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+ orVascade 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
Dispersion in Optical Fiber

Chromatic dispersion is a property of optical fiber where different wavelengths of light propagate 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 propagation velocity of light as a function of wavelength.

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-dispersion 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).

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

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

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. 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**

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.

<table>
<thead>
<tr>
<th>Bit rate per channel (Gbps)</th>
<th>SDH</th>
<th>SONET</th>
<th>SSMF</th>
<th>NZ-DSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 Gbps</td>
<td>STM-16</td>
<td>OC-48</td>
<td>640 km</td>
<td>4400 km</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>STM-64</td>
<td>OC-192</td>
<td>50-100 km</td>
<td>300-500 km</td>
</tr>
<tr>
<td>40 Gbps</td>
<td>STM-256</td>
<td>OC-768</td>
<td>5 km</td>
<td>20-30 km</td>
</tr>
</tbody>
</table>

*ITU: International Telecommunication Union  
NZ-DSF: Non-Zero Dispersion Shifter Fiber  
SDH: Synchronous Digital Hierarchy  
SONET: Synchronous Optical Network  
SSMF: Standard Single Mode 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:

\[
CD_{\text{total}} = CD_f + CD_{DCM} + CD_{\text{other}}
\]

Where:

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

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

**Dispersion Compensating Planning Example**

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

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

To reach the positive limit:

\[
CD_{\text{DCM}} \leq 1000 \text{ ps/nm} - 1800 \text{ ps/nm} = -800 \text{ ps/nm}
\]

To reach the negative limit:

\[
CD_{\text{DCM}} \geq -1000 \text{ ps/nm} - 1800 \text{ ps/nm} = -2800 \text{ ps/nm}
\]

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

Our total dispersion is then \( CD_{\text{tot}} = -1003.2 \text{ ps/nm} + 1800 \text{ ps/nm} = 796.8 \text{ ps/nm} \), which is below the dispersion compensation limit.
Damage Mechanisms on the Undamaged Fiber End

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.

Estimated Optical Power Densities on Air / Glass Interface

<table>
<thead>
<tr>
<th>Type</th>
<th>Theoretical Damage Threshold</th>
<th>Practical Safe Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW (Average Power)</td>
<td>~1 MW/cm²</td>
<td>~250 kW/cm²</td>
</tr>
<tr>
<td>10 ns Pulsed (Peak Power)</td>
<td>~5 GW/cm²</td>
<td>~1 GW/cm²</td>
</tr>
</tbody>
</table>

- 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:**

\[
\text{Area} = \pi \times \left(\frac{\text{MFD}}{2}\right)^2 = \pi \times (1.5 \, \mu m)^2 = 7.07 \, \mu m^2 = 7.07 \times 10^{-8} \, cm^2
\]

**SMF-28 Ultra Fiber:**

\[
\text{Area} = \pi \times \left(\frac{\text{MFD}}{2}\right)^2 = \pi \times (5.25 \, \mu m)^2 = 86.6 \, \mu m^2 = 8.66 \times 10^{-7} \, cm^2
\]

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:**

\[
7.07 \times 10^{-8} \, \text{cm}^2 \times 1 \, \text{MW/cm}^2 = 7.1 \times 10^{-8} \, \text{MW} = 71 \, \text{mW} \text{ (Theoretical Damage Threshold)}
\]

\[
7.07 \times 10^{-8} \, \text{cm}^2 \times 250 \, \text{kW/cm}^2 = 1.8 \times 10^{-5} \, \text{kW} = 18 \, \text{mW} \text{ (Practical Safe Level)}
\]

**SMF-28 Ultra Fiber:**

\[
8.66 \times 10^{-7} \, \text{cm}^2 \times 1 \, \text{MW/cm}^2 = 8.7 \times 10^{-7} \, \text{MW} = 870 \, \text{mW} \text{ (Theoretical Damage Threshold)}
\]

\[
8.66 \times 10^{-7} \, \text{cm}^2 \times 250 \, \text{kW/cm}^2 = 2.1 \times 10^{-4} \, \text{kW} = 210 \, \text{mW} \text{ (Practical Safe Level)}
\]

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.

**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.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Price</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCF38</td>
<td>Customer Inspired Dispersion Compensating Fiber for SMF-28e+, Dispersion: -38 ps/nm*km</td>
<td>$6.25 Per Meter</td>
<td>Volume Pricing Available</td>
</tr>
</tbody>
</table>