Optical Imaging Needles: Bringing Optics Deep Inside the Body

Presented by:

OSA Imaging Optical Design Technical Group

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Technical Group Leadership:

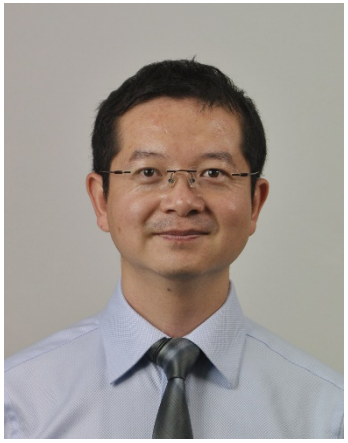
[1]Peng Xi, Peking University, China (Chair)

[2]Rui Liu, Allen Institute of Brain Science, USA (Vice Chair)

[3]Ayan Chakrabarty, JPL,Calfornia Institute of Technology, USA (Events Officer)

[4]Hui Zhang, Domilight Optics Co.,ltd, China(Social Media Officer)

[5]Woei Ming Lee, Australian National University, (Webinar)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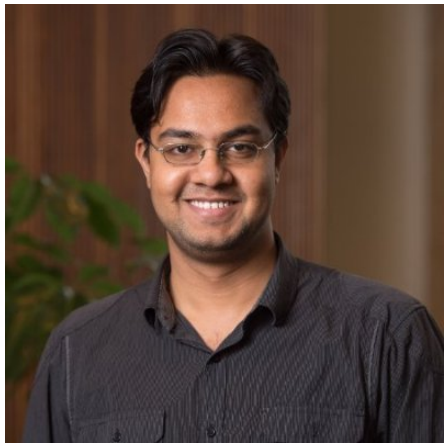
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OSA Imaging Optical Design Technical Group

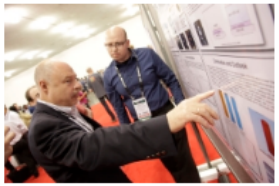
Find us online at www.osa.org/fd

Imaging Optical Design (FD)

Get Involved

- Public Policy
- Diversity & Inclusion in OSA
- Technical Divisions +
  - Bio-Medical Optics
  - Fabrication, Design & Instrumentation +
    - Fiber Modeling and Fabrication (FF)
    - Gamma, X-Ray and Extreme UV Optics (FX)
    - Holography and Diffractive Optics (FH)
    - Imaging Optical Design (FD)
    - Lasers in Manufacturing (FL)
    - NonImaging Optical Design (FN)
    - Optical Fabrication and Testing (FM)
    - Polarization (FP)
    - Systems and Instrumentation (FS)
    - Thin Films (FT)
  - Information Acquisition, Processing & Display

Imaging Optical Design (FD)



This group encompasses the design and characterization of traditional optical systems utilizing lens design, geometric ray-tracing, and physical optics modeling. The evolution and development of design codes and software to assist in designing components and systems are included here. Typical applications include astronomical telescopes, microscopes, cameras, stray light, and adaptive optics.

GROUP LEADERSHIP | UPCOMING MEETINGS | RECENTLY PUBLISHED

Name	Affiliation	Title
Peng Xi	Peking University	Chair
Rui Liu	Allen Institute for Brain Science	Vice Chair
Ayan Chakrabarty	JPL,Calfornia Institute of Technology	Events Officer
Hui Zhang	Domilight Optics Co.,ltd	Social Media Officer
Woei Ming Lee	Australian National University	Webinar Officer

Announcements

Congratulations to Peng Xi, the new chair of the Imaging Optical Design Technical Group! If you are a member of this group and have ideas for activities and initiatives to help engage this community, please share them with Peng as he begins his term as chair.

Join our Online Community

LinkedIn

Work in Optics

Lead FPGA Engineer | Thorlabs Inc
Mon, 13 Feb 2017 09:04:00 EST

Marketing and Technical Sales Associate | Boston Micromachines Corporation
Wed, 25 Jan 2017 16:57:00 EST

Marketing/ Sales Intern | Boston Micromachines Corporation
Wed, 25 Jan 2017 17:08:00 EST

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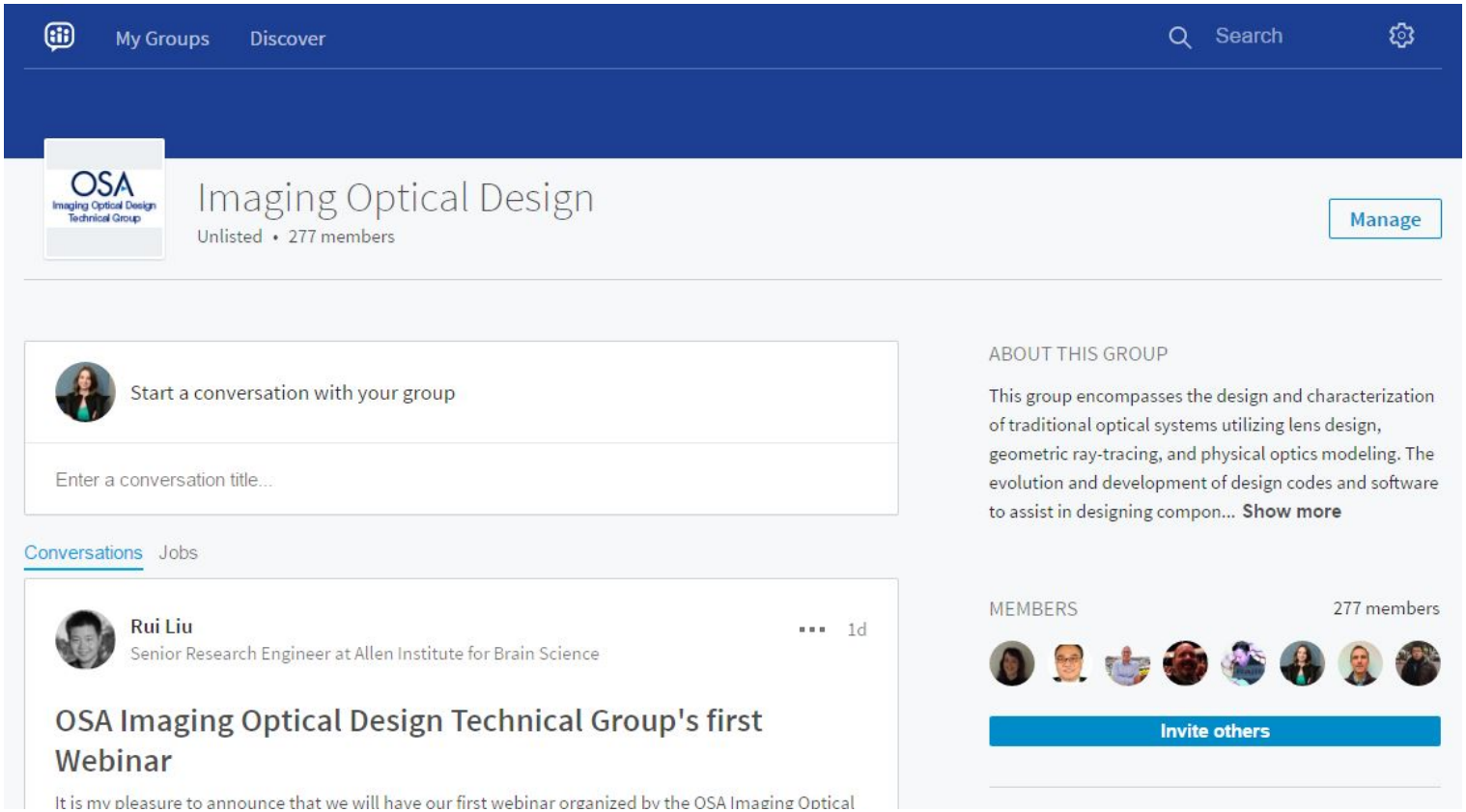
Contact IOD Technical Group and Get Involved!

OSA Imaging Optical Design Technical Group

|Linked-In Group| Facebook | Announce new activities|

|Promote interactions | Complement the OSA Technical Group Member List



Technical Group activities:

OSA Imaging Optical Design Technical Group

Webinars:
Suggestions are welcome

Social gatherings at conferences : CLEO, Topical Meeting

Suggestions: Involvement of conference organization: Potential OSA Incubator meetings co-organized with other technical groups

Welcome to Today's Webinar!

OSA Imaging Optical Design Technical Group

Optical Imaging Needles: Bringing Optics Deep Inside the Body

https://cc.callinfo.com/r/1v75mwdl63jc4&eom

Dr. Robert McLaughlin

University of Adelaide

Abstract

Optical imaging technologies, such as optical coherence tomography (OCT), have the potential to acquire exquisitely high-resolution images of tissue and provide a new generation of intra-operative guidance tools for surgeons. However, their limited image penetration depth places most diseases beyond their reach. In this webinar hosted by the OSA Imaging Optical Design Technical Group, Dr. Robert McLaughlin from the University of Adelaide will present his team's work focused on the development of OCT imaging needles, highly miniaturized imaging probes that are encased within a hypodermic needle, which may be inserted deep into tissue. During the webinar, Dr. McLaughlin will describe their development of OCT imaging needles and give specific case studies of clinical applications. Dr. McLaughlin and his team have recently integrated their probes into brain biopsy needles to enable safer neurosurgery and have recently performed their first experiments in humans. In addition, the team has developed the first dual-modality needle probes, capable of simultaneously acquiring OCT and fluorescence images, and showed them to be sufficiently sensitive to detect signal from fluorescently-labelled anti-bodies targeted for specific cells types.

What You Will Learn:

- What imaging needles are and how they are fabricated
- Optical design for micro-optics
- Biomedical applications for imaging needles

Who Should Attend:

- Optical engineers
- Optical imaging specialists
- Clinical imaging professionals
- Graduate students

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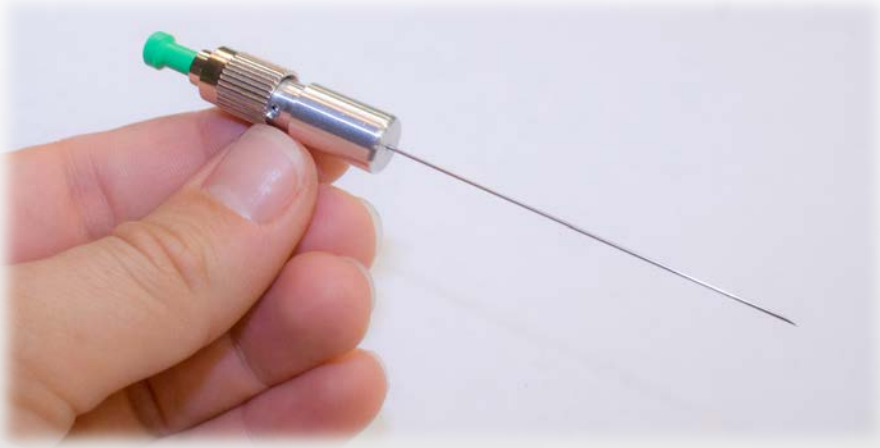
Creating windows into the body



Optical Imaging Needles

Bringing optics deep inside the body

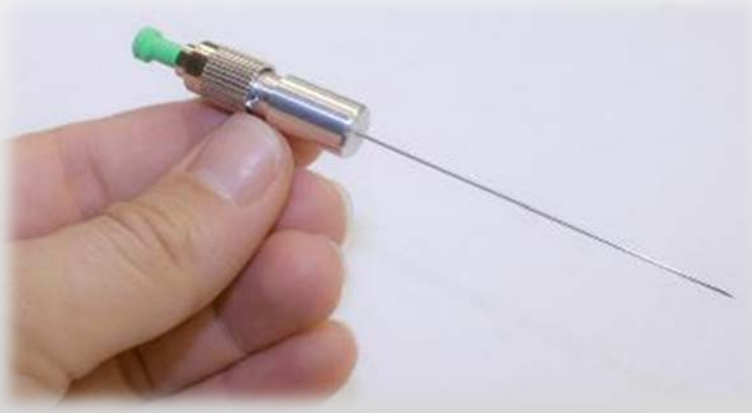
Prof. Robert McLaughlin

University of Adelaide

robert.mclaughlin@adelaide.edu.au

Overview

- Optical coherence tomography
- Lens design
- Applications
  - Blood vessel avoidance
  - Endoscopic needle probe
  - Fluorescence + OCT needles



