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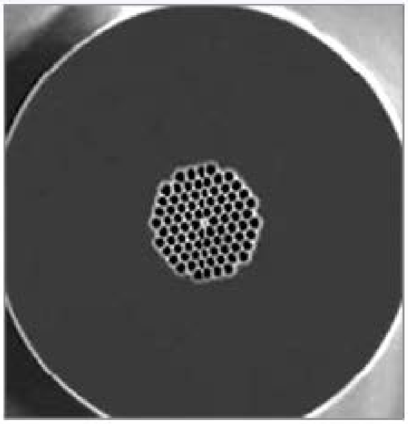
THORLABS

NL-PM-750 - November 07, 2017

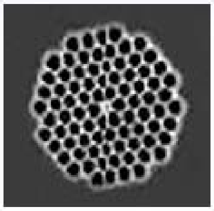
Item # NL-PM-750 was discontinued on November 07, 2017. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

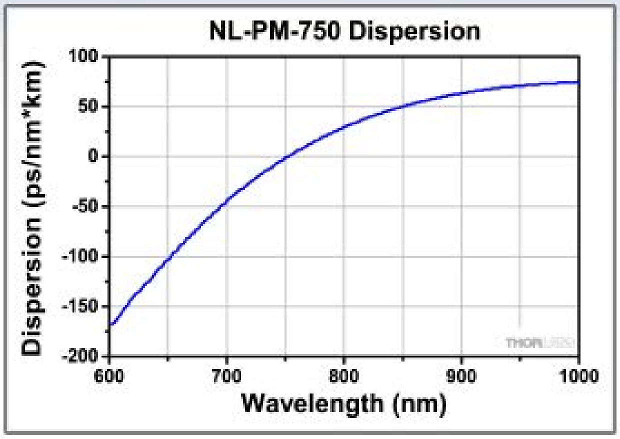
NONLINEAR PHOTONIC CRYSTAL FIBERS

- Zero Dispersion Wavelengths from 800 - 890 nm
- PM Version with Zero Dispersion at 750 nm Wavelength
- Core Diameter from 1.8 - 3.2 µm



NL-PM-750





Highly Nonlinear PCF for 800 nm Pump Lasers

OVERVIEW

Features

- Zero Dispersion Wavelengths from 800 - 890 nm
- Core Diameter from 2.4 - 3.2 µm
- Nonlinear Coefficients from 37 to 70 $(W\cdot km)^{-1}$
- Near-Gaussian Mode Profile
- Pure Silica Core and Cladding

These highly nonlinear photonic crystal fibers guide light in a small solid silica core surrounded by large air holes. The optical properties of these structures closely resemble those of a rod of glass suspended in air, resulting in strong confinement of the light and, correspondingly, a large nonlinear coefficient. By selecting the appropriate core diameter, the zero-dispersion wavelength can be chosen over a wide range in the visible and near infrared spectrum, making these fibers particularly suited to the generation of supercontinuum radiation with Ti:Sapphire or diode-pumped Nd^{3+} lasers, or for optical switching and signal processing applications. These fibers are sold based on the overall optical specifications and not the physical structure.

Applications

- Supercontinuum Generation for Frequency Metrology, Spectroscopy, or Optical Coherence Tomography Using Ti:Sapphire, Nd^{3+} Microchip
- Four-Wave Mixing and Self-Phase Modulation for Switching, Pulse-Forming and Wavelength Conversion Applications
- Raman Amplification

Please note that these fibers will ship with both ends sealed in order to prevent moisture and dust from entering the hollow capillary structure during storage. It is necessary to cleave them prior to use using, for example, our S90R Ruby Fiber Scribe or our Vytran™ CAC400 Compact Fiber Cleaver.

SPECS

λ_0 is the zero dispersion wavelength for the nonlinear photonic crystal fibers.

