

APP NOTE # 1.0

AUGUST 09

FIBER HANDLING, STRIPPING, CLEAVING AND COUPLING

This application note addresses general handling of fibers from NKT Photonics, including how to strip the protective coating, how to cleave the fibers and tips for coupling light to and from the fibers. If you are new to fiber optics or PCFs, this note is a good place to start.

Stripping the Coating

The fibers supplied by Crystal Fibre are all equipped with a standard single layer acrylate coating or, in the case of our high power products, a high temperature coating. Compared to dual layer coatings, single layer coatings are more smooth and brittle. The coating can readily be removed with conventional fiber stripping tools such as the *Clauss CFS-1* or *Fitel S-210* for fiber with a 125 µm cladding diameter or a *Clauss No Nik* stripper for cladding diameters larger than 125 m. For fibers with a non-standard outer diameter, we recommend an adjustable stripper. Thermal strippers (like the stripper attached to the *Vytran FFS-2000* or the *FiberStrip 7030* from *Schleuniger*) can also be used safely on all fibers.



Figure 1: Clauss coating stripper

Alternatively, the fibers can be stripped chemically using a suitable solvent (e.g. by exposing the coating to 120°C sulfuric acid, H₂SO₄, for one minute).

Prior to dipping the fiber into the liquid, seal the tip with a 2 mm diameter drop of glue or by collapsing the holes at the end of the fiber with a fusion splicer. Note that this acid dissolves most types of glue, but two-component epoxies like the *Epotek ND353* will dissolve slower than the coating.

Chemical stripping can also be obtained by applying paint stripper near the fiber tip. Such paint stripper is typically in gel form to reduce out-gassing and is easily applied with a small brush. The coating will be soft after approximately one minute and can easily be removed using lens tissue. NOTE: Paint stripper often contains dichloromethane (CH₂Cl₂) and local regulations may restrict the use of this.

For faster, lower quality stripping, one can choose to burn the coating off with a normal cigarette lighter. However, this can result in a brittle fiber and is generally not recommended.

Please note that all mechanical methods carry the small risk of damaging the fiber surface, which can lead to reliability problems. Consequently, chemical stripping is recommended when very high reliability is required.

If removal of coating debris is needed, use a folded sheet of lint free lens tissue. To avoid leakage of liquid into the holes, use only a very small amount of clean *isopropyl alcohol* (also known as IPA, 2-propanol or rubbing alcohol) to moist (not soak) the folded corner of the sheet. Put the fiber into the fold, press firmly around the fiber with the fingers and pull the tissue towards the fiber end.

Warning: Never expose an untreated fiber tip to solvents or other liquids as capillary forces might cause the liquid to enter the microstructure of the fiber, resulting in unpredictable performance and possible damage of the fiber. If it is necessary to expose the fiber end to liquids, the fiber should be sealed by collapsing the microstructure at the end using a fusion splicer or by gluing the end of the fiber. A sealed fiber can be treated like solid standard fiber.

Cleaving

General cleaving remarks

When a cleaving occurs, a shock wave starts at the scribing point and propagates perpendicularly to the fiber. The wave front forms a circle with the scribing point as the center.

Holes in the fibers act to locally prevent propagation of this wave. The wave will thus split up and travel around either side of the hole and meet on a line pointing away

from the scribing point. These lines are sometimes visible under a microscope (see LMA image below). Typically, the step height of those lines are <math><200\text{ nm}</math>.

For simple fiber-end inspection, using a scribing tool (e.g. a scribing pen or a ceramic blade) and bending can often lead to flat cleaved surfaces.

Warning: Cleaning a contaminated cleaved facet is not recommended. The fiber should instead be re-cleaved to achieve a fresh contaminant free facet. Re-cleaving can be avoided by using connectorized fiber with sealed, cleanable end-facets (see more information about connectors and end-sealing in the section on Connectors).

Cleaving fibers with standard diameter

All fibers with standard diameter (125 μm range) can be cleaved with conventional high precision cleavers (like the *Fujikura CT-series* or the cleaver attached to the *Vytran FFS-2000* splicer). The fibers can also be cleaved using e.g. a diamond scribe, but cleaving by hand might yield high cleaving angles or bad cleave quality, reducing the coupling efficiency.

