

Photonic Integration in Healthcare

‘Towards optical coherence tomography on a chip’

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Academic Medical Center
University of Amsterdam**

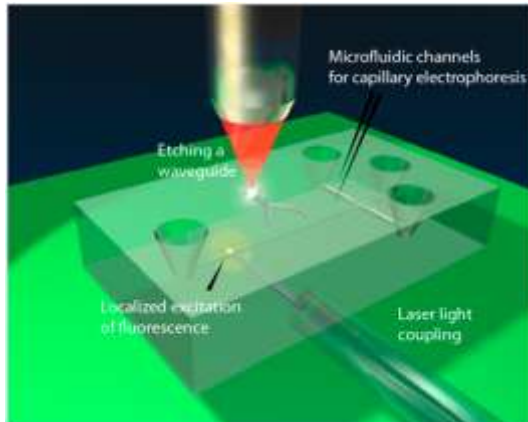


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Lab on a chip

Advantages

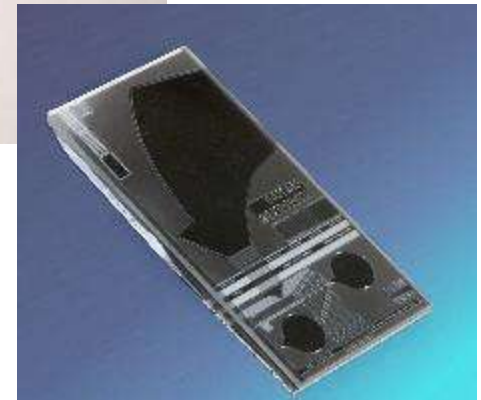
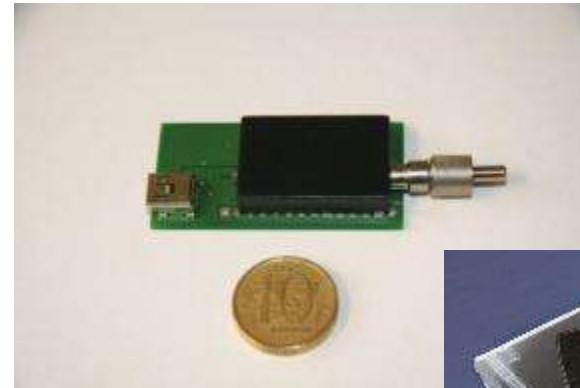
- high sensitivity
- high analysis speed
- low sample consumption
- measurement automation



Vazquez et al., Lab on a Chip, 2009, 9, p. 91–96

Measurement principle

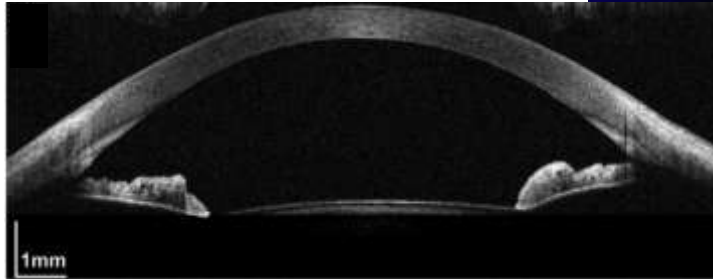
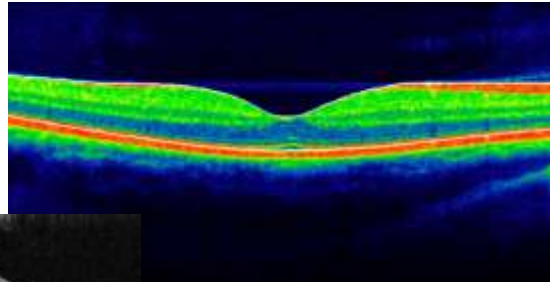
- interference (Mach-Zehnder)
- scattering (Raman spectra)
- fluorescence



www.serstech.com

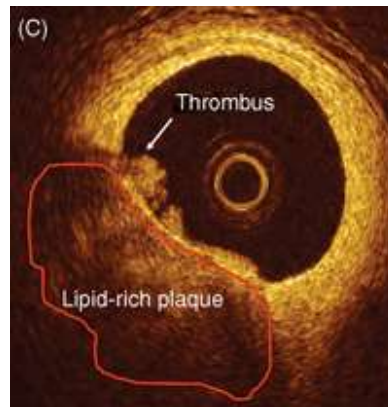
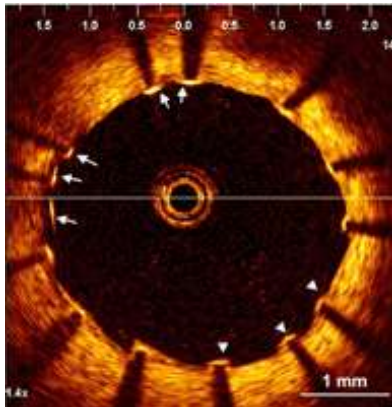
Optical coherence tomography on tissue

Ophthalmology



TopCon 3D OCT

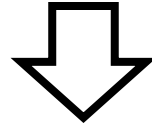
Intravascular OCT



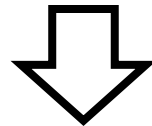
LightLab

Motivation

Current commercial OCT systems are rather bulky and expensive.



**Applications of OCT limited to 'high end' applications:
ophthalmology, intravascular imaging**



Use integrated optics for cost and size reduction

With OCT **cost reduction** new, 'low-cost' applications become feasible:



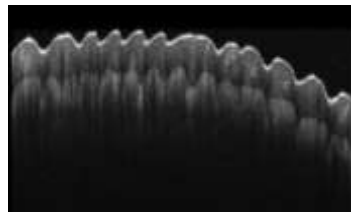
Dermal screening



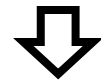
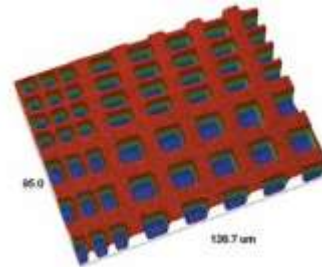
M. Mogenson et al., J. Biophot. 2, 442 (2009)



