Imaging and Sensing via Specialty Optical Fibers

Udo Fetzer - June 11th, 2024

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Guiding Light For a Better Life:

Imaging and Sensing via Specialty Optical Fibers

- Specialty Fiber Designs
- Shape Sensing
- Next Gen Imaging Technologies
- New Fiber and Splicing Technologies

OFS – Premium Manufacturer of Optical Fibers, Cables, and Modules

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OFS Specialty

We work closely with clients to ensure our products meet specific needs, no matter how unusual or complex.

Customized Solutions for:

- Medical Applications
- Commercial Fiber Laser
- Specialty Communications
- Ocean
- Industrial Networks
- Aerospace & Defense
- Sensing

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Specialty Fiber Designs

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Fiber, Coating, Buffer and Cable Designs/Materials

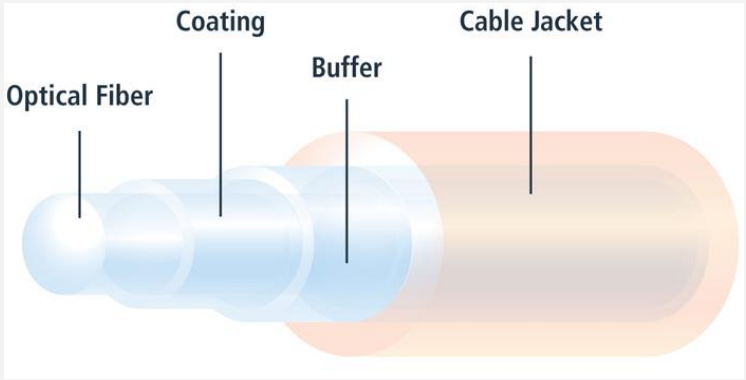
Fibers
- Core Dia 3 to 1500 µm
- SI, GI,
- SM, MM and Few-mode
- HCS® cladding & silica
- Single core - and multicore and coreless
- PMFs
- Bend Insensitive
- Dispersion shifted
- NA 0.1 to 0.5
- Low and high OH
- Er, Tm, Yb doped
- Ribbon & rollable ribbon
- AcoustiSens®
- Hollowcore
- Multicore

Coatings
- Acrylate
- High temp acrylate
- Fluoroacrylate
- Silicone
- Low temp silicone
- Silicone/acrylate
- Carbon
- Polyimide - Pyrocoat®
- HCS®
- Metallization

Buffers
- PFA
- FEP
- ETFE
- PVDF
- PEEK
- Thermoplastic elastomer
- PVC
- Nylon

Jackets
- PFA
- FEP
- ETFE
- PVDF
- PVC
- PU
- PE
- TPO
- LSZH

meeting different environmental requirements
temp range, chemical resistance, abrasion, radiation, strain, flexibility, UV, flame, biocompatible, …



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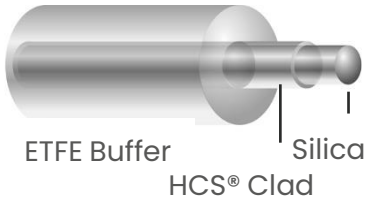
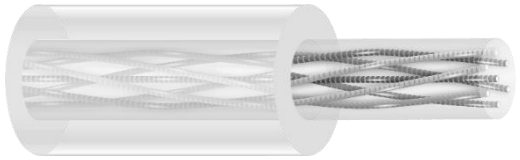
Specialty Fiber Designs

