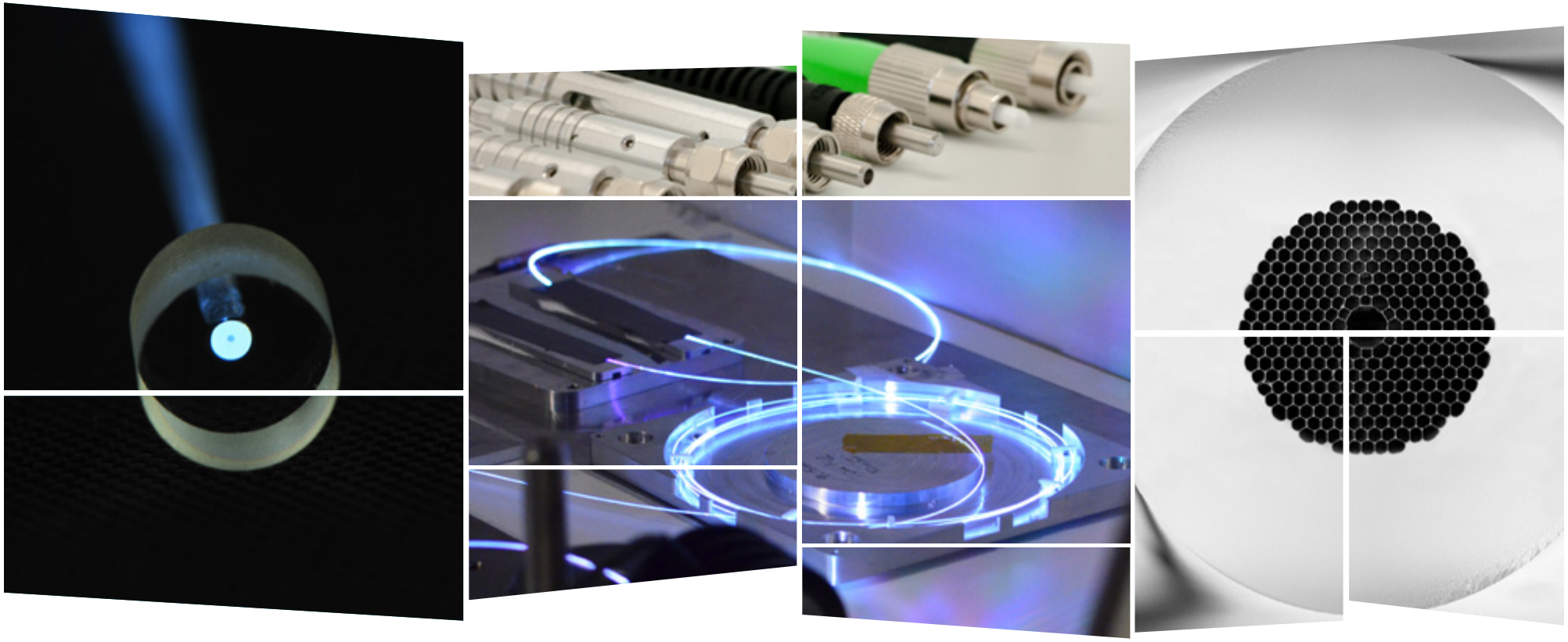
ALPhA NOV

Optics & Lasers Technology Center



# Photonic Crystal Fiber Interfacing

With strong expertise in designing fiber lasers and fused fiber components, ALPhANOV, the Technology Center in Optics and Lasers, entered a partnership with NKT Photonics for supplying end-treatment solutions to Photonics Crystal Fibers (PCF). Such fiber preparation includes PCF connectors, sealed and cleaved PCF, end-capped PCF and PCF with mode-adaptors. ALPhANOV addresses the whole PCF product line of NKT Photonics, ranging from active double-clad large mode area fibers, such as the DC-200/40-PZ-Yb and rod-type fibers to passive PCF such as hollow-core fibers and nonlinear PCF.

