56 Sparta Avenue • Newton, New Jersey 07860
(973) 300-3000 Sales • (973) 300-3600 Fax
www.thorlabs.com

THORLABS

BFL48-600 - August 4, 2015

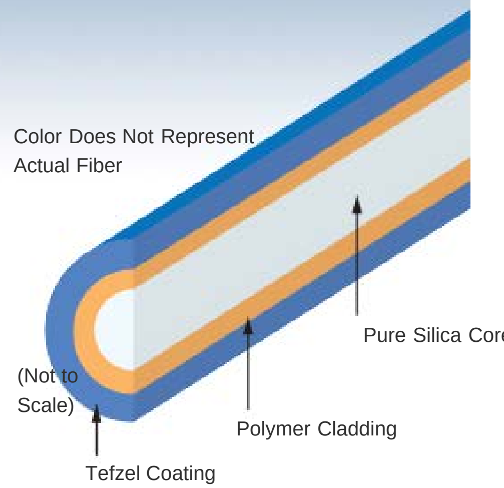
Item # BFL48-600 was discontinued on August 4, 2015. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

0.48/0.50 NA STEP-INDEX MULTIMODE FIBERS

- Broad UV/VIS/NIR Spectral Range
- Reduced Static Fatigue
- Lower Microbend Losses

Ø1000 µm Core Fiber

Ø400 & Ø600 um Core Fiber



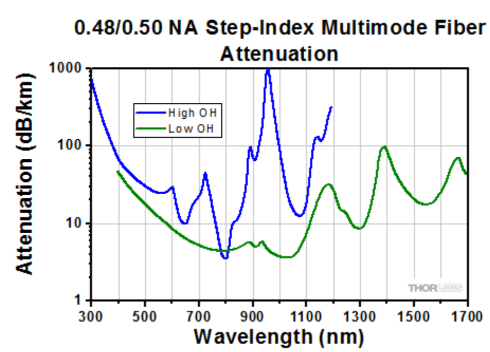
0.48/0.50 NA Step-Index Multimode Fiber Cross Section

Hide Overview

OVERVIEW

Features

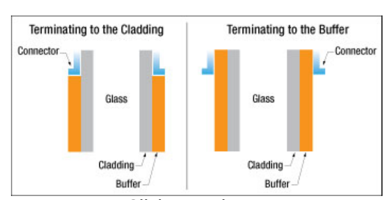
- Broad UV/VIS/NIR Spectral Range:
  - 300 to 1200 nm (High OH)
  - 400 to 2200 nm (Low OH)
- Reduced Static Fatigue, Lower Microbend Losses
- Biocompatible Materials, Radiation Resistant
- Can be Sterilized by Ethylene Oxide Cleaning Method



Click to Enlarge

Our 0.48 and 0.50 NA polymer-clad fibers offer high numerical apertures to suit a broad range of applications, from remote illumination to photodynamic therapy. The fiber is encased in a Tefzel coating that has an operating temperature range of -40 to 150 °C.

0.48 NA Fiber Structure



Click to Enlarge

Figure 1. Illustration of 0.48 NA Fiber Termination

The cladding material utilized to achieve the large 0.48 NA of the BFH and BFL fibers is a softer polymer than normally found in polymer clad step-index multimode fibers. Consequently, the cladding material has a higher probability of being removed from the fiber when the buffer is being stripped for normal connectorization. The difference between the indices of refraction of the core and the cladding determine the NA. Thus, without the cladding, the performance of this fiber is greatly diminished. To combat this problem, Thorlabs terminates to the buffer instead of terminating to the cladding, as illustrated in Figure 1. That is, the connector is epoxied directly onto the fiber buffer, thereby eliminating the need to strip the buffer, and the cladding, off of the fiber. The image in the upper right corner shows this difference. Please note that standard connectorization practices may be used with our 0.50 NA FP series fiber.

0.50 NA Fiber Structure
Our 0.50 NA fiber employs a polymer cladding that is harder than the cladding used in the 0.48 NA fibers. This cladding makes the fiber easier to strip and handle during connectorization. Currently we offer this fiber in a Ø1000 µm high-OH version.

