Лекция профессора Кирилла Ларина (Университет Хьюстона)

В рамках программы Фонда Дмитрия Зимина «Династия»
«Краткосрочные визиты иностранных ученых в российские научные центры»
19 сентября 2015г. – 28 сентября 2015 г.

Теоретические основы методов оптической визуализации и зондирования

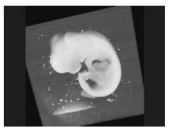
BioOpt Lab
Biomedical Optics Laboratory

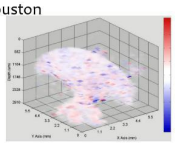
Optical coherence tomography: The basics

Kirill V. Larin

Department of Biomedical Engineering
College of Optometry

University of Houston





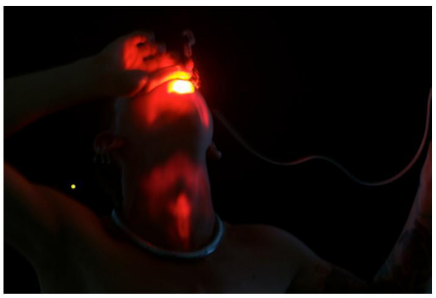
Houston

- **Houston, Texas**, the nation's **fourth-largest city** and the energy capital of the world.
- City of Houston has a 2010 population of 2.1 million (the metro area's population of **5.95 million**)
- If Houston were an independent nation, it would rank as the world's **30th largest economy**
- Houston has a Theater District second only to New York City with its concentration of seats in one geographic area
- And, of cause, Houston is the home for **NASA** and word-famous **Rodeo**

University of Houston

- **40,000 students** enrolled
- Earns **Tier One research university** distinction (Research-Very High) from the Carnegie Foundation
- Chosen as one of the nation's **best colleges for undergraduate education** (The Princeton Review, 2011)
- Among the nation's **top 50** public research universities (Top American Research University Report, 2010)
- Voted in 2014 as 3rd **most beautiful campus** in US

Introduction



4

Introduction

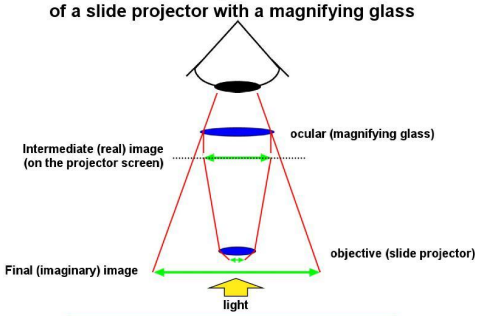
5

Introduction

- One of the most prospective trends of biomedical optics is medical noninvasive optical diagnostics and monitoring of diseases
- The complexity of tissue organization and its involvement into living organism (organ) functioning require the development of multidisciplinary approaches for description of tissue optics (or biophotonics)
- Light application in medicine is based on the usage of a great number of phenomena connected with different types of coherent and non-coherent light interaction with tissues and cells

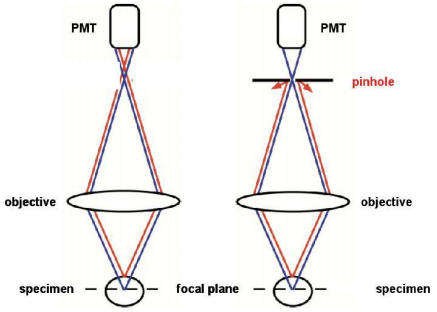
6

A light microscope is a combination of a slide projector with a magnifying glass

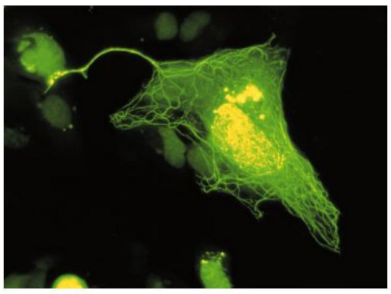


Total magnification = $M_{objective} \times M_{ocular}$

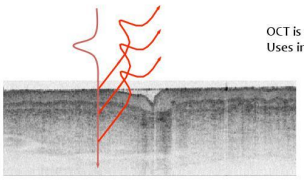
Confocal microscope: the power of the pinhole



Confocal microscope: the power of the pinhole



Optical Coherence Tomography

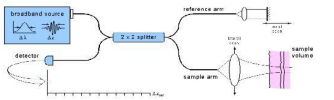


OCT is analogous to ultrasound imaging
Uses infrared light in stead of sound

Speed of sound ~ 1480 m/sec (in water)
Speed of light – $3x10^8$ m/sec

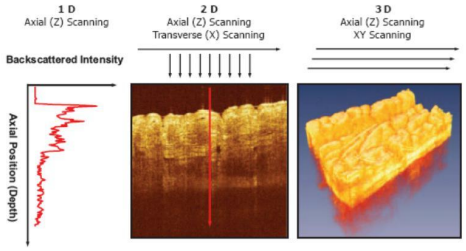
Human skin
5 mm wide x 1.6 mm deep
Resolution: 10-30 μm