Optical Properties

Item #	λ_0	Dispersion Slope[a]	Attenuation	MFD[a,b]	NA[a,c]	Effective Nonlinear Area	Nonlinear Coefficient[a]	Core Index	Cladding Index
NL-2.4-800	800 ± 5 nm	0.55 ps/(nm^{2}km)	λ_0: < 80 dB/km 1550 nm: < 50 dB/km 1380 nm: < 420 dB/km 1000 nm: < 60 dB/km 600 nm: < 100 dB/km	1.5 ± 0.1 µm	0.19	2.8 µm^2	70 (W·km)$^{-1}$	Proprietary[d]	Proprietary[d]
NL-2.8-850-02	850 ± 5 nm	0.48 ps/(nm^{2}km)	λ_0: < 10 dB/km 1550 nm: < 6 dB/km 1380 nm: < 40 dB/km 1000 nm: < 10 dB/km 600 nm: < 17 dB/km	1.9 ± 0.1 µm	0.38	4.0 µm^2	47 (W·km)$^{-1}$		
NL-3.3-890-02	890 ± 5 nm	0.33 ps/(nm^{2}km)	λ_0: < 10 dB/km 1550 nm: < 5 dB/km 1380 nm: < 40 dB/km 1000 nm: < 10 dB/km 600 nm: < 20 dB/km	2.1 ± 0.1 µm	0.35	4.8 µm^2	37 (W·km)$^{-1}$		

- Measured at λ_0
- Mode Field Diameter
- Numerical Aperture
- We regret that we cannot provide this proprietary information.

Physical Properties

Item #	Core Diameter	Pitch	Air Fill in Holey Region	Diameter of Holey Region	Diameter of Outer Silica Cladding	Fiber O.D.
NL-2.4-800	2.4 µm ± 0.1 µm	2.9 µm ± 0.1 µm	>90%	27 µm ± 0.5 µm	105 µm ± 1 µm	230 µm ± 5 µm
NL-2.8-850-02	2.8 µm ± 0.1 µm	2.7 µm	>88%	28 µm	136 µm	220 µm
NL-3.3-890-02	3.2 µm ± 0.1 µm	3.1 µm	>88%	32 µm	154 µm	220 µm

SUPERCONTINUUM

The term **supercontinuum generation** includes many **nonlinear effects** that lead to a substantial spectral broadening. These nonlinear effects include Raman scattering, self-phase modulation and solitons. Supercontinuum spectra are typically produced by inputting short (femtosecond range) high power pulses into a nonlinear medium. Since the dispersion in a photonic crystal fiber can be tailored to facilitate the generation of supercontinuum spectra in a specific region, nonlinear photonic crystal fibers are an attractive media.

Supercontinuum (SC) sources are a new type of light source that combine the high radiant power and high degree of spatial coherence of a laser with a spectral bandwidth usually associated with an incandescent source. Supercontinuum sources can often drastically improve the signal-to-noise ratio, reduce the measurement time, or widen the spectral range in applications that require a broadband source, including high-resolution spectroscopy, the characterization of optical components, or optical coherence tomography (OCT). Despite the complex nature of the non-linear optical processes that convert the narrowband output of a laser into a supercontinuum, the practical realization can be surprisingly straight forward. All that is required is a high peak power pulsed laser, and a non-linear element with the right dispersion characteristics. The high power density, long length at comparatively low loss and the ability to achieve zero dispersion at wavelength shorter than 1250 nm - something that is not achievable with conventional fibers - makes small-core PCF ideally suited as the nonlinear element in a SC source. NKT Photonics offers small-core fibers suitable for use with femtosecond Ti:sapphire lasers (NLxx-xxx), as well as a fiber specifically designed to generate SC radiation from the output of a compact, low-cost Nd3+-YAG microchip laser (SC-5.0-1040). Please see detailed application note linked below for more information.

When selecting a fiber for supercontinuum generation, the relationship between a fiber’s zero dispersion wavelength and the pump is the most important consideration. The table below provides a general guideline for cases when pumping the photonic crystal fiber with femtosecond laser sources. The attached pdf file offers more details regarding supercontinuum generation using the NL series of Photonic Crystal Fiber.

Pump Wavelength	Output Spectrum
Below the zero dispersion wavelength	Stable, smooth and narrow spectrum
At the zero dispersion wavelength	Irregular, medium-wide and with a dip at the zero-dispersion wavelength
Above the zero dispersion wavelength	Irregular and wide spectrum

Part Number	Description	Price	Availability
NL-2.4-800	**Highly Nonlinear PCF, 800 nm ZDW, 2.4 µm Core**	**$1,590.00** **Per Meter** **Volume Pricing Available**	**Today**
NL-2.8-850-02	**Highly Nonlinear PCF, 850 nm ZDW, 2.8 µm Core**	**$1,590.00** **Per Meter** **Volume Pricing Available**	**Today**
NL-3.3-890-02	**Highly Nonlinear PCF, 890 nm ZDW, 3.2 µm Core**	**$1,590.00** **Per Meter** **Volume Pricing Available**	**Lead Time**

