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THORLABS

M19L01 - Aug. 17, 2015

Item # M19L01 was discontinued on Aug. 17, 2015. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

SOLARIZATION-RESISTANT MULTIMODE FIBER OPTIC PATCH CABLES: SMA-SMA

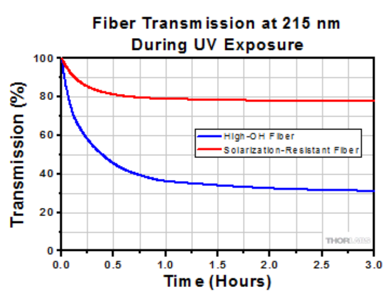
- ▶ Fiber Patch Cables for Use Down to 180 nm
- ▶ Core Sizes: Ø105 to Ø600 µm
- ▶ 1 and 2 m Lengths
- ▶ Custom Cables Available


Hide Overview

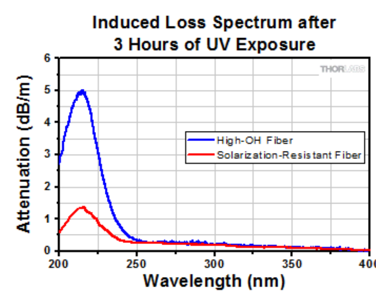
OVERVIEW

Features

- Resists Transmission Loss from UV Radiation
- Step-Index Multimode Fiber
- Cores Sizes from Ø105 to Ø600 µm
- SMA905 Connectors on Both Ends
- Ø3 mm Orange Reinforced Outer Jacket
- Custom Cables Available



Click to Enlarge
Solarization-Resistant Fiber Transmission Compared to Standard High-OH Silica Fiber (25 W Deuterium Lamp; 1 m Fiber Length)



Click to Enlarge
Comparison of Loss Induced by Solarization in 1 m of High-OH fiber
compared to Solarization-resistant fiber after 3 hours of UV exposure
(25 W Deuterium Lamp; 1 m Fiber Length)

These fiber optic patch cables are similar to our other multimode SMA-to-SMA patch cables but incorporate solarization-resistant fiber for UV applications. Solarization refers to the formation of color centers within a fiber that lead to transmission degradation. These color centers form when exposed to light below 300 nm. Solarization-Resistant fibers are thus desirable when working in the UV due to their superior transmission and prolonged performance. Typical applications for these fibers are spectroscopy and medical diagnostics.

High-OH fiber experiences significant transmission losses when exposed to UV radiation. In contrast, solarization-resistant fiber offers higher transmission. For optimal performance, expose the fiber to UV radiation for 5 minutes prior to use in your application to allow initial degradation. After this time, equilibrium is reached and the fiber can be used normally.

The maximum power these cables can withstand is limited by the connectorization process. Please see the *Damage Threshold* tab for more information about the damage mechanisms of fiber.

Each patch cable includes two protective caps that shield the connector ends from dust and other hazards. Additional CAPM Rubber Fiber Caps and

CAPMM Metal-Threaded Fiber Caps for SMA-terminated ends are also sold separately.

If you do not see a stock cable suitable for your application, please see our Custom Patch Cables webpage to request a cable that meets your specific needs.

In-Stock Multimode Fiber Optic Patch Cable Selection															
Step Index														**Graded Index**	**Fiber Bundles**
SMA	FC/PC	FC/PC to SMA	High-Power SMA	Solarization-Resistant SMA	AR-Coated SMA	HR-Coated FC/PC	Beamsplitter-Coated FC/PC	Armored SMA	Fluoride FC and SMA	Rotary Joint FC/PC and SMA	Lightweight FC/PC	Lightweight SMA	Vacuum-Compatible SMA	FC/PC	

Hide Numerical Aperture

NUMERICAL APERTURE

Numerical Aperture

Numerical Aperture (NA), a measure of the acceptance angle of a fiber, is a dimensionless quantity. For applications, it is most commonly expressed as

$$NA = n_i \sin(\theta_a)$$

where

θ_a is the maximum 1/2 acceptance angle of the fiber,

and

n_i is the index of refraction of the material outside of the fiber; this material is typically air, making it equal to approximately 1.0, as shown in the figure below.

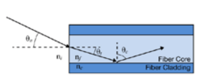


Figure: A ray at the maximum 1/2 acceptance angle propagates into a fiber.