Thorlabs offers SMA-terminated patch cables with our low-OH 0.48 NA multimode fibers (see table to the right). If you require another connector type, we offer the ADAFCSMA1 FC/PC-to-SMA Mating Sleeve that can be used to couple an SMA connector to an FC/PC connector, as well as hybrid patch cables. Alternatively, we offer 0.39 NA fiber as bare fiber or in patch cables with various connectors. Please contact Tech Support for further information.

Stock Patch Cables (0.48 NA, Low OH Multimode Fiber)			
Fiber Type	**Connector**	**Available Lengths**	**Item #**
BFL48-400	SMA	1 m or 2 m	M40L0x
BFL48-600	SMA	1 m or 2 m	M41L0x
BFL48-1000	SMA	1 m or 2 m	M71L0x

Alternate Numerical Aperture Step-Index Fibers			
0.1 NA High-Power, Small-Core Fibers	0.22 NA High- and Low-OH Fibers	0.39 NA High- and Low-OH Fibers	0.48/0.50 NA High- and Low-OH Fibers

Hide Specs

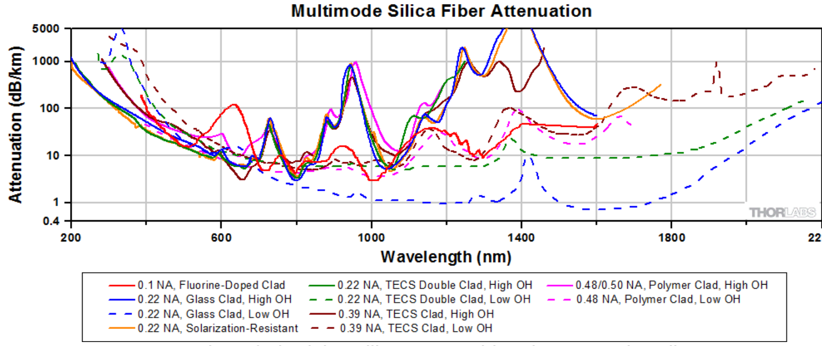
SPECS

<table>
<tr><th rowspan="2">Item #</th><th rowspan="2">Wavelength Range</th><th rowspan="2">Hydroxyl Content</th><th rowspan="2">NA</th><th rowspan="2">Core Diameter</th><th rowspan="2">Cladding Diameter</th><th rowspan="2">Coating Diameter</th><th rowspan="2">Core / Cladding</th><th rowspan="2">Coating</th><th colspan="2">Bend Radius</th><th rowspan="2">Proof Test</th><th rowspan="2">Operating Temperature</th></tr>
<tr><th>Short Term</th><th>Long Term</th></tr>
<tr><td>BFH48-400</td><td>300 - 1200 nm</td><td>High OH</td><td rowspan="4">0.48 ± 0.02</td><td rowspan="2">400 µm ± 2%</td><td rowspan="2">430 µm ± 2%</td><td rowspan="2">730 µm ± 5%</td><td rowspan="4">Pure Silica / Polymer</td><td rowspan="6">Tefzel</td><td rowspan="2">22 mm</td><td rowspan="2">65 mm</td><td rowspan="4">70 kpsi</td><td rowspan="6">-40 to 150 °C</td></tr>
<tr><td>BFL48-400</td><td>400 - 2200 nm</td><td>Low OH</td></tr>
<tr><td>BFH48-600</td><td>300 - 1200 nm</td><td>High OH</td><td rowspan="2">600 µm ± 2%</td><td rowspan="2">630 µm ± 2%</td><td rowspan="2">1040 µm ± 5%</td><td rowspan="2">32 mm</td><td rowspan="2">95 mm</td></tr>
<tr><td>BFL48-600</td><td>400 - 2200 nm</td><td>Low OH</td></tr>
<tr><td>FP1000URT</td><td>300 - 1200 nm</td><td>High OH</td><td>0.50 ± 0.02</td><td rowspan="2">1000 µm ± 2%</td><td rowspan="2">1035 µm ± 2%</td><td rowspan="2">1400 µm ± 5%</td><td>Pure Silica / Hard Polymer</td><td>40 mm</td><td>80 mm</td><td>≥100 kpsi</td></tr>
<tr><td>BFL48-1000</td><td>400 - 2200 nm</td><td>Low OH</td><td>0.48 ± 0.02</td><td>Pure Silica / Polymer</td><td>52 mm</td><td>155 mm</td><td>70 kpsi</td></tr>
</table>

