Lens fabrication technologies used in OCT probe

In the optical fiber implementation of OCT, light is guided by single mode optical fibers. Light emitted from the fiber tip is a nearly Gaussian beam and focused on a sample using a lens. Retro-reflected light is then coupled back through the lens into the fiber.

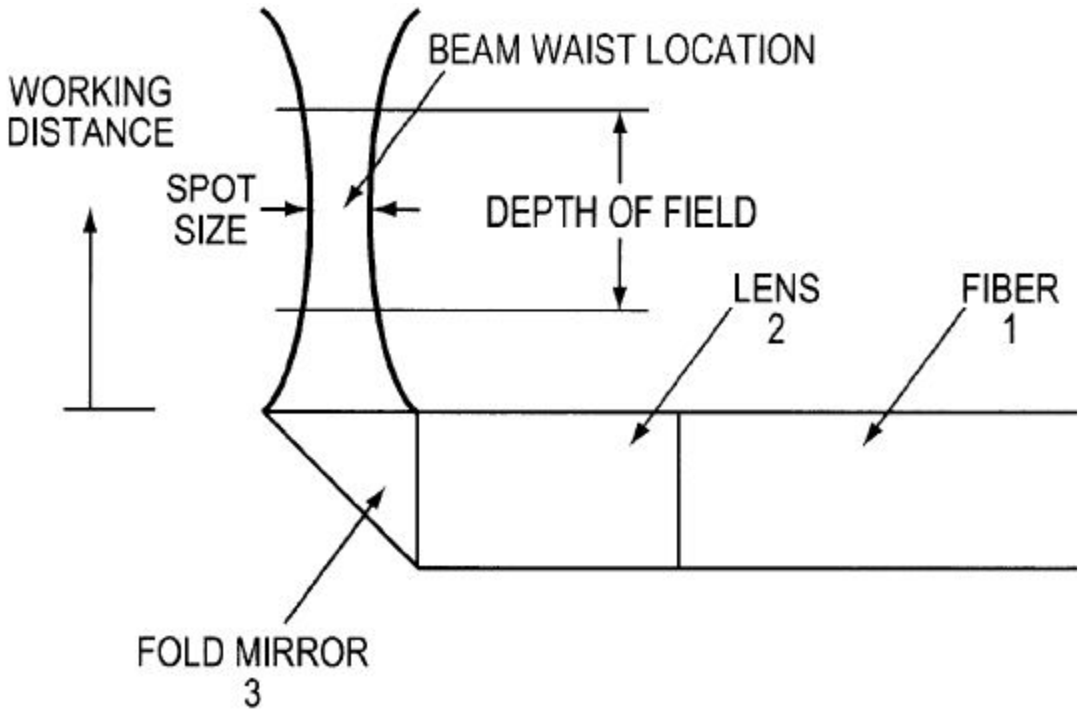

FIG. 1

The challenge in making small optical systems has been to achieve a both a large working distance and a large depth of field and still maintain a small beam spot size.

Most small optical probes also suffer from large back-reflections of light as it is difficult to match the indices of refraction of the various optical elements of the probe (e.g., fiber, lens and fold mirror/prism) to each other. These back-reflections of light can significantly impact the quality of images obtained.

Optowaves now could provide the probe using commercial Graded Index Lens (GRIN Lens) or patented 45° offset axis concave reflection mirror. As shown in table 1, the various probe structures are presented.

Till now these three methods have overcome all the challenge listed above.

Table 1.

Lens Technology	Characteristics	Advantages	Disadvantages
Graded Index, commercial GRIN material	High optical quality. Highly repeatable.	Does not require significant tooling or customization expense	Requires mechanical bonding to silica fibers – not compatible with high-temp fusion processes. May have biocompatibility risks due to materials. May be expensive in volume.
Graded Index Fiber	Developed for short-haul telecomm applications.	Highly customizable graded-index profile and diameter. Compatible with conventional fusion splicing techniques. Low costs in volume. Can be directly immersed in fluid.	Requires significant up-front costs for customized fiber. Requires specialized tools and processes to fabricate lens assembly. Difficult to overcome cylindrical distortion from sheath.
Concave reflection mirror lens	High optical quality. Highly repeatable.	Almost there is no back-reflection assured by the structure. Small size. Compatible with conventional fusion splicing techniques or easy bonding to silica fibers with small diameter tube. Low costs in volume. Can be directly immersed in fluid.	The fabrication of such micro lens is challenging, we have the experience the yield can improve dramatically with special lens toolings, in addition, such micro lens can also be fabricated by molding synthetic glass.

In the following, the detailed optical/physical parameters and assemble method from Optowaves will be disclosed.