Forensics/biometrics

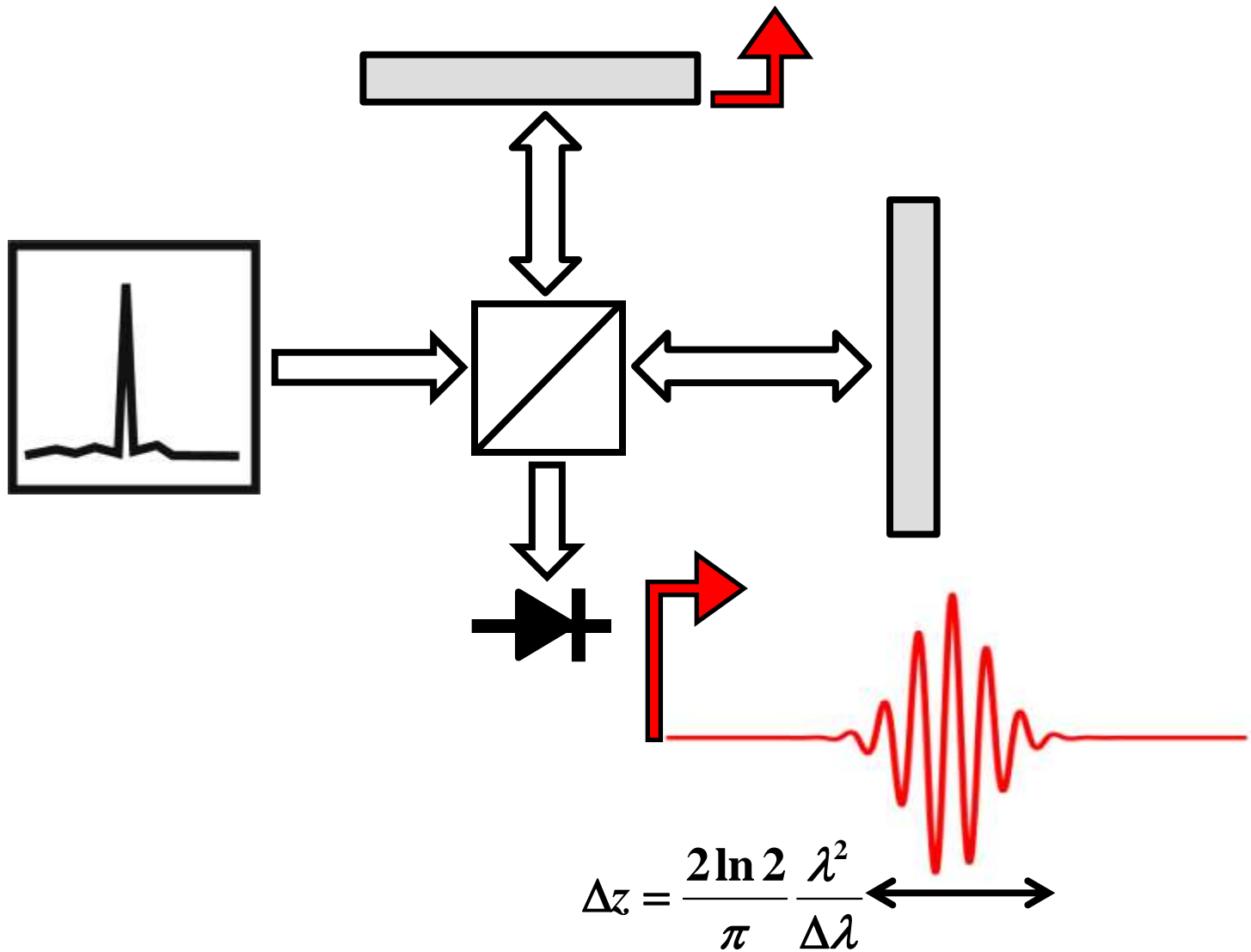


Process/quality control

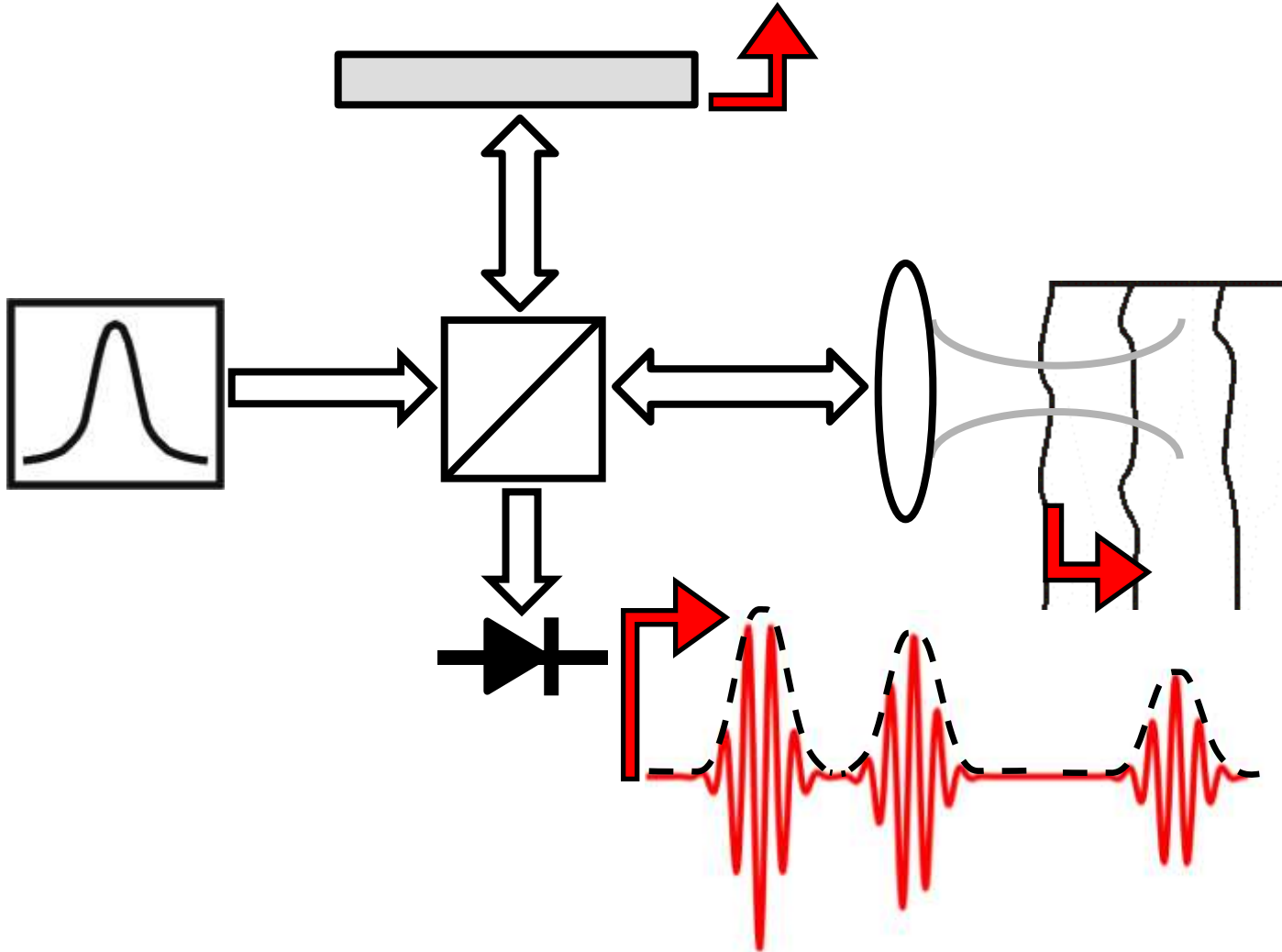


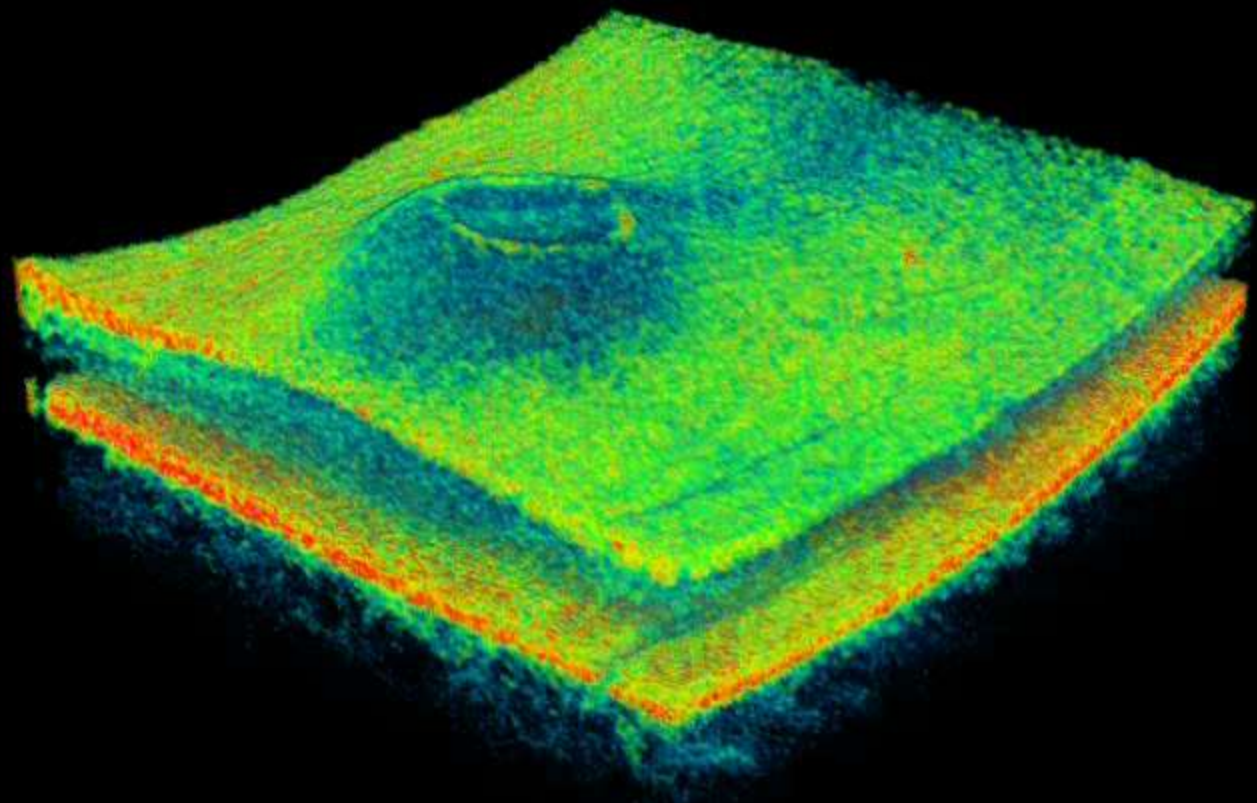
more...