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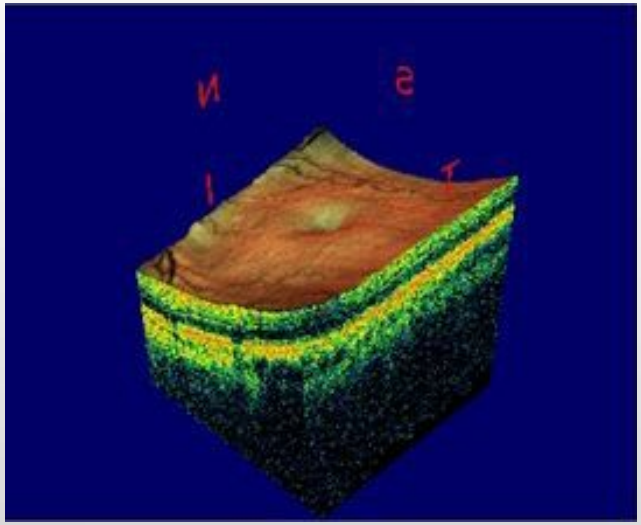
OCT cheat sheet



- Optical Coherence Tomography
  - High resolution in vivo imaging technology
  - Analogous to ultrasound
  - Uses light waves instead of sound
- Strength
  - Much higher resolution than ultrasound
  - Resolution approx. 1-20 microns.
- Weakness
  - Shallow penetration depth (1mm-3mm)
- Current clinical uses
  - Ophthalmology
  - Cardiology

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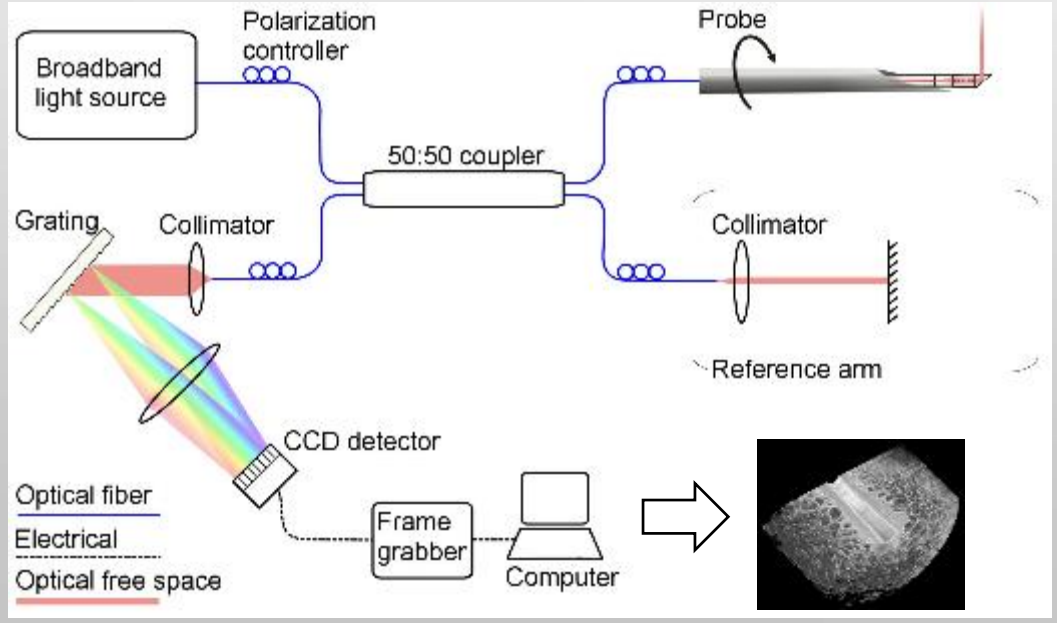
OCT cheat sheet

- Optical Coherence Tomography
  - Detects backscattered light up to 2-3mm in tissue
  - 800nm – 1300nm
  - Light is detected from multiple depths
  - Uses interferometry to distinguish backscatter from different depths
  - Split into two paths
  - Reference: mirror
  - Sample: illuminates tissue
  - Reflected light is combined, interfered and detected

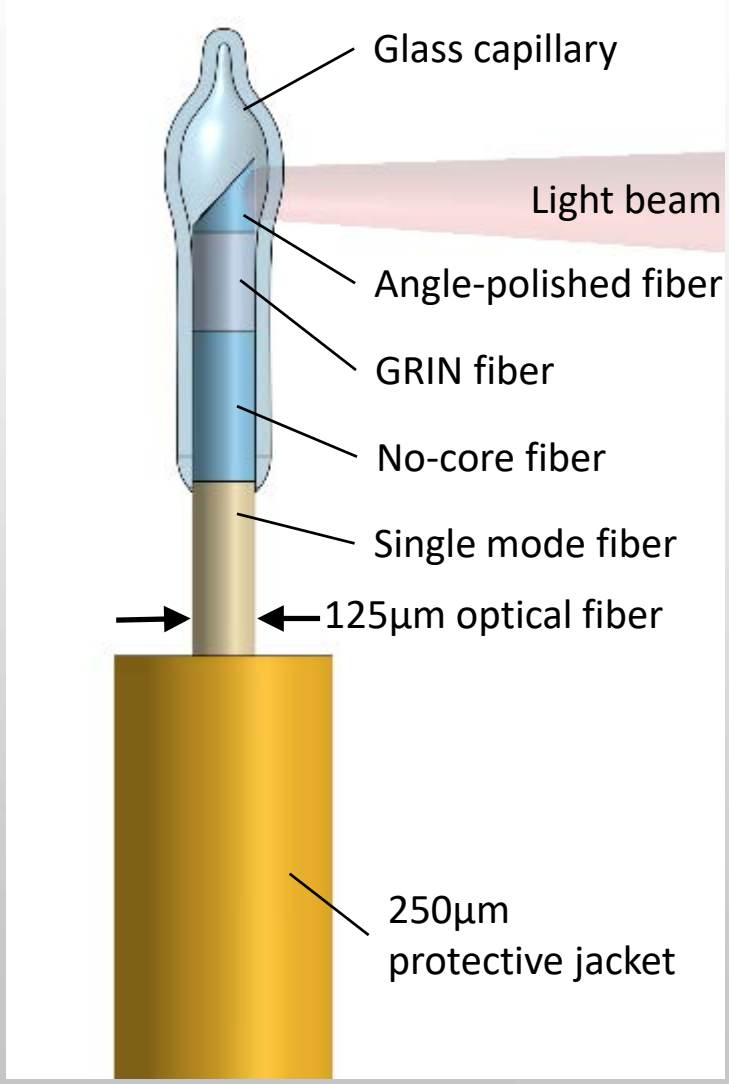


Overview

- Optical coherence tomography
- Lens design
- Applications
  - Blood vessel avoidance
  - Endoscopic needle probe
  - Fluorescence + OCT needles

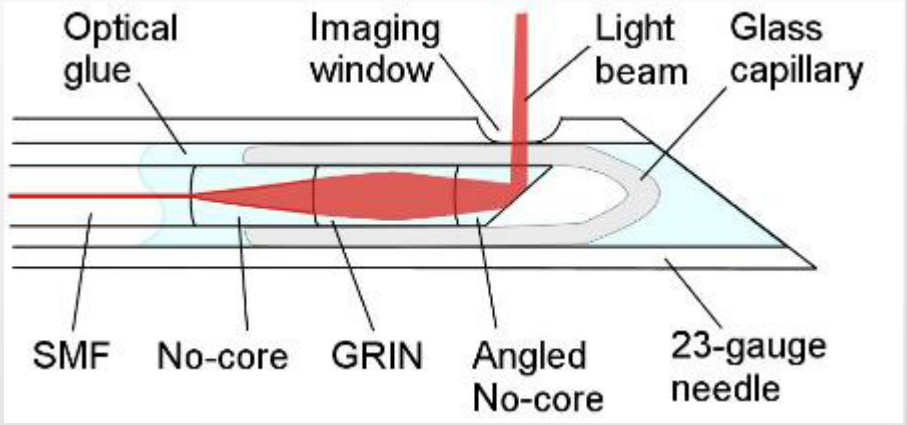
Imaging needles

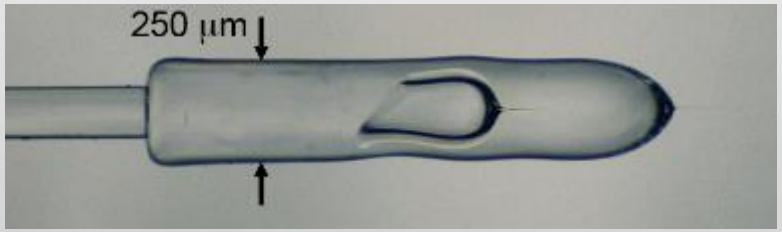
- Miniaturized OCT probe
  - Can be encased in a range of needles
  - 24-gauge to 14 gauge needle
  - Needle outer diameter 560µm – 2.1mm
- Design:
  - All-fiber focusing optics
  - Multiple layers of fiber fused together to focus the light beam
  - Terminated with angle-polished fiber to reflect light beam at right angles



Imaging needles

- Optical design
  - Single mode fiber
    - Connected to OCT scanner
  - No core
    - Expands the light beam
  - GRIN
    - focusing element
  - Angle-polished no-core fiber
    - Reflector
    - Total internal reflection. Angle=48˚
  - Encased in glass capillary





Scolaro et al., "High-sensitivity anastigmatic imaging needle for optical coherence tomography," *Optics Letters*, 37(24):5247-5249, 2012.

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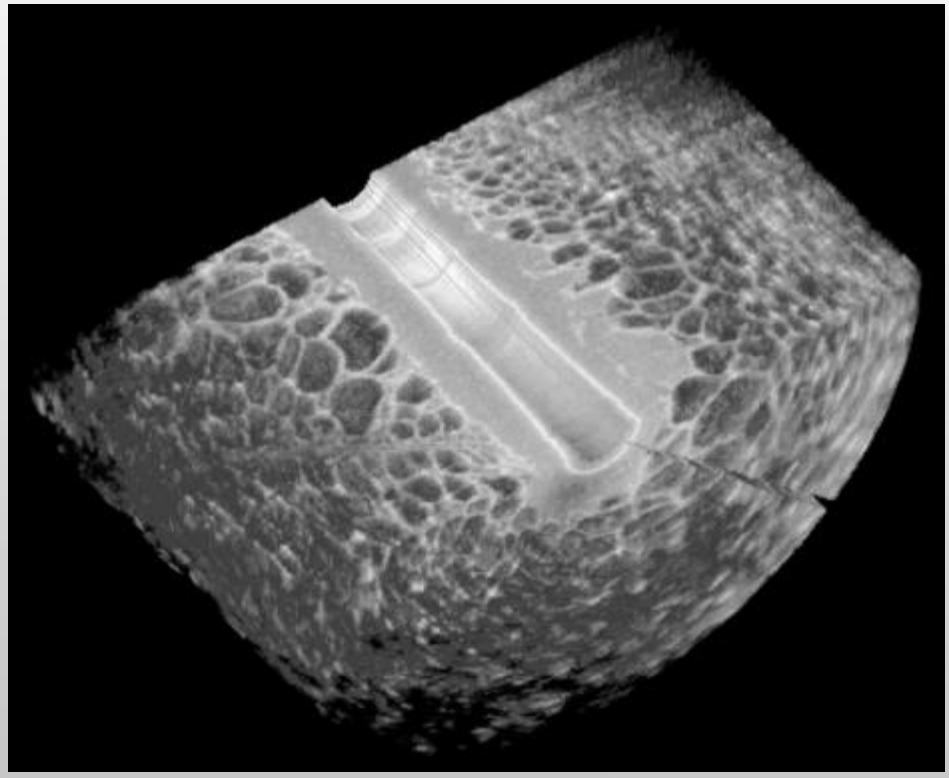
Imaging needles