Hide MM Fiber Selection

MM FIBER SELECTION

Thorlabs offers multimode bare optical fiber with silica, zirconium fluoride (ZrF_4), or indium fluoride (InF_3) cores. The graph below is an attenuation comparison of our step-index silica core fibers. We also offer fluoride core fiber for higher transmission into the mid-infrared as well as graded-index fiber. The table below details all of Thorlabs' multimode bare optical fiber offerings.



Attenuation of Thorlabs' Silica Core Multimode Step-Index Fibers

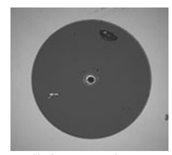
Index Profile	NA	Fiber Type	Item #	Core Size	Wavelength Range
Step Index	0.1	Double Clad, Enhanced Coating View These Fibers	HPSC10	Ø10 µm	400 - 550 nm and 700 - 1400 nm
			HPSC25	Ø25 µm	
	0.22	Glass-Clad Slilca Multimode Fiber View These Fibers	FG050UGA	Ø50 µm	250 - 1200 nm (High OH)
			FG105UCA	Ø105 µm	
			FG200UEA	Ø200 µm	
			FG050LGA	Ø50 µm	400 - 2400 nm (Low OH)
			FG105LCA	Ø105 µm	
			FG200LEA	Ø200 µm	
		High Power Double TECS / Silica Cladding Multimode Fiber View These Fibers	FG200UCC	Ø200 µm	250 - 1200 nm (High OH)
			FG365UEC	Ø365 µm	
			FG550UEC	Ø550 µm	
			FG910UEC	Ø910 µm	
			FG200LCC	Ø200 µm	400 - 2200 nm (Low OH)
			FG365LEC	Ø365 µm	
			FG550LEC	Ø550 µm	
			FG910LEC	Ø910 µm	
		Solarization-Resistant Multimode Fiber for UV Use View These Fibers	FG105ACA	Ø105 µm	180 - 1200 nm Acrylate Coating for Ease of Handling
			FG200AEA	Ø200 µm	
			FG300AEA	Ø300 µm	
			FG400AEA	Ø400 µm	
			FG600AEA	Ø600 µm	
			UM22-100	Ø100 µm	180 - 1150 nm Polyimide Coating for Use up to 300 °C
			UM22-200	Ø200 µm	
			UM22-300	Ø300 µm	
			UM22-400	Ø400 µm	
			UM22-600	Ø600 µm	
	0.39	High Power TECS Cladding Multimode Fiber View These Fibers	FT200UMT	Ø200 µm	300 - 1200 nm (High OH)
			FT300UMT	Ø300 µm	
			FT400UMT	Ø400 µm	
			FT600UMT	Ø600 µm	
			FT800UMT	Ø800 µm	
			FT1000UMT	Ø1000 µm	
			FT1500UMT	Ø1500 µm	
			FT200EMT	Ø200 µm	400 - 2200 nm (Low OH)
			FT300EMT	Ø300 µm	
			FT400EMT	Ø400 µm	
			FT600EMT	Ø600 µm	
			FT800EMT	Ø800 µm	
			FT1000EMT	Ø1000 µm	