For cleaving PCFs the cleaving tension used should be reduced by $\sim 30\%$ compared to solid fibers. Below is an image of an acceptable cleave of an LMA fiber. The core area is flat and flawless and the cleave angle is less than 1 degree. Note the debris at either side of the fiber. This can be reduced by further reducing tension.

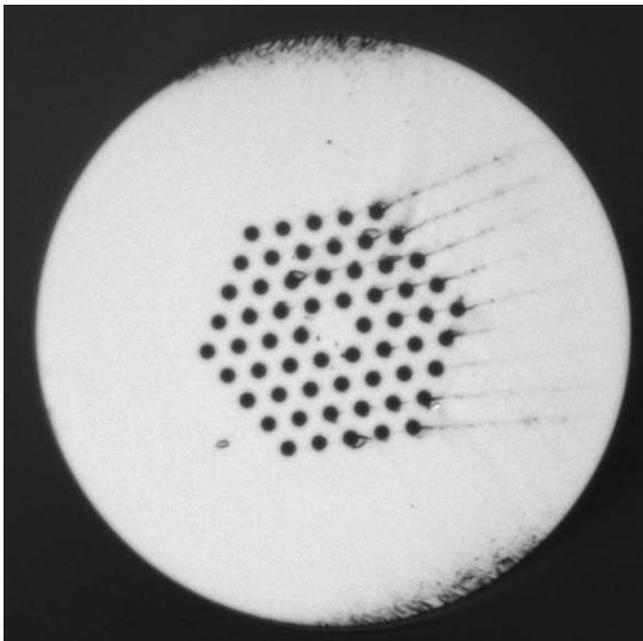


Figure 2: Optical microscope picture of the cross section of a single mode LMA fiber with good cleave



Figure 3: Fujikura CT-04 cleaver

Cleaving large diameter fibers and airclad fibers

For fibres with diameters in excess of 125 μm , more cleave tension is needed and only a few off-the-shelf cleavers exist. However, once a few precautions have been taken, large airclad can be cleaved routinely with high consistent quality.

Many of the large diameter fibers have airclad features, which presents an increased challenge for the cleaving procedure. The airclad is a ring of closely spaced air holes, which, when cleaved, acts as an efficient barrier for the shock wave associated with the cleave. Special care must, therefore, be taken to use an appropriate amount of tension. Using too little tension results in no cleave occurring. Using too much tension, results in a time delay between the cleaving of the outer and inner cladding. In this case the inner cladding experience too much stress during cleave and glass debris can be seen at the facet.

During cleaving, two parts of the shock wave propagates around the outer cladding and meet at the far side of the fiber. Since these two waves travel far before they meet, the step at this meeting point is typically larger. Typically, up to 2 μm step height is acceptable. The step height can be reduced by carefully aligning the fibre and the cleaver.

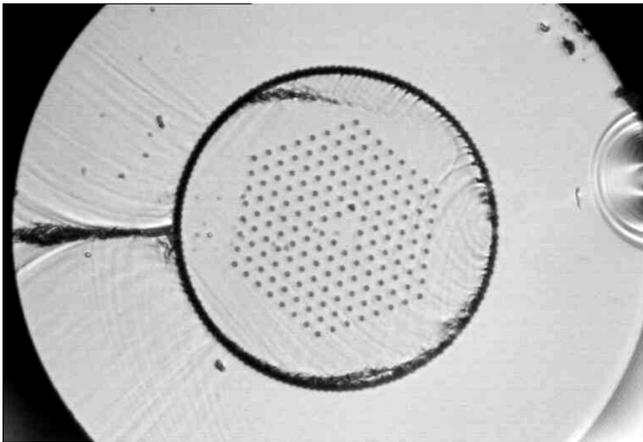


Figure 4: Airclad fiber with a pump cladding NA of 0.6 and an outer diameter of ~450 μm.

Many of our large diameter fibers include single mode cores with a very large Mode Field Diameter.

Such fibers are typically designed for being used in fiber lasers or amplifiers. In case perpendicular cleaved facets are desired to act as a mirror in one side of a laser cavity, extra care must be taken. The facet must be flat over the core region. This should be checked under a high magnification microscope. Also, the cleave angle must be very low. The cleave angle can be measured by taking an image from the side of the cleaved end from two perpendicular sides. Add the two cleave angles to obtain the total cleave angle. To ensure that the reflection is close to 4%, the total cleave angle must typically be less than 0.3° (see graph below).