Interferometry
is used to measure
small time delays
of scattered photons



Courtesy of Dr. Johannes F. de Boer

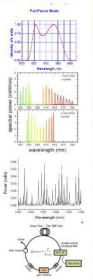
OCT: optical analogue of pulsed-wave ultrasound



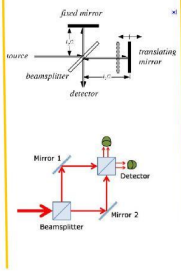
J. Fujimoto, 2008

Requirements

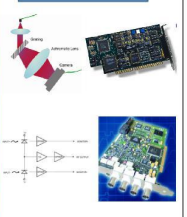
Laser Source



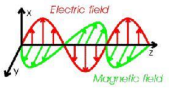
Interferometer



Detection and computational unit



Interference



Electromagnetic wave:

$$E = A\cos(\omega t + \phi)$$

Interference: Superposition of waves

$$E = E_1 + E_2 = A_1\cos(\omega t + \phi_1) + A_2\cos(\omega t + \phi_2)$$

Detection of light waves:

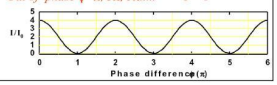
$$I \propto \langle E^2 \rangle = \langle (A_1\cos(\omega t + \phi_1) + A_2\cos(\omega t + \phi_2))^2 \rangle$$

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\varphi)$$

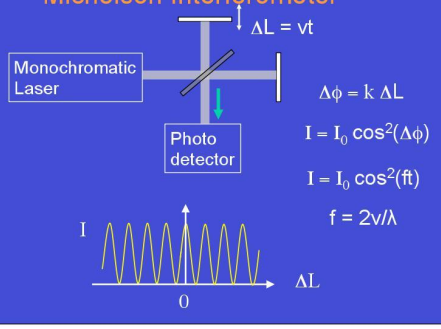
If $I_1 = I_2 = I_0$ $\quad I = 2I_0(1+\cos(\phi))$