			FT1500EMT	Ø1500 µm	
	0.48/0.50	High NA Multimode Fiber View These Fibers	BFH48-400	Ø400 µm	300 - 1200 nm (High OH)
			BFH48-600	Ø600 µm	
			FP1000URT	Ø1000 µm	
			BFL48-400	Ø400 µm	400 - 2200 nm (Low OH)
			BFL48-600	Ø600 µm	
			BFL48-1000	Ø1000 µm	
	0.20	Mid-IR Fiber with Zirconium Fluoride (ZrF_4) Core View These Fibers		Various Sizes Between Ø50 µm and Ø600 µm	285 nm - 4.5 µm
	0.20 or 0.26	Mid-IR Fiber with Indium Fluoride (InF_3) Core View These Fibers		Ø50 µm or Ø100 µm	310 nm - 5.5 µm
Graded Index	0.20	Graded-Index Fiber for Low Bend Loss View These Fibers	GIF50C	Ø50 µm	750 - 1450 nm
	0.275		GIF625	Ø62.5 µm	800 - 1350 nm

Hide Damage Threshold

DAMAGE THRESHOLD

Laser Induced Damage in Optical Fibers



Click to Enlarge
Damaged Fiber End

Click to Enlarge
Undamaged Fiber End

The following tutorial details damage mechanisms in unterminated (bare) and terminated optical fibers, including damage mechanisms at both the air-to-glass interface and within the glass of the optical fiber. Please note that while general rules and scaling relations can be defined, absolute damage thresholds in optical fibers are extremely application dependent and user specific. This tutorial should only be used as a guide to estimate the damage threshold of an optical fiber in a given application. Additionally, all calculations below only apply if all cleaning and use recommendations listed in the last section of this tutorial have been followed. For further discussion about an optical fiber's power handling abilities within a specific application, contact Thorlabs' Tech Support.

Damage at the Free Space-to-Fiber Interface

There are several potential damage mechanisms that can occur at the free space-to-fiber interface when coupling light into a fiber. These come into play whether the fiber is used bare or terminated in a connector.

Unterminated (Bare) Fiber

Damage mechanisms in bare optical fiber can be modeled similarly to bulk optics, and industry-standard damage thresholds for UV Fused Silica substrates can be applied to silica-based fiber (refer to the table to the right). The surface areas and beam diameters involved at the air-to-glass interface are extremely small compared to bulk optics, especially with single mode (SM) fiber, resulting in very small damage thresholds.

Unterminated Silica Fiber Maximum Power Densities		
Type	**Theoretical Damage Threshold**	**Practical Safe Value**
CW (Average Power)	1 MW/cm^2	250 kW/cm^2
10 ns Pulsed (Peak Power)	5 GW/cm^2	1 GW/cm^2

The effective area for SM fiber is defined by the mode field diameter (MFD), which is the effective cross-sectional area through which light propagates in the fiber. A free-space beam of light must be focused down to a spot of roughly 80% of this diameter to be coupled into the fiber with good efficiency. MFD increases roughly linearly with wavelength, which yields a roughly quadratic increase in damage threshold with wavelength. Additionally, a beam coupled into SM fiber typically has a Gaussian-like profile, resulting in a higher power density at the center of the beam compared with the edges, so a safety margin must be built into the calculated damage threshold value if the calculations assume a uniform density.

Multimode (MM) fiber's effective area is defined by the core diameter, which is typically far larger than the MFD in SM fiber. Kilowatts of power can be typically coupled into multimode fiber without damage, due to the larger core size and the resulting reduced power density.

It is typically uncommon to use single mode fibers for pulsed applications with high per-pulse powers because the beam needs to be focused down to a very small area for coupling, resulting in a very high power density. It is also uncommon to use SM fiber with ultraviolet light because the MFD becomes extremely small; thus, power handling becomes very low, and coupling becomes very difficult.

Example Calculation

For SM400 single mode fiber operating at 400 nm with CW light, the mode field diameter (MFD) is approximately Ø3 µm. For good coupling efficiency, 80% of the MFD is typically filled with light. This yields an effective diameter of Ø2.4 µm and an effective area of 4.52 $µm^2$:

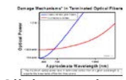
$$\text{Area} = \pi r^2 = \pi(\text{MFD}/2)^2 = \pi \bullet 1.2^2\ \mu m^2 = 4.52\ \mu m^2$$

This can be extrapolated to a damage threshold of 11.3 mW. We recommend using the "practical value" maximum power density from the table above to account for a Gaussian power distribution, possible coupling misalignment, and contaminants or imperfections on the fiber end face:

$$250\ kW/cm^2 = 2.5\ mW/\mu m^2$$

$$4.25\ \mu m^2 \bullet 2.5\ mW/\mu m^2 = 11.3\ mW$$

Terminated Fiber



Click to Enlarge

Optical fiber that is terminated in a connector has additional power handling considerations. Fiber is typically terminated by being epoxied into a ceramic or steel ferrule, which forms the interfacing surface of the connector. When light is coupled into the fiber, light that does not enter the core and propagate down the fiber is scattered into the outer layers of the fiber, inside the ferrule.