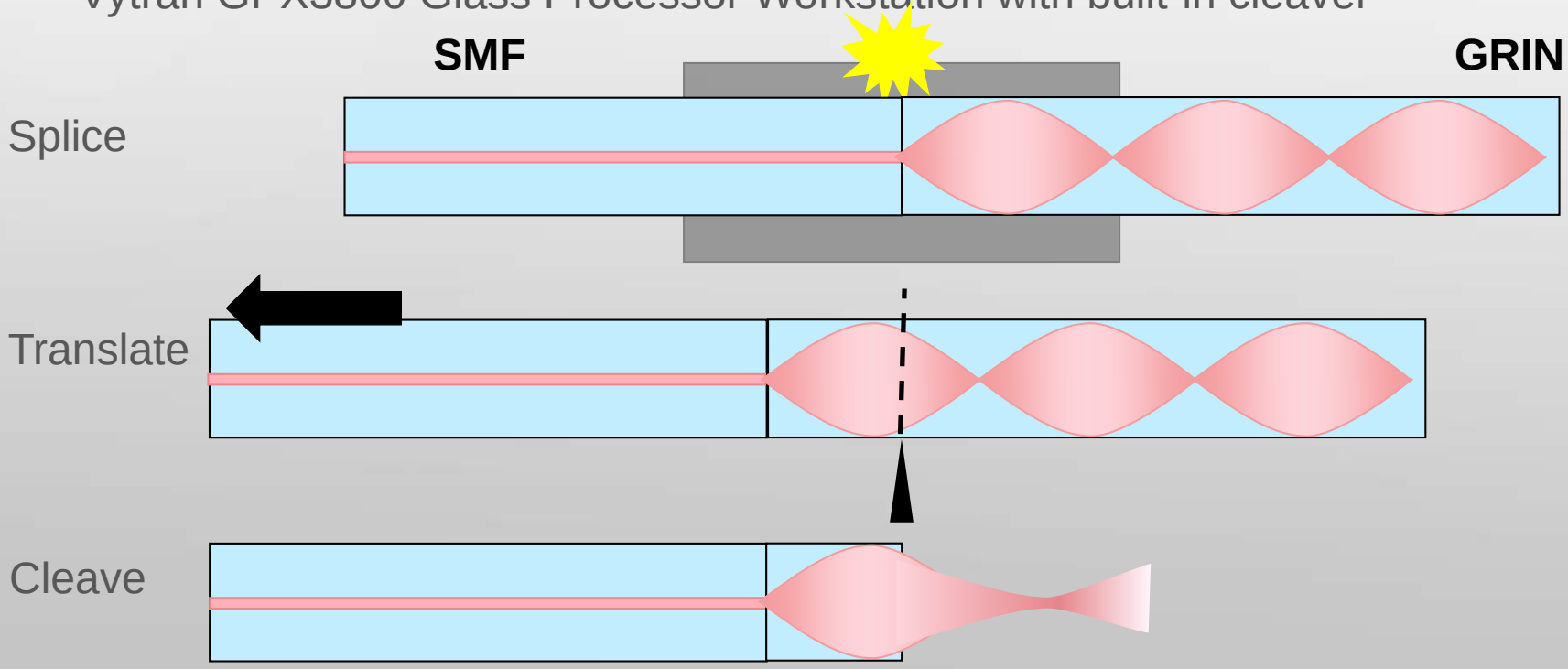
- Performance
  - High sensitivity of 112 dB
- Specifications
  - Imaging distance: 1-2 mm
  - Lateral resolution: 10-20 µm



Scolaro et al., "High-sensitivity anastigmatic imaging needle for optical coherence tomography," *Optics Letters*, 37(24):5247-5249, 2012.

Fabrication

- Fabricate fiber lengths with high accuracy (< 5μm tolerance)
- Vytran GPX3800 Glass Processor Workstation with built-in cleaver



Commercial imaging needles

- www.miniprobes.com
  - Commercially available imaging needles
  - Designed for product prototyping and R&D

MINIPROBES

Handheld interferometer

Pathlength-matched imaging needles FC/APC

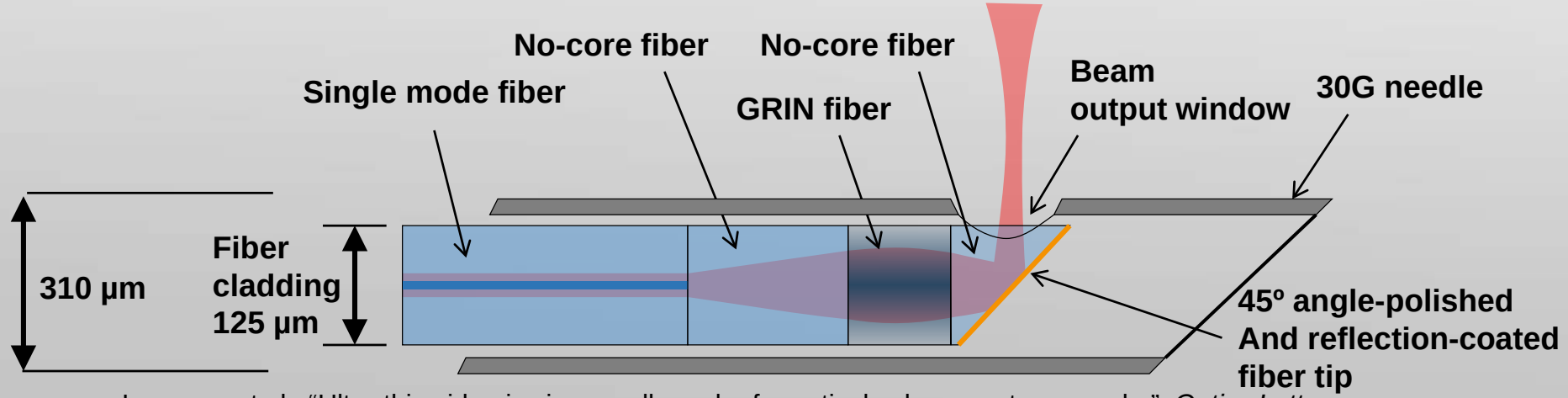
Commercial imaging needles

- www.miniprobes.com
  - 640µm diameter needle
  - Integrated with ThorLabs Telesto and Axsun swept-source OCT scanners
  - Can integrate with other 1300nm OCT systems
  - Light beam is near collimated to maximize imaging distance

MINIPROBES

Small imaging needles

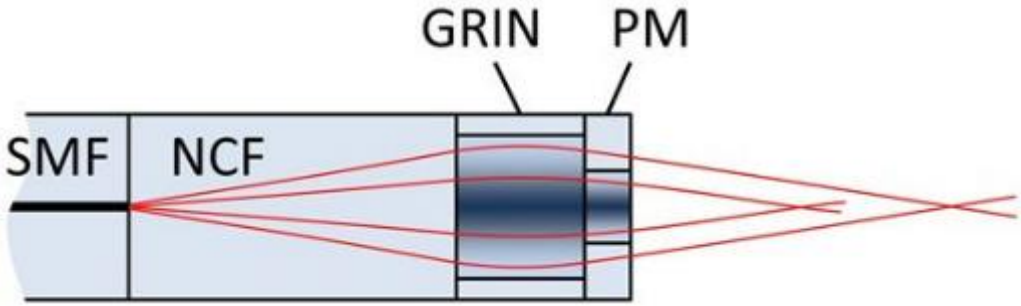
- 30-gauge OCT needle probe
  - Outer diameter 310µm
  - Design: single-mode fiber, no-core fiber, GRIN fiber
- Deflector is made from angle-polished no-core fiber
  - chrome/gold 10nm/300nm coating
- Working distance: 600µm
- Lateral resolution: 7.7µm and 13.6µm
  - astigmatism of curved output surface

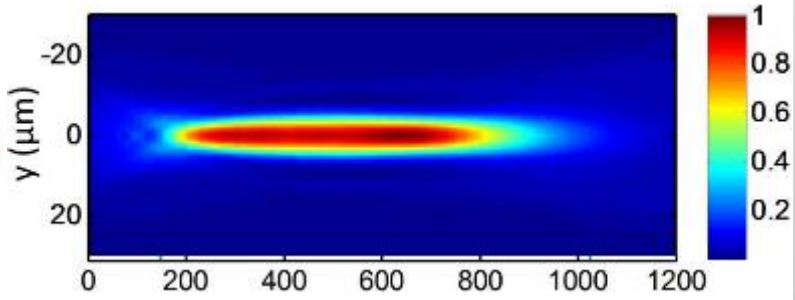


Lorenser et al., "Ultra-thin side-viewing needle probe for optical coherence tomography", *Optics Letters*, 36(19):3894-3896 (2011)

Imaging needles

- Extended depth-of-focus probes
  - GRIN phase mask design
  - ‘double focus’ lens
  - GRIN fiber lens: 190µm length of 100µm core GRIN
  - GRIN Phase Mask (PM): 14µm length of 32µm core GRIN
  - 1.55 x improvement in depth-of-focus



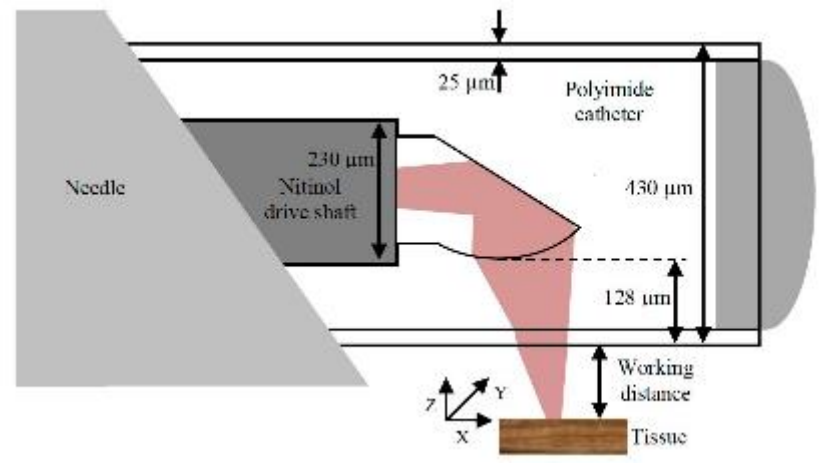


Beam intensity distribution

Lorenser et al., “Ultrathin fiber probes with extended depth of focus for optical coherence tomography”, Optics Letters, 37(10):1616-1618 (2012)

Imaging needles

- Ball-lens design
  - Ball-lens fabricated on end of no-core fiber
  - Ball radii approx. 75 - 100µm
  - Angle-polished for side-imaging probe
  - Spliced to single mode fiber



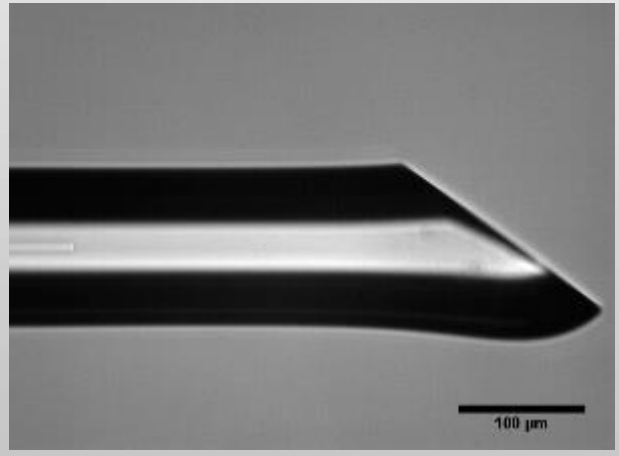
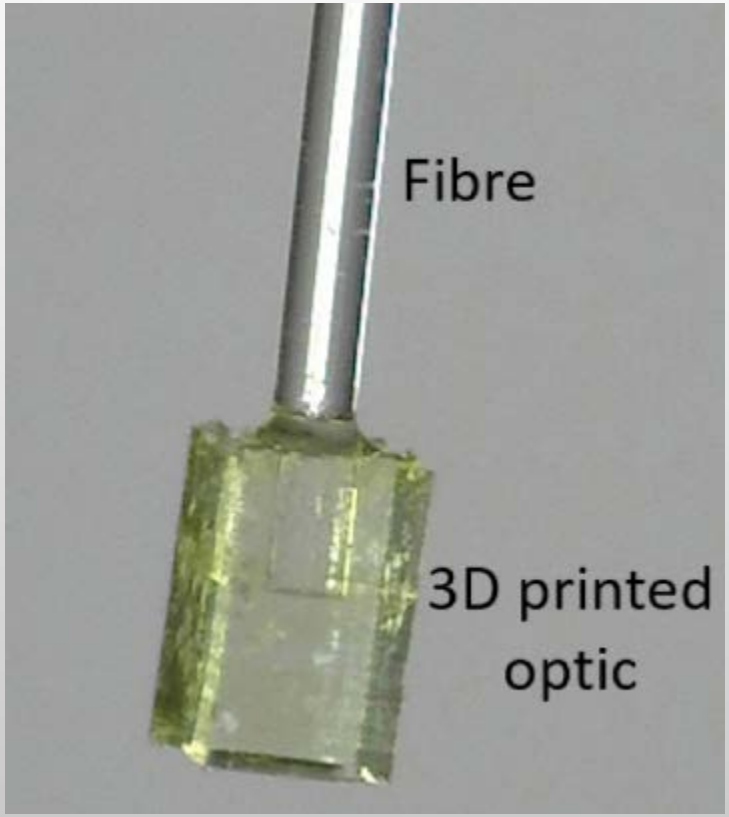