One of ALPhANOV's main missions is to help companies develop innovative products based on optics and lasers. Introducing PCF often gives a real advantage in terms of performance, compactness and reliability. Through this partnership with NKT Photonics, ALPhANOV can share its expertise with PCF users and helps them reach innovative and efficient solutions faster.

## Contents

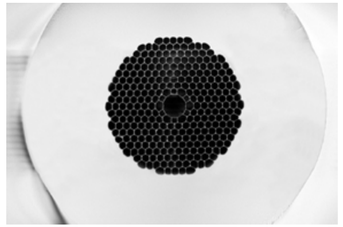


In partnership with NKT Photonics the power of light

# PHOTONIC CRYSTAL FIBERS

*« PICK THE RIGHT PCF FOR YOUR APPLICATION »*

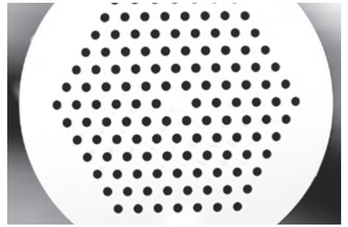
## HOLLOW-CORE FIBERS



Hollow-core photonic bandgap fibers use a micro-structured cladding region with air holes to guide light in a hollow core. The photonic bandgap guiding mechanism is fundamentally different from the traditional total internal reflection guiding principle. This new technology provides the basis for high power delivery without nonlinear effects or material damage.

Fiber example: HC-440; HC-532; HC-580; HC-800; HC-1060; HC-1550; HC-19-1550; HC-2000

## LARGE MODE AREA FIBERS



The selection of Large Mode Area Crystal fibers covers a range of fibers for diffraction limited high power delivery, and provide single mode operation in a large wavelength range - endlessly single mode operation. The very large mode area enables high power levels without nonlinear effects or material damage.

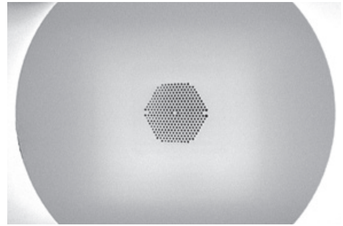
Fiber example: LMA-5; LMA-10; LMA-10-UV; LMA-15; LMA-25; LMA-PM-5; LMA-PM-10; LMA-PM-15

## YTTERBIUM DOPED DOUBLE CLAD FIBERS

The ytterbium doped double clad fibers offer the largest single-mode cores enabling amplification to unprecedented power levels while preserving very good mode quality and stability.

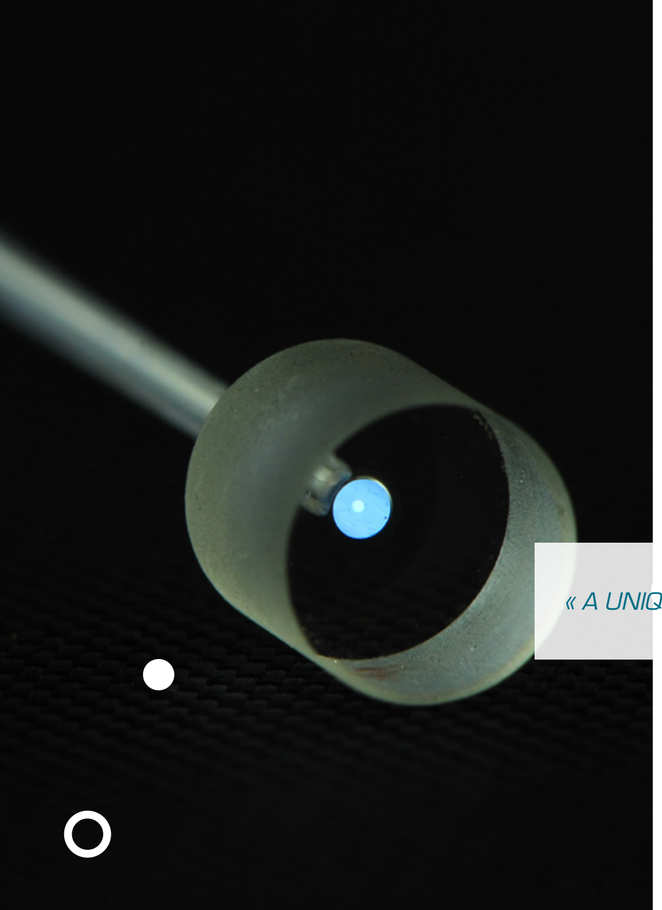
Fiber example: DC-135-14-PM-Yb; DC-200/40-PZ-Yb

## NONLINEAR FIBER



Optimized for supercontinuum generation and nonlinear wavelength conversion, nonlinear photonic crystal fibers offer a unique combination of tailored dispersion profile and very high nonlinear coefficient.