HCS® Fibers

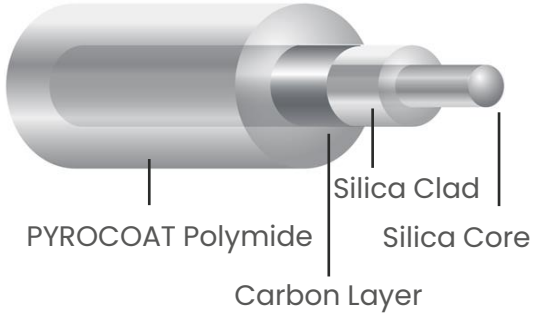


Shape Sensing Multicore Fibers

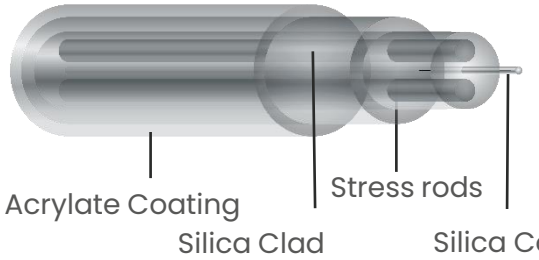


Multiple Twisted Cores with continuous gratings

High-Temperature Hermetic Fibers



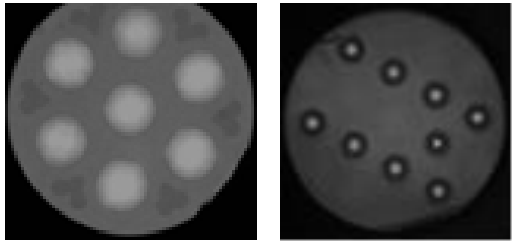
Polarization Maintaining Fibers



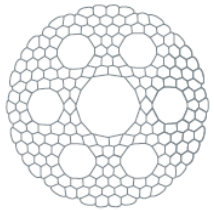
- **Communication & Control (Telecom, Datacom, Industrial Networks,…)**
- **Power Delivery (PDT, Ablation, Welding,…)**
- **Imaging (OCT, Fluorescence, Spectroscopy,…)**
- **Sensing (Shape, Acoustic, Temperature, Strain,…)**

Combination of Applications into a single fiber?

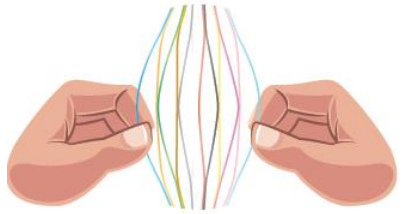
Multicore Fibers



Hollowcore Fibers



Ribbon and Rollable Ribbon Fibers



Engineered fibers for sensing
Active fibers - Bi, Er, Tm, Yb,…
Coreless fibers and more

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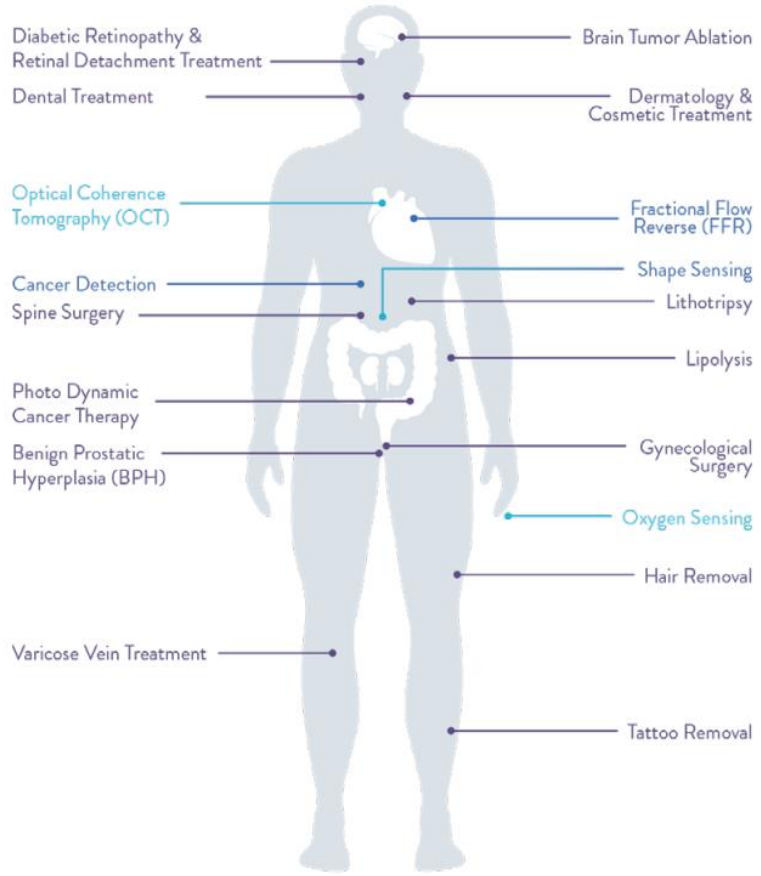
Next Generation Medical Fibers