Image taken from Tan et al., ”Flexible transbronchial optical frequency domain imaging smart needle for biopsy guidance”, Biomedical Optics Letters, 3(8):1947-1954 (2012)

3D printed lenses

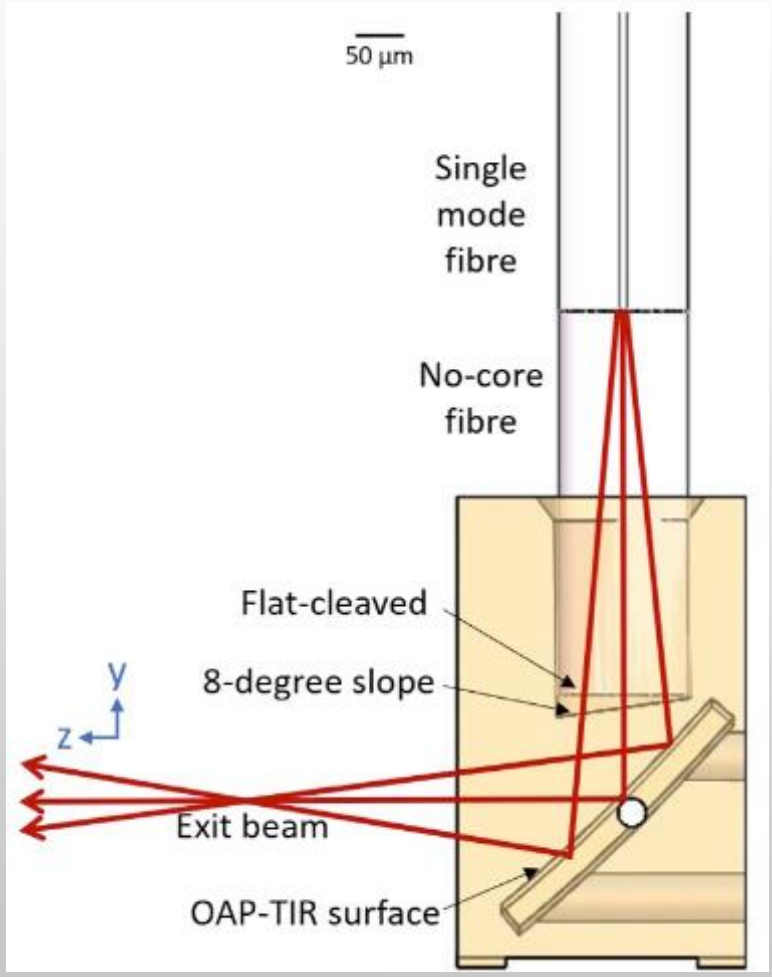
- High-resolution 3D printing
  - Two photon direct laser writing
  - Nanoscribe GmbH, Germany
- Probe size: 0.3mm x 0.6mm
  - Dip-in lithography
  - Layer thickness 100nm
  - Surface roughness 15nm



Images taken from: J. Li et al., "3D printed freeform micro-optics for optical coherence tomography fibre probes," Submitted to *Scientific Reports*, 2018.

3D printed lenses

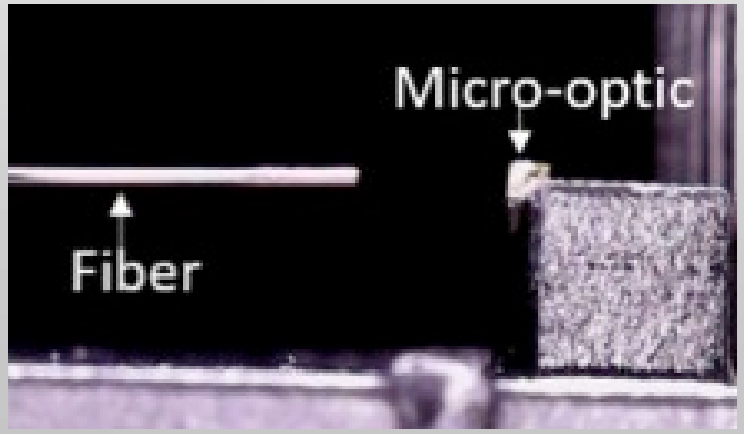
- Design
  - No-core fiber to expand beam
  - Couple fiber into 3D printed fiber slot
  - Reference reflection from fiber-tip
  - Redirect with total internal reflection
  - Focus with paraboloid mirror

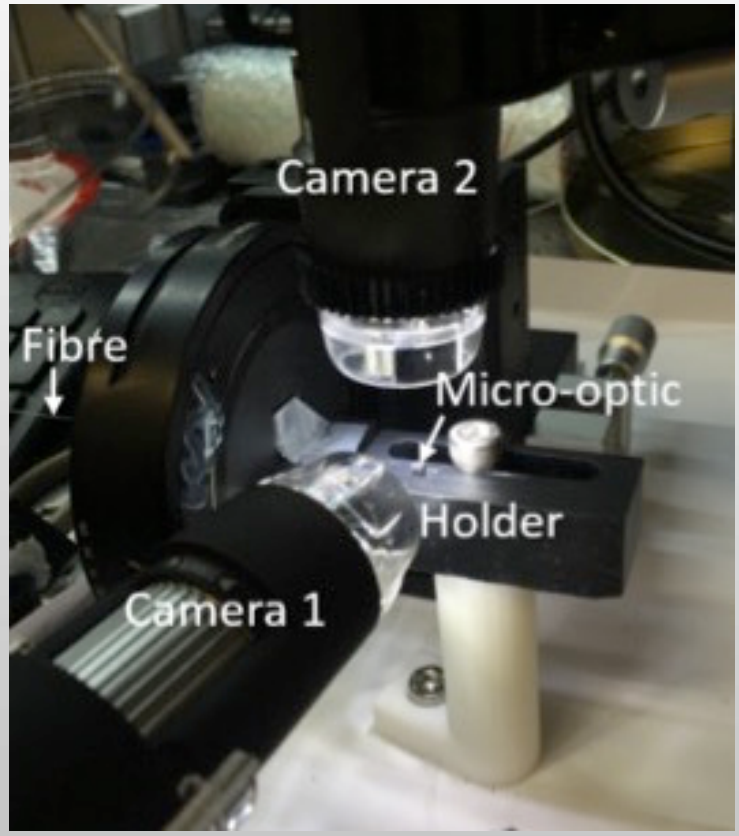


Images taken from: J. Li et al., "3D printed freeform micro-optics for optical coherence tomography fibre probes," Submitted to *Scientific Reports*, 2018.

3D printed lenses

- Assembly
  - Custom holders printed with Form2 printer (Formlabs, USA)
  - Use translation stages to move fiber
  - Fiber attached with optical adhesive





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Overview

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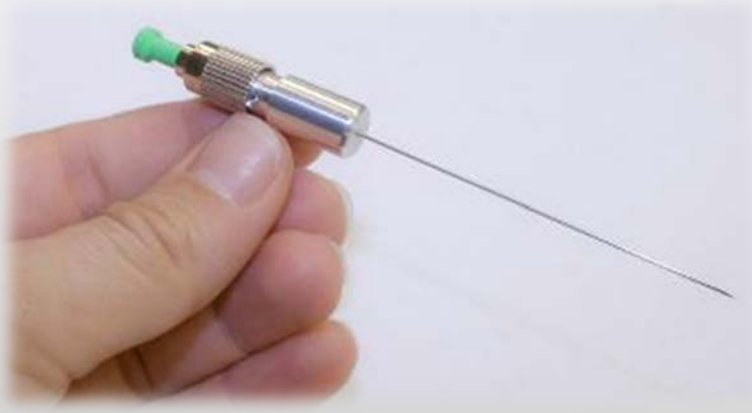
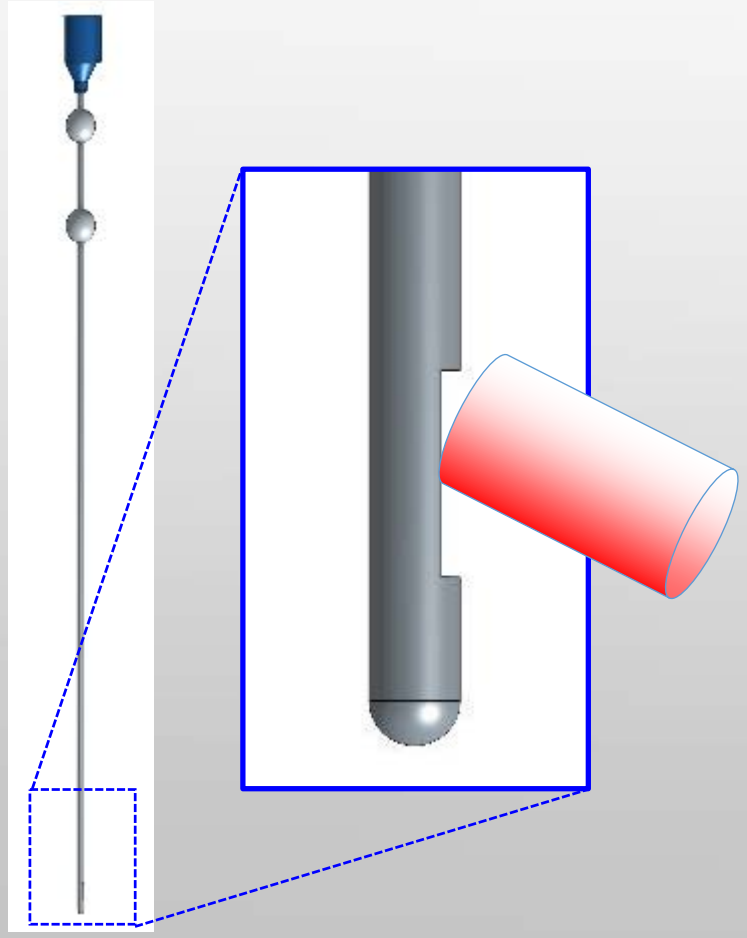
- Lens design
- Applications
  - Blood vessel avoidance
  - Endoscopic needle probe
  - Fluorescence + OCT needles

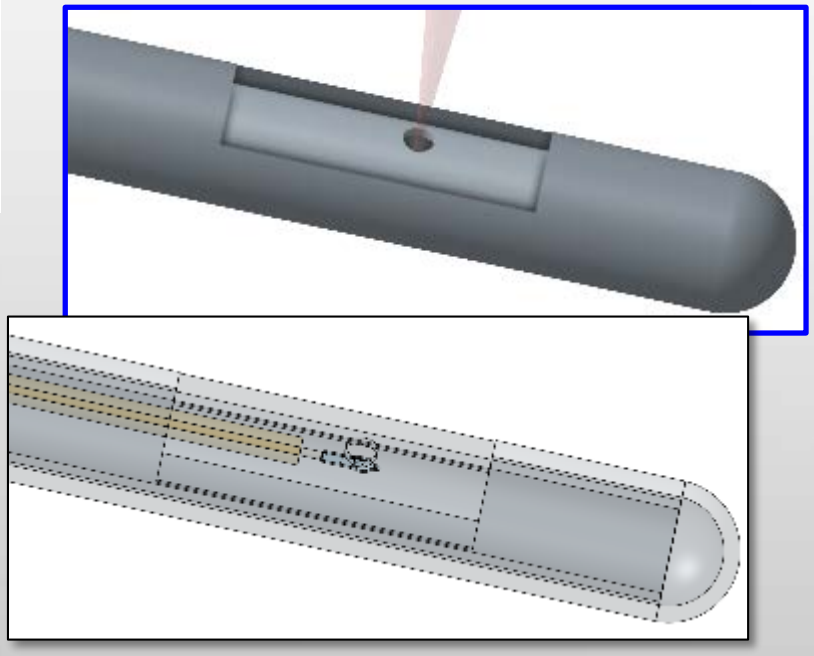


Clinical problem

- Brain biopsy
  - Worldwide, 256,000 new cases of brain cancer each year
  - 23,000 in the USA
  - Brain biopsy is a standard diagnostic technique
  - 2% - 3% risk of serious complications from hemorrhage
  - 1% risk of death
- Task
  - Detect blood vessel next to the biopsy window