In phase $\phi = 0, 2\pi, 4\pi, \ldots$ $\quad I = 4I_0$

Out of phase $\phi = \pi, 3\pi, 5\pi, \ldots$ $\quad I = 0$



Michelson Interferometer

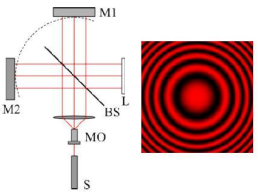


$\Delta\phi = k\,\Delta L$

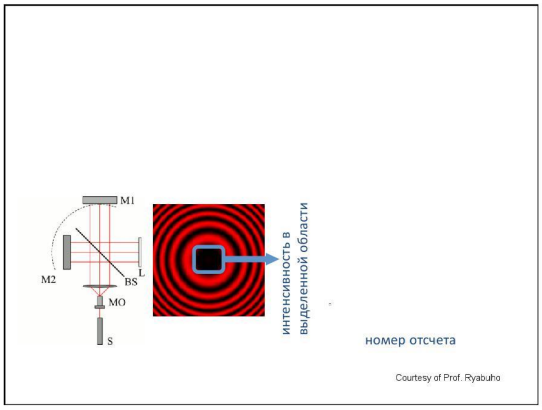
$I = I_0\cos^2(\Delta\phi)$

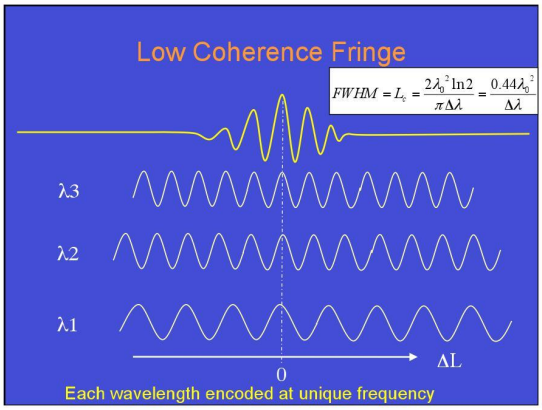
$I = I_0\cos^2(ft)$

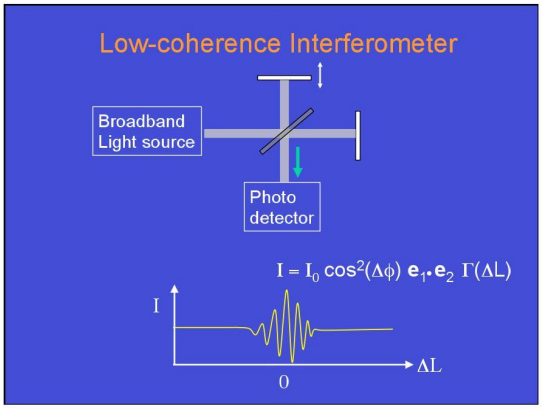
$f = 2v/\lambda$

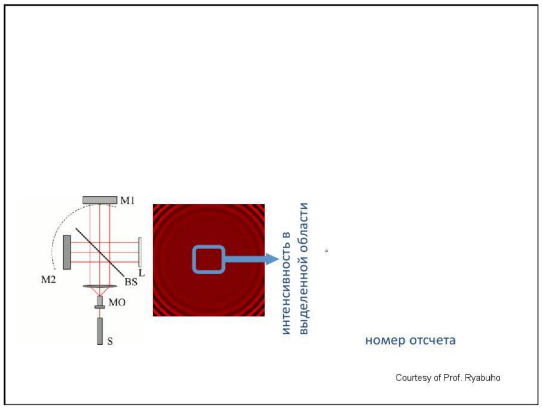


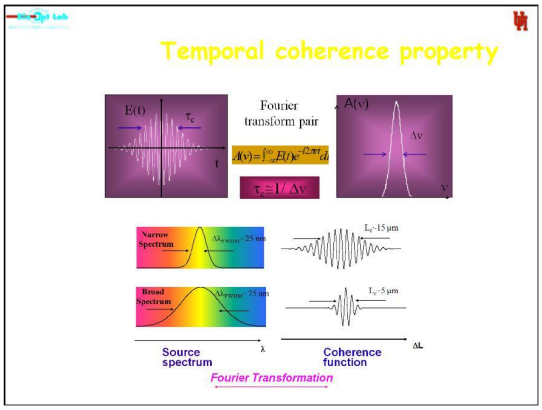
Courtesy of Prof. Ryabuho

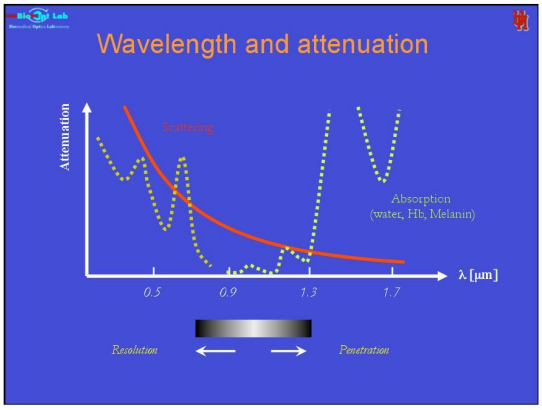

M1
M2
BS
L
MO
S
интенсивность в выделенной области
номер отсчета
Courtesy of Prof. Ryabuho


Low Coherence Fringe
$FWHM = L_c = \frac{2\lambda_0^2 \ln 2}{\pi \Delta\lambda} = \frac{0.44\lambda_0^2}{\Delta\lambda}$
λ3
λ2
λ1
ΔL
0
Each wavelength encoded at unique frequency

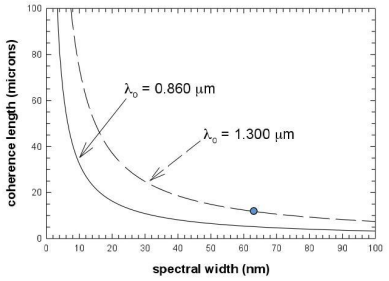

Low-coherence Interferometer
Broadband Light source
Photo detector
$I = I_0 \cos^2(\Delta\phi)\ \mathbf{e}_1 \cdot \mathbf{e}_2\ \Gamma(\Delta L)$
I
ΔL
0


M1
M2
L
BS
MO
S
интенсивность в выделенной области
номер отсчета
Courtesy of Prof. Ryabuho

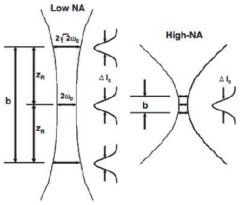

Temporal coherence property
E(t)
Fourier transform pair
A(ν)
Narrow Spectrum
Broad Spectrum
Source spectrum
Coherence function
Fourier Transformation


Wavelength and attenuation
Attenuation
Scattering
Absorption
(water, Hb, Melanin)
λ [μm]
0.5
0.9
1.3
1.7
Resolution
Penetration