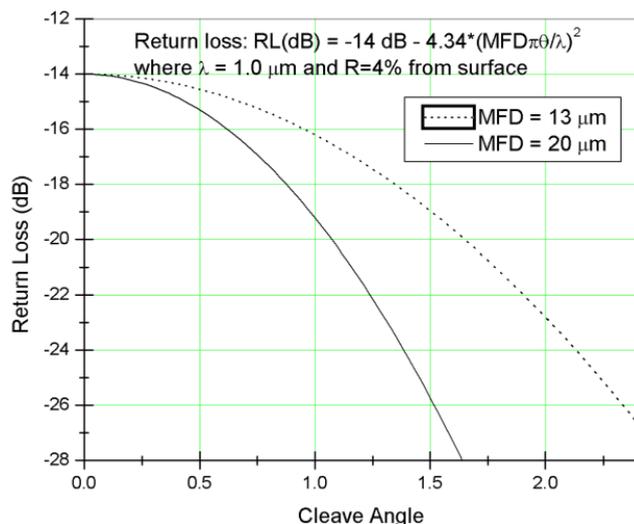


Figure 5: Calculation of reflection back into the fiber as a function of cleave angle.

We recommend using the Vytran LCD-200-G cleaver, which uses the *scribe and pull* technique. Further, this cleaver can apply up to 4 kg precisely controlled tension. The fiber is held straight during cleaving. The cleaver tension is adjusted to be as low as possible and the scribing blade just touches the fiber. Ideally, the fiber cleave occurs several seconds after the scribing.



Figure 6: Vytran LCD-200-G large diameter cleaver

Splicing

All our fibers with a core size above 2 μm can be spliced to other PCFs or step-index fibers using standard splicing equipment.

For splices to small core fibers, such as the non-linear fibers, we recommend using active alignment during splicing, as the fibers need to be aligned with sub-μm precision to obtain maximum transmission.

Splices to single mode fibers with large mode-field diameter required very low angle cleaves and attention must be paid to the cleaving process as described above.

For solid fiber splices, a high temperature splice process is used to completely melt the fiber glass. For PCFs, however, such process would cause the holes to collapse through surface tension. Therefore, we recommend splicing these fibers at lower temperature. Typically, the fusing power applied must be reduced by 20-40% compared to solid fibers. The correct amount of power can be determined using active alignment, where the transmission loss introduced by the splice can be monitored and minimized.

Low power splices can be mechanically weaker than high power splices, and we, therefore, recommend using extra splice protection (such as splice sleeves).

Furthermore, we recommend using filament fusion splicers (like the Vytran FFS-2000 or GPX-3400) as they offer a larger degree of control in the splice process compared to most other fusion splicers.



Figure 7: Vytran FFS-2000 filament fusion splicer.

Connectors

General remarks

When connectorizing PCFs, we heat treat the fiber ends before connectorization to carefully collapse the holes (see picture below). The fiber end can now be inserted into the connector ferrule and the end facet can be polished. The distance between the connector facet and the position of the collapsed hole-region can be chosen freely (up to 1700 μm). This enables beam expansion inside the connector, increasing the spot size at the facet, which is beneficial in many high power applications.

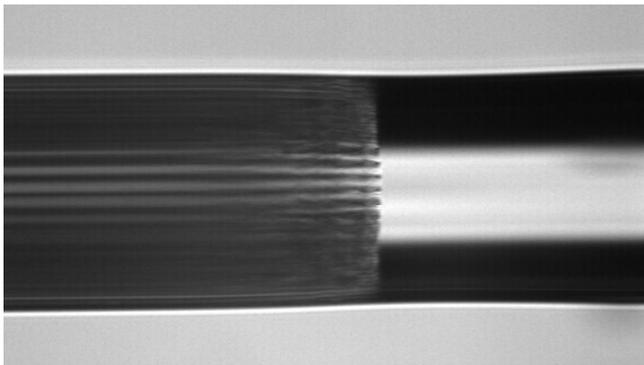


Figure 8: Fiber with partially collapsed microstructure

Note that the facet-to-hole-region distance typically cannot be lower than 50 μm , which often prohibits direct fiber-to-fiber coupling.