The scattered light propagates into the epoxy that holds the fiber in the ferrule. If the light is intense enough, it can melt the epoxy, causing it to run onto the face of the connector and into the beam path. The epoxy can be burned off, leaving residue on the end of the fiber, which reduces coupling efficiency and increases scattering, causing further damage. The lack of epoxy between the fiber and ferrule can also cause the fiber to be decentered, which reduces the coupling efficiency and further increases scattering and damage.

The power handling of terminated optical fiber scales with wavelength for two reasons. First, the higher per photon energy of short-wavelength light leads to a greater likelihood of scattering, which increases the optical power incident on the epoxy near the end of the connector. Second, shorter-wavelength light is inherently more difficult to couple into SM fiber due to the smaller MFD, as discussed above. The greater likelihood of light not entering the fiber's core again increases the chance of damaging scattering effects. This second effect is not as common with MM fibers because their larger core sizes allow easier coupling in general, including with short-wavelength light.

Fiber connectors can be constructed to have an epoxy-free air gap between the optical fiber and ferrule near the fiber end face. This design feature, commonly used with multimode fiber, allows some of the connector-related damage mechanisms to be avoided. Our high-power multimode fiber patch cables use connectors with this design feature.

Combined Damage Thresholds

As a general guideline, for short-wavelength light at around 400 nm, scattering within connectors typically limits the power handling of optical fiber to about 300 mW. Note that this limit is higher than the limit set by the optical power density at the fiber tip. However, power handing limitations due to connector effects do not diminish as rapidly with wavelength when compared to power density effects. Thus, a terminated fiber's power handling is "connector-limited" at wavelengths above approximately 600 nm and is "fiber-limited" at lower wavelengths.

The graph to the right shows the power handling limitations imposed by the fiber itself and a surrounding connector. The total power handling of a terminated fiber at a given wavelength is limited by the lower of the two limitations at that wavelength. The fiber-limited (blue) line is for SM fibers. An equivalent line for multimode fiber would be far above the SM line on the Y-axis. For terminated multimode fibers, the connector-limited (red) line always determines the damage threshold.

Please note that the values in this graph are rough guidelines detailing estimates of power levels where damage is very unlikely with proper handling and alignment procedures. It is worth noting that optical fibers are frequently used at power levels above those described here. However, damage is likely in these applications. The optical fiber should be considered a consumable lab supply if used at power levels above those recommended by Thorlabs.

Damage Within Optical Fibers

In addition to damage mechanisms at the air-to-glass interface, optical fibers also display power handling limitations due to damage mechanisms within the optical fiber itself. Two categories of damage within the fiber are damage from bend losses and damage from photodarkening.

Bend Losses

Bend losses occur when a fiber is bent to a point where light traveling in the core is incident on the core/cladding interface at an angle higher than the critical angle, making total internal reflection impossible.Under these circumstances, light escapes the fiber, often in one localized area. The light escaping the fiber typically has a high power density, which can cause burns to the fiber as well as any surrounding furcation tubing.

A special category of optical fiber, called double-clad fiber, can reduce the risk of bend-loss damage by allowing the fiber's cladding (2nd layer) to also function as a waveguide in addition to the core. By making the critical angle of the cladding/coating interface higher than the critical angle of the core/clad interface, light that escapes the core is loosely confined within the cladding. It will then leak out over a distance of centimeters or meters instead of at one localized spot within the fiber, minimizing damage. Thorlabs manufactures and sells 0.22 NA double-clad multimode fiber, which boasts very high, megawatt range power handling.