Time-domain OCT

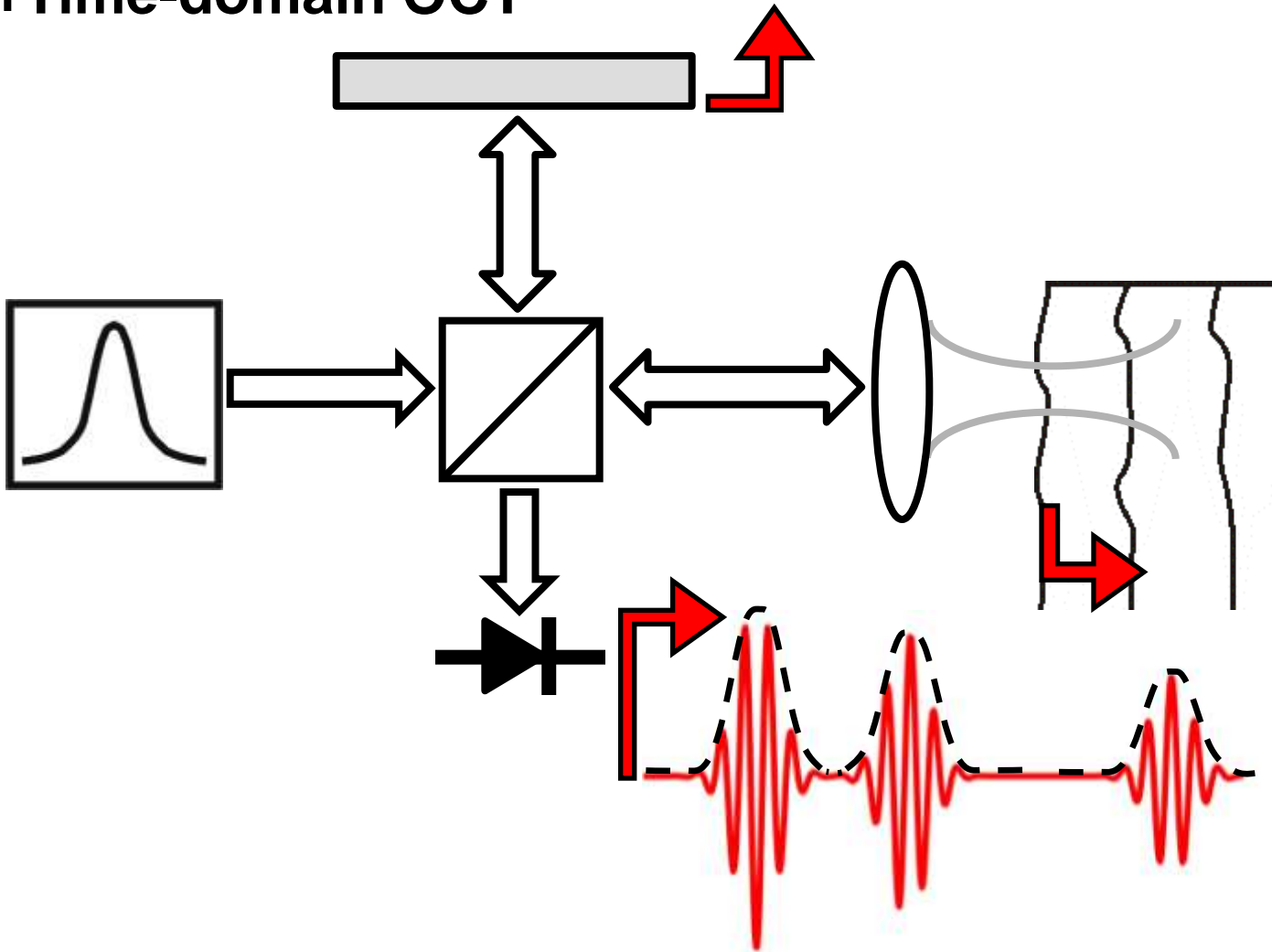


Time-domain OCT



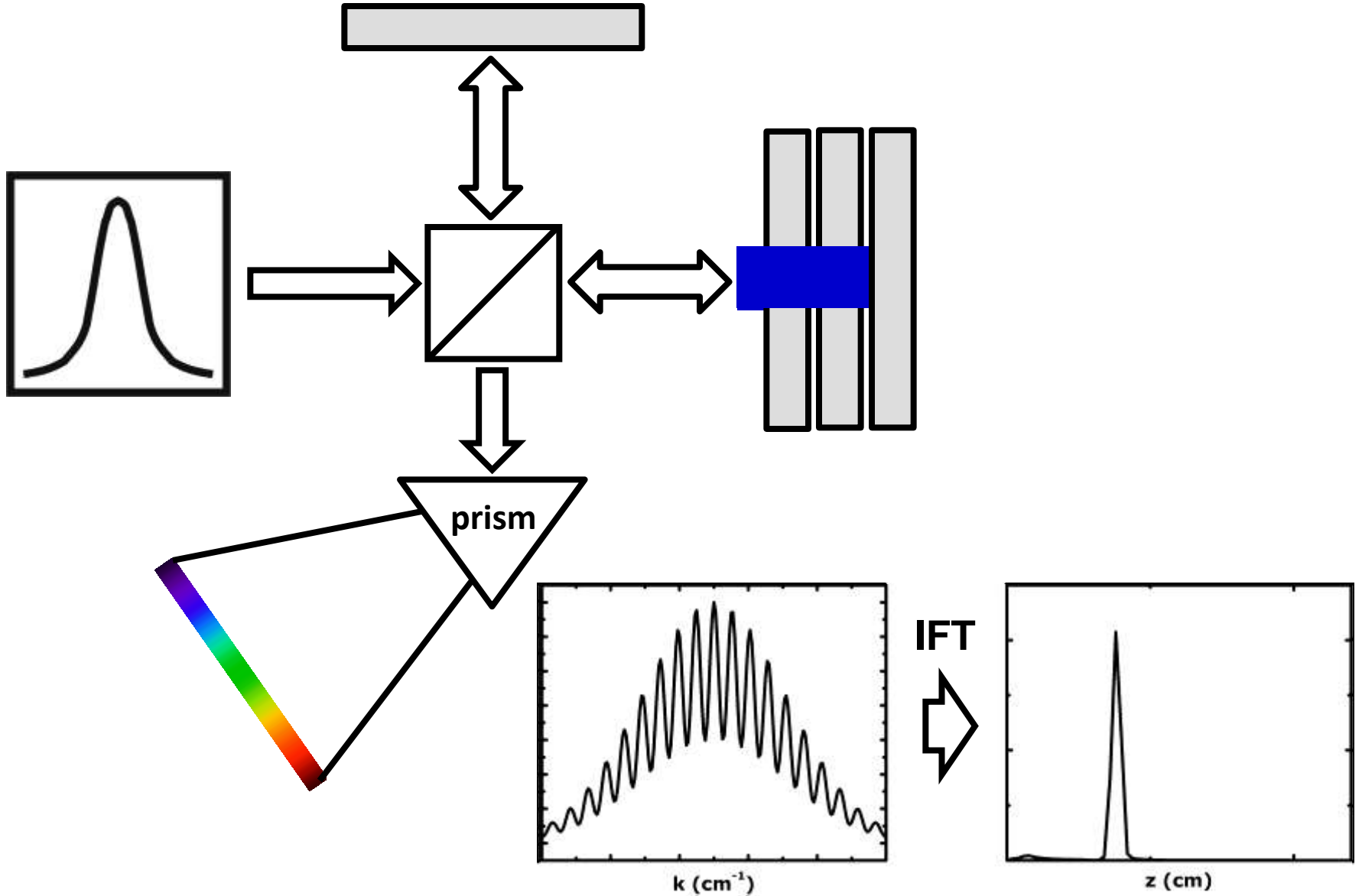


Time-domain OCT

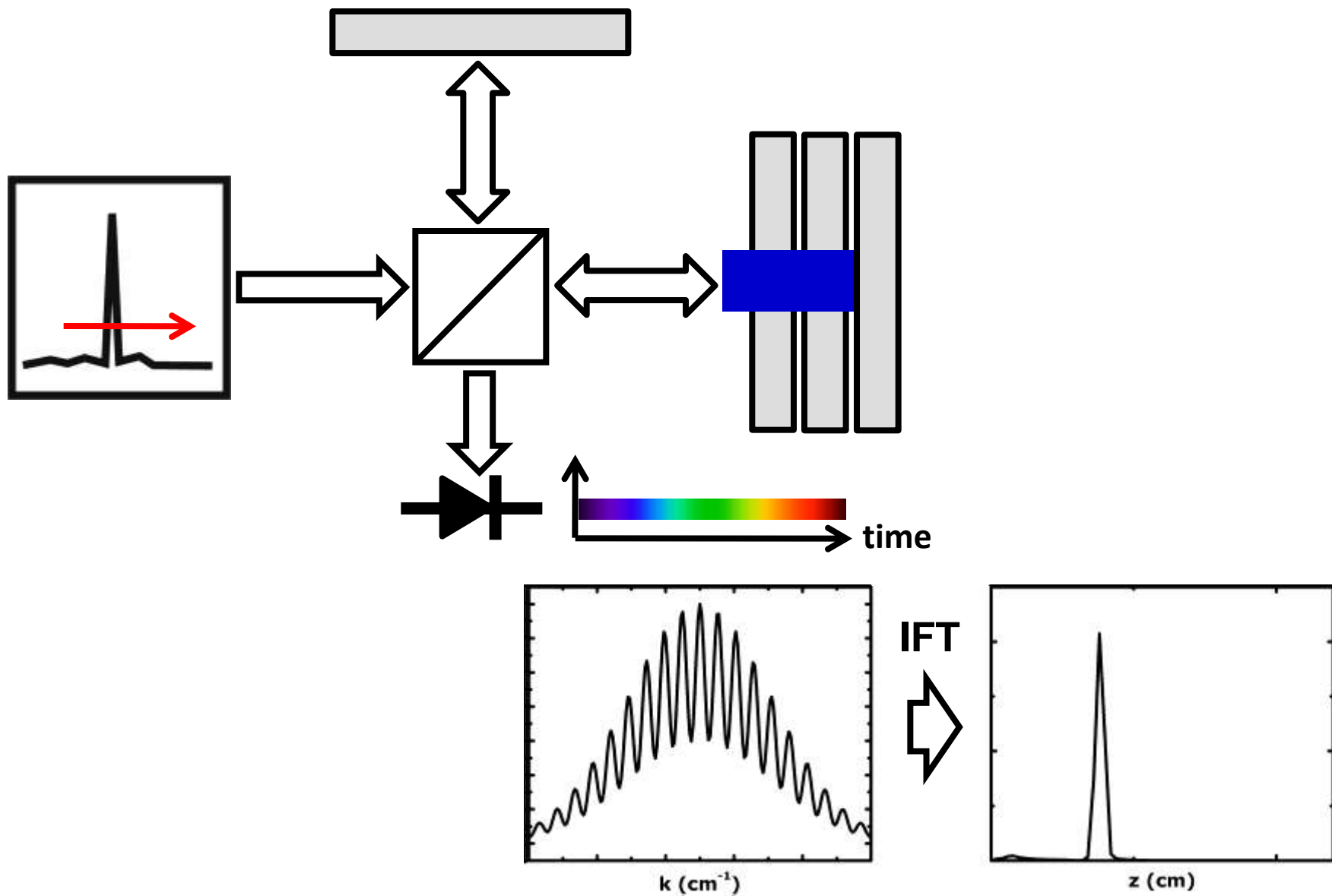


Time-domain OCT \Rightarrow Fourier-domain OCT \Rightarrow Spectral-domain OCT
 \Rightarrow Swept-source OCT