For minimally invasive procedures

- Smaller fibers (<200 µm diameter)
- Diagnostic and Treatment in one procedure

Multi-functional capabilities

- Navigation - fiber shape & position
- Sensing - force, pressure, temperature…
- Imaging/Diagnostics - Fluorescence, OCT, Hyperspectral, Raman Spectroscopy…
- Treatment - Tumor ablation, laser-induced thermo-therapy, lithotripsy, PDT…



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Shape Sensing

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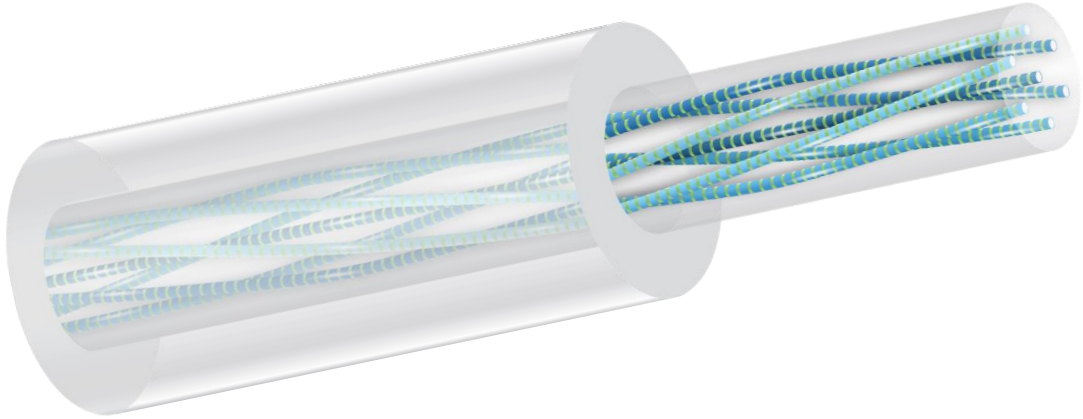
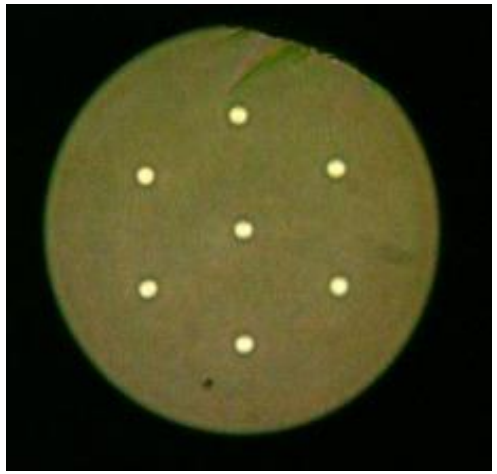
Fiber Navigation - Shape Sensing Fiber





- Twisted, multicore fiber with continuous FBGs
- Monitoring differential strain in off-axis cores allows for shape reconstruction
- Used in minimally invasive surgery, robotics, structural health monitoring, etc.