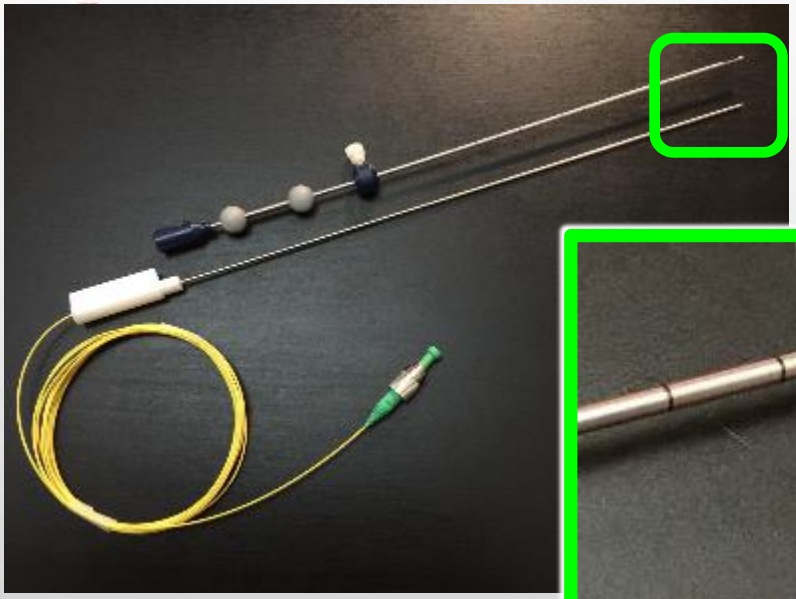


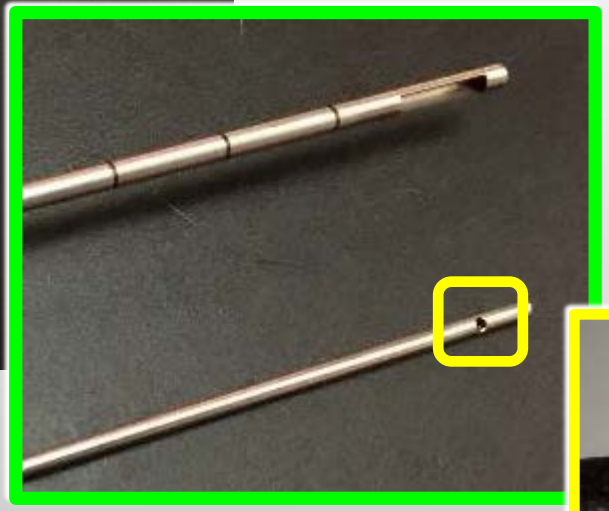
Imaging needles



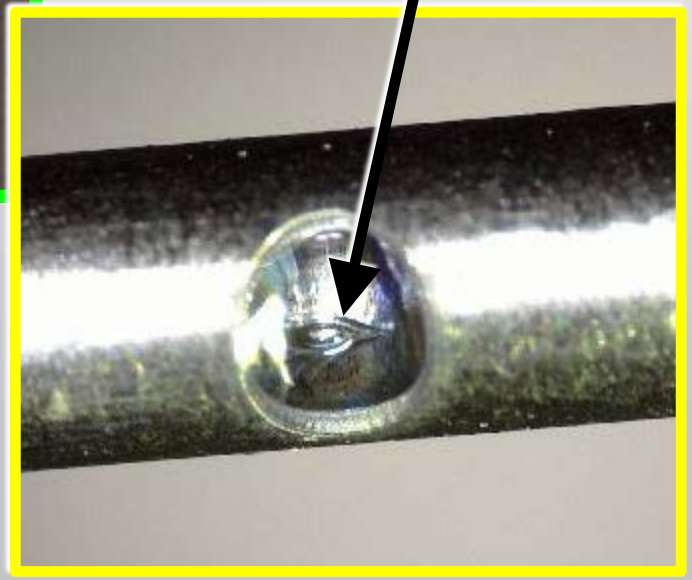
- Integrated into Medtronic brain biopsy needle
  - Replace inner stylet with imaging needle
  - Light beam emitted through imaging aperture in the style

Imaging needles





Optical fiber probe in inner stylet



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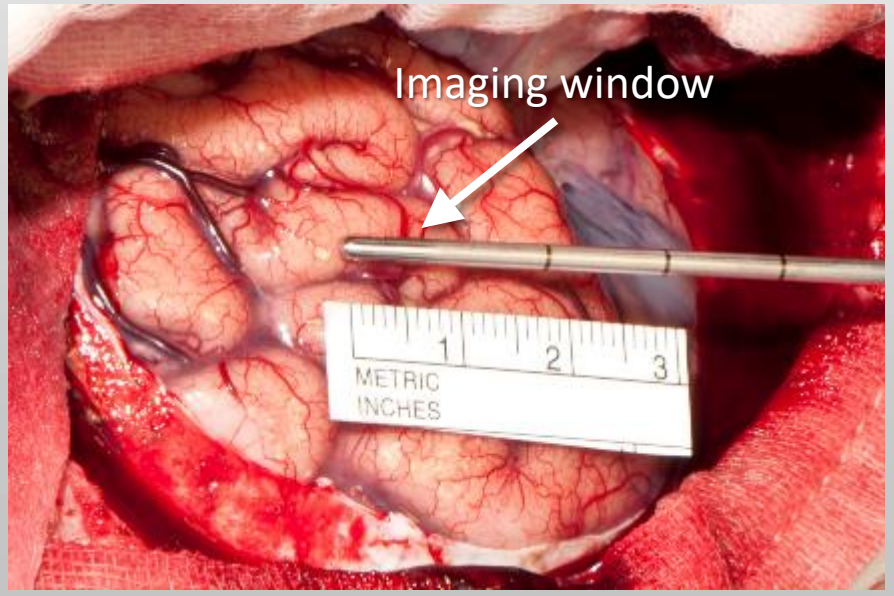
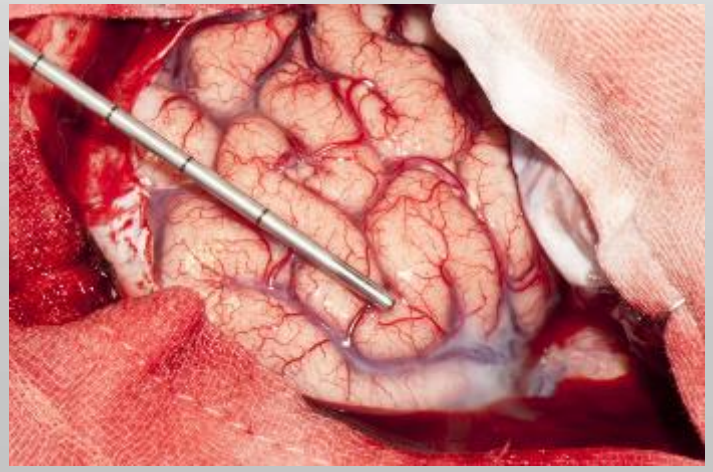
Brain biopsy – Human trial

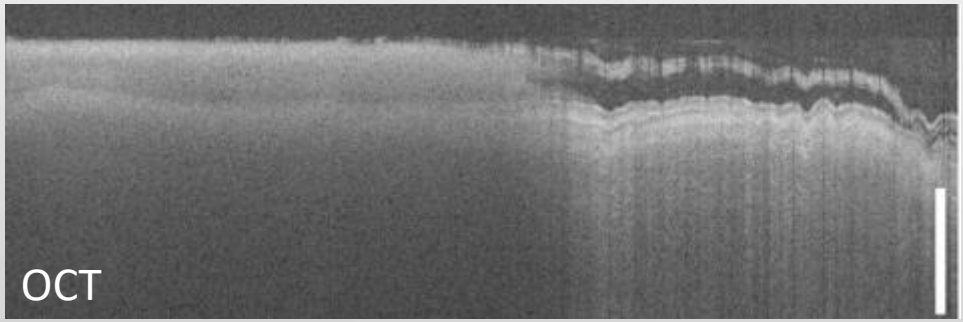
- Human trial – Superficial study
  - Vessel detection validated on superficial vessels
  - Sir Charles Gairdner Hospital, Western Australia
  - 11 patients undergoing craniotomy
  - Automatic vessel detection based on speckle decorrelation

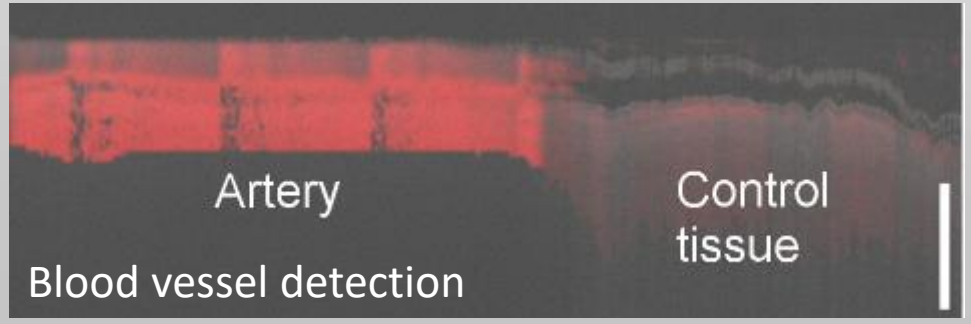


Results

- Patient 1
  - 30-year-old male undergoing craniotomy
  - Speckle decorrelation differentiates blood from solid tissue
  - Scalebar 500μm







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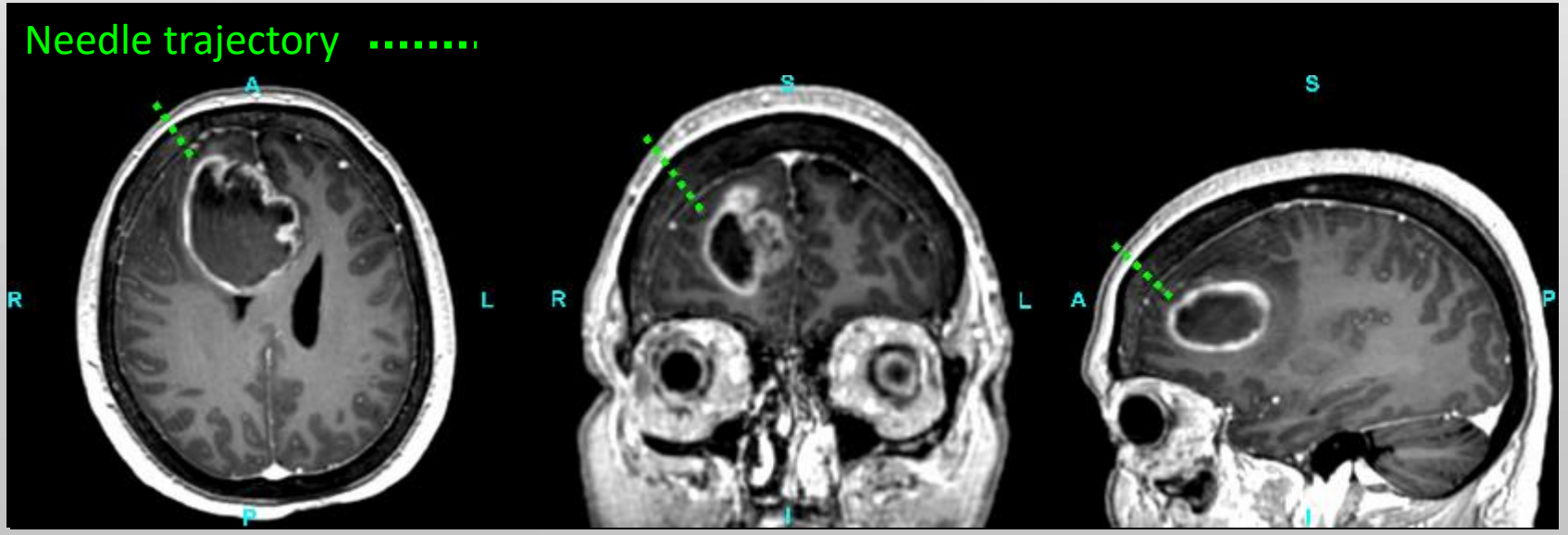
Needle insertion

- Human trial – Deep insertion
  - Needle inserted though burr hole for 3 patients
  - Targeted vessel identified on pre-op MRI
- Case study:
  - 60yo female undergoing right frontal craniotomy