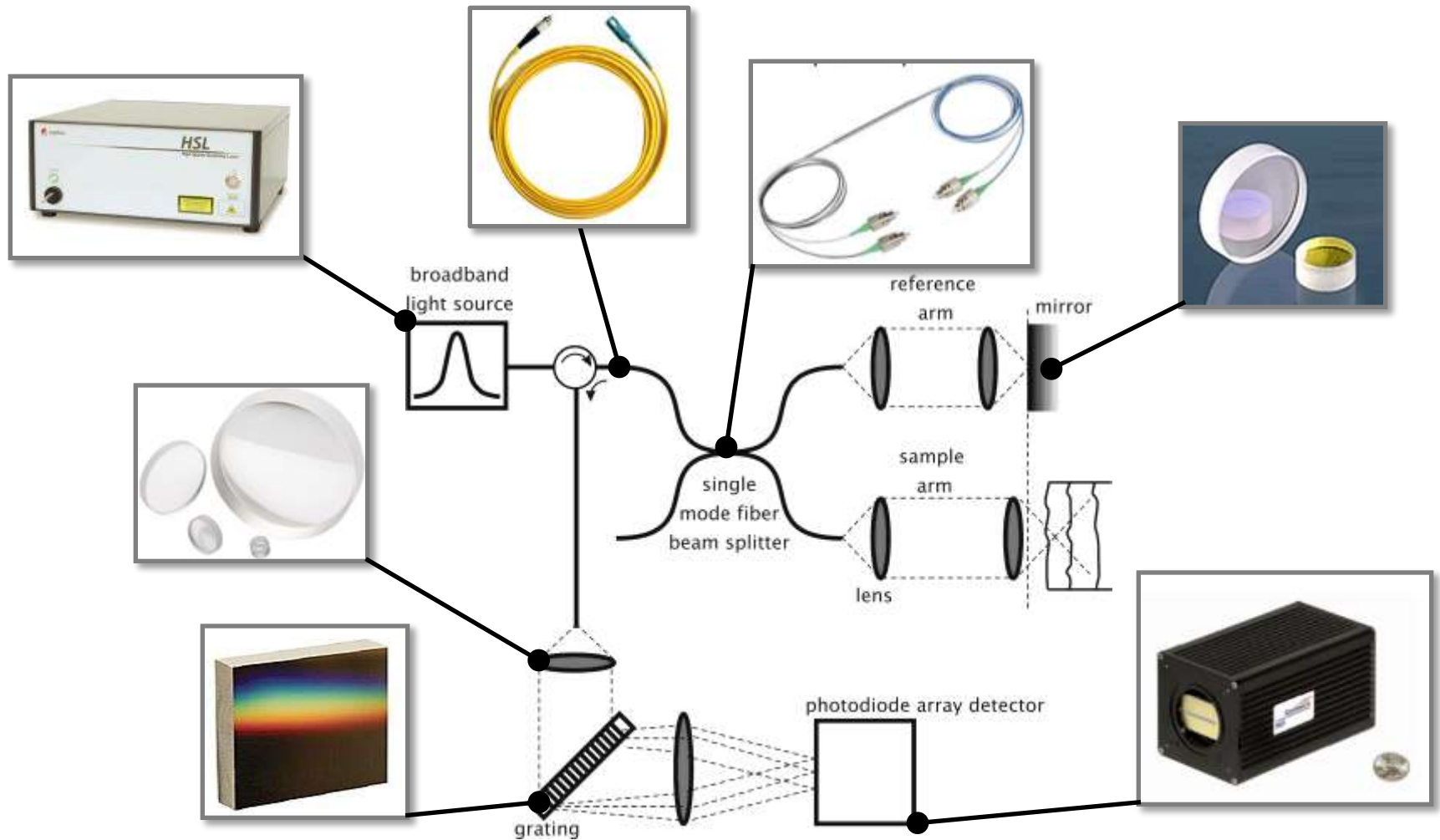
Spectral-domain OCT



Swept-source OCT



Bulk-optics spectral-domain OCT systems

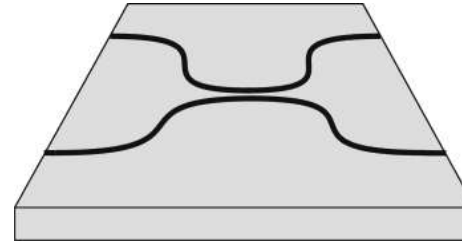
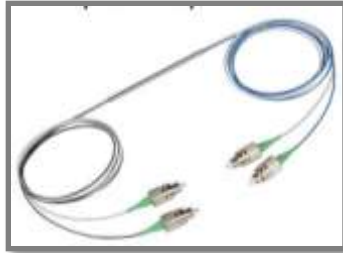


The integrated optics toolbox for OCT components

Bulk optics

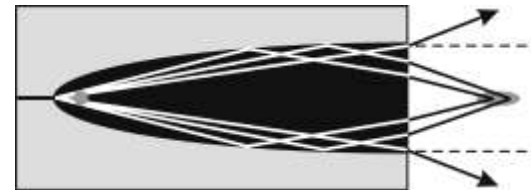
Integrated optics

Splitters



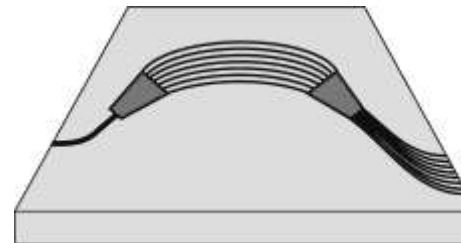
Directional coupler

Lenses



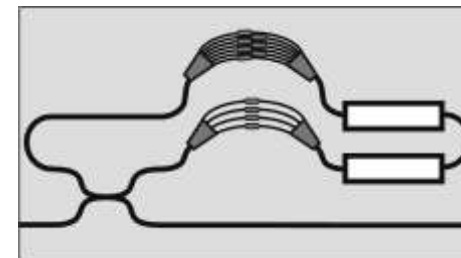
Elliptic couplers

Gratings



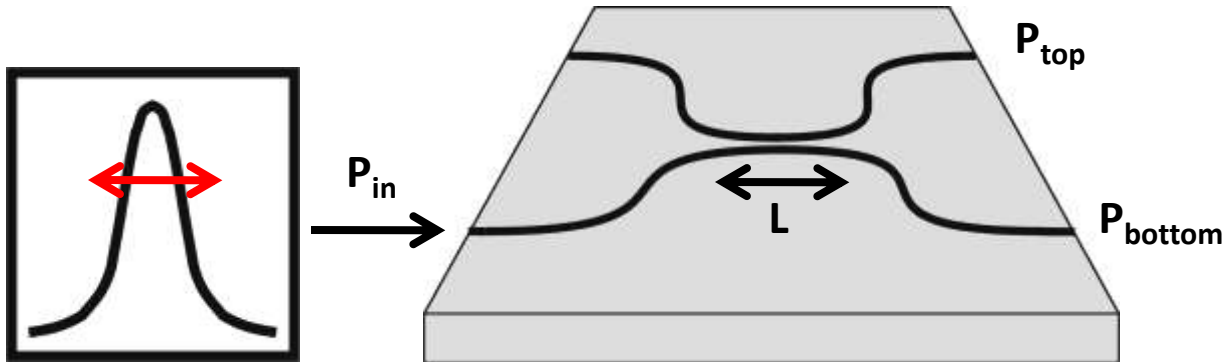
Arrayed waveguide grating

Swept source

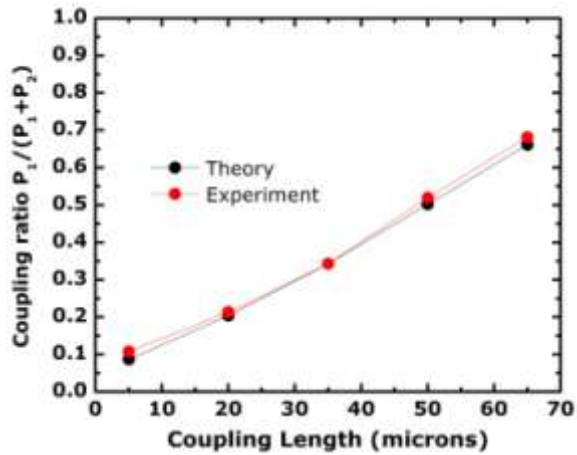


Integrated swept-source

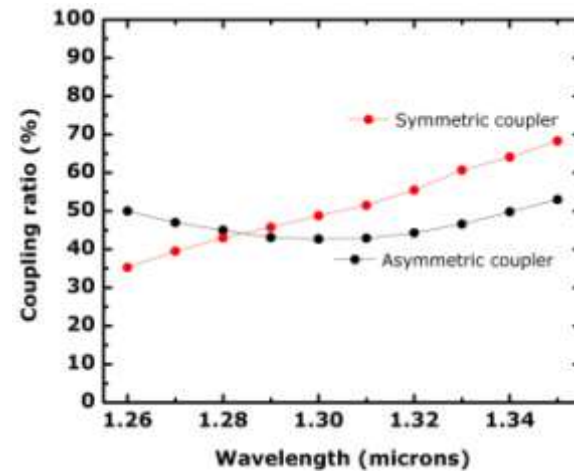
Directional coupler for broadband application



