Vanishing Core Fiber Spot Size Converter Interconnect
(Polarizing or Polarization Maintaining)

The Go!Foton™ Interconnect (Go!Foton™ FSSC) is an in-fiber, spot size converting interconnect for convenient and efficient coupling of light from an optical fiber into a planar waveguide device, photodiode or other high numerical aperture (NA) waveguide. A vanishing-core fiber design allows light from a conventional low NA fiber to be coupled to another waveguide with much smaller mode field dimensions at high coupling efficiency. The Go!Foton™ FSSC can be used with an air gap but it also allows index-matching compounds to be used between the coupler and waveguide as opposed to microlens-based coupling in which an air gap is unavoidable. The Go!Foton™ FSSC is available in three basic polarization maintaining or polarizing variations:

FSSC-PL: Linearly polarizing tapered coupler
FSSC-PC: Circularly polarizing tapered coupler
FSSC-PM: Polarization maintaining tapered coupler

The Go!Foton™ FSSC products are endface coupled and are provided within an all-glass construct (Package A) or within a metal tube (Packages B and C). Either design is pigtailed with a PM fiber pigtail. Standard central wavelengths provided are 1550, 1310, 1060 and 980 nm. The technology is readily scalable, and other central wavelengths as well as custom mode field diameters can be provided. A coupler chuck with standard 6.35 mm (0.25") outer diameter, for compatibility with standard mounts, is also available, in conjunction with the standard metal tube package (Package B).

Applications:
- Planar waveguide device coupling
- Photodiode coupling
- Laser diode coupling
- Nanostructure coupling

### PROPERTIES

<table>
<thead>
<tr>
<th></th>
<th>Central Wavelength</th>
<th>Mode Field size</th>
<th>Bandwidth</th>
<th>Polarization Extinction Ratio</th>
<th>Typical Insertion Loss</th>
<th>Package Style</th>
<th>Pigtailed</th>
<th>Operating Temperature</th>
<th>Storage Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>980/1060 nm</td>
<td>0.5 x 0.8 µm</td>
<td>&gt;50 nm</td>
<td>&gt;25 dB</td>
<td>&lt;1 dB</td>
<td>All-glass</td>
<td>PM, 1 m, inside 900 µm furcation tube</td>
<td>-40 to +85°C</td>
<td>-70 to +85°C</td>
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<tr>
<td></td>
<td>1310 nm</td>
<td>0.7 x 1.0 µm</td>
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<tr>
<td></td>
<td>1550 nm</td>
<td>0.8 x 1.2 µm</td>
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</table>

1 Other wavelengths available upon request
2 Mode field dimensions can be tailored upon request
3 Typical passing polarization aligned to fiber’s slow axis
4 Connectorization available upon request

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www.gofoton.com
Package Styles:

A. All-Glass (Fiber Spot Size Converter)

B. Multi Channel Array (custom) channel to channel pitch can be < 20 um
Technical Description / Discussion:

The essence of the approach to matching both the mode profiles and numerical apertures (NAs) of two distinct waveguides is illustrated schematically in Fig. 1. This figure illustrates the couplers use as an interconnect between a standard single mode fiber and a waveguide. A custom fiber with a central core with index of refraction, \( n_1 \), centered in a rectangular section with slightly smaller index, \( n_2 \), is surrounded by the cladding with significantly lower index, \( n_3 \). The wide end of the fiber coupler is typically spliced to standard single mode or polarization maintaining fiber. The outer core serves as the main effective constituent of the cladding at the wide end of the coupler and this segment of the fiber may support the propagation of only a single core mode. The indices of refraction are chosen so that the NA of the wide end of the coupler, \( NA_{low} = \sqrt{n_1^2 - n_2^2} \), matches the NA of the fiber to which it is connected, while the diameters of the inner and outer cores are chosen so that the mode field diameters of the connected fibers are the same.

The fiber is tapered so that the inner core is too small to support propagation. The fiber then acts as if it has a single core of index close to \( n_2 \) surrounded by cladding with index \( n_3 \). The indices of refraction are chosen so that the NA of the narrow end of the fiber coupler, \( NA_{high} = \sqrt{n_2^2 - n_3^2} \), matches the NA of the waveguide to which it is connected. The width of the tapered end of the fiber is chosen to create a mode field diameter matching that for the waveguide mode.

Matching the NA via the indices of the inner and outer cores and cladding makes it possible to couple to waveguides without the use of a lens. Lenses are most compact and efficient when they are attached to the end of the fiber. However, lens-coupling to the waveguide necessitates an air gap with a significant index mismatch between the waveguide and air. Because the FSSC does not require use of a lens, an index matching compound with index between that of the high index core and the still higher index of the waveguide can be used to substantially mitigate reflection losses. Another drawback of commercial couplers utilizing lenses is that mode field diameters of less than 2 \( \mu m \) are not available. In contrast, we are able to provide mode field diameters of under 1 \( \mu m \).

Fig.1. Tapered optical fiber coupler connecting a standard fiber (left) to a planar waveguide (right). The mode field diameter (MFD) is transformed from 10 to 1 \( \mu m \).
It is often desirable to couple highly polarized radiation into or out of the waveguide. This can be accomplished by maintaining polarization through or incorporating a linear polarizer into the FSSC. A schematic of the polarizing coupler is shown in Fig. 2, which shows a sketch of a tapered fiber followed by a microscopic image of a chiral fiber linear polarizer. The chiral polarizer consists of a double-helix GolFoton grating with pitch which is smoothly accelerated to a constant value for some length and then decelerated to the initial untwisted state. The double helix grating is formed by twisting a birefringent fiber with $180^\circ$ rotation symmetry. The cross section of the core of a fiber with core suitable for a chiral fiber tapered polarizer is shown in Fig. 3. The untwisted fiber preform consists of a high-index outer rectangular core with an aspect ratio of 2:1 surrounded by a cladding with circular outer perimeter. The birefringence is proportional to the index difference between the core and cladding. Tapered couplers with polarization extinction ratio exceeding 30 dB are available.

Using an exemplary InP waveguide that approximates the near field image you sent us, as shown in Figure 4, we calculated coupling losses between our standard tapered coupler product and the waveguide. The coupling loss was calculated for abutted waveguides when both are oriented similarly and when they are oriented at 90 degrees to each other. An index matching fluid of index 2 was assumed. Fig. 5 shows the calculated losses...
as a function of the gap distance between the two waveguides for both linear polarizations.

![Graph showing transmission losses as a function of gap width](image)

**Fig. 5.** Transmission losses for parallel (top) and perpendicularly (bottom) abutted TC and waveguide of Figs 3 and 4. The losses are given for both polarizations as a function of gap width in microns, assuming an index matching compound of refractive index of 2 fills the gap.

A comparison of the measured and calculated far-field energy distributions of the tapered coupler is shown in Figure 6.
Lastly, we have measured coupler-to-coupler losses directly using two 3-coordinate stages, which have 0.5 micron accuracy and have measured overall losses to be 5 dB or 2.5 dB per tapered coupler.