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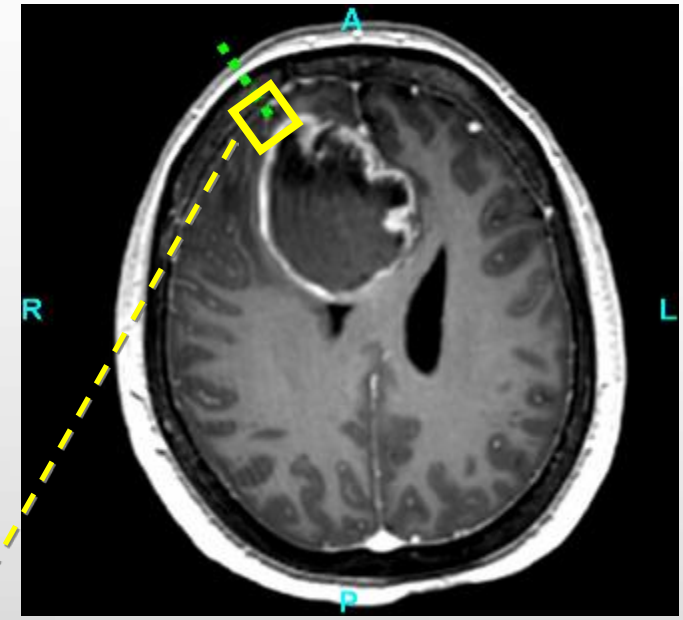
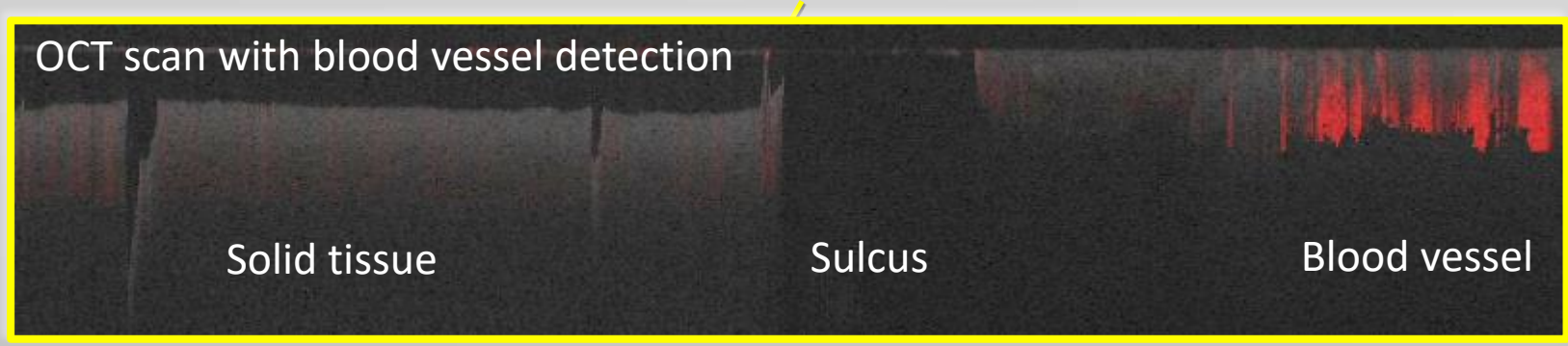
Needle insertion

- Human trial – Deep insertion study
  - Validated against MRI registered with Medtronic Stealth system
  - Imaging needle detected blood vessel
  - Image below shows tissue and blood vessel along needle trajectory





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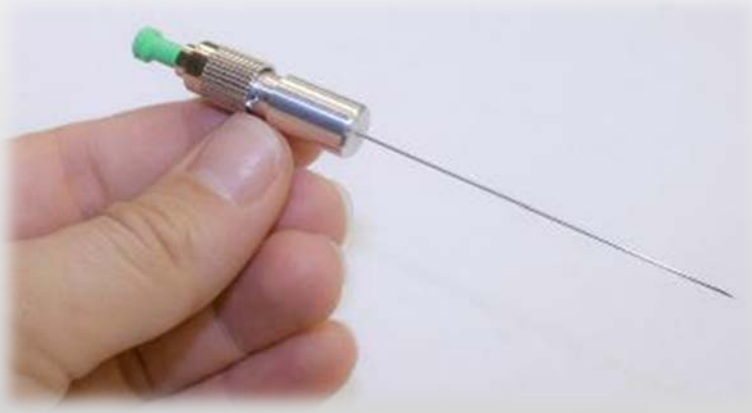


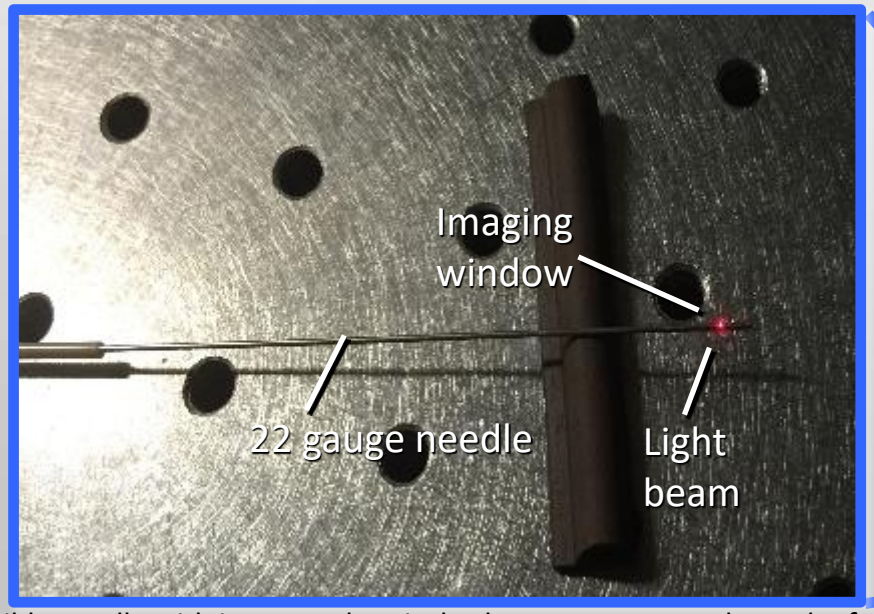
Clinical problem

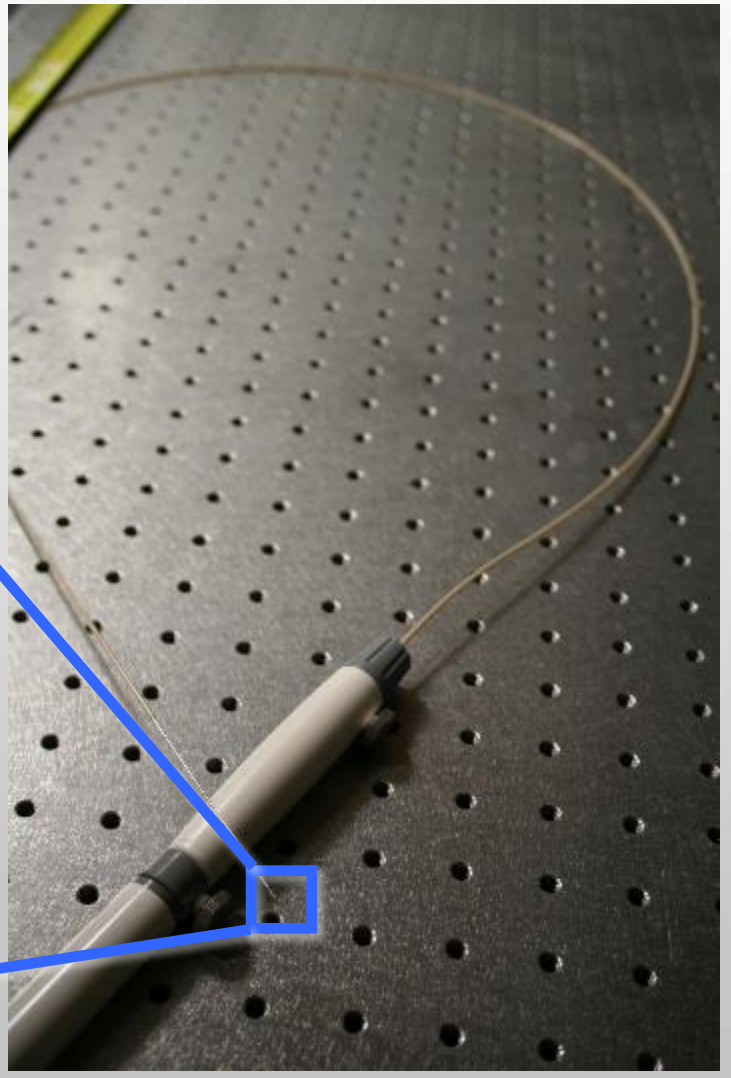
- Project goal
  - Incorporate probe into a flexible needle for endoscopic use
- Clinical problem
  - Staging of lung cancer is critical for treatment planning
  - Transbronchial needle aspiration (TBNA) is commonly used to assess lesions and lymph nodes
  - Flexible needle
  - Introduced into the airway and inserted through the airway wall into lymph node or lesion

J. Li, "Flexible needle with integrated optical coherence tomography probe for imaging during transbronchial tissue aspiration," *J. Biomedical Optics*, 22(10)106002, 2017

Endoscopic needle probes

- Endoscopic imaging needle
  - 22-gauge Olympus EZ Shot 2 aspiration needle with sideport
  - Outer diameter: 720μm
  - Flexible needle shaft





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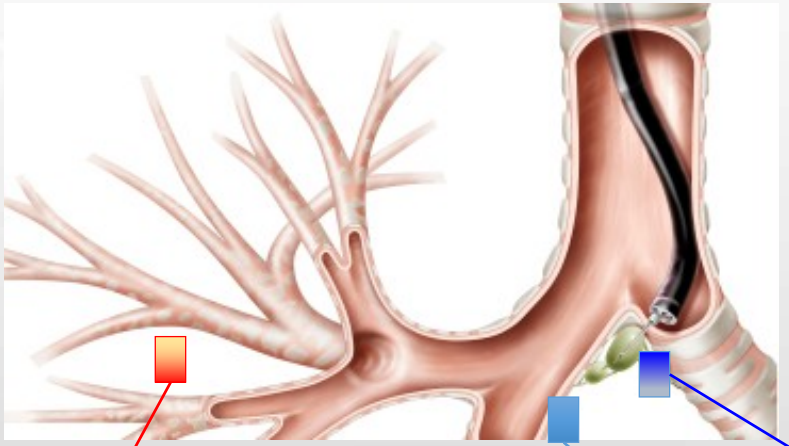
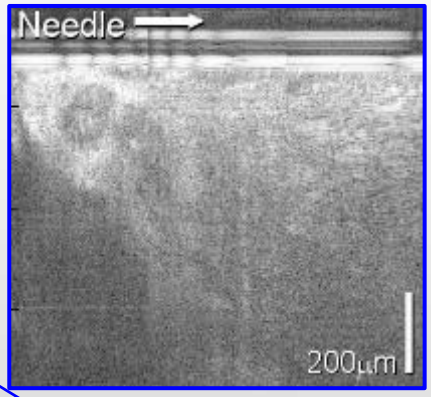
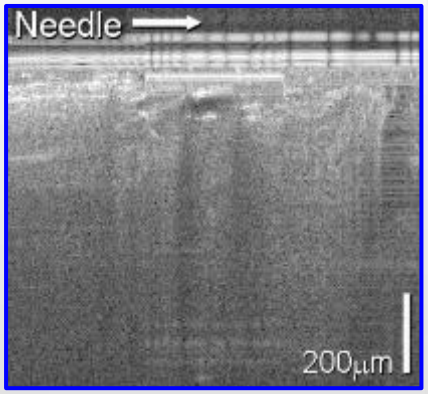
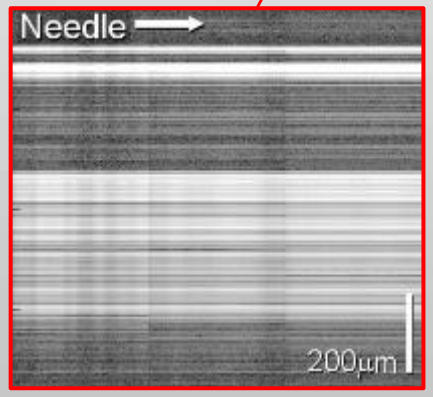
Results