https://www.ofsoptics.com/shape-sensing/

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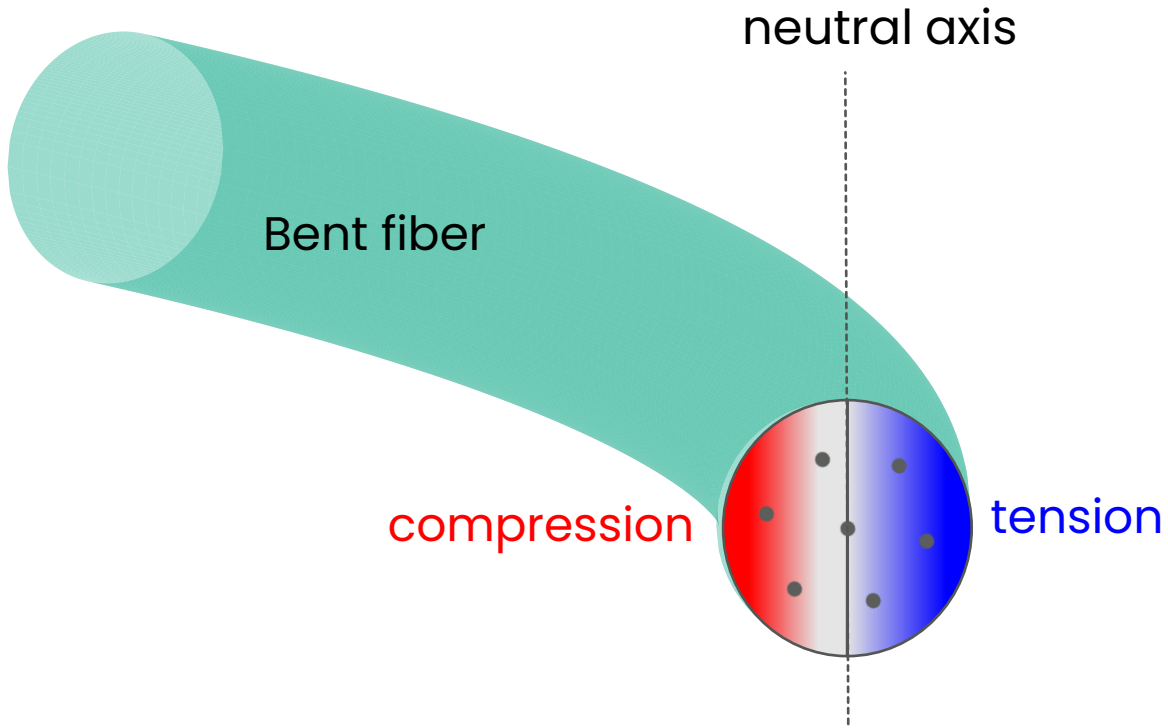
Shape Sensing Using Multicore Fibers



Bend – differential strain among off-axis cores

Twist – common strain among outer cores

Temperature (or axial strain) - equally affects inner and outer FBGs

R. G. Duncan et al., Proc. SPIE 6530, 65301S–65311S (2007).
J. P. Moore et al., Opt. Express, Vol. 20 No. 3 2967 (2012).
P. S. Westbrook et al., Proc. SPIE Vol. 8938, 89380H (2014).
W. Ko et al., Opt. Express, Vol. 30 No. 14 24452 (2022).

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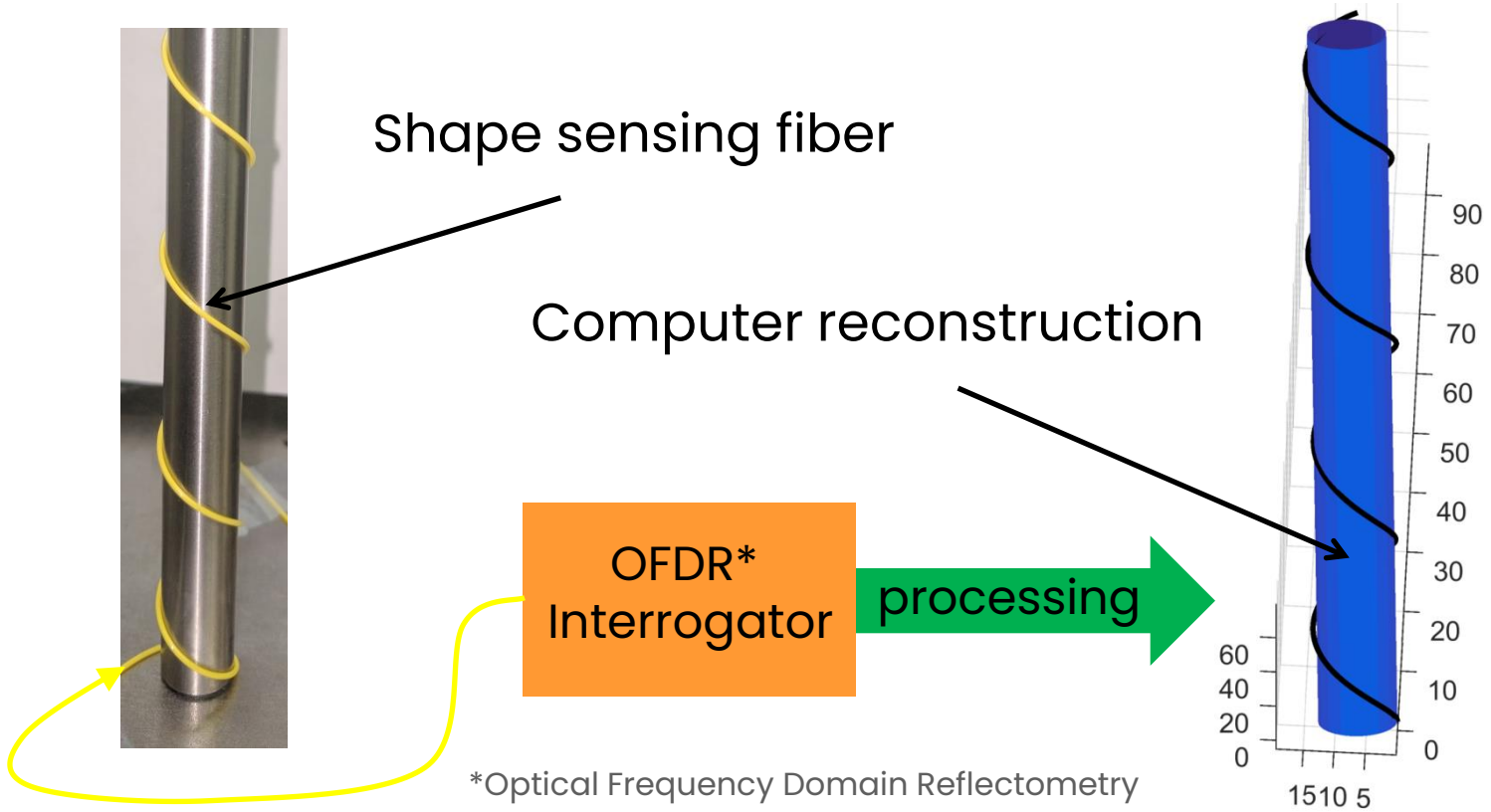
Optical Fiber Shape Sensing