Fiber example: NL-PM-750; SC-5.0-1040 (PM)



# END-CAPPING KNOW-HOW

*« A UNIQUE KNOW-HOW, AT THE CORE OF OUR EXPERTISE »*

## SMALL END-CAPS

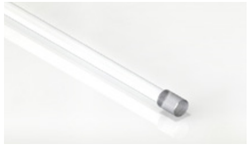
***Protect your PCF***

- For all PCF fibers
- Pure silica
- Different diameters and lengths available
- On-demand polished angle

**A small end-cap can be used either to protect the fiber micro-structure from dust and humidity or to decrease the beam fluency at the input or output interface without modification of the N.A.**

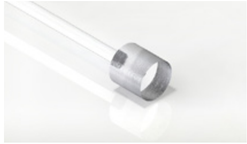
### S-end-cap

- End-cap diameter: 125 µm
- End-cap length: ≤100 µm
- Polished angle: 0°
- Material: Pure silica



### M-end-cap

- End-cap diameter: from 125 µm to 400 µm
- End-cap length: ≤400 µm
- Polished angle: 0°
- Material: Pure silica



### L-end-cap

- End-cap diameter: from 400 µm to 1.5 mm
- End-cap length: ≤1.5 mm
- Polished angle: 0°
- Material: Pure silica

### Options available on-demand for all end-caps

- Custom polished angle (up to 12°)
- Custom length
- AR coating

Special End-Capping development upon request

## LARGE END-CAPS

***For high-energy laser beams***

- For LMA or DC fiber
- Conical geometry
- Pure silica
- 0° or 5° polished angle with AR coating

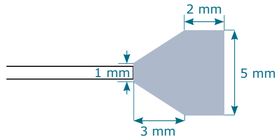
**These end-caps are used for high-energy systems. Their unique geometry allows for a strong bond with the fiber, providing the possibility to attach them easily in a mount.**

### Standard specifications

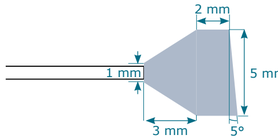
- End-cap diameter: 5 mm
- End-cap length: 5 mm
- Polished angle: 5° or 0° with AR@800-1300 nm
- Material: Pure silica