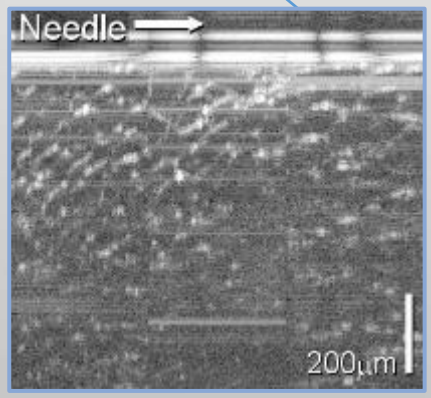




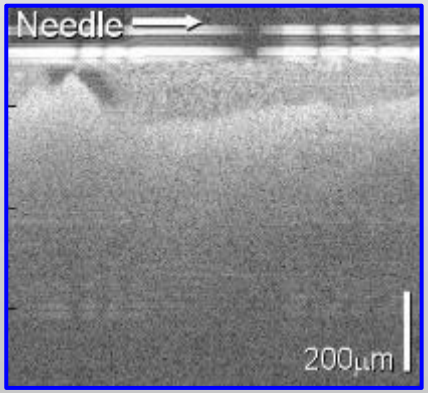


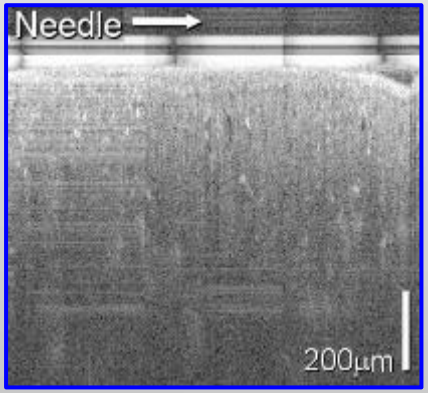


Alveoli



Adipose (fat)



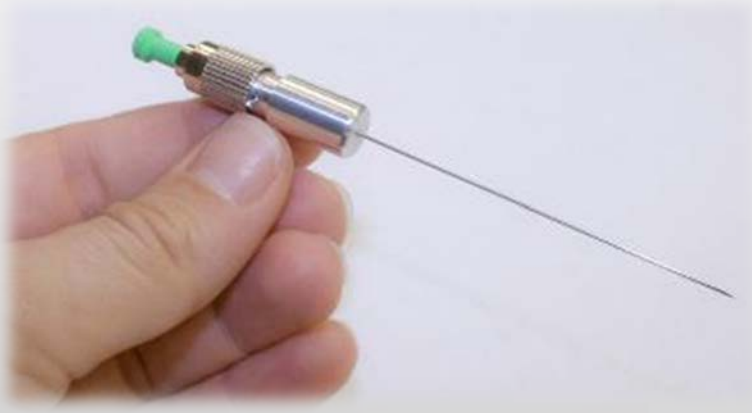


Solid tissue

J. Li, "Flexible needle with integrated optical coherence tomography probe for imaging during transbronchial tissue aspiration," *J. Biomedical Optics*, 22(10)106002, 2017

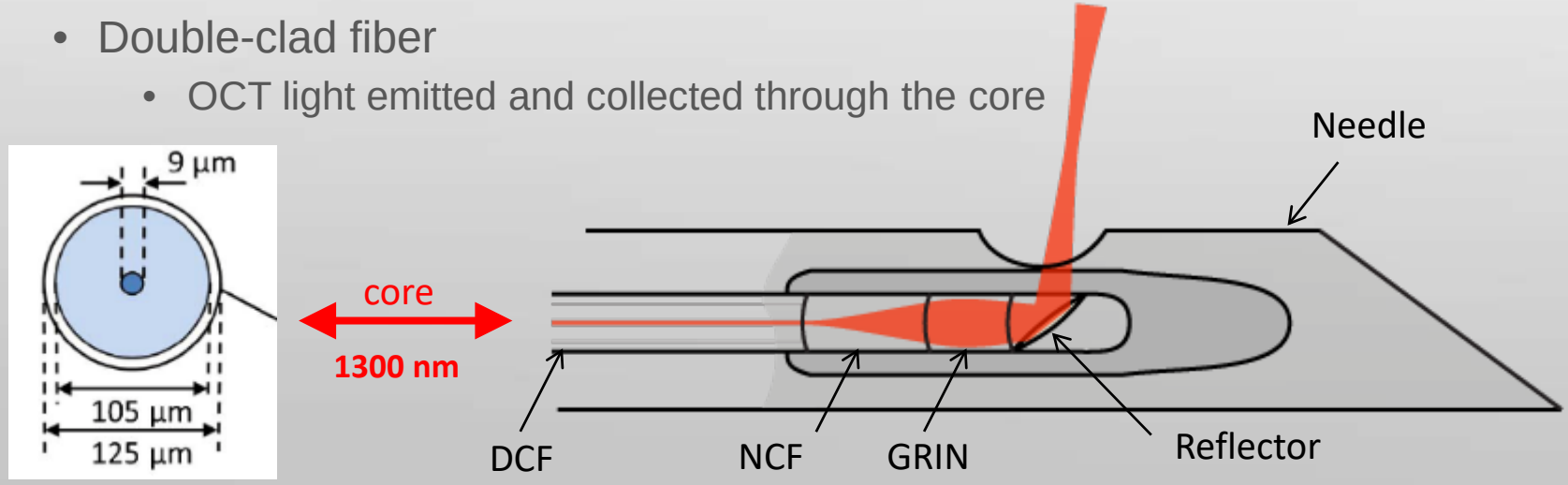
Overview

- Optical coherence tomography
- Lens design
- Applications
  - Blood vessel avoidance
  - Endoscopic needle probe
  - Fluorescence + OCT needles



Fluorescence + OCT needles

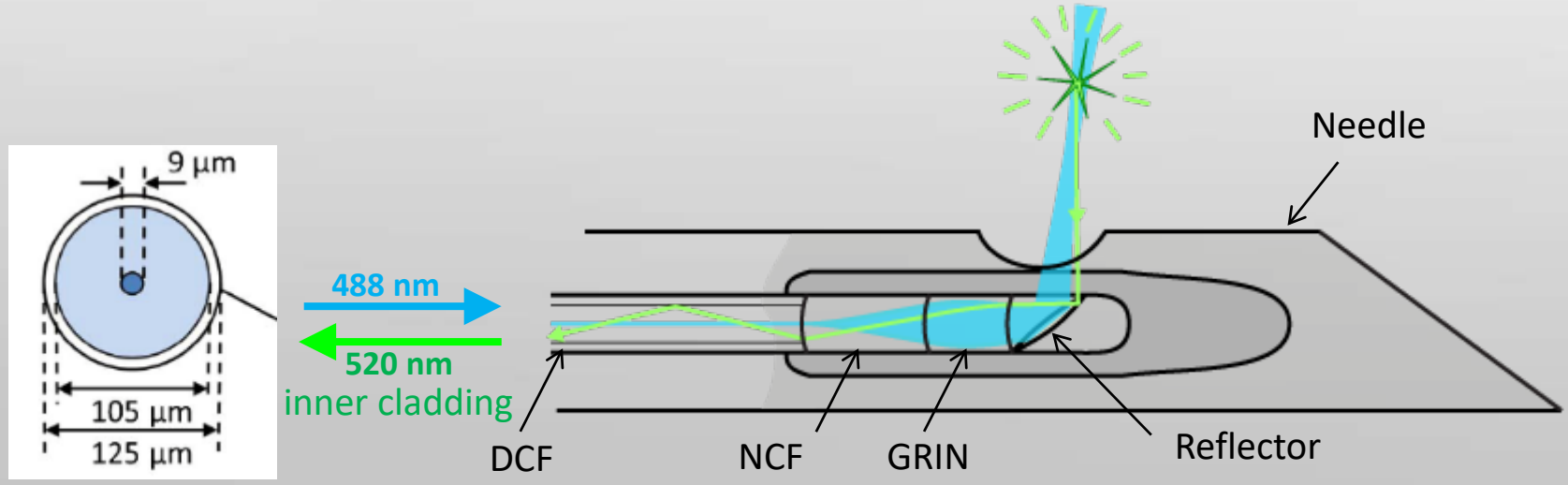
- Seeing two images at once
  - OCT provides structural images of tissue
  - Add a functional imaging modality → information about biochemical composition
- Collaboration
  - Ecole Polytechnique Montreal
- Double-clad fiber
  - OCT light emitted and collected through the core



Scolaro, et al., "Molecular imaging needles: dual-modality optical coherence tomography and fluorescence imaging of fluorescently labeled antibodies deep in tissue," Biomedical Optics Express, 6(5):1767-1781, 2015.

Fluorescence + OCT needles

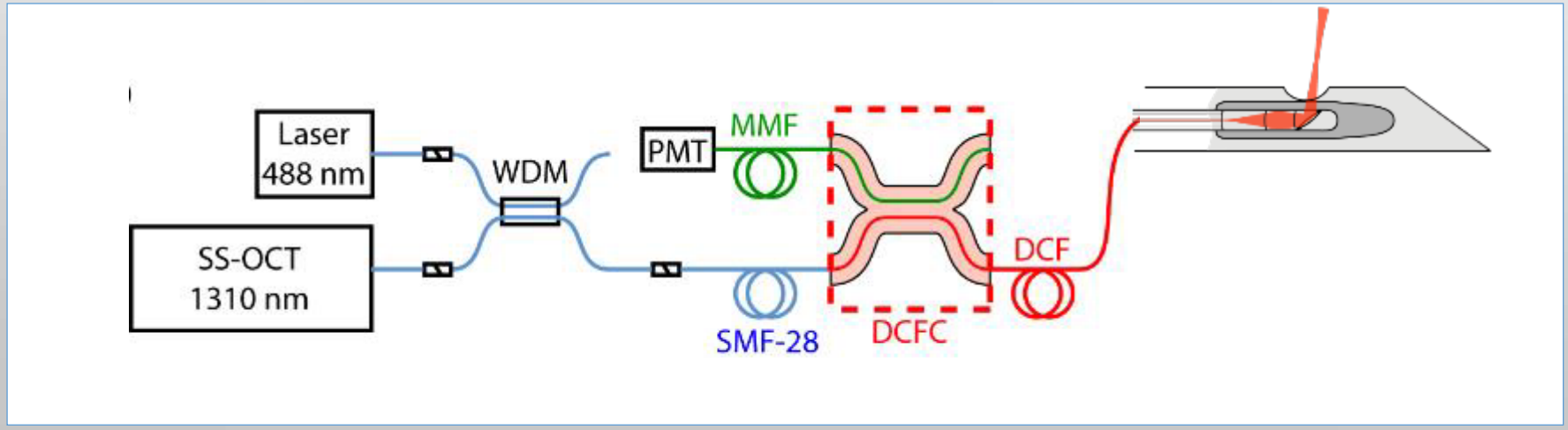
- Double-clad fiber
  - Excitation light emitted through core
  - Fluorescence signal collected through inner cladding
  - Inner cladding gives us a much large aperture for collecting fluorescence



Scolaro, et al., "Molecular imaging needles: dual-modality optical coherence tomography and fluorescence imaging of fluorescently labeled antibodies deep in tissue," Biomedical Optics Express, 6(5):1767-1781, 2015.

