**

- Use a **50/50 coupler** to split the **femtosecond laser** source into **two** paths: the reference and sample arms
- **Polarize** light source before **collimating** and **reflecting** reference wave
- Strongly **focus** light source into sample
- Measure the **interference pattern** between the **reflected** reference and **backscattered** sample waves

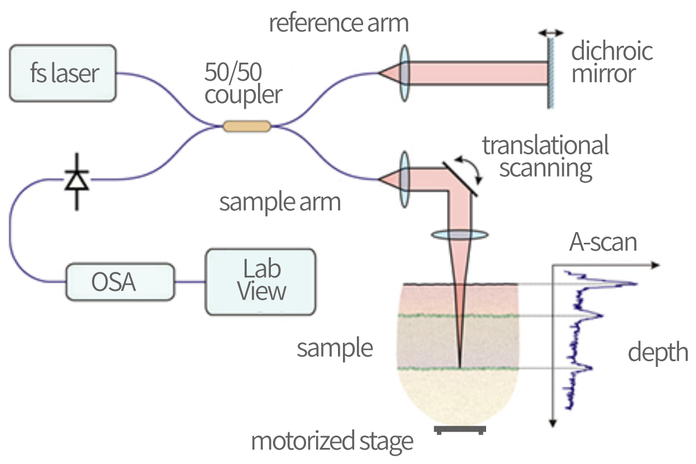

Fig. 2 depicts the optical system, which channels a femtosecond laser **(fs)** light source into two separate pathways which later **recombine** at different timings. The **backscattered** signal can be measured to **extract** volumetric information about the sample.

(2) **Develop** custom **Labview** programs to **automate** data collection

- **Interface** with an Optical Spectrum Analyzer (OSA)
- Automatically **scan** image samples

(3) **Calculate** imaging resolution

- Fast Fourier Transformation **(FFT)**
- Full Width at Half Maximum **(FWHM)**

5.1 Optical Alignment

The **travel delay** between the reference and sample arms must be within **±10** microns in order for the waves to interfere **constructively** and **destructively.**

Sample Arm Power	Reference Arm Power	Margin of Separation
17.2 μW	24.9 μW	7.7 μW

By measuring the **backscattered** signal from the reference arm, a **reflectivity** profile of the sample can be obtained. Areas of the sample that have **greater interference** will create **higher contrast.**

5.2 Axial Resolution

Signals **backscattered** from different **depths** of a sample are **amplified** at different optical frequencies.

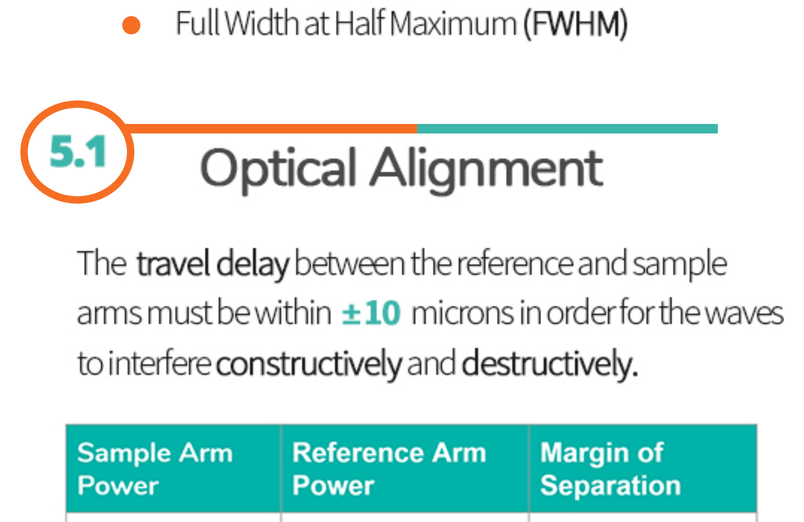

Fig. 3. By applying a Fast Fourier Transformation **(FFT)**, the **spectral** encoding is converted to a **temporal** encoding scheme, which translates a **Gaussian** wave in the frequency domain to a **Soliton** in the time domain. The interference pattern is shown above.