*(Other AR coating on-demand)*

### Dimensions



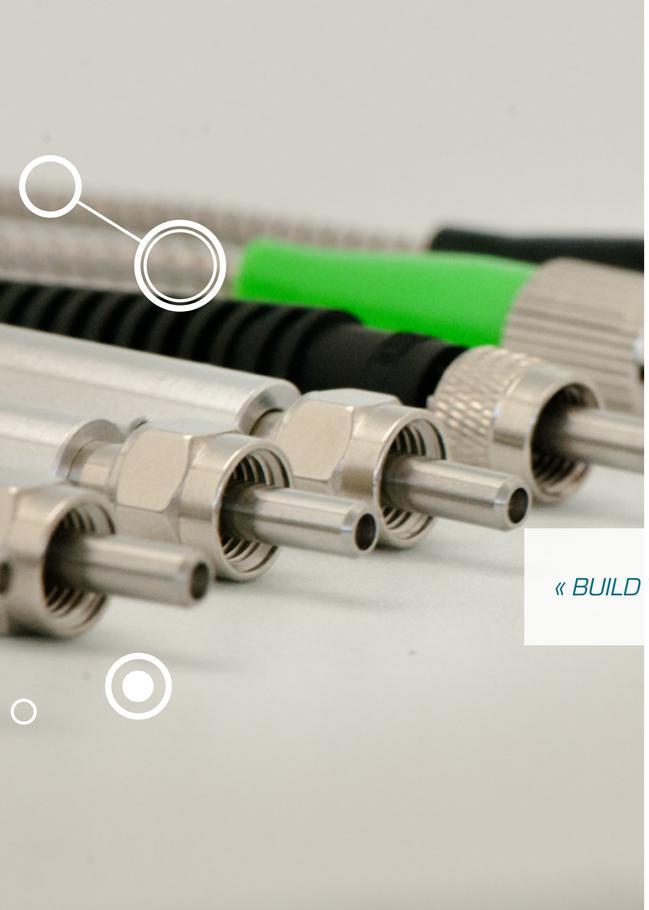

*Conical end-cap polished at 0° with 800 nm - 1300 nm AR coating*




*Conical end-cap polished at 5°*

### Options available on-demand for all end-caps

- Custom polished angle (up to 12°)
- AR coating
- Custom V-groove processed by laser micromachining



# PCF PATCH-CORDS

*« BUILD THE PATCH-CORD YOUR PCF DESERVES »*

## PATCH-CORDS

Because every project is different, ALPhANOV is willing to guide you through the right choice for your application depending on your laser regime.

Our connectors include a unique cladding light stripping technology and are able to handle high average power.

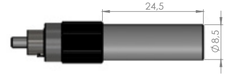
Several options are available, from our FC to our SMA-6 connector. As an option, we can also propose an AR coating to enhance the transmission. Finally, we can adapt the end-cap length to push the damage threshold of the fiber and make it compatible with high energy application.

### FC (PC or APC) connectors

| Specifications | |
|---|---|
| Standard end-cap diameter | Fiber clad diameter - Adapted to your PCF |
| Standard end-cap length | <100 µm |
| Power limitations | 500 mW injection loss - Handles 2 W @75% coupling efficiency (*) |
| Ferrule type | Ceramic |
| Ferrule diameter | 2.5 mm |
| Polished angle | 0° (PC) or 8° (APC) |
| PER (if PM fiber) | 15 dB |

| Options | |
|---|---|
| On-demand end-cap length | From 20 µm - 400 µm |
| On-demand end-cap diameter | From fiber size to 400 µm |
| PM alignment | Fast or slow axis |
| AR coating | Wavelength to be defined, narrowed or broadband, R < 0.5% |

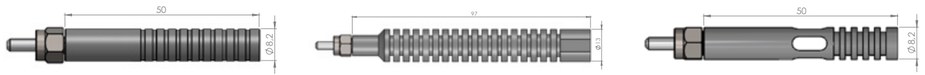
**Dimensions**




*(*) The power handling specification is enhanced by the use of a cladding light stripper technology inside the connectors. However, it also depends on how well the injection is done.*

| Specifications | SMA-2 connectors | SMA-6 connectors | SMA-AF connectors<br>For active fibers ONLY! |
|---|---|---|---|
| Standard end-cap diameter | Fiber clad diameter | Fiber clad diameter | Fiber clad diameter |
| Standard end-cap length | <100 µm | <100 µm | <100 µm |
| Power limitations | 2 W injection loss | 6 W injection loss | 200 W pump limit |
| Ferrule type | Metallic | Metallic | Metallic |
| Ferrule diameter | 3.2 mm | 3.2 mm | 3.2 mm |
| Polished angle | 0-12° +/-1 | 0-12° +/-1 | 0-12° +/-1 |
| **Options** | | | |
| On-demand end-cap length | From 20 µm - 1.5 mm | From 20 µm - 1.5 mm | From 20 µm - 1.5 mm |
| On-demand end-cap diameter | From fiber size to 1.5 mm | From fiber size to 1.5 mm | From fiber size to 1.5 mm |
| PM alignment | Fast or slow axis | Fast or slow axis | Fast or slow axis |
| AR coating | Wavelength to be defined, narrowed or broadband, R < 0.5% | Wavelength to be defined, narrowed or broadband, R < 0.5% | Wavelength to be defined, narrowed or broadband, R < 0.5% |