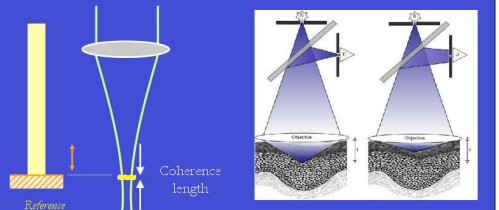
Axial (depth) resolution in OCT



Transverse resolution



OCT vs. CM



OCT

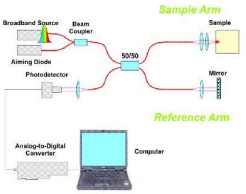
TDOCT
Time Domain OCT

FDOCT
Fourier Domain OCT

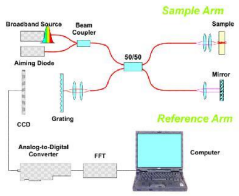
- Spectroscopic OCT
- Swept-Source OCT

Doppler OCT
Polarization Sensitive OCT
Phase Sensitive OCT
Full Field OCT

Time-Domain OCT

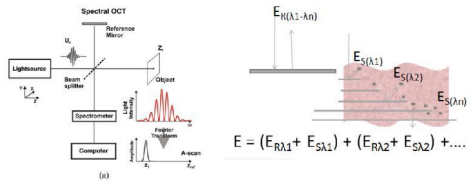


Spectroscopic OCT



Spectroscopic OCT

Depth information encoded in the wavelength



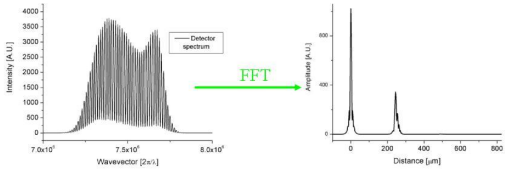
Like in TDOCT, resolution depends on the bandwidth of the Laser source.

SD-OCT

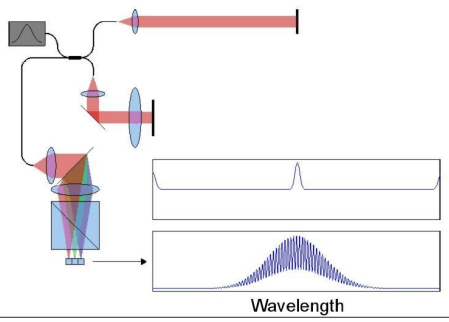
$$I(k) = I_r(k) + 2\sqrt{I_s(k)I_r(k)}\sum_n \alpha_n \cos(k\, z_n) + I_s(k)$$

FFT

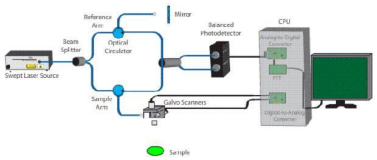
$$\left|FT^{-1}[I(k)]\right|^2 = \Gamma^2(z) \otimes \left\{\delta(0) + \sum_n \alpha_n^2 \delta(z - z_n) + \sum_n \alpha_n^2 \delta(z + z_n) + O\left[I_s^2 / I_r^2\right]\right\}$$



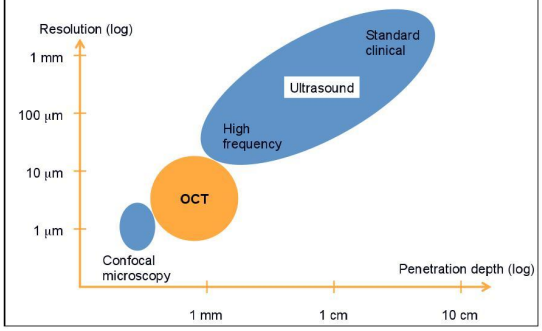
Spectral Domain OCT



Swept-Source OCT

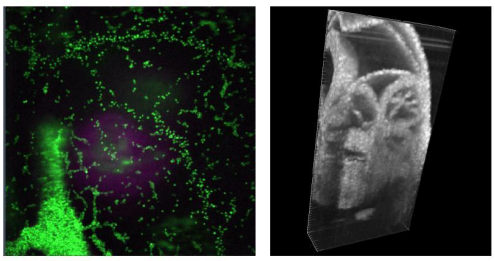


Optical Coherence Tomography vs Standard Imaging



OCT vs Confocal Microscopy

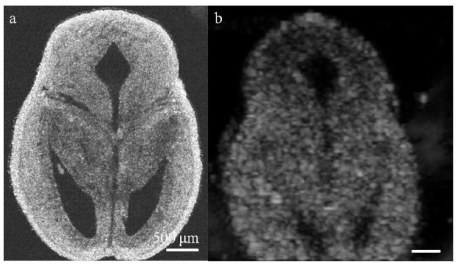
E14.5 mice embryo



K. Larin et. al., *Journal of Optical Innovative Sciences*, 2009

OCT vs HFUS

E14.5 mice embryo



N. Sudheendranet, ..., K. Larin, *Journal of Biomedical Optics*, 2013