Connector types and handling



Figure 9: Connector types. A) Standard FC/PC connector. B) SMA connector. C) High power SMA connector with mode stripper.

For most applications, FC/PC or FC/APC connectors will be sufficient. The connectorization procedures are equivalent to telecom-grade connectors (quality of connectors, UPC polishing quality etc.). In terms of high power handling, FC-type connectors can typically handle up to 5 W of average optical powers before thermal induce degradation takes place.

For higher optical power, we recommend using SMA-type connectors. For average powers up to 50 W, a standard SMA-905 connector is offered. Here, the connector ferrule consists of solid stainless steel. The fiber at the tip of the connector is cantilevered to increase power capabilities.

For even higher powers (up to 200 W average powers), a specially designed SMA-905 connector is offered. This connector is designed to have open optical windows at the side of the connector. These windows allow direct optical removal of cladding guided light and thus reduces the need for thermal heat sinking.

Cleaning

FC/PC and FC/APC connectors can be cleaned and re-polished like standard telecom connectors. For SMA connectors with cantilevered fiber tip, attention must be paid not to break the fiber. In general, we recommend avoiding cleaning of such connectors. If the facet is too dirty to be used, we recommend using a piece of lens tissue moist (not soaked) with IPA and wipe the facet very lightly under a microscope.

Coupling

Coupling light into a PCF is as easy (or hard) as coupling into a standard fiber, however knowledge of the mode size and numerical aperture is required. In standard single-mode fibers, the numerical aperture is typically designed to be approximately 0.12. The fibers offered by NKT Photonics, however, span a wide range of numerical apertures from 0.02 in the largest ROD fibers to 0.5 in the small core nonlinear fibers.

Light may be coupled into a PCF in a number of different ways (see Figure 10), e.g. by butt-coupling to another fiber, using a microscope objective to couple a free-space beam into the PCF or by using a telescope to couple from a single-mode fiber to a PCF having a significantly different mode size.

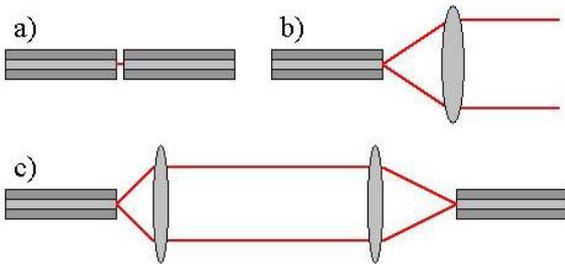


Figure 10: Three different way of coupling in to a PCF. a) Butt-coupling, b) Free-space coupling and c) Fiber-to-fiber coupling with a telescope.

Butt coupling

For *butt-coupling*, it is important to match the modes of the two fibers in order to minimize the coupling losses. For Gaussian mode profiles, the minimum loss (in dB units) through the butt-coupling is given by:

$$\alpha_{butt} = -20 \log \left(\frac{2\omega_{PCF}\omega_{SM}}{\omega_{PCF}^2 + \omega_{SM}^2} \right)$$

- where ω_{PCF} and ω_{SM} are the Gaussian mode field diameters of the PCF and standard single-mode fiber respectively.

Free space coupling

For *free-space coupling*, it is important to choose the NA of the microscope objective large enough to match the NA of the PCF. The minimum loss (in dB units) for the free-space coupling is given by:

$$\alpha_{butt} = -20 \log \left(\frac{2NA_{PCF}NA_{launch}}{NA_{PCF}^2 + NA_{launch}^2} \right)$$

- where NA_{PCF} and NA_{launch} are the numerical apertures of the PCF and the launched light respectively. Note, that the NA of the launched light depends both on the NA of the microscope objective and how large a fraction of the aperture is filled by the free-space beam.

Fiber to fiber coupling

For *fiber-to-fiber coupling with a telescope*, it is important to match the focal lengths of the lenses to obtain the magnification required to match the modes of the two fibers. The ratio of the focal lengths is given by:

$$\frac{f_1}{f_2} = \frac{\omega_{PCF}}{\omega_{SM}}$$

- where f_1 is the focal length of the lens facing the PCF and f_2 is the focal length of the lens facing the single-mode fiber.