Fluorescence + OCT needles

- Double-clad fiber couple separates the two signals (OCT and fluorescence) for detection
  - DCF couplers developed by Castor Optics, Canada
- Allows simultaneous OCT and fluorescence images to be acquired
  - Images are co-registered



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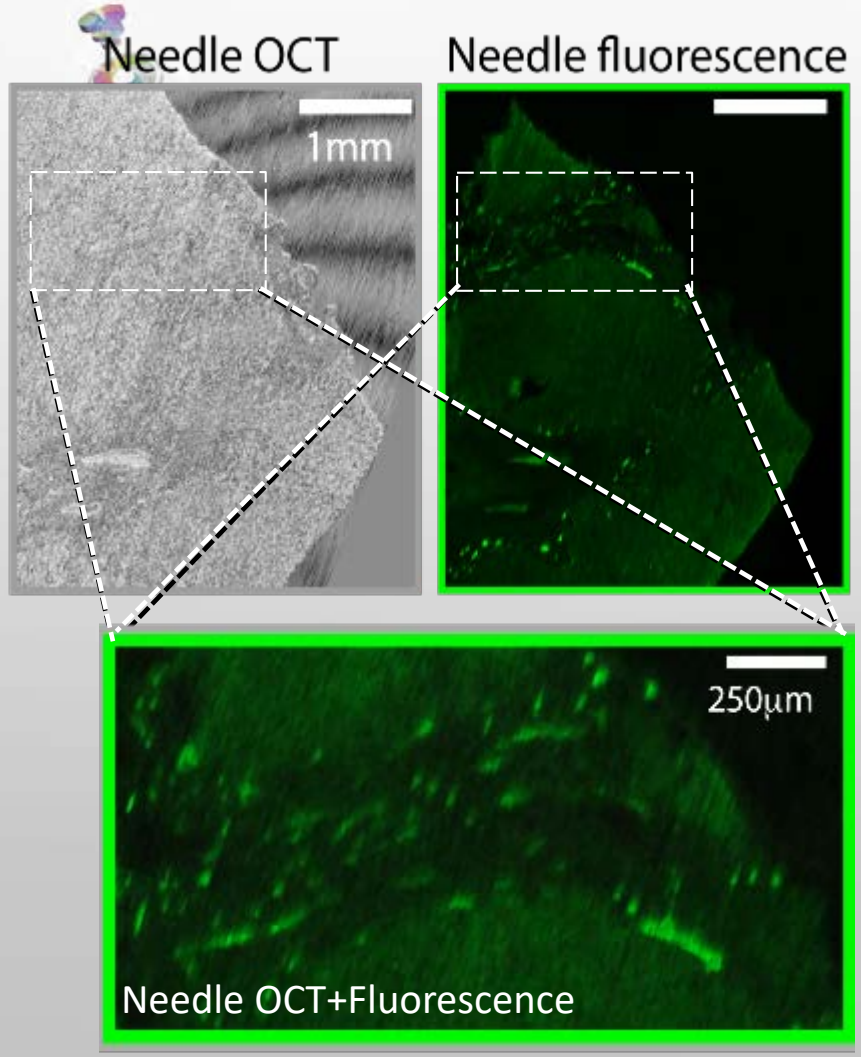
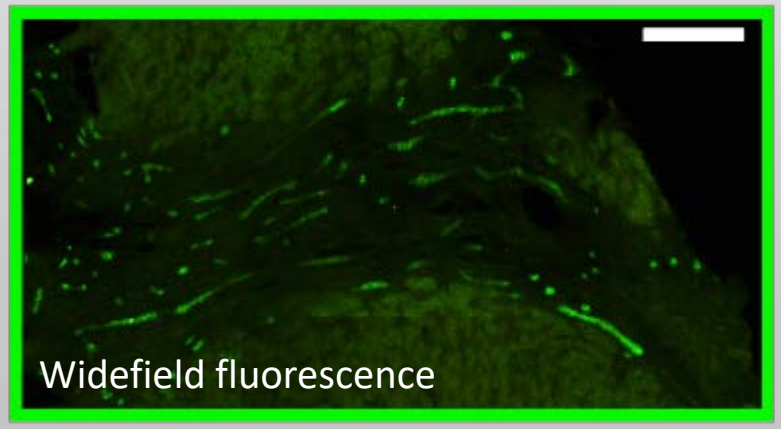
Fluorescence + OCT needles

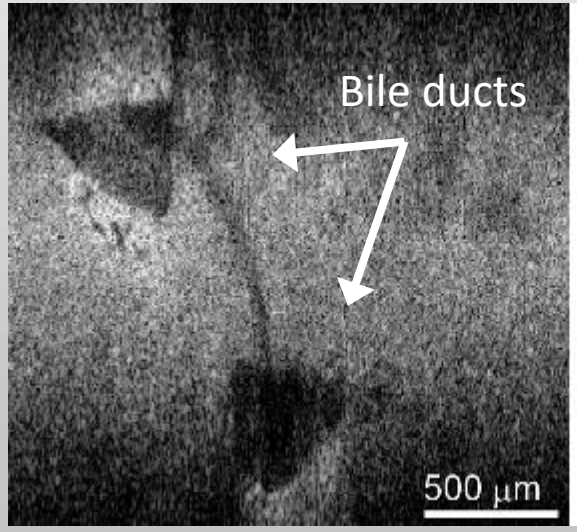


- Collaboration with Prof. George Yeoh, Anne Kramer,
  Harry Perkins Medical Research Institute + University of Western Australia
- Human ex vivo liver section
  - Atypical ductular reaction
- Detected antibodies bound to liver cells
  - Atypical proliferating ductal epithelial cells
- Strong match to widefield fluorescence microscope imag

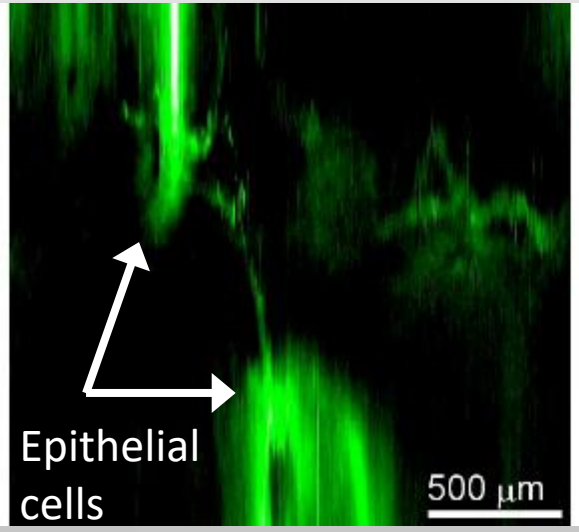


Fluorescence + OCT needles

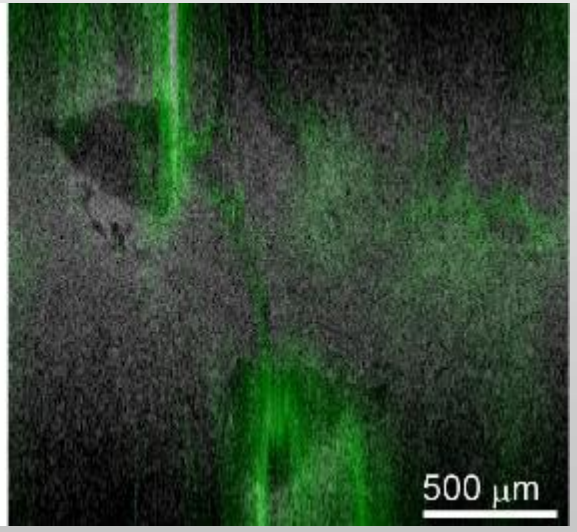
- Imaging deep within a mouse liver
  - Labelling of epithelial cells
  - EpCAM antibody conjugated with Alexa Fluor 488



Needle OCT



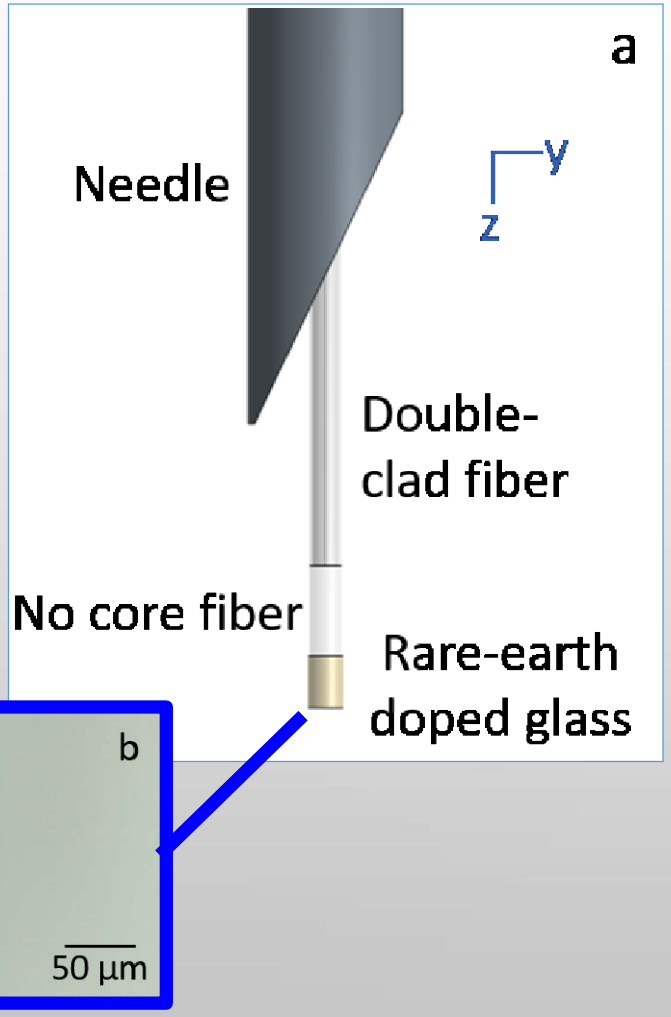
Needle fluorescence



OCT + fluorescence

Imaging + Sensing needles

- Work led by Dr. Jiawen Li, Uni. Adelaide
- OCT: imaging
- Fluorescence: temperature sensing
  - Tellurite glass doped with rare earths (erbium and ytterbium)
  - Fluorescence spectrum varies with temperature
- Image-guided probe placement
  - Avoidance of blood vessels
- Pilot experiments on ex vivo rat brain



J. Li, "Miniaturized single-fiber-based needle probe for combined imaging and sensing in deep tissue," *Optics Letters*, accepted for publication 2018

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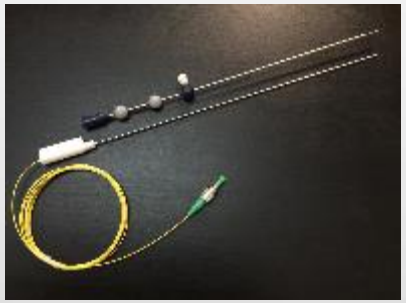
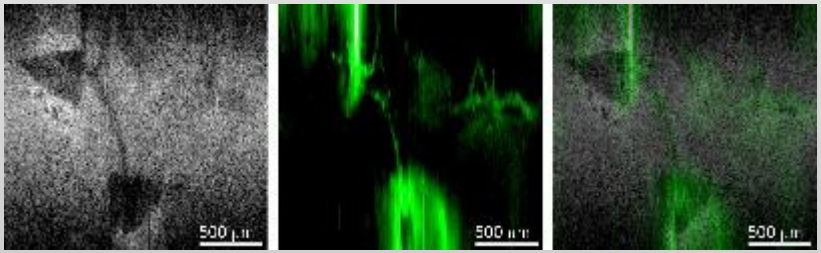
Summary

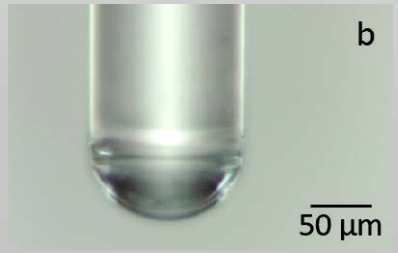
- Imaging needles
  - Miniature fiber-optic probes



- All-fiber design
  - No-core, GRIN, polished no-core
  - Ball lenses
  - 3D printed lenses



- Applications
  - Blood vessel avoidance
  - Flexible needles
  - Fluorescence + OCT needle probes
  - Sensing + imaging



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  - Shaghayegh Eshaghian
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  - Karol Karnowski
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  - **University of Toronto**
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  - **Ryerson University**
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  - **Sir Charles Gairdner Hospital**
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  - **UWA School of Anatomy, Physiology and Human Biology**
    A/Prof. P. Noble
  - **UWA School of Sports Science, Exercise and Health**
    Danny Green

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  - Intuitive Surgical

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Summary

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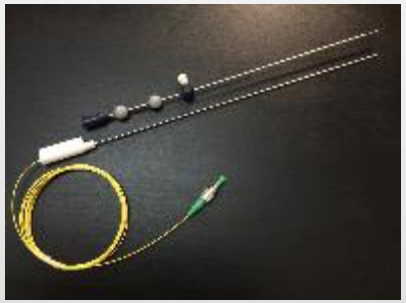

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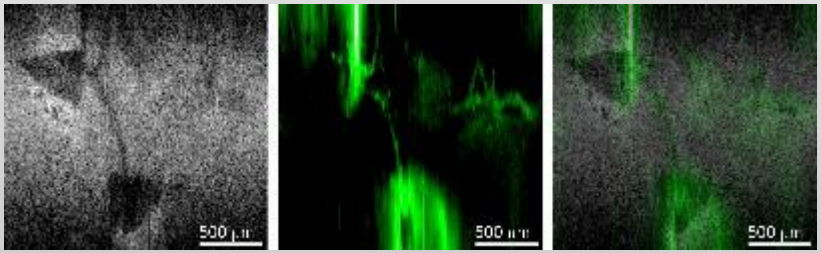

- Applications
  - Blood vessel avoidance
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  - Sensing + imaging