Splitting ratio



Wavelength dependence

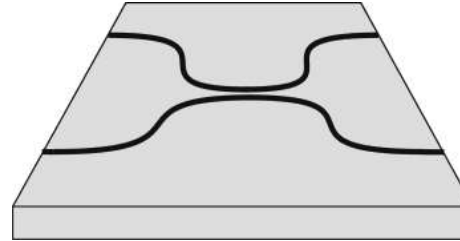


The integrated optics toolbox for OCT components

Bulk optics

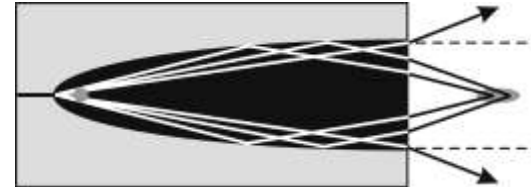
Integrated optics

Splitters



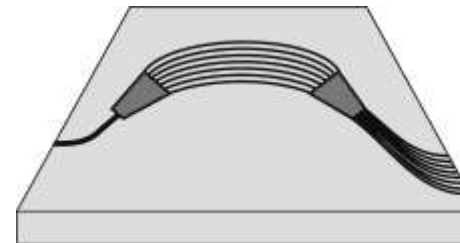
Directional coupler

Lenses



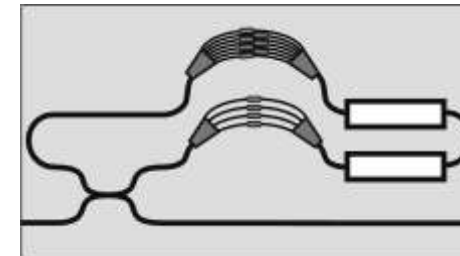
Elliptic couplers

Gratings



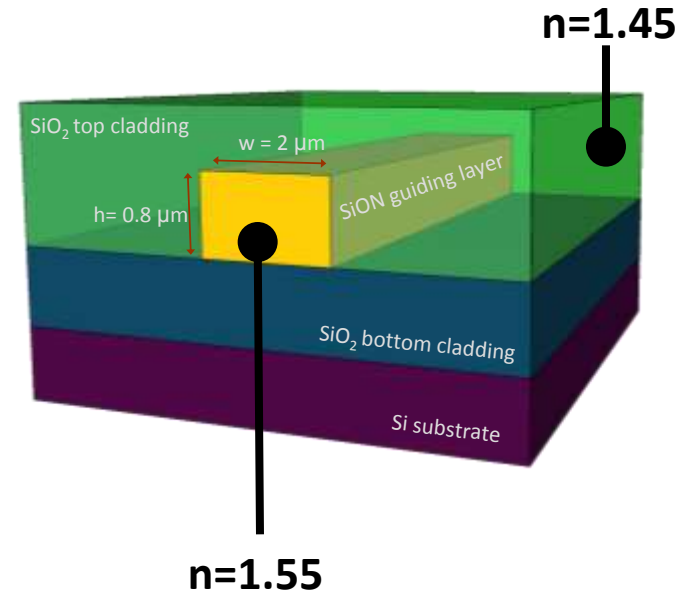
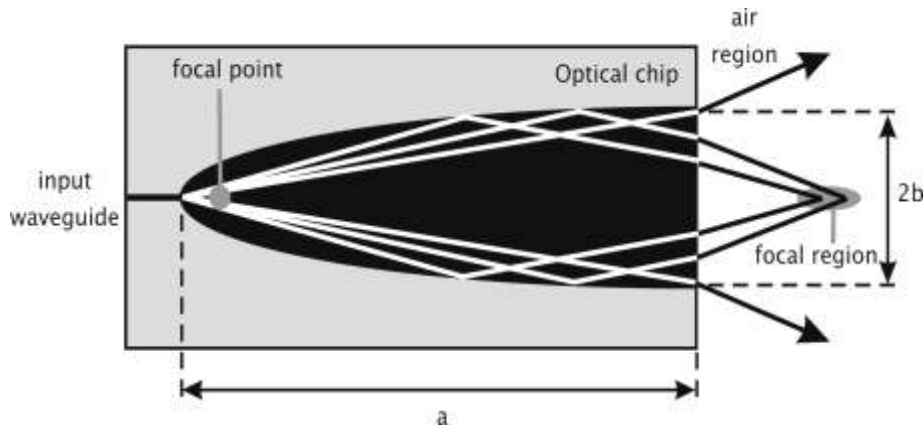
Arrayed waveguide grating

Swept source



Integrated swept-source

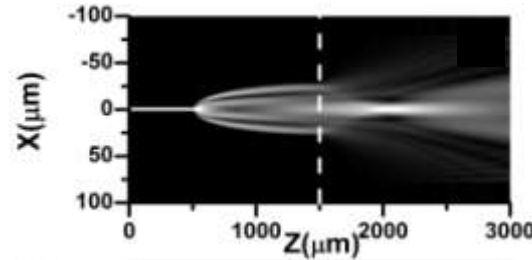
Elliptic coupler for focusing



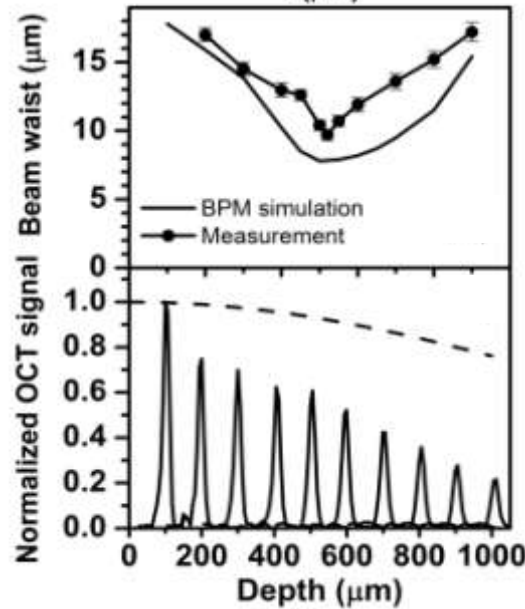
- Focusing of light into the off-chip environment
- Achromatic focusing
- Self interference at coupler interface (Fizeau interferometer)

Elliptic coupler for focussing

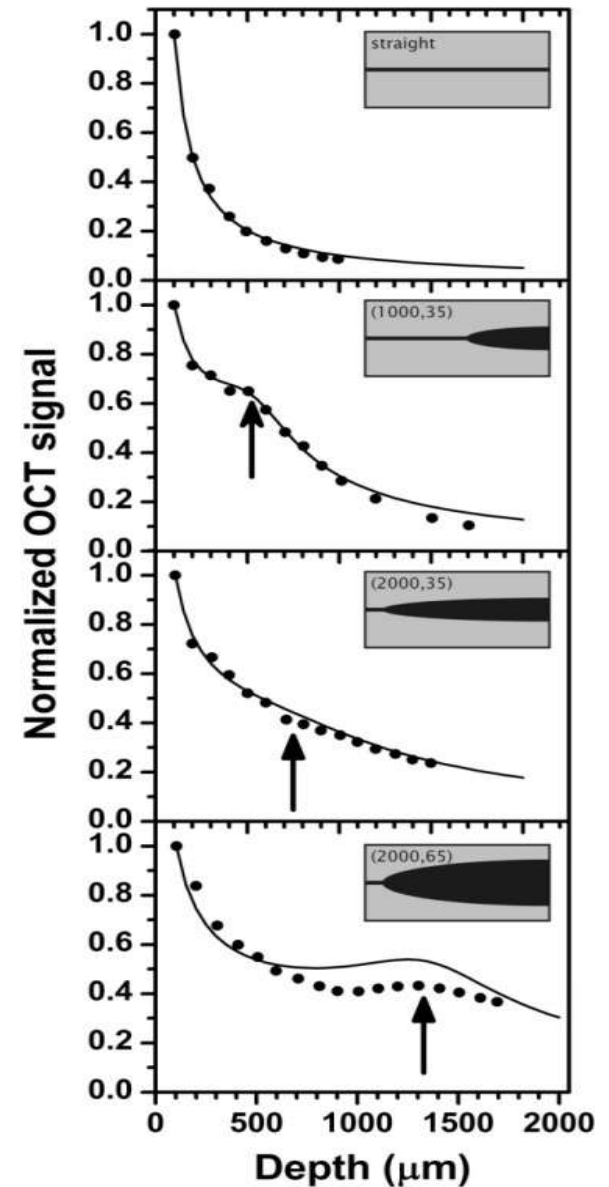
BPM simulation
(Optodesigner Phoenix bv)