Highly Nonlinear PM PCF for 800 nm Pump Lasers

OVERVIEW

Features

- Polarization Beat Length at 1550 nm is typically <2 mm
- DGD at 1550 nm is typically 2 ns/km
- Near-Gaussian Mode Profile, Ellipticity of 1.13 at 830 nm

NKT Photonics' polarization-maintaining (PM) highly nonlinear photonic crystal fibers guide light in a small solid silica core, surrounded by a microstructure cladding formed by a periodic arrangement of air holes in the silica. The optical properties of the core closely resemble those of a slightly elliptical rod of glass suspended in air; this results in a strong confinement of the light, a large nonlinear coefficient, and a substantial splitting of the effective indices of the polarization modes. The zero-dispersion (ZD) wavelength has been chosen for use with Ti:Sapphire laser sources, but the dispersion is also anomalous at the fundamental Neodymium wavelength (1060 nm). These fibers are sold based on the overall optical specifications and not the physical structure.

Please note that these fibers will ship with both ends sealed in order to prevent moisture and dust from entering the hollow capillary structure during storage. It is necessary to cleave them prior to use using, for example, our S90R Ruby Fiber Scribe or our Vytran™ CAC400 Compact Fiber Cleaver.

SPECS

Specifications

Item #	NL-PM-750
Optical Properties	
Short Zero Dispersion Wavelength	750 ± 15 nm
Long Zero Dispersion Wavelength	1270 ± 30 nm
Attenuation @ 780 nm	<0.05 dB/m
Cut-Off Wavelength	< 650 nm
Mode Field Diameter @ 780 nm	1.6 ± 0.3 µm
Numerical Aperture @ 780 nm	0.38 ± 0.05
Nonlinear Coefficient @ 780 nm	~95 (Wkm)$^{-1}$
Birefringence @ 780 nm	>3 x 10^{-4}
Core Index	Proprietary[a]
Cladding Index	Proprietary[a]
Physical Properties	
Material	Pure Silica
Core Diameter	1.8 µm
Cladding Diameter[b]	120 ± 5 µm
Coating Diameter	240 ± 10 µm
Coating Material, Single Layer	Acrylate

- We regret that we cannot provide this proprietary information.
- Please note the larger tolerance when connectorizing this fiber. The tolerance could make the diameter of the fiber larger than the inner bore of the connector. We recommend selecting a connector with a bore size of at least 125 µm to ensure compatibility.

SUPERCONTINUUM

The term **supercontinuum generation** includes many **nonlinear effects** that lead to a substantial spectral broadening. These nonlinear effects include Raman scattering, self-phase modulation and solitons. Supercontinuum spectra are typically produced by inputting short (femtosecond range) high power pulses into a nonlinear medium. Since the dispersion in a photonic crystal fiber can be tailored to facilitate the generation of supercontinuum spectra in a specific region, nonlinear photonic crystal fibers are an attractive media.

Supercontinuum (SC) sources are a new type of light source that combine the high radiant power and high degree of spatial coherence of a laser with a spectral bandwidth usually associated with an incandescent source. Supercontinuum sources can often drastically improve the signal-to-noise ratio, reduce the measurement time, or widen the spectral range in applications that require a broadband source, including high-resolution spectroscopy, the characterization of optical components, or optical coherence tomography (OCT). Despite the complex nature of the non-linear optical processes that convert the narrowband output of a laser into a supercontinuum, the practical realization can be surprisingly straight forward. All that is required is a high peak power pulsed laser, and a non-linear element with the right dispersion characteristics. The high power density, long length at comparatively low loss and the ability to achieve zero dispersion at wavelength shorter than 1250 nm - something that is not achievable with conventional fibers - makes small-core PCF ideally suited as the nonlinear element in a SC source. NKT Photonics offers small-core fibers suitable for use with femtosecond Ti:sapphire lasers (NLxx-xxx), as well as a fiber specifically designed to generate SC radiation from the output of a compact, low-cost Nd3+-YAG microchip laser (SC-5.0-1040). Please see detailed application note linked below for more information.