Photodarkening

A second damage mechanism within optical fiber, called photodarkening or solarization, typically occurs over time in fibers used with ultraviolet or short-wavelength visible light. The pure silica core of standard multimode optical fiber can transmit ultraviolet light, but the attenuation at these short wavelengths increases with the time exposed to the light. The mechanism that causes photodarkening is largely unknown, but several strategies have been developed to combat it. Fibers with a very low hydroxyl ion (OH) content have been found to resist photodarkening. Other dopants, including fluorine, can also reduce photodarkening.

Germanium-doped silica, which is commonly used for the core of single mode fiber for red or IR wavelengths, can experience photodarkening with blue visible light. Thus, pure silica core single mode fibers are typically used with short wavelength visible light. Single mode fibers are typically not used with UV light due to the small MFD at these wavelengths, which makes coupling extremely difficult.

Even with the above strategies in place, all fibers eventually experience photodarkening when used with UV light, and thus, fibers used with these wavelengths should be considered consumables.

Tips for Maximizing an Optical Fiber's Power Handling Capability

With a clear understanding of the power-limiting mechanisms of an optical fiber, strategies can be implemented to increase a fiber's power handling capability and reduce the risk of damage in a given application. All of the calculations above only apply if the following strategies are implemented.

One of the most important aspects of a fiber's power-handling capability is the quality of the end face. The end face should be clean and clear of dirt and other contaminants that can cause scattering of coupled light. Additionally, if working with bare fiber, the end of the fiber should have a good quality cleave, and any splices should be of good quality to prevent scattering at interfaces.

The alignment process for coupling light into optical fiber is also important to avoid damage to the fiber. During alignment, before optimum coupling is achieved, light may be easily focused onto parts of the fiber other than the core. If a high power beam is focused on the cladding or other parts of the fiber, scattering can occur, causing damage.

Additionally, terminated fibers should not be plugged in or unplugged while the light source is on, again so that focused beams of light are not incident on fragile parts of the connector, possibly causing damage.

Bend losses, discussed above, can cause localized burning in an optical fiber when a large amount of light escapes the fiber in a small area. Fibers carrying large amounts of light should be secured to a steady surface along their entire length to avoid being disturbed or bent.

Additionally, choosing an appropriate optical fiber for a given application can help to avoid damage. Large-mode-area fibers are a good alternative to standard single mode fibers in high-power applications. They provide good beam quality with a larger MFD, thereby decreasing power densities. Standard single mode fibers are also not generally used for ultraviolet applications or high-peak-power pulsed applications due to the high spatial power densities these applications present.

Hide Ø400 µm Core Step-Index Multimode Fiber, 0.48 NA

Ø400 µm Core Step-Index Multimode Fiber, 0.48 NA

Item #	Wavelength Range	Hydroxyl Content	NA	Core Diameter	Cladding Diameter	Coating Diameter	Core / Cladding	Coating	Stripping Tool
BFH48-400	300 - 1200 nm	High OH	0.48 ± 0.02	400 µm ± 2%	430 µm ± 2%	730 µm ± 5%	Pure Silica / Polymer	Tefzel	T21S31
BFL48-400	400 - 2200 nm	Low OH							

Part Number	Description	Price	Availability
BFH48-400	0.48 NA, Ø400 µm Core Multimode Fiber, High OH	$3.80 Per Meter Volume Pricing Available	Today
BFL48-400	0.48 NA, Ø400 µm Core Multimode Fiber, Low OH	$5.60 Per Meter Volume Pricing Available	Today

Hide Ø600 µm Core Step-Index Multimode Fiber, 0.48 NA

Ø600 µm Core Step-Index Multimode Fiber, 0.48 NA

Item #	Wavelength Range	Hydroxyl Content	NA	Core Diameter	Cladding Diameter	Coating Diameter	Core / Cladding	Coating	Stripping Tool
BFH48-600	300 - 1200 nm	High OH	0.48 ± 0.02	600 µm ± 2%	630 µm ± 2%	1040 µm ± 5%	Pure Silica / Polymer	Tefzel	T28S46
BFL48-600	400 - 2200 nm	Low OH							