Knife edge method
compared to simulations



Interference measurements
roll-off in depth due to OCT
and field evolution

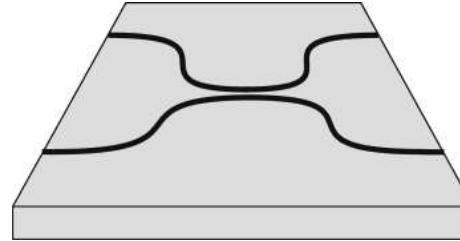


The integrated optics toolbox for OCT components

Bulk optics

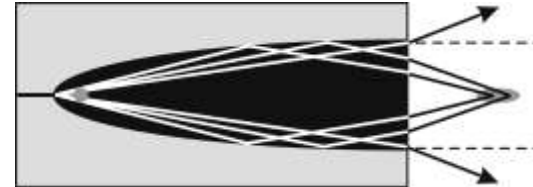
Integrated optics

Splitters



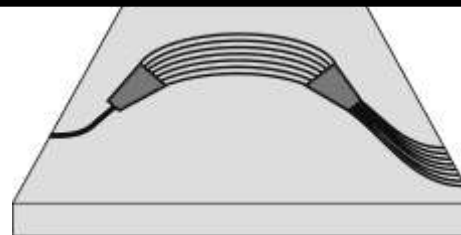
Directional coupler

Lenses



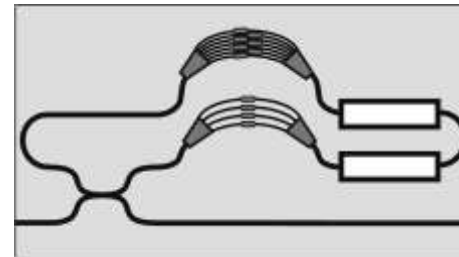
Elliptic couplers

Gratings



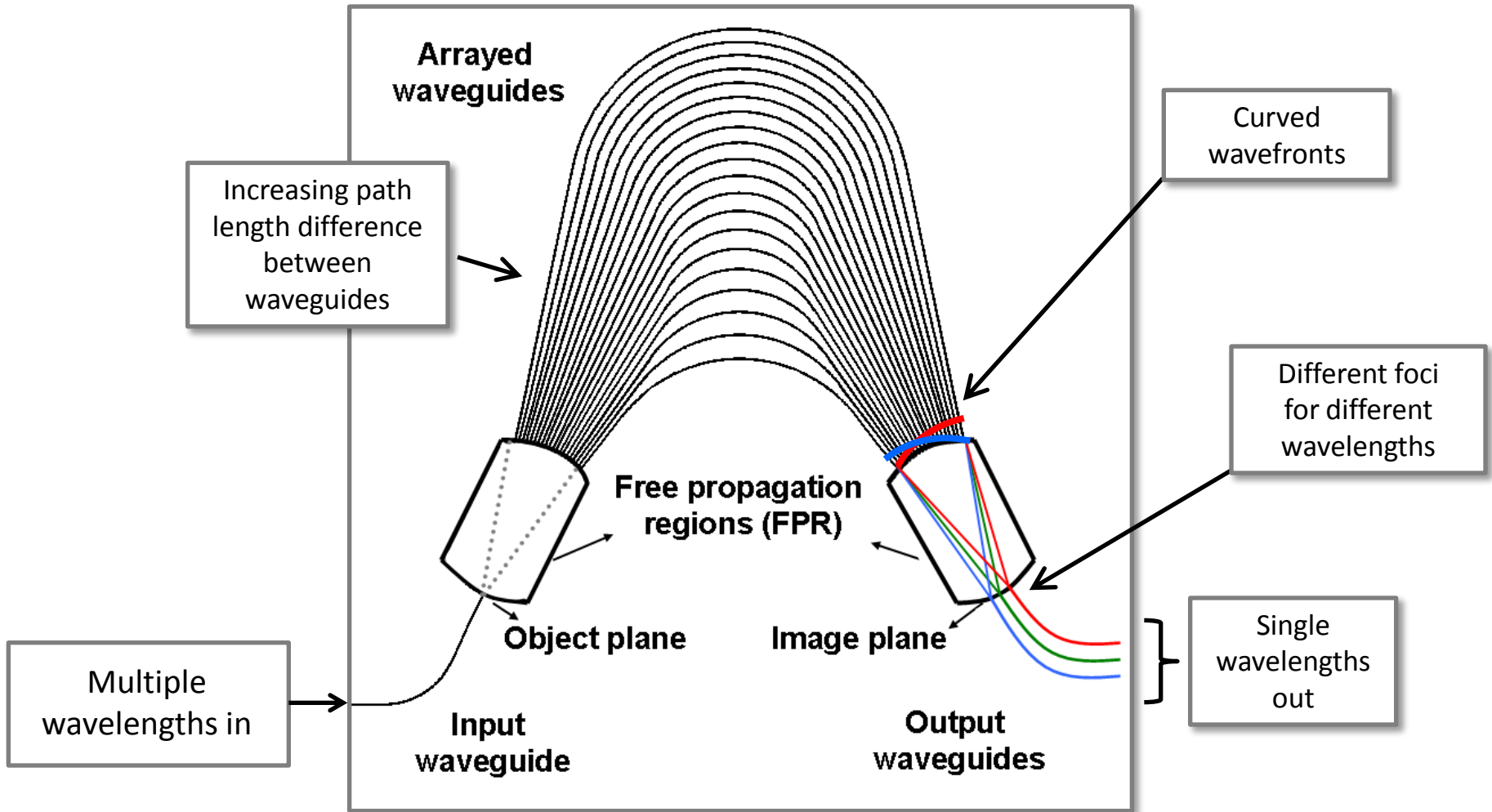
Arrayed waveguide grating

Swept source

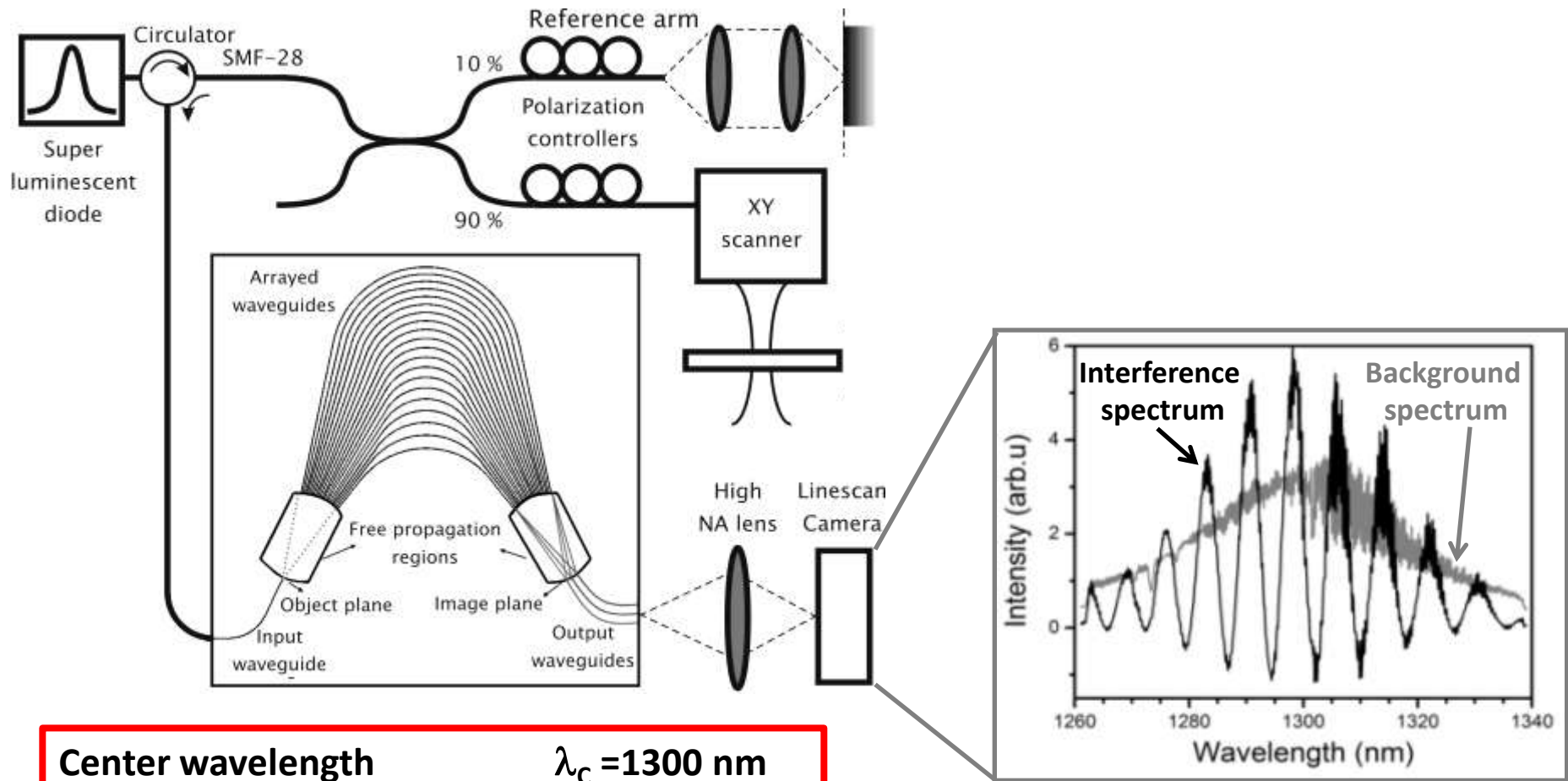


Integrated swept-source

Arrayed waveguide grating (AWG) operating principle

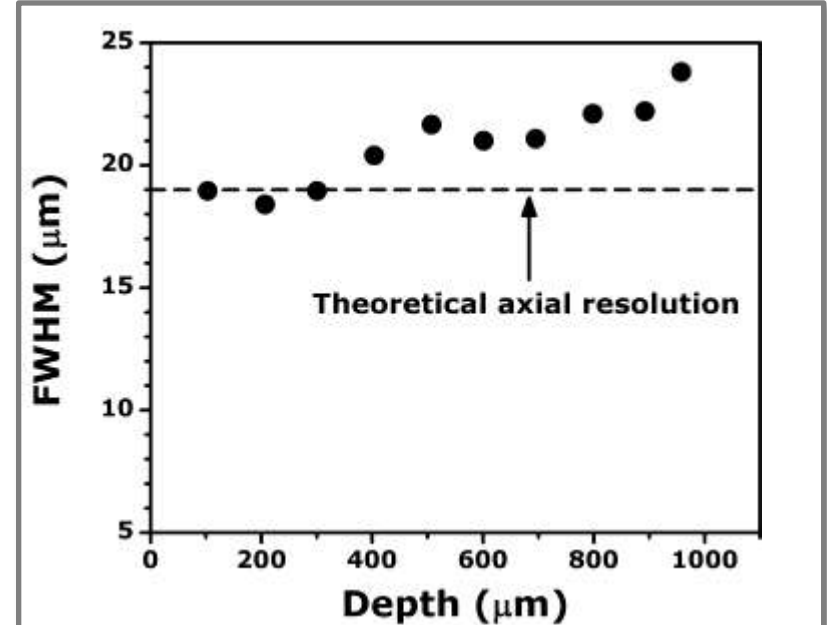
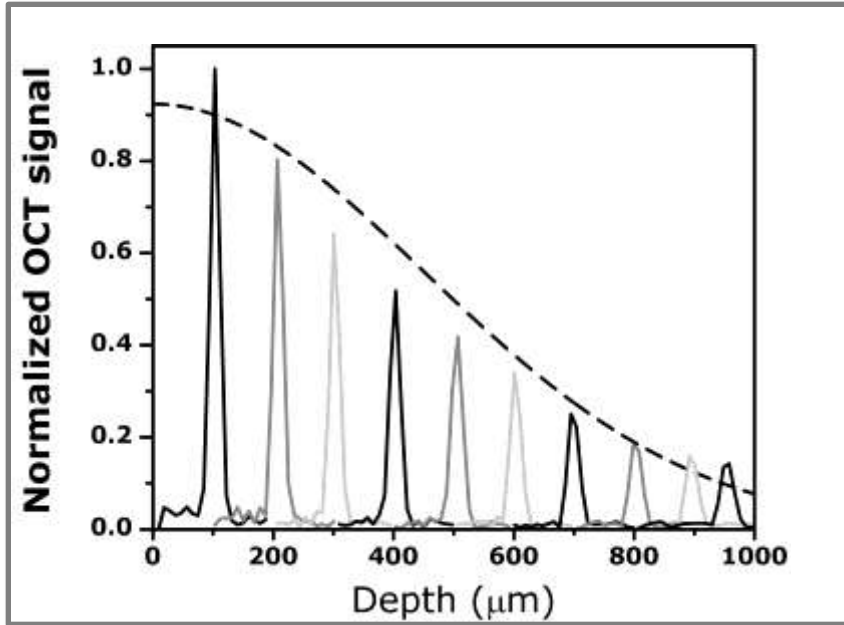


Arrayed waveguide grating spectrometer for OCT



Center wavelength	$\lambda_c = 1300 \text{ nm}$
free spectral range	FSR=78 nm
channel spacing	$\delta\lambda = 0.4 \text{ nm}$
# of output waveguides	N=195
maximum imaging depth	$z_{\max} = 1056 \mu\text{m}$