Part 1: GRIN Lens type

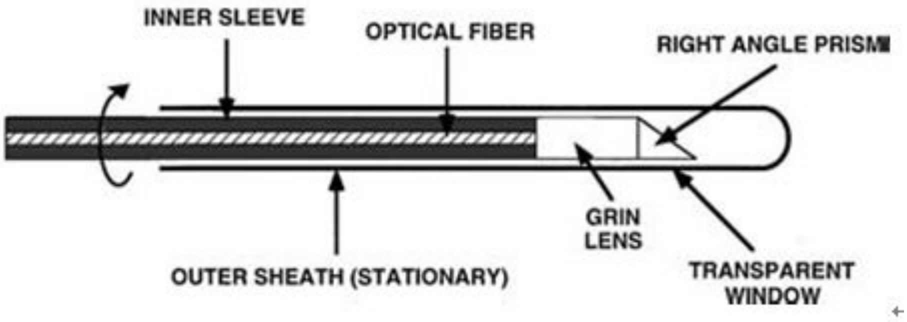

FIG. 2

Parameters of the GRIN lens

Diameter	0.50mm
Focal length	0.46mm
Length along the axis	1.17mm
Working wavelength	1280~1360 nm
Index gradient coefficient	1.340 mm^{-1}
Index on the axis	1.616

Assembled parameters for GRIN Lens probe

Parameter	Nominal	Min, Max
Working distance	1mm	0.8mm, 1.1 mm
Probe Diameter	0.7mm	0.6 mm (Min)
Lens Diameter	500 um	
Depth of Field	3.5mm	4mm (max)
Spot Size (at focus)	15 um diameter	--
Spot Size at 3.5mm	100 um diameter	
Center Wavelength	1.3 µm	--
Imaging Medium Index	1.00	--

Part 2: Concave lens type

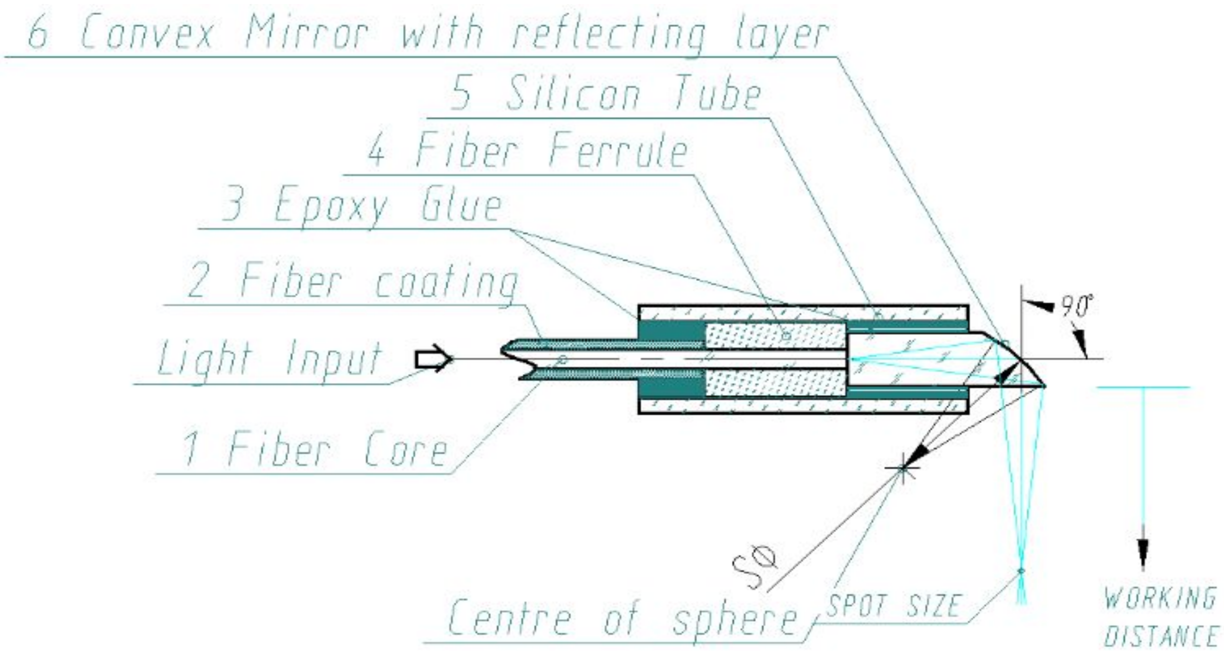

FIG. 3

Parameters of the Concave lens

Shape	0.126mm diameter
Focal length	2.0 – 5.0 mm
Length along the axis	0.5 – 0.8 mm
Working wavelength	1280~1360 nm
R of the sphere	0.3 – 1.0 mm
Index of Silicon material	1.458
Sphere axis deviate from the fiber axis	About 45°

Assembled parameters for Concave Lens probe

Parameter	**Nominal**	**Min, Max**
Working distance	2.0 – 5.0 mm	
Probe Diameter	0.15mm	
Lens Diameter	0.126um	
Rayleigh Range	0.6mm	
Spot Size (at focus)	18 um diameter	--
Spot Size at 5mm	55 um diameter	
Center Wavelength	1.3 μm	--
Imaging Medium Index	1.00 or 1.45	--

The Radius of our concave lens could be chosen between 0.6mm to 3.4mm, and the Min diameter could be as small as 0.25mm in a D shape.

If it is needed in large, we could use mold-casting.

