# Splicing Single Mode PCFs

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*This application note addresses general advice about fusion splicing of photonic crystal fibers (PCFs). The note is limited to the work related directly to the fusion splicer, whereas guidelines for general handling of the PCFs can be found in the application note "Fiber Handling, Stripping, Cleaving and Coupling", found at www.nktphotonics.com/support.*

*High quality splicing of PCFs has been demonstrated for both scientific and industrial applications. However, developing splicing recipes for PCFs can be challenging and require special attention to conserving optical properties at the splice interface.*

*We recommend the Vytran FFS-2000 filament fusion splicer due to the precision and large flexibility of this model, and this application note deals exclusively with this machine. The general advice, however, is also applicable to other models.*

## Contents



# Preparation

## Fiber preparation

The two fibers to be spliced together need to be stripped and cleaved to high quality. The cleaved facets should be flat and the cleave angles should be low. Below are graphs showing how the cleave angle can affect the splice loss. The larger the Mode Field Diameter (MFD), the higher demands for the cleave angle.

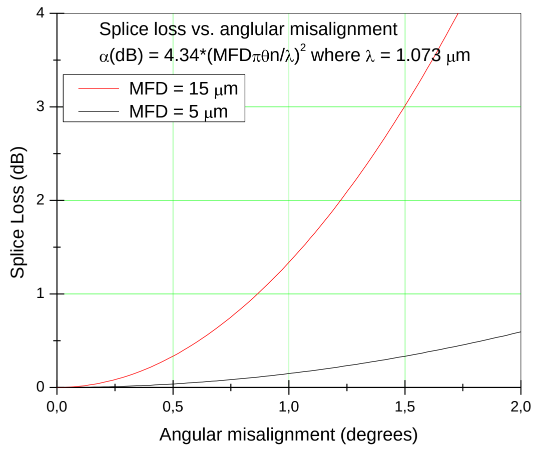



**Figure 1 Example of splice loss vs. angular misalignment for two different fibers with 5 and 15 µm mode field diameters, respectively.**

## Setting up active alignment

It is recommended to use active alignment for measuring the transmission losses and for alignment during the splicing (see Figure 2). Choose a SM fiber pigtailed laser with an appropriate wavelength and couple light into fiber A. Fiber A could typically be a non-PCF fiber, such as SMF-28 or HI1060. Strip and cleave the other end of fiber A and insert this end into an integrating sphere. Turn on the laser and note the signal strength as 0.00 dB. Make sure that the SNR (signal-to-noise ratio) is better than 20 dB.

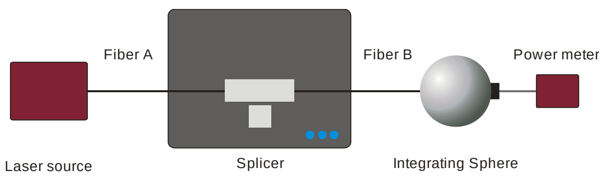



**Figure 2 Splicing fiber A to fiber B using active alignment.**

### Setting up splicer

In the FFS-2000, insert appropriate filament (many 125µm splices can be performed with the default F35-2520 filament) and perform standard burn-back to calibrate the filament power.

Make sure the laser is turned off, strip and cleave Fiber A and insert into the Fiber Holding Block (FHB) of the FFS-2000 splicer. For fiber B, strip and cleave both ends. One end is inserted into the integrating sphere and the other into the FHB.


**Figure 3 Vytran FFS-2000 filament fusion splicer.**

### Splice quality, optical considerations

Typical splice recipes for PCFs will result in “cold” splices. In such cold splices a complete melting of the glass is avoided to preserve the holes and thereby the waveguide. Depending on the fiber, partial collapse of the holes may be an advantage, but should generally be avoided. Consequently, a typical splice interface between the fibers acts as a butt-coupling with physical contact. For such an interface, transmission is typically limited by:

- XY alignment
- Angular alignment
- Mode Field Diameter mismatch (see Figure 4)

For nonlinear fibers, the biggest challenge is XY alignment, as the cores are small. In this case, mechanical stability, adjustment resolution and back-lash are important factors.

For SM fibers with large cores, the typical Numerical Apertures involved can be very small (as low as 0.03). In that case, alignment of the fiber mounting mechanics and the cleave angles are important.

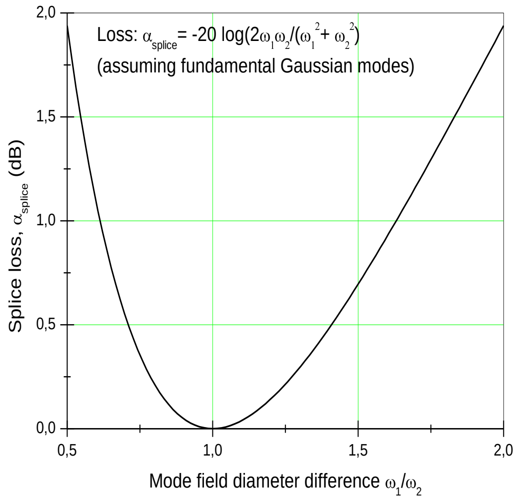



**Figure 4 Attenuation induced by mode field diameter mismatch.**

For different MFDs of Fiber A and Fiber B, there is a lower limit to the splice loss. For solid doped fibers one can utilize the Thermal Expanded Core (TEC) technique where extended heating duration results is dopant diffusion inside the fiber, whereby the core and MFD expands. Well-controlled TEC can yield low loss splices between fibers with very different MFDs.