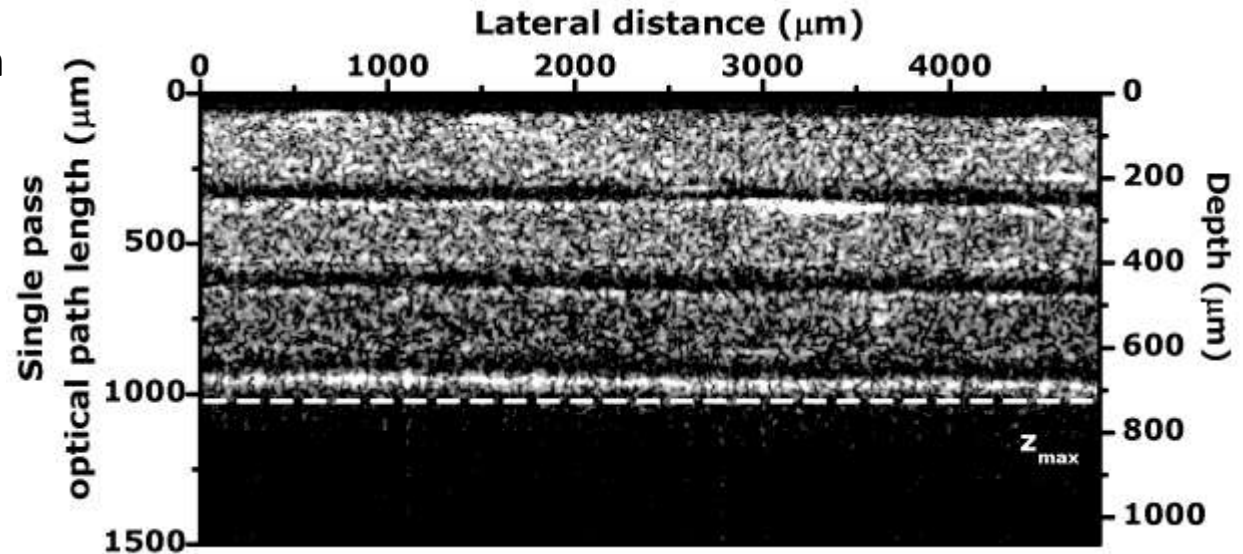
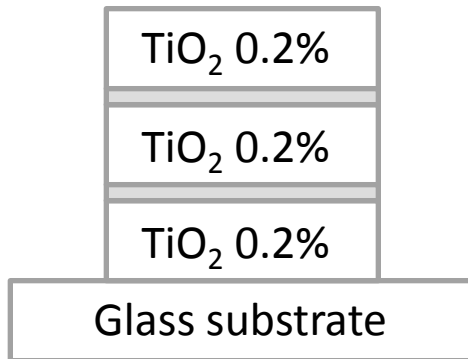
OCT benchmarking



- Signal to noise ratio 75 dB
- Maximum imaging depth 1 mm
- Axial resolution 19 μm

Spectral-domain OCT with AWG spectrometer

TiO₂ phantom interleaved with non-scattering tape



Spectral domain optical coherence tomography imaging with an integrated optics spectrometer;

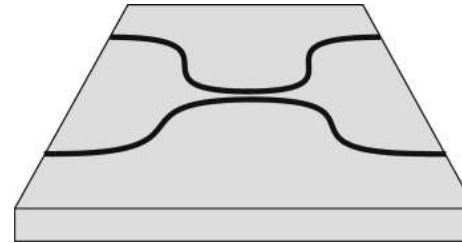
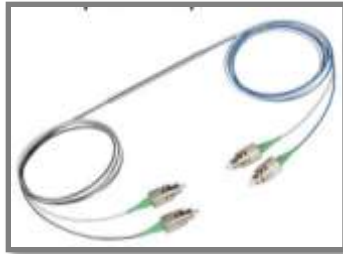
V.D. Nguyen, B.I. Akca, K. Wörhoff, R.M. de Ridder, M. Pollnau, T.G. van Leeuwen, and J. Kalkman, Optics Letters **36**, 1293 (2011)

The integrated optics toolbox for OCT components

Bulk optics

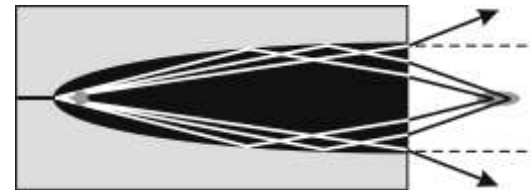
Integrated optics

Splitters



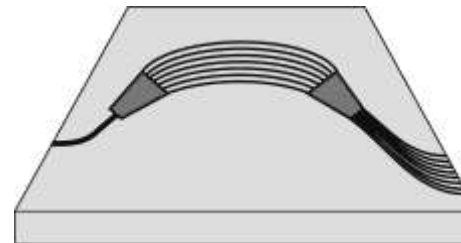
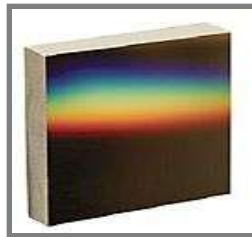
Directional coupler

Lenses



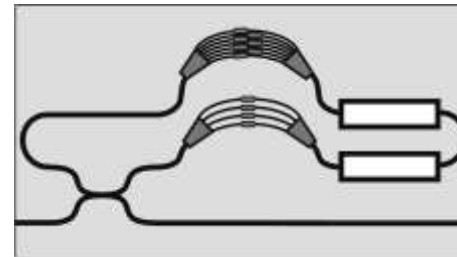
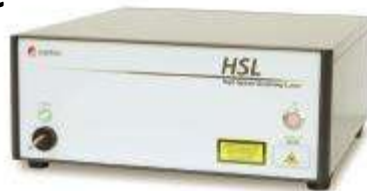
Elliptic couplers