W. Ko, et al., Opt. Express, Vol. 30 No. 14 24452 (2022).

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Next Gen Imaging

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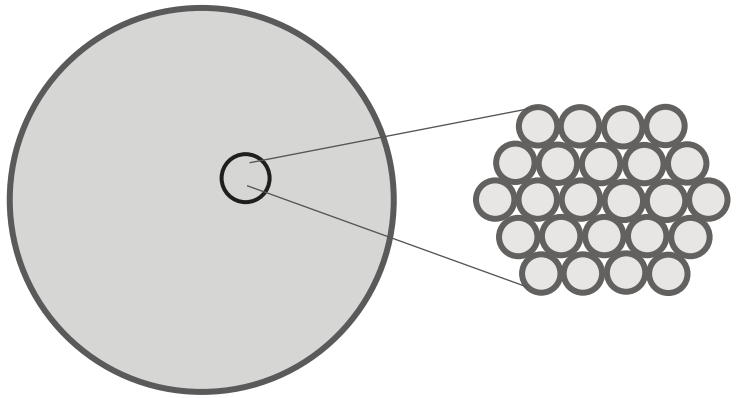
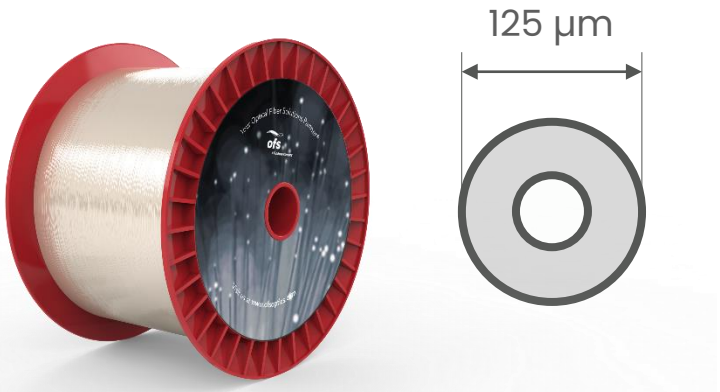
Thinner and Higher Resolution Medical Endoscopes