For PCFs, TEC methods cannot be used, since the waveguide are typically not given by dopants but rather by holes. However, other methods are applicable, including:

- TEC of solid fiber prior to splicing
- Use of intermediate/bridging fiber
- Tapering of PCF or solid fiber
- Core expansion by partially collapsing the holes

These, more advanced methods, are not part of this application note.

# Splicing

### General guidelines to splicing PCF to solid fiber

PCF splices are different from standard fiber splices as the core cannot be seen through the side of the fiber and the power must be reduced to avoid hole collapse. Typical splice powers are about 25% less than what would be used for comparable solid fibers. The lower splice power increases the risk of low mechanical strength and when optimizing the splice parameter, the goal is,

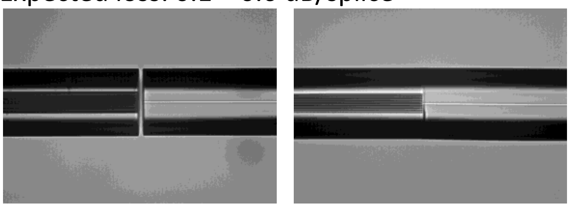
therefore, to find the best compromise between transmission loss and mechanical strength.
For developing a splice recipe, we recommend the following splice series:
Make a splice with low fusion power and short heating time. Leave fiber in the splicer and repeatedly heat the fiber interface at increasing powers or increasing heating times until the holes starts collapsing. Such series will give a good indication on the maximum powers and on-times. Following this, make a new series of splices, where the hotpush is increased until transmission starts to decrease. In this way, mechanical strength is optimized. Further splice improvements can be obtained by repeated heating cycles.
In the following, detailed guidelines for splicing between specific fiber pairs are given.

### Specific: Hollow Core fiber to solid fiber

Filament offset: 50 steps towards the solid fiber
Splice power: 9.5 W
Splice duration: 5000 ms
Pregap: 8 µm
Prepush: 6 µm
Hotpush: 10-15 µm
Use slim tungsten filament (F35-1520)
NOTE: there is a 4 % reflection from the glass-air interface at each end of the HC fiber.
Expected loss: 0.8 – 2 dB/splice

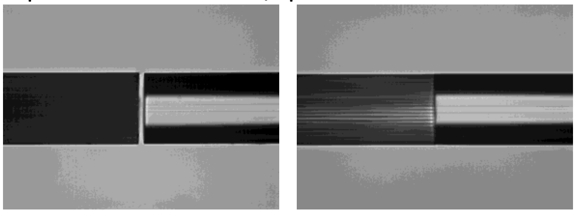
### Specific: NL PCF to solid fiber, 125 µm OD

Filament offset: 50 steps towards the solid fiber
Splice power: ~17 W
Splice duration: 500-1000 ms
Pregap: 8 µm
Prepush: 7 µm
Hotpush: 10-15 µm
Use default tungsten filament (F35-2520)
Expected loss: 0.1 – 0.6 dB/splice



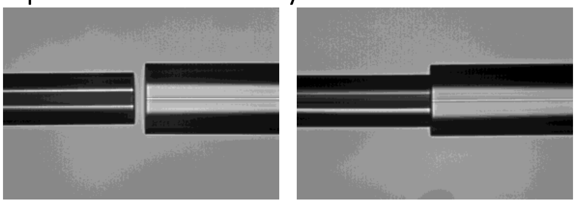
### Specific: LMA-16 to solid fiber, 125 µm OD

Filament offset: none
Number of heating runs: 2
Splice power: ~17 W
Splice duration: 1000-2000 ms
Pregap: 8 µm
Prepush: 7 µm
Hotpush: 10-15 µm
Use default tungsten filament (F35-2520)
Expected loss: ~0.4 dB/splice



### Specific: Thin PCF to thicker solid fiber

Filament offset: 50 steps towards the solid fiber
Splice power: 16.3 W
Splice duration: 300 ms
Pregap: 8 µm
Prepush: 7 µm
Hotpush: 8 µm
Use default tungsten filament (F35-2520)
NOTE: Several short heating steps (Power: 21 W, Duration: 170 ms, hotpush: 5 um) have been observed to increase mechanical strength)
Expected loss: Limited by MFD mismatch



# Splice protection

### Splice quality, mechanical considerations

Since a complete melting of the glass is avoided, the fiber interface is very abrupt. This affects the strength of the splice/interface, which can be measured as a bending radius at which the fiber breaks at or near the joint. For a splice between a solid fiber and a NL fiber, such bending diameter would typically be ~50 mm.
To protect the splice it is recommend using a splice protection sleeve and for most applications, a standard 60 mm splice sleeve with an internal steel pin will be sufficient. For high power applications (higher than 10 W optical power), more advanced methods have to be considered.