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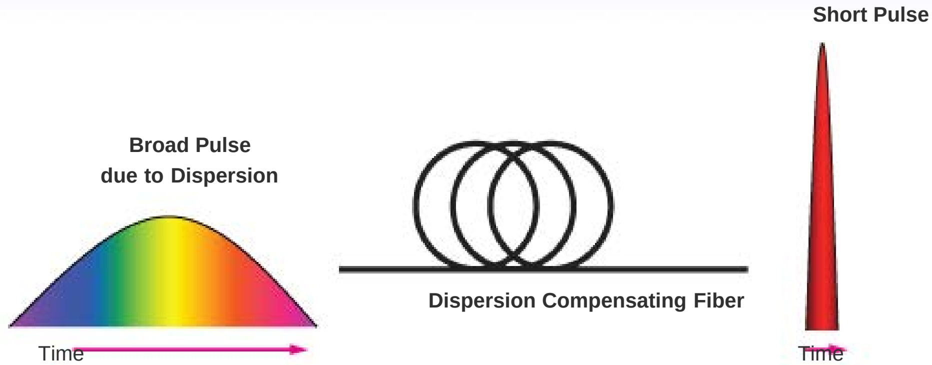
THORLABS

DCF38 - October 24, 2017

Item # DCF38 was discontinued on October 24, 2017. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

DISPERSION COMPENSATING FIBER

- Dispersion-Compensating SM Fiber for Telecom Wavelengths (1520 - 1625 nm)
- DCF38 is Specifically Designed to Compensate Corning SMF-28e+ Fiber

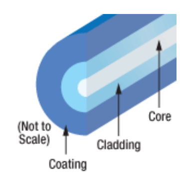


OVERVIEW

Features

- Dispersion Compensating Fiber for Telecom Wavelengths (1520 - 1625 nm)
- Designed to Compensate Corning SMF-28e+ Fiber
- Outer Jacket Available upon Request
- Shipped from Stock with No Minimum Order

Compatible Connector Supplies	
FC/APC Connector	30126K1
FC/PC Connector	30126D1
Stripping Tool	T06S13
Cleaving Tool	S90R
FC/APC Connectorization Kit	CK05
FC/PC Connectorization Kit	CK03



Click to Enlarge
Single Mode Fiber Cross Section

Thorlabs offers dispersion compensating optical fiber for custom solutions across a broad spectral range in the telecom region. DCF38 has dispersion designed specifically to match and compensate Corning SMF-28e+ or Vascade L1000 fiber. Please see the *Dispersion Tutorial* tab for more detailed information about dispersion compensating fibers. Please note that these fibers are not designed for underwater applications.

Connectorization

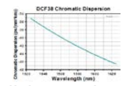
Dispersion compensating fibers are fully compatible with typical connectors and termination tools. Loss is slightly higher than typical SM fibers at around 1 dB. Lower losses can be achieved by splicing. Various compatible connectors and tools are summarized in the table to the upper right.

Splicing

Splicers and tooling designed for Ø125 µm fiber can be used with this fiber. To achieve an optimized fuse, the program should use a shorter fusion time than with conventional SM fibers. This is due to excess diffusion of the core dopants, which alters the guiding properties of the fiber in the splice region. For more information, see "New Technique for Reducing the Splice Loss to Dispersion Compensating Fiber", *Edvold B., Gruner-Nielsen, L., Optical Communication, **2**, 245-248 (September 19, 1996).*