Fiber Imaging Bundle



Typical: 1-3 mm
Thinnest: 200-300 µm

Multimode Optical Fiber



- Replace fiber bundle with single multimode fiber for applications requiring ultra thin medical endoscopes
- Increase resolution of probe by eliminating pixilation caused by core spacing

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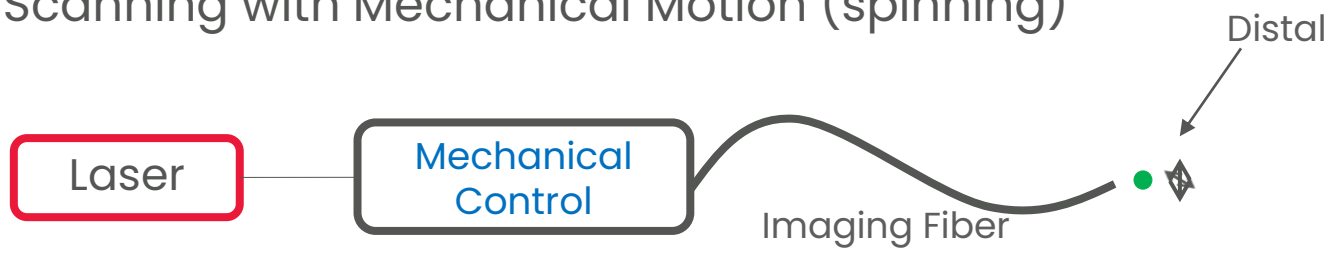
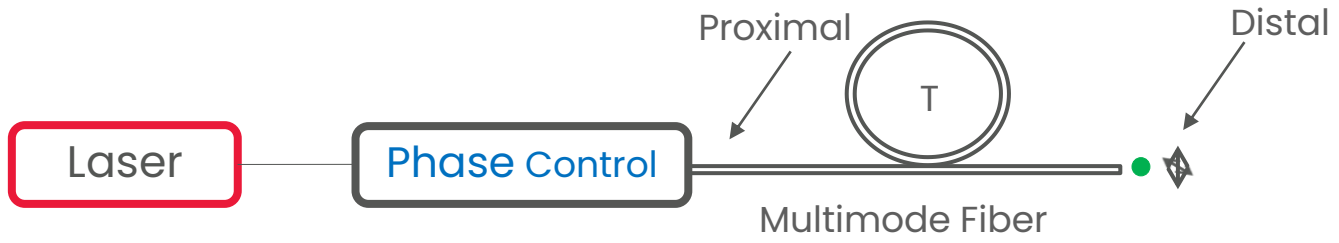
Spot Scanning without Mechanical Motion

Current: Spot Scanning with Mechanical Motion (spinning)



Next generation: Utilize Tailored Input States to Scan Spot Without Moving Parts



Remaining challenge: calibration of fiber changes as it is bent
→ **Fiber Shape Sensing**

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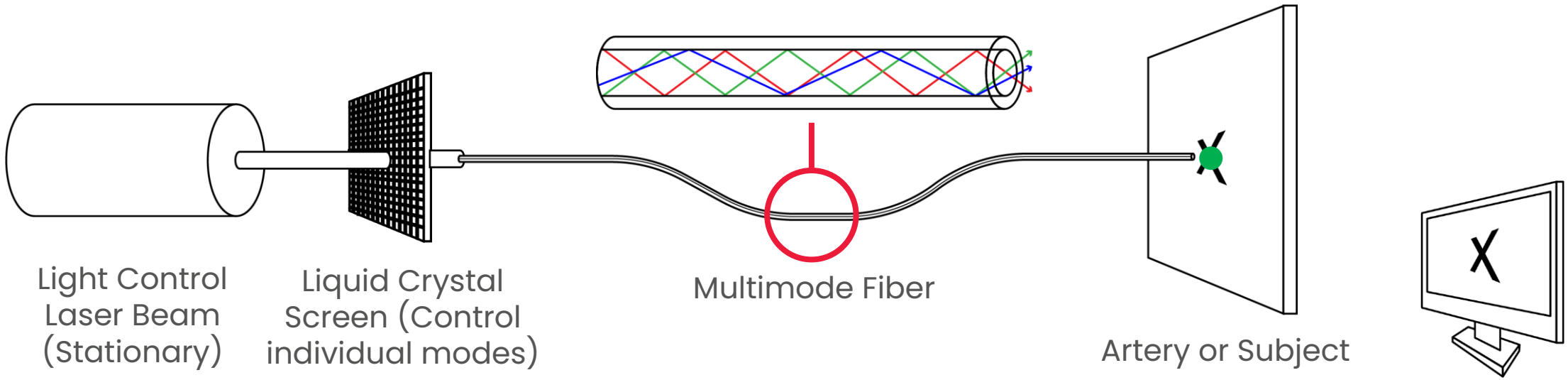
Raster Scanning Imaging through Multimode Fiber