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DAMAGE THRESHOLD

Laser-Induced Damage in Silica Optical Fibers

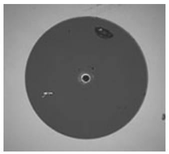
Quick Links
Damage at the Air / Glass Interface
Intrinsic Damage Threshold
Preparation and Handling of Optical Fibers

The following tutorial details damage mechanisms relevant to unterminated (bare) fiber, terminated optical fiber, and other fiber components from laser light sources. These mechanisms include damage that occurs at the air / glass interface (when free-space coupling or when using connectors) and in the optical fiber itself. A fiber component, such as a bare fiber, patch cable, or fused coupler, may have multiple potential avenues for damage (e.g., connectors, fiber end faces, and the device itself). The maximum power that a fiber can handle will always be limited by the lowest limit of any of these damage mechanisms.

While the damage threshold can be estimated using scaling relations and general rules, absolute damage thresholds in optical fibers are very application dependent and user specific. Users can use this guide to estimate a safe power level that minimizes the risk of damage. Following all appropriate preparation and handling guidelines, users should be able to operate a fiber component up to the specified maximum power level; if no maximum is specified for a component, users should abide by the "practical safe level" described below for safe operation of the component. Factors that can reduce power handling and cause damage to a fiber component include, but are not limited to, misalignment during fiber coupling, contamination of the fiber end face, or imperfections in the fiber itself. For further discussion about an optical fiber's power handling abilities for a specific application, please contact Thorlabs' Tech Support.

Damage at the Air / Glass Interface

There are several potential damage mechanisms that can occur at the air / glass interface. Light is incident on this interface when free-space coupling or when two fibers are mated using optical connectors. High-intensity light can damage the end face leading to reduced power handling and permanent damage to the fiber. For fibers terminated with optical connectors where the connectors are fixed to the fiber ends using epoxy, the heat generated by high-intensity light can burn the epoxy and leave residues on the fiber facet directly in the beam path.


Click to Enlarge
Damaged Fiber End


Click to Enlarge
Undamaged Fiber End

Damage Mechanisms on the Bare Fiber End Face

Damage mechanisms on a fiber end face can be modeled similarly to bulk optics, and industry-standard damage thresholds for UV Fused Silica substrates can be applied to silica-based fiber. However, unlike bulk optics, the relevant surface areas and beam diameters involved at the air / glass interface of an optical fiber are very small, particularly for coupling into single mode (SM) fiber. therefore, for a given power density, the power incident on the fiber needs to be lower for a smaller beam diameter.

The table to the right lists two thresholds for optical power densities: a theoretical damage threshold and a "practical safe level". In general, the theoretical damage threshold represents the estimated maximum power density that can be incident on the fiber end face without risking damage with very good fiber end face and coupling conditions. The "practical safe level" power density represents minimal risk of fiber damage. Operating a fiber or component beyond the practical safe level is possible, but users must follow the appropriate handling instructions and verify performance at low powers prior to use.

Estimated Optical Power Densities on Air / Glass Interface[a]		
Type	**Theoretical Damage Threshold[b]**	**Practical Safe Level[c]**
CW (Average Power)	~1 MW/cm^2	~250 kW/cm^2
10 ns Pulsed (Peak Power)	~5 GW/cm^2	~1 GW/cm^2

- All values are specified for unterminated (bare) silica fiber and apply for free space coupling into a clean fiber end face.
- This is an estimated maximum power density that can be incident on a fiber end face without risking damage. Verification of the performance and reliability of fiber components in the system before operating at high power must be done by the user, as it is highly system dependent.
- This is the estimated safe optical power density that can be incident on a fiber end face without damaging the fiber under most operating conditions.

Calculating the Effective Area for Single Mode and Multimode Fibers

The effective area for single mode (SM) fiber is defined by the mode field diameter (MFD), which is the cross-sectional area through which light propagates in the fiber; this area includes the fiber core and also a portion of the cladding. To achieve good efficiency when coupling into a single mode fiber, the diameter of the input beam must match the MFD of the fiber.

As an example, SM400 single mode fiber has a mode field diameter (MFD) of ~Ø3 µm operating at 400 nm, while the MFD for SMF-28 Ultra single mode fiber operating at 1550 nm is Ø10.5 µm. The effective area for these fibers can be calculated as follows:

SM400 Fiber: Area = Pi x $(\text{MFD}/2)^2$ = Pi x $(1.5\ \mu\text{m})^2$ = $7.07\ \mu\text{m}^2$ = $7.07 \times 10^{-8}\ \text{cm}^2$

SMF-28 Ultra Fiber: Area = Pi x $(\text{MFD}/2)^2$ = Pi x $(5.25\ \mu\text{m})^2$ = $86.6\ \mu\text{m}^2$ = $8.66 \times 10^{-7}\ \text{cm}^2$