Small core fibers

Coupling to small-core PCFs can be realized with relatively high coupling efficiency using a bulk optics set-up coupled to standard fiber patch cables.

In Fig. 11 a drawing of the launch set-up is shown consisting of a collimating objective, a focusing objective and a small-core PCF.

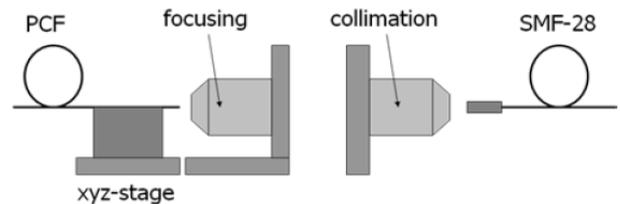


Figure 11: Schematic drawing of the launch optics, for coupling light from a standard SMF-28 fiber into a PCF.

The light emerging from a standard fiber patch cable (e.g. an *SMF-28*) fiber is collimated using a free space fiber coupler (*Thorlabs KT110*) and focused into the PCF with a high-NA objective. The PCF is mounted on a very precise and stable xyz-stage (*Thorlabs MDT610*), minimizing the long term drift of the set-up and facilitating fine adjustment of the coupling into the PCF. The lenses used at the input are IR-coated aspheric lenses (*NewFocus lens kit no. 5720C*) having a nearly diffraction limited performance, which is important to match the small core size of the PCF. A combination of a x16 (f=11.0 mm, NA=0.25) objective for the collimation and a x40 (f=4.5 mm, NA=0.55) objective for focusing into the PCF, yields the optimal coupling from a SMF-28 fiber into most small core PCFs.

The alignment of the set-up is most conveniently done using a visible fiber coupled laser source (e.g. at 635 nm) and a detector at the output of the PCF to maximize the light throughput. When switching to another wavelength only a slight refocusing of the collimating and focusing lenses is needed to obtain the optimal coupling. Typically one can achieve a coupling efficiency on the order of 40-50% for the smallest fibers (cores around 2 μm) and higher for the larger fibers.

Depending on the specific application, the output of the PCF may be coupled back into a standard fiber, using either a butt-coupling or another launch set-up similar to the one described above. Due to the large mode mismatch the efficiency of the butt-coupling is typically around 10%.

NKT Photonics recommends using high quality stages for holding and translating the PCFs in the in-coupling setup, e.g. the Thorlabs MDT610 single mode fiber launch system or the *Melles-Griot NanoBlock* system.

Coupling to the very low NA ROD fibers is covered in a separate application note available at our website.

Safety

Operators familiar with electronic wires and cables may not be aware of the special features of optical fiber and components. Optical fibers are made of glass. Although such material is inherently strong and flexible, optical fibers require proper handling to ensure long lifetime and prevent fiber breaking. Listed below is a set of general rules/guidelines that are commonly used to ensure handling procedures that are safe both for the fiber and the operator.

Fiber Handling

- **Never expose the fiber to a bend diameter less than 200 times the fiber diameter:**
 - For 125 μm fiber: 25 mm bend diameter
 - For 400 μm fiber: 80 mm bend diameter
- **Never place tools or other hard and heavy items on top of the fiber**
- **Never allow the fiber to come into contact with sharp edges (such as edges of optical tables)**
- **Never wipe an optical fiber with abrasive material or organic solvents such as acetone**
- **Dispose of all cleaved pieces of fiber into a debris container. Alternatively, a small Petri dish lined with double-sided adhesive tape can be used**

- **Never dispose of loose glass fibers into a wastebasket and never allow loose pieces of glass to accumulate**
- **Do not eat or drink in the termination area. Ingested fibers can cause internal damage**

Safety Precautions

Normally, for optical fibers with a diameter of 125 μm , cleaving, cutting and breaking of the fiber will result in the fiber breaking into 2 pieces. However, for thick, stiff fibers, a fiber break often results in glass pieces flying away from the break.

- **Wear safety glasses with side shields to protect the eyes from errant pieces of fiber. Note: safety glasses will not protect the retina from light damage**
- **Do not touch your eyes or face at any time while handling bare fiber. Wash your hands immediately after working with bare fiber or solvents**
- **Never look into a fiber, or connect to a fiber microscope, while system laser is on**