SPECS

Item #	DCF38
Description	High dispersion fiber with negative slope. Designed to be paired with Corning SMF-28e+ or Vascade L1000 Fiber
Dispersion Specifications	
Dispersion	-49.00 to -30.00 ps/(nm*km)
Dispersion Slope	-0.155 to -0.075 ps/(nm^2*km)
Effective Area	27 µm^2
Polarization Mode Dispersion	≤0.05 ps/√km
Index of Refraction	1.476 at 1310 nm 1.474 at 1550 nm
General Specifications	
Nominal Mode Field Diameter @ 1550 nm	6.01 µm ± 0.29 µm
Numerical Aperture @ 1550 nm	0.14
Cladding Diameter	125.0 µm ± 1.0 µm
Coating Diameter	250 µm ± 5 µm
Cutoff Wavelength	≤1520 nm
Attenuation @ 1550 nm	≤0.265 dB/km
Attenuation Slope from 1530 - 1565 nm	-0.00040 to -0.00011 dB/(nm*km)



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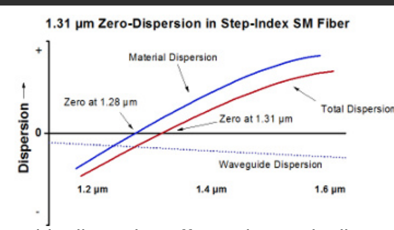
DISPERSION TUTORIAL

Dispersion in Optical Fiber

Chromatic dispersion is a property of optical fiber where different wavelengths of light propogate at different velocities. Chromatic dispersion is a function of wavelength, and is the sum of two components: material and waveguide dispersion. *Material dispersion* arises from the change in a material's refractive index with wavelength, which changes the propogation velocity of light as a function of wavelength.



Waveguide dispersion offsets chromatic dispersion to produce zero dispersion at 1.31 µm in step-index SM fiber (Click to Enlarge).

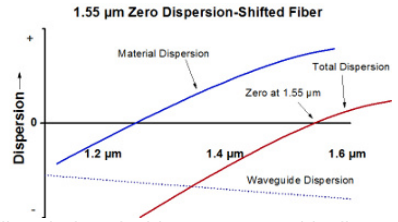
Waveguide dispersion is a separate effect, arising from the geometry of the fiber optic waveguide. Waveguide properties are a function of wavelength; consequently, changing the wavelength affects how light is guided in a single-mode fiber. For example, decreasing the wavelength will increase the relative waveguide dimensions, causing a change in the distribution of light in the cladding and core. In general:

$$\text{Dispersion}_{\text{chromatic}}(\lambda) = \text{Dispersion}_{\text{material}}(\lambda) + \text{Dispersion}_{\text{waveguide}}(\lambda)$$

Since material and waveguide dispersion are wavelength dependent, the dispersion is a function of wavelength. The *dispersion slope* can be positive or negative.

Dispersion-Shifted Fiber

In standard step-index single-mode fiber, the sum of the material and waveguide dispersion is zero near 1310 nm, which is called the *zero-disperion wavelength*. By varying the fiber's waveguide structure, the waveguide dispersion can be shifted up or down, thus changing the zero-dispersion point. Fiber in which the zero-dispersion wavelength has been changed is called *zero dispersion-shifted fiber*.

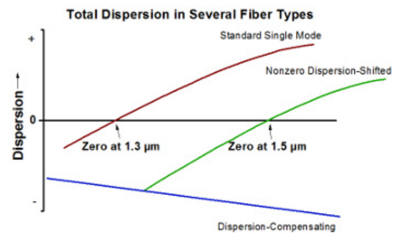


A fiber designed with more waveguide dispersion shifts the zero-dispersion wavelength to 1.55 µm (Click to Enlarge).

An initial strategy was to alter the waveguide structure to shift the zero-dispersion point to the signal wavelength of 1550 nm, creating zero-dispersion shifted fiber (see the diagram to the right).