Generally this lens could achieve Working distance > 1mm;

Depth of field > 2mm;

Spot size < 100 um.

For the 0.35*0.35 square type lens with coating, it could achieve>90% coupling efficiency, defined as the amount of light energy recoupled by the lens system back into fiber.

If we choose pure silicon to form the concave lens, its index is the same as the fiber. Also because the axis is greatly deviated, there is almost no light back-reflected into fiber as the noise. We have the ability to polish bare fiber end face to any desired angle to eliminate the back-reflection.

We could polish the end of single mode fiber to form compound lens like below picture. Then the MFD is condensed to 3+/-0.5 um at the distance 15 um from the tip. And then if this tip coupled with the above concave lens, we could get a spot size about 4.5 um in diameter at 3mm working distance.

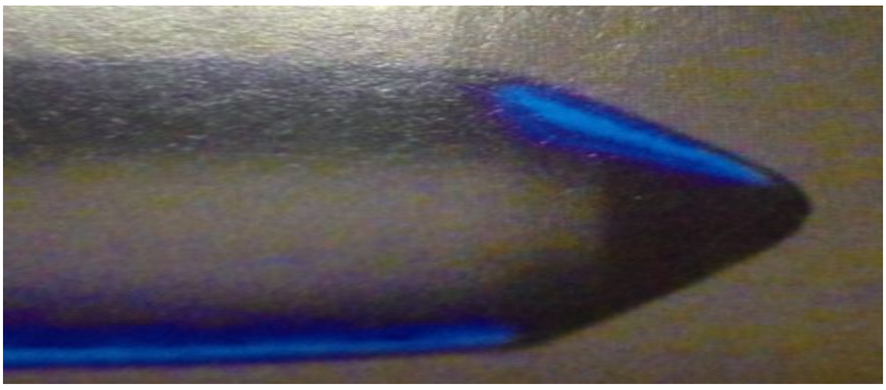

Fig. 4 Lensed Fiber

For the concave lens, we have another variation showed in Fig. 5. The working principle is the same except an additional window is needed on the metal tube.

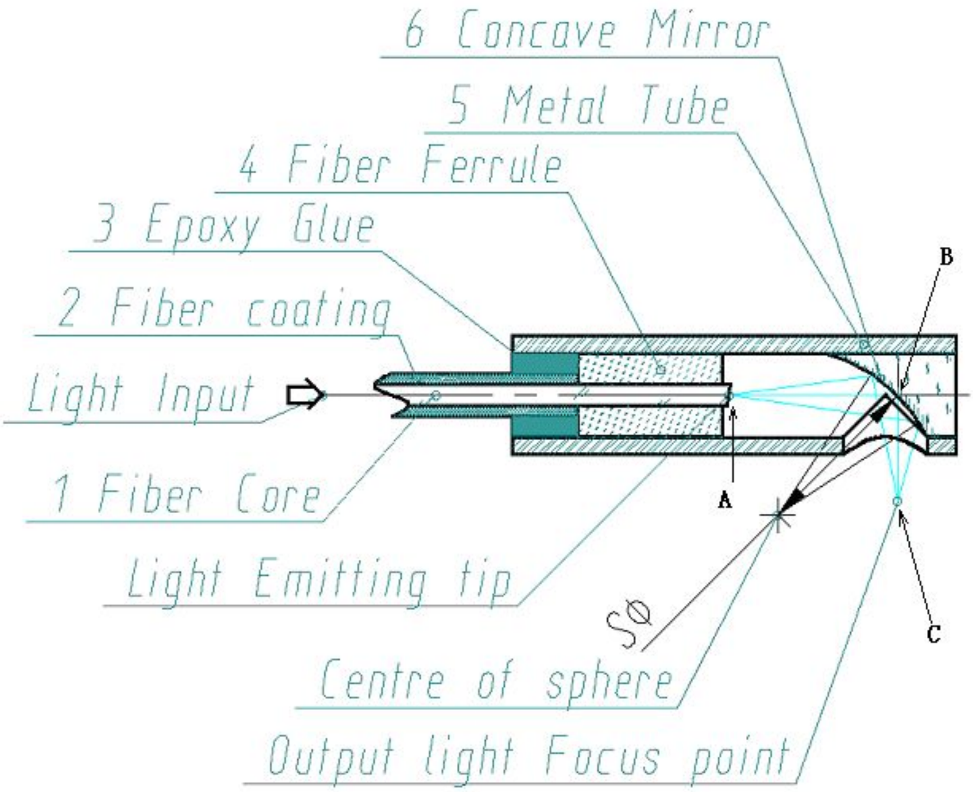

FIG. 5

In conclusion, our proposed OCT probe has better spot size and much lower reflection loss, the size of the probe can be reduced or even using synthetic glass molding fabricated. The process steps of assembling will be greatly reduced such that the yield and reliability should get improved. The cost of material and the probe assembly hours will be greatly saved as well. As the proposed micro lens been ready soon, further study and more detailed parameters shall be presented with probe sample testing.

Written by Sam Su at Optowaves, Inc

2015.1.29