Gratings



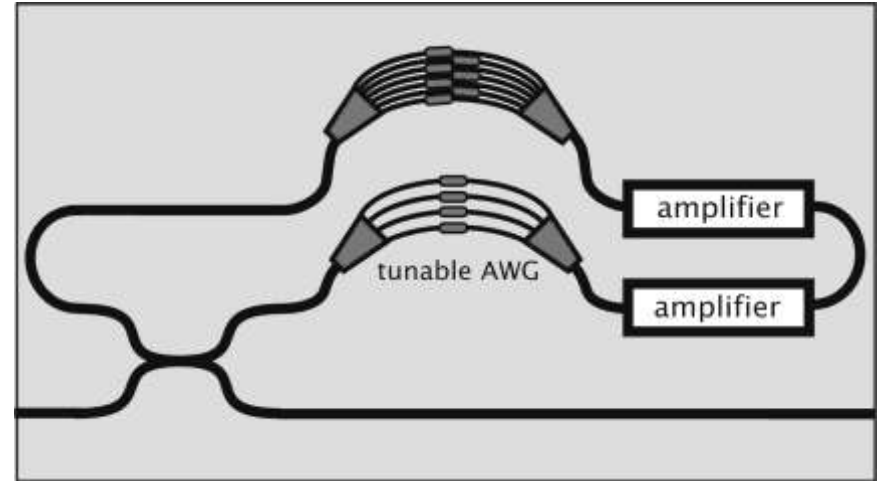
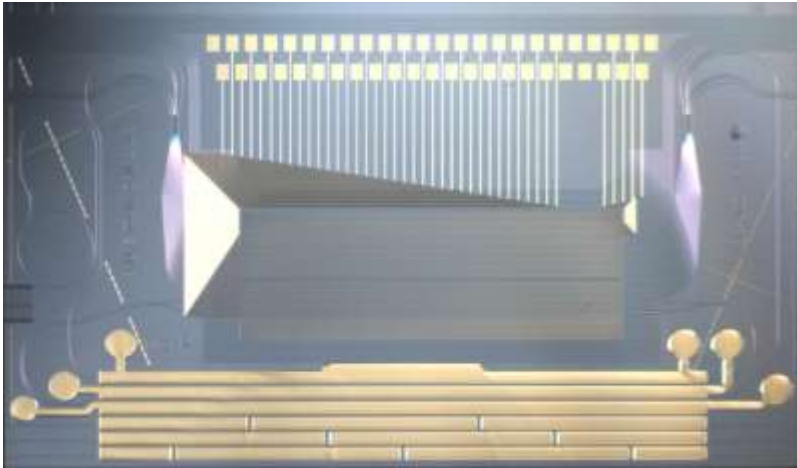
Arrayed waveguide grating

Swept source



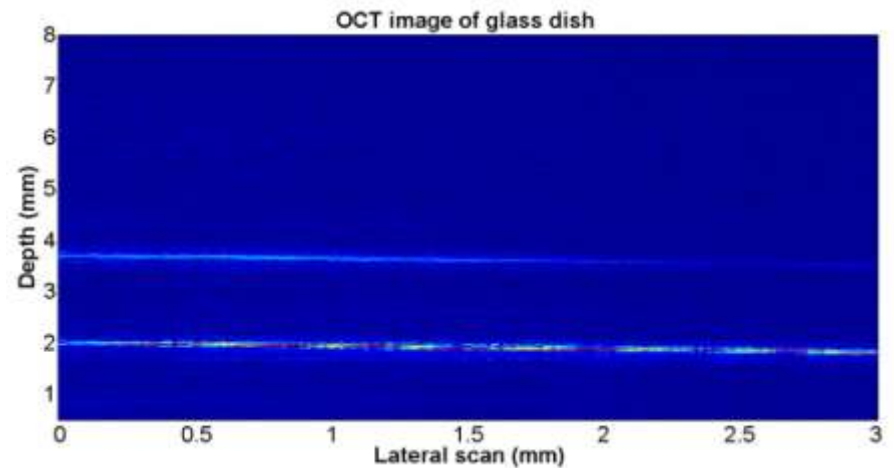
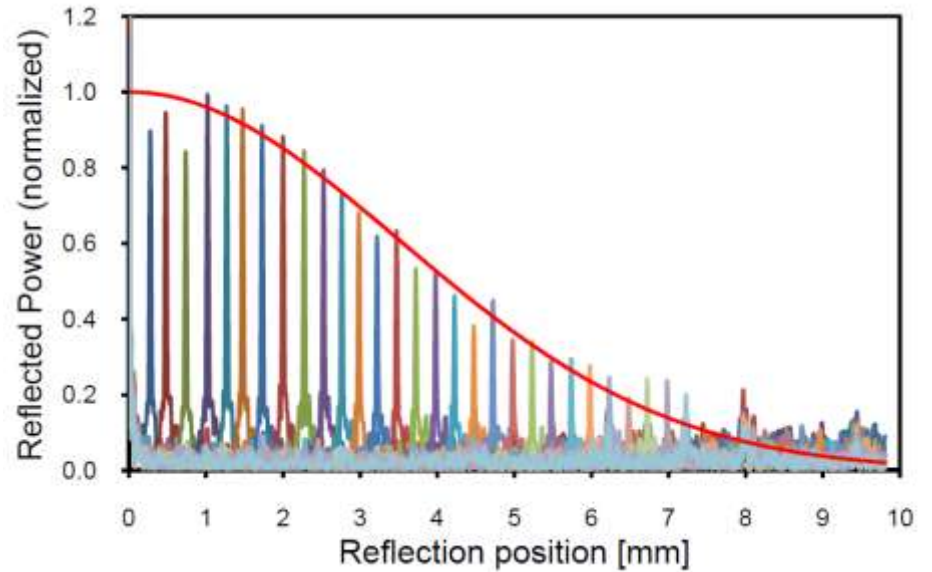
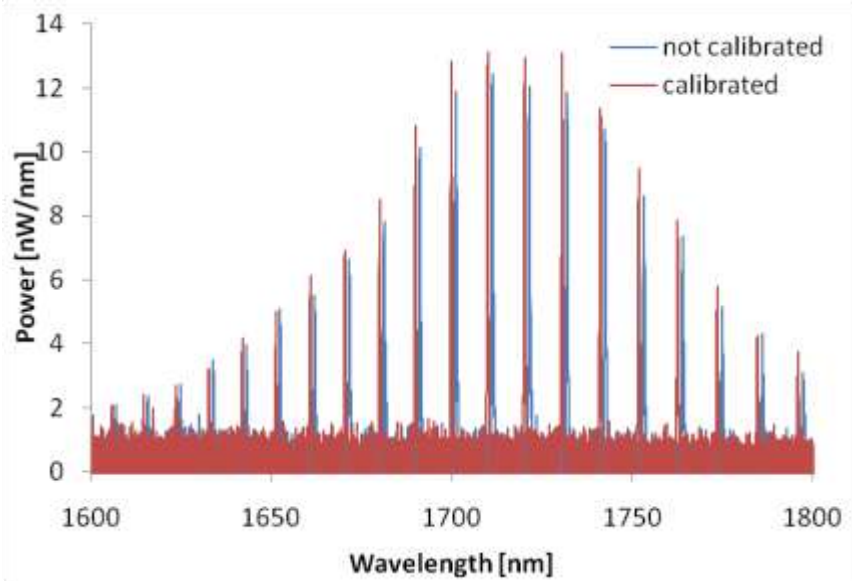
Integrated swept-source

Swept-source for OCT



- Fully integrated tunable laser at 1.7 μm
- Based on quantum dot material
- Two cascaded AWG filters
- 100 nm bandwidth
- 6.5 mm instantaneous coherence length
- 20 kHz sweep speed

Swept-source for OCT



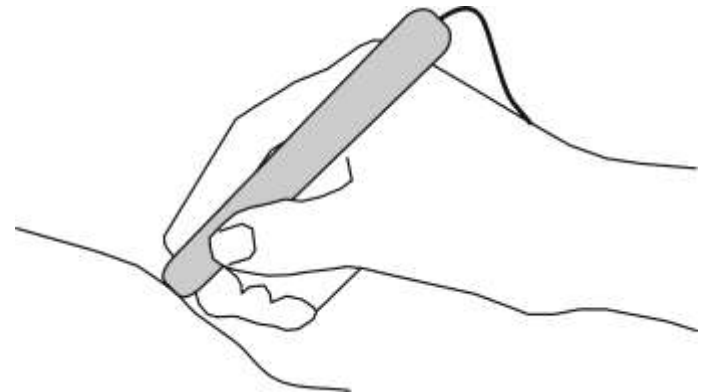
Integrated tunable quantum-dot laser for optical coherence tomography in the 1.7 μm wavelength region

B. W. Tilma, Y. Jiao, J. Kotani, B. Smalbrugge, H. P. M. M. Ambrosius, P. J. Thijs, X. J. M. Leijtens, R. Nötzel, M. K. Smit, and E. A. J. M. Bente
IEEE J. Quantum Electr.

Outlook

Further electronic and photonic integration

- Chip/environment connection
efficient chip tissue coupling
- Hybrid integration of active and passive materials on single platform
passive materials for waveguiding (low loss)
active materials as source, detectors, and modulators
- Photonic/electronic integration
connectivity of electronic components to optical chip
electronic components dedicated to optical signal processing





Agentschap NL
Ministerie van Economische Zaken

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Thanks to:

D. V. Nguyen , T. G. van Leeuwen, B. I. Akca , K. Wörhoff, R. M. de Ridder, M. Pollnau, N. Ismail, F. Sun, E. Bente, B. W. Tilma, Y. Jiao