Part Number	Description	Price	Availability
BFH48-600	**0.48 NA, Ø600 µm Core Multimode Fiber, High OH**	**$8.30** **Per Meter** **Volume Pricing Available**	**Today**
BFL48-600	**0.48 NA, Ø600 µm Core Multimode Fiber, Low OH**	**$10.80** **Per Meter** **Volume Pricing Available**	**Today**

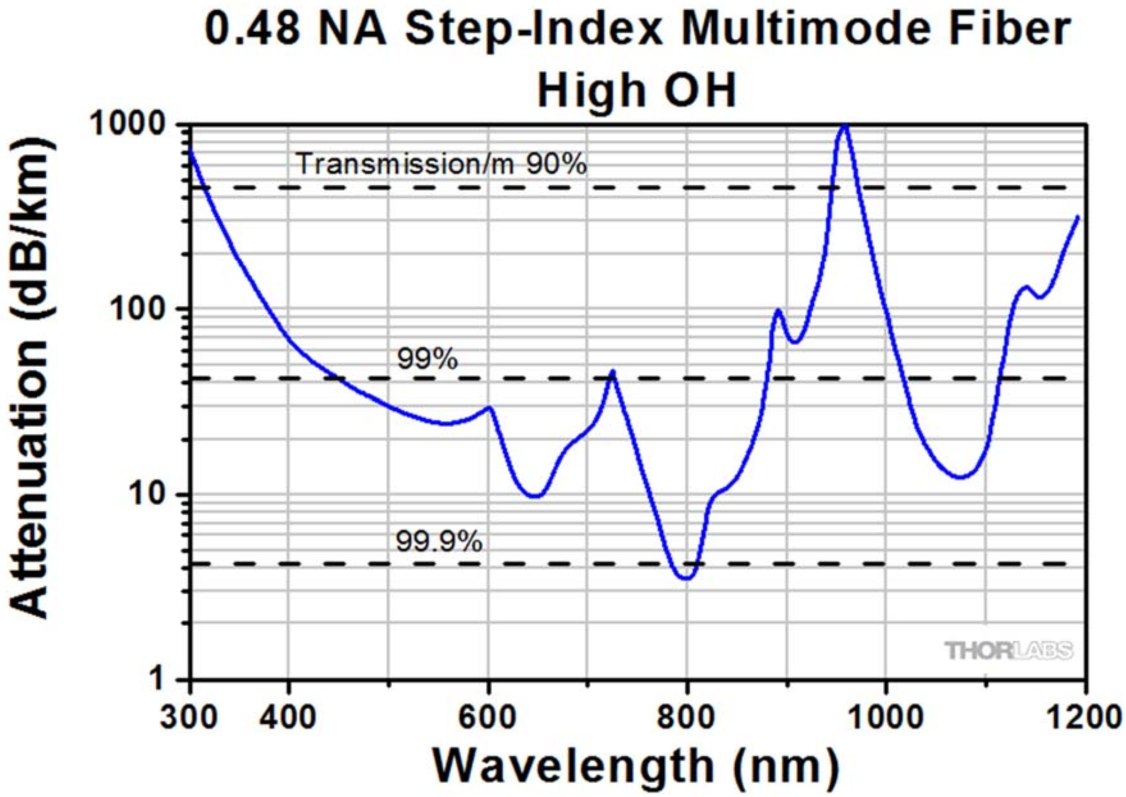
Hide Ø1000 µm Core Step-Index Multimode Fiber, 0.48/0.50 NA