To estimate the power level that a fiber facet can handle, the power density is multiplied by the effective area. Please note that this calculation assumes a uniform intensity profile, but most laser beams exhibit a Gaussian-like shape within single mode fiber, resulting in a higher power density at the center of the beam compared to the edges. Therefore, these calculations will slightly overestimate the power corresponding to the damage threshold or the practical safe level. Using the estimated power densities assuming a CW light source, we can determine the corresponding power levels as:

SM400 Fiber: $7.07 \times 10^{-8}\ \text{cm}^2 \times 1\ \text{MW/cm}^2 = 7.1 \times 10^{-8}\ \text{MW}$ = 71 mW (Theoretical Damage Threshold)
$7.07 \times 10^{-8}\ \text{cm}^2 \times 250\ \text{kW/cm}^2 = 1.8 \times 10^{-5}\ \text{kW}$ = 18 mW (Practical Safe Level)

SMF-28 Ultra Fiber: $8.66 \times 10^{-7}\ \text{cm}^2 \times 1\ \text{MW/cm}^2 = 8.7 \times 10^{-7}\ \text{MW}$ = 870 mW (Theoretical Damage Threshold)
$8.66 \times 10^{-7}\ \text{cm}^2 \times 250\ \text{kW/cm}^2 = 2.1 \times 10^{-4}\ \text{kW}$ = 210 mW (Practical Safe Level)

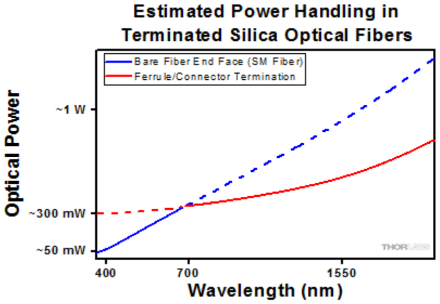
The effective area of a multimode (MM) fiber is defined by the core diameter, which is typically far larger than the MFD of an SM fiber. For optimal coupling, Thorlabs recommends focusing a beam to a spot roughly 70 - 80% of the core diameter. The larger effective area of MM fibers lowers the power density on the fiber end face, allowing higher optical powers (typically on the order of kilowatts) to be coupled into multimode fiber without damage.

Damage Mechanisms Related to Ferrule / Connector Termination

Fibers terminated with optical connectors have additional power handling considerations. Fiber is typically terminated using epoxy to bond the fiber to a ceramic or steel ferrule. When light is coupled into the fiber through a connector, light that does not enter the core and propagate down the fiber is scattered into the outer layers of the fiber, into the ferrule, and the epoxy used to hold the fiber in the ferrule. If the light is intense enough, it can burn the epoxy, causing it to vaporize and deposit a residue on the face of the connector. This results in localized absorption sites on the fiber end face that reduce coupling efficiency and increase scattering, causing further damage.

For several reasons, epoxy-related damage is dependent on the wavelength. In general, light scatters more strongly at short wavelengths than at longer wavelengths. Misalignment when coupling is also more likely due to the small MFD of short-wavelength SM fiber that also produces more scattered light.

To minimize the risk of burning the epoxy, fiber connectors can be constructed to have an epoxy-free air gap between the optical fiber and ferrule near the fiber end face. Our high-power multimode fiber patch cables use connectors with this design feature.



Click to Enlarge

Plot showing approximate power handling levels for single mode silica optical fiber with a termination. Each line shows the estimated power level due to a specific damage mechanism. The maximum power handling is limited by the lowest power level from all relevant damage mechanisms (indicated by a solid line).

Determining Power Handling with Multiple Damage Mechanisms

When fiber cables or components have multiple avenues for damage (e.g., fiber patch cables), the maximum power handling is always limited by the lowest damage threshold that is relevant to the fiber component.

As an illustrative example, the graph to the right shows an estimate of the power handling limitations of a single mode fiber patch cable due to damage to the fiber end face and damage via an optical connector. The total power handling of a terminated fiber at a given wavelength is limited by the lower of the two limitations at any given wavelength (indicated by the solid lines). A single mode fiber operating at around 488 nm is primarily limited by damage to the fiber end face (blue solid line), but fibers operating at 1550 nm are limited by damage to the optical connector (red solid line).