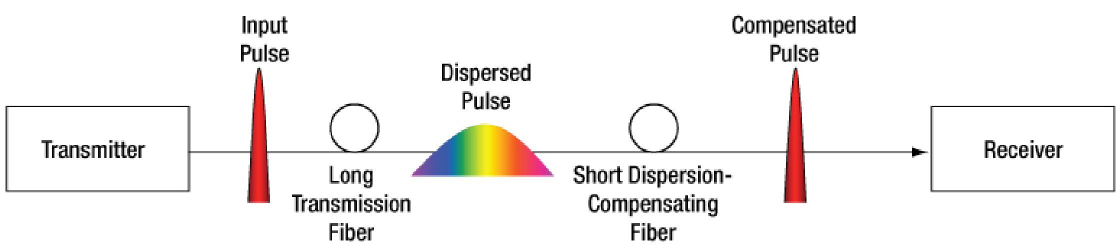
Unfortunately, fixing the dispersion problem is not so simple. When multiple optical channels pass through the same fiber at wavelengths where dispersion is very close to zero, they suffer from a type of crosstalk called four-wave mixing. The degradation is so severe that zero dispersion-shifted fiber cannot be used for dense-WDM systems. To avoid four-wave mixing, the zero-dispersion wavelength is moved outside the transmission band. So-called *nonzero dispersion-shifted fibers* have a dispersion that is low, but nonzero in the 1550 nm band (typically 0.1 to 6 ps/nm*km). Although dispersion is minimized, it is still present.

Dispersion-Compensating Fiber



Only total dispersion is shown in this graph. (Click to Enlarge)

Since dispersion is inevitable in optical fibers, dispersion-compensating fibers, such as those sold on this page, can be incorporated into optical systems. The overall dispersion of these fibers is opposite in sign and much larger in magnitude than that of standard fiber, so they can be used to cancel out or compensate the dispersion of a standard single-mode fiber, such as a nonzero dispersion-shifted fiber. A negative dispersion slope enables effective cancellation of dispersion over a larger wavelength range, since the dispersion slope of standard fiber is usually positive. Generally, a short length of dispersion-compensating fiber is spliced into a longer length of standard fiber to compensate for dispersion, as in the example below.



Dispersion Management

Dispersion can cause various penalties in signal transmission in optical communications systems. Thus, dispersion management is a very important part of designing a fiber optic transmission system. The following table, provided by ITU* standards, which gives the maximum distances for different transmission bit rates and fiber types at around 1550 nm as limited by dispersion.

Bit rate per channel (Gbps)	SDH	SONET	SSMF	NZ-DSF
2.5 Gbps	STM-16	OC-48	640 km	4400 km
10 Gbps	STM-64	OC-192	50-100 km	300-500 km
40 Gbps	STM-256	OC-768	5 km	20-30 km

*ITU: International Telecommunication Union
SDH: Syhcnronous Digital Hierarchy
SONET: Sychronous Optical Network
SSMF: Standard Single Mode Fiber
NZ-DSF: Non-Zero Dispersion Shifter Fiber
STM: SDH Level and Frame Format
OC: SONET Optical Carrier Level

There are different techniques to reduce the impact of chromatic dispersion, among them fiber with small dispersion, using fiber with negative dispersion, or dispersion compensating optics. Chromatic dispersion may or may not need to be compensated for in an optical system. Total fiber system dispersion can be estimated by:

$$CD_{total} = CD_{fi} + CD_{DCM} + CD_{other}$$

Where:
CD_{fi} = total fiber chromatic dispersion
CD_{DCM} = total chromatic dispersion of dispersion compensating systems

CD_{other} = total chromatic dispersion due to other components

A dispersion limit, CD_{limit}, is provided by ITU standards providing the maximum allowable accumulated chromatic dispersion. In general, the relation $CD_{limit} \geq CD_{total}$ should be true. When $CD_{limit} = CD_{total}$, a 1 dB decrease in signal strength as a function of bit rate will be present.