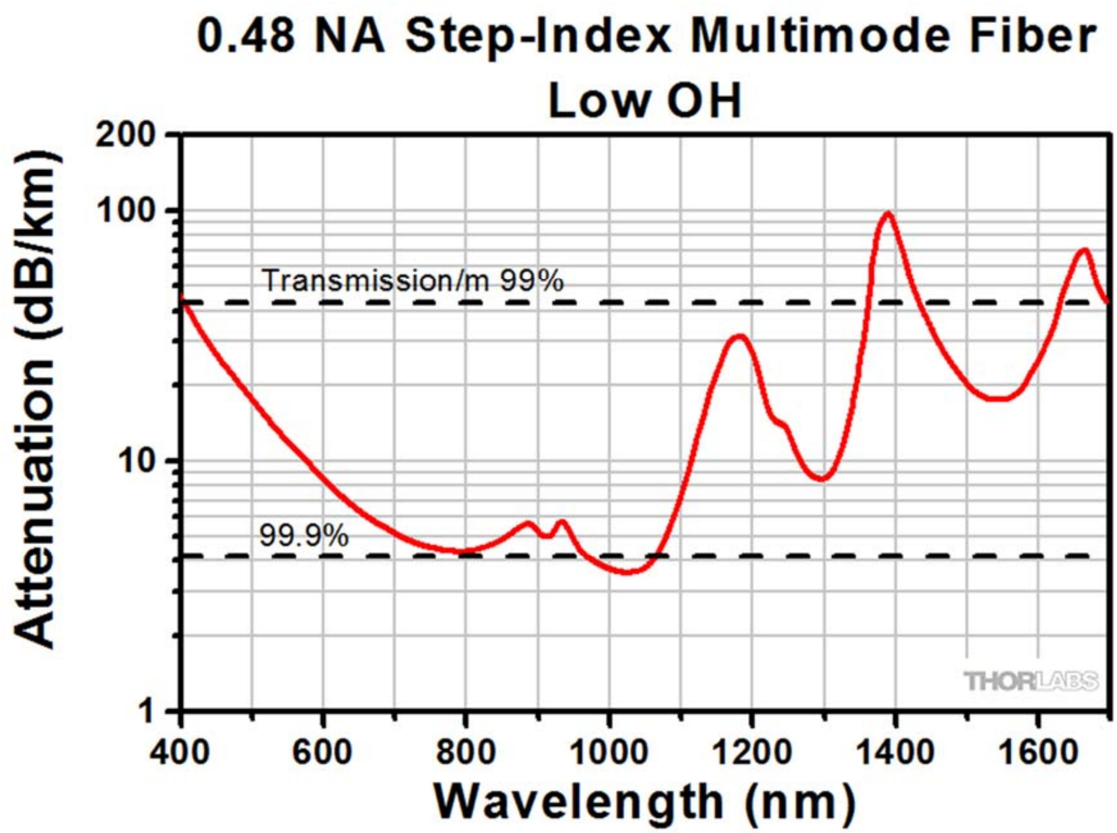
Ø1000 µm Core Step-Index Multimode Fiber, 0.48/0.50 NA

Item #	Wavelength Range	Hydroxyl Content	NA	Core Diameter	Cladding Diameter	Coating Diameter	Core / Cladding	Coating	Stripping Tool
FP1000URT	300 - 1200 nm	High OH	0.50 ± 0.02	1000 µm ± 2%	1035 µm ± 2%	1400 µm ± 5%	Pure Silica / Hard Polymer	Tefzel	M44S63
BFL48-1000	400 - 2200 nm	Low OH	0.48 ± 0.02				Pure Silica / Polymer		

Part Number	Description	Price	Availability
FP1000URT	**NEW! 0.50 NA, Ø1000 µm Core Multimode Fiber, High OH**	**$23.49** **Per Meter** **Volume Pricing Available**	**Today**
BFL48-1000	**0.48 NA, Ø1000 µm Core Multimode Fiber, Low OH**	**$29.10** **Per Meter** **Volume Pricing Available**	**Lead Time**

Visit the *0.48/0.50 NA Step-Index Multimode Fibers* page for pricing and availability information:
http://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=362


0.48 NA Step-Index Multimode Fiber
High OH
Attenuation (dB/km)
1000
100
10
1
Transmission/m 90%
99%
99.9%
THORLABS
300
400
600
800
1000
1200
Wavelength (nm)


0.48 NA Step-Index Multimode Fiber
Low OH
Attenuation (dB/km)
200
100
10
1
Transmission/m 99%
99.9%
THORLABS
400
600
800
1000
1200
1400
1600
Wavelength (nm)