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New Fiber and Splicing Technologies

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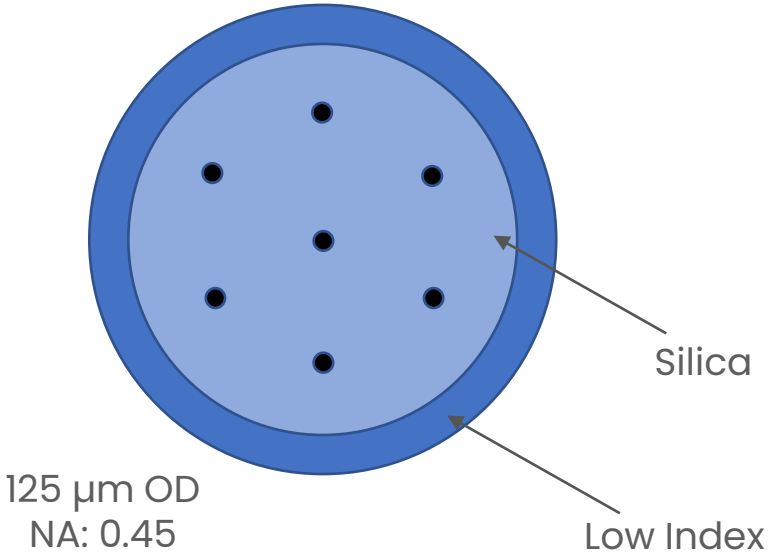
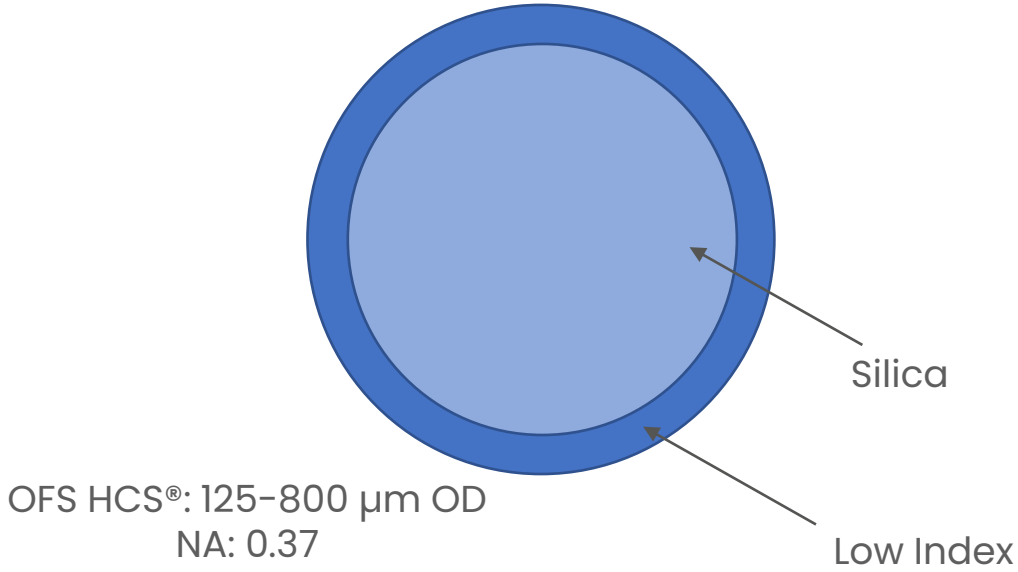
Next Gen Fiber – Combine Shape Sensing, Imaging, and Power Delivery



Shape Sensing fiber with low-index coating

- Guide imaging and power delivery light in cladding glass
- Single mode cores with gratings support shape sensing function