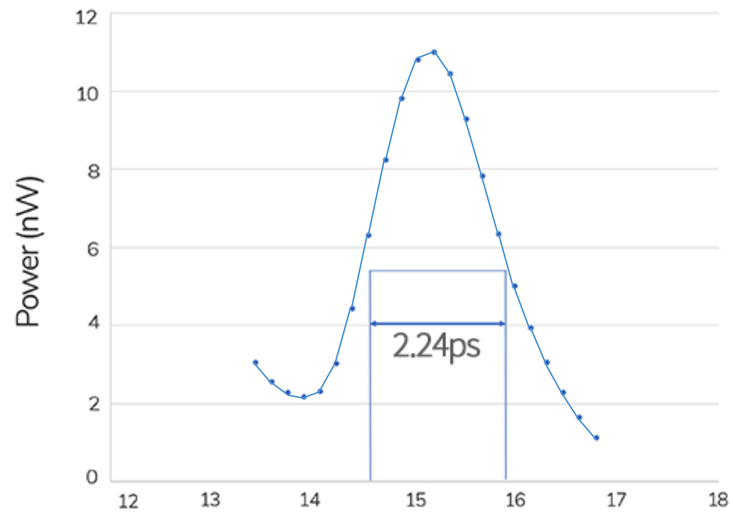

Fig. 4. A **FWHM** calculation **(2.24ps)** combined with the constant speed of light is used to determine the smallest **spatial** increment the microscope can resolve, its **axial resolution**, which was found to be **8 microns.**

5.3 Transverse Resolution

Transverse resolution, a lens' **focusing** power in the **x-y** plane, typically ranges from **3-5 μm** and correlates to higher **2D** imaging quality.

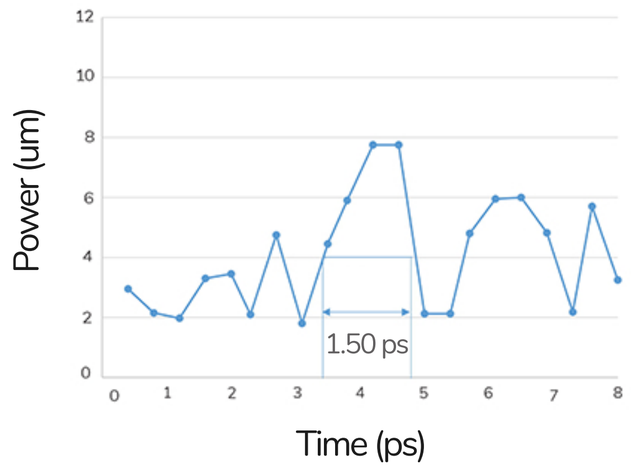

Fig. 5. Running through **FWHM** and **FFT** calculations, a transverse resolution of **4.95 microns** was obtained.

6 Conclusions

- The **travel delay (7.7 μm)** is well within the **acceptable** range of **±10** microns producing **high-contrast** interference patterns.
- An **8 μm axial** resolution achieves optimum **Z**-axis imaging quality in the preferred range of **5** to **10μm.**
- **Transverse** resolution **(4.95 μm)** is at the higher end of the **3** to **5 μm** spectrum correlating to **near-maximum** translational **XY** plane imaging quality.

7 Further Research

- With **optimum** imaging **resolution** capabilities achieved, the existing **1550 nm** laser will now be converted to a **1700 nm** signal, which can penetrate **deeper** into tissue.
- A **nonlinear** optics process called optical parametric amplification **(OPA)** can be used to **mitigate** the degraded sensitivty of the **1700 nm** signal.
- The **continued** development of this OCT system under the **Huang** research group will aim towards greater **imaging depths** and **faster imaging speeds.**