Bit Rate per Channel (Gbps)	SDH	SONET	Total Allowable Dispersion Coefficient at 1550 nm for a Given Link with SSMF (CD_{limit})
2.5 Gbps	STM-16	OC-48	12000 to 16000 ps/nm
10 Gbps	STM-64	OC-192	800 to 1000 ps/nm
40 Gbps	STM-256	OC-768	60 to 100 ps/nm

Dispersion Compensating Planning Example

Transmitted Power: 4 dBm
Signal: 10 Gbps
CD_{limit}: ±1000 ps/nm
Length: 100 km
Fiber: Single Mode with Dispersion: 18.0 ps/(nm x km) at λ = 1550 nm

First, is dispersion compensation necessary? CD_{fi} = Dispersion x Length = 18.00 ps/(nm x km) x 100 km = 1800 ps/nm. The dispersion limit for this system is CD_{limit} = ±1000 ps/nm, and so we need dispersion compensation. For this example, we need $CD_{limit} - CD_{DCM} \geq CD_{fi}$.

To reach the positive limit:
CD_{DCM} ≤ 1000 ps/nm - 1800 ps/nm = -800 ps/nm
To reach the negative limit:
CD_{DCM} ≥ -1000 ps/nm - 1800 ps/nm = -2800 ps/nm

Thus, we need -2800 ps/nm ≤ CD_{DCM} ≤ -800 ps/nm. Our DCF38 fiber has dispersion -38.0 ps/(nm x km), so we can use two 13.2 km segments for a total CD_{DCM} of: CD_{DCM} = 2 x 13.2 km x -38.0 ps/ (nm x km) = -1003.2 ps/nm.

Our total dispersion is then CD_{tot} = -1003.2 ps/nm + 1800 ps/nm = 796.8 ps/nm, which is below the dispersion compensation limit.

DAMAGE THRESHOLD

Laser-Induced Damage in Silica Optical Fibers

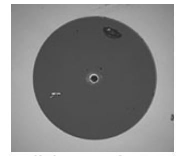
Quick Links
Damage at the Air / Glass Interface
Intrinsic Damage Threshold
Preparation and Handling of Optical Fibers

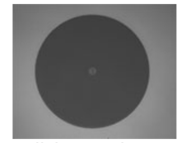
The following tutorial details damage mechanisms relevant to unterminated (bare) fiber, terminated optical fiber, and other fiber components from laser light sources. These mechanisms include damage that occurs at the air / glass interface (when free-space coupling or when using connectors) and in the 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 (MFD/2)^2 = Pi x (1.5 µm)^2 = 7.07 µm^2 = 7.07 x 10^{-8} cm^2

SMF-28 Ultra Fiber: Area = Pi x (MFD/2)^2 = Pi x (5.25 µm)^2 = 86.6 µm^2 = 8.66 x 10^{-7} 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 x 10^{-8} cm^2 x 1 MW/cm^2 = 7.1 x 10^{-8} MW = 71 mW (Theoretical Damage Threshold)
7.07 x 10^{-8} cm^2 x 250 kW/cm^2 = 1.8 x 10^{-5} kW = 18 mW (Practical Safe Level)

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

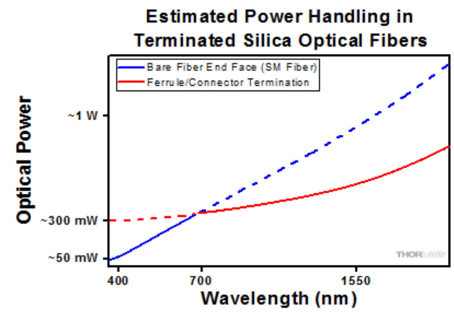
The effective area of a multimode (MM) fiber is defined by the core diameter, which is typically far larger than the MFD of an SM fiber. For optimal coupling, Thorlabs recommends focusing a beam to a spot roughly 70 - 80% of the core diameter. The larger effective area of MM fibers lowers the power density 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
DCF38	**Customer Inspired!Dispersion Compensating Fiber for SMF-28e+, Dispersion: -38 ps/nm*km**	**$6.25** **Per Meter** **Volume Pricing Available**	**Today**