E. S. Lamb et al., Proc. SPIE Vol. 12851 (2024).



Similar to regular HCS® fiber, with added shape sensing capability

- Medical power delivery for ablation, PDT, …
- Industrial power delivery
- Medical or industrial imaging

E. S. Lamb et al., Proc. SPIE Vol. 12388 (2023).

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Splicing Multicore Fibers

- Fusion Splicer using 3 electrode system – “Ring of Fire”
- Rotational Alignment
- Fast Splice Time
  – 90 seconds typical splice time for a 4-core fiber
- Low Splice loss from uniform heat across all cores
- Typical splice loss <0.03 dB

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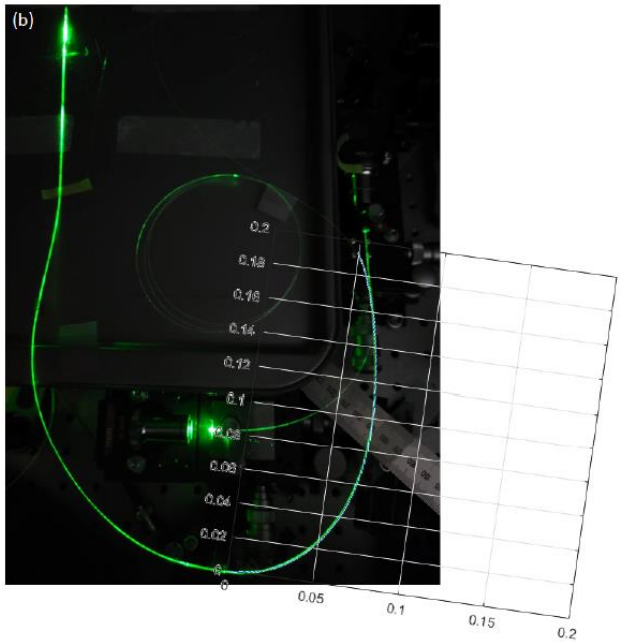
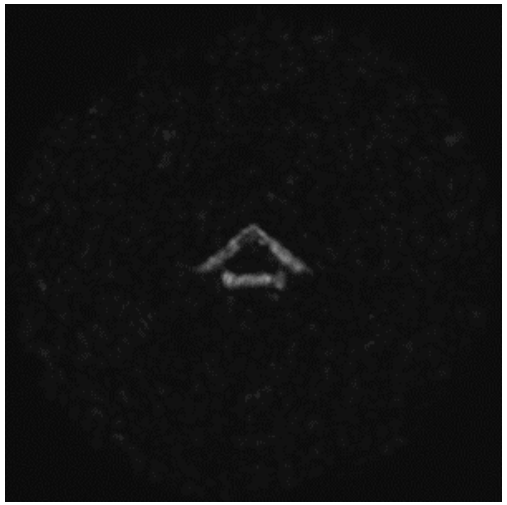
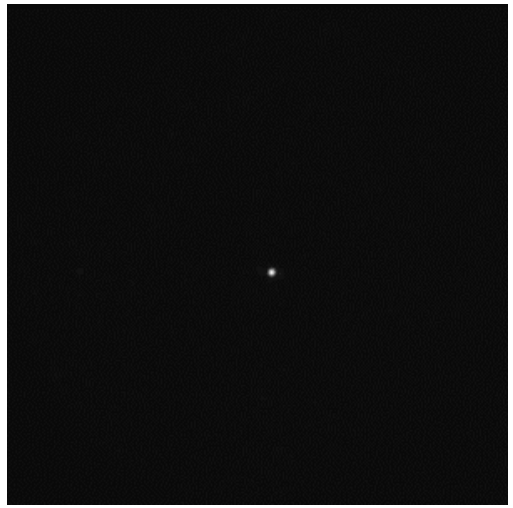
Conclusion

- Demonstrated novel low-index shape sensor fiber for dual use in shape sensing and light/power delivery
- Simultaneous use of same fiber for shape sensing and distal spot creation for imaging
- Provides platform to study how shape changes of fibers influence the transmission matrix calibration







Imaging through shape sensing fiber

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Looking forward to discussing with you about specialty Fiber Optics.
Please reach out to me in the breaks or contact me after the event.

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