In the case of a multimode fiber, the effective mode area is defined by the core diameter, which is larger than the effective mode area for SM fiber. This results in a lower power density on the fiber end face and allows higher optical powers (on the order of kilowatts) to be coupled into the fiber without damage (not shown in graph). However, the damage limit of the ferrule / connector termination remains unchanged and as a result, the maximum power handling for a multimode fiber is limited by the ferrule and connector termination.

Please note that these are rough 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, these applications typically require expert users and testing at lower powers first to minimize risk of damage. Even still, optical fiber components should be considered a consumable lab supply if used at high power levels.

Intrinsic Damage Threshold

In addition to damage mechanisms at the air / glass interface, optical fibers also display power handling limitations due to damage mechanisms within the optical fiber itself. These limitations will affect all fiber components as they are intrinsic to the 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 a localized area. The light escaping the fiber typically has a high power density, which burns the fiber coating 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 the risk of 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, called photodarkening or solarization, can occur in fibers used with ultraviolet or short-wavelength visible light, particularly those with germanium-doped cores. Fibers used at these wavelengths will experience increased attenuation over time. The mechanism that causes photodarkening is largely unknown, but several fiber designs have been developed to mitigate it. For example, fibers with a very low hydroxyl ion (OH) content have been found to resist photodarkening and using other dopants, such as fluorine, can also reduce photodarkening.

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

Preparation and Handling of Optical Fibers

General Cleaning and Operation Guidelines

These general cleaning and operation guidelines are recommended for all fiber optic products. Users should still follow specific guidelines for an individual product as outlined in the support documentation or manual. Damage threshold calculations only apply when all appropriate cleaning and handling procedures are followed.

1. All light sources should be turned off prior to installing or integrating optical fibers (terminated or bare). This ensures that focused beams of light are not incident on fragile parts of the connector or fiber, which can possibly cause damage.
2. The power-handling capability of an optical fiber is directly linked to the quality of the fiber/connector end face. Always inspect the fiber end prior to connecting the fiber to an optical system. The fiber end face should be clean and clear of dirt and other contaminants that can cause scattering of coupled light. Bare fiber should be cleaved prior to use and users should inspect the fiber end to ensure a good quality cleave is achieved.
3. If an optical fiber is to be spliced into the optical system, users should first verify that the splice is of good quality at a low optical power prior to high-power use. Poor splice quality may increase light scattering at the splice interface, which can be a source of fiber damage.
4. Users should use low power when aligning the system and optimizing coupling; this minimizes exposure of other parts of the fiber (other than the core) to light. Damage from scattered light can occur if a high power beam is focused on the cladding, coating, or connector.

Tips for Using Fiber at Higher Optical Power

Optical fibers and fiber components should generally be operated within safe power level limits, but under ideal conditions (very good optical alignment and very clean optical end faces), the power handling of a fiber component may be increased. Users must verify the performance and stability of a fiber component within their system prior to increasing input or output power and follow all necessary safety and operation instructions. The tips below are useful suggestions when considering increasing optical power in an optical fiber or component.

1. Splicing a fiber component into a system using a fiber splicer can increase power handling as it minimizes possibility of air/fiber interface damage. Users should follow all appropriate guidelines to prepare and make a high-quality fiber splice. Poor splices can lead to scattering or regions of highly localized heat at the splice interface that can damage the fiber.
2. After connecting the fiber or component, the system should be tested and aligned using a light source at low power. The system power can be ramped up slowly to the desired output power while periodically verifying all components are properly aligned and that coupling efficiency is not changing with respect to optical launch power.
3. Bend losses that result from sharply bending a fiber can cause light to leak from the fiber in the stressed area. When operating at high power, the localized heating that can occur when a large amount of light escapes a small localized area (the stressed region) can damage the fiber. Avoid disturbing or accidently bending fibers during operation to minimize bend losses.
4. Users should always choose the appropriate optical fiber for a given application. For example, large-mode-area fibers are a good alternative to standard single mode fibers in high-power applications as they provide good beam quality with a larger MFD, decreasing the power density on the air/fiber interface.
5. Step-index silica single mode fibers are normally not used for ultraviolet light or high-peak-power pulsed applications due to the high spatial power densities associated with these applications.

Part Number	Description	Price	Availability
NL-PM-750	**Highly Nonlinear PM PCF, Supercontinuum Generation, 750 nm ZD, 1.8 µm Core**	**$1,590.00 Per Meter Volume Pricing Available**	**Lead Time**