Numerical Aperture can also be defined in terms of the index of refraction of the fiber core and the cladding. Due to Snell's law, there is a critical angle above which all of the light at a fiber-cladding interface will experience total internal reflection. In turn, this means that there is a maximum acceptance angle at which light can enter the fiber. Following Snell's law, the maximum acceptance angle can be determined:

$$\sin\theta_C = \frac{n_c}{n_f} = \cos(\theta_t)$$

$$\frac{n_c}{n_f} = \sqrt{1 - \sin^2\theta_t}$$

$$NA = n_i \sin\theta_a = \sqrt{n_f^2 - n_c^2}$$

Here,

n_f is the index of refraction of the fiber core,

n_C is the index of refraction of the cladding,

θ_C is the critical angle for total internal reflection, and

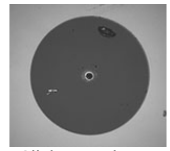
θ_a is the maximum 1/2 acceptance angle.

This is the common way numerical aperture is defined for optical fibers. It is also important to note that these equations assume that a Gaussian beam is being outputted from the fiber.

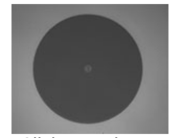
Hide Damage Threshold

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

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

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.

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:

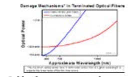
$$\text{Area} = \pi r^2 = \pi(\text{MFD}/2)^2 = \pi \cdot 1.2^2\ \mu\text{m}^2 = 4.52\ \mu\text{m}^2$$

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:

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

$$4.25\ \mu\text{m}^2 \cdot 2.5\ \text{mW}/\mu\text{m}^2 = 11.3\ \text{mW}$$

Terminated Fiber



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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 Ø105 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Ø105 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Fiber	Wavelength Range	Attenuation Plot	NA	Core Diameter	Cladding Diameter	Coating Diameter	Bend Radius		Jacket
							Short Term	Long Term	
FG105ACA	180 to 1200 nm		0.22	105 ± 2.1 µm	125 ± 1 µm	250 ± 10 µm	15 mm	30 mm	FT030 (Ø3 mm)

Part Number	Description	Price	Availability
M111L01	**NEW! Ø105 µm, 0.22 NA, SMA-SMA Solarization-Resistant Cable, 1 m**	**$84.00**	**Today**
M111L02	**NEW! Ø105 µm, 0.22 NA, SMA-SMA Solarization-Resistant Cable, 2 m**	**$86.00**	**Today**

Hide Ø200 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Ø200 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Fiber	Wavelength Range	Attenuation Plot	NA	Core Diameter	Cladding Diameter	Coating Diameter	Bend Radius		Jacket
							Short Term	Long Term	
UM22-200	180 to 1150 nm		0.22	200 ± 4 µm	220 ± 4 µm	239 ± 5 µm	22 mm	66 mm	FT030 (Ø3 mm)

Part Number	Description	Price	Availability
M19L01	**Ø200 µm, 0.22 NA, SMA-SMA Solarization-Resistant Patch Cable, 1 m**	**$96.80**	**Today**
M19L02	**Ø200 µm, 0.22 NA, SMA-SMA Solarization-Resistant Patch Cable, 2 m**	**$103.00**	**Today**

Hide Ø400 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Ø400 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Fiber	Wavelength Range	Attenuation Plot	NA	Core Diameter	Cladding Diameter	Coating Diameter	Bend Radius		Jacket
							Short Term	Long Term	

UM22-400	180 to 1150 nm	[i]	0.22	400 ± 8 µm	440 ± 9 µm	480 ± 7 µm	44 mm	132 mm	FT030 (Ø3 mm)

Part Number	Description	Price	Availability
M22L01	**Ø400 µm, 0.22 NA, SMA-SMA Solarization-Resistant Patch Cable, 1 m**	**$92.70**	**Today**
M22L02	**Ø400 µm, 0.22 NA, SMA-SMA Solarization-Resistant Patch Cable, 2 m**	**$97.90**	**Today**

Hide Ø600 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Ø600 µm, 0.22 NA Solarization-Resistant SMA905 Multimode Patch Cable

Fiber	Wavelength Range	Attenuation Plot	NA	Core Diameter	Cladding Diameter	Coating Diameter	Bend Radius		Jacket
							Short Term	Long Term	
FG600AEA	180 to 1200 nm	[i]	0.22	600 ± 12 µm	660 ± 6 µm	750 ± 20 µm	80 mm	159 mm	FT030 (Ø3 mm)

Part Number	Description	Price	Availability
M114L01	**NEW! Ø600 µm, 0.22 NA, SMA-SMA Solarization-Resistant Cable, 1 m**	**$130.70**	**Today**
M114L02	**NEW! Ø600 µm, 0.22 NA, SMA-SMA Solarization-Resistant Cable, 2 m**	**$179.40**	**Today**

Visit the *Solarization-Resistant Multimode Fiber Optic Patch Cables: SMA-SMA* page for pricing and availability information:
http://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=5591