**Dimensions**

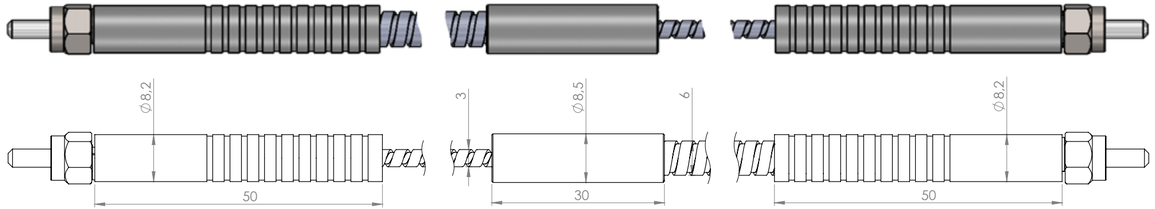



Specific connectorization on demand

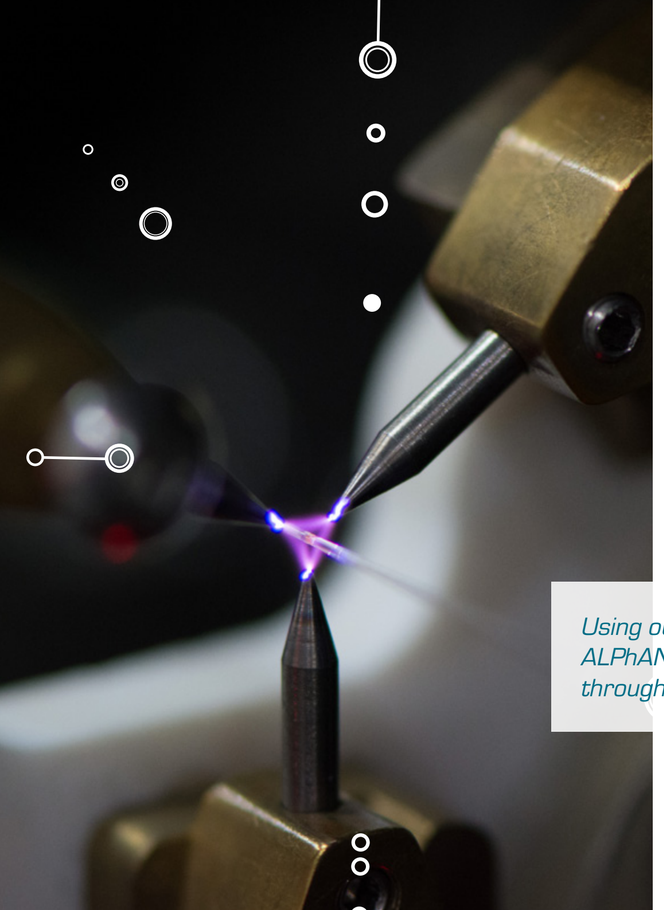


## TUBING

Because Photonic Crystal Fiber are valuable, your patch-cord deserves a robust solution for tubing. On standard, our PCF patch-cords are delivered with a robust steel jacketing, with a minimum bend radius adapted to avoid the fiber to break inside the jacket.




For very-demanding application, ALPhANOV can also provide outdoor-rated sheathing for extreme environments, with flexible and robust inner and outer tubing, and a pulling-sack to ease the deployment.



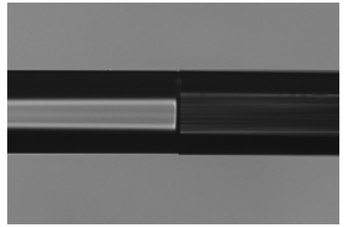
# SPECIAL TERMINATION

*Using our state-of-the-art fiber processing platform, ALPhANOV can address specific and demanding requests through feasibility studies and custom developments.*

## SPLICES - OPTIMIZATION STUDIES

- All kinds of PCF fibers
- PCF-to-PCF or PCF-to-standard fiber
- PM alignment

**Different kinds of splices can be proposed: PCF-to-PCF splices or PCF-to-Standard fiber.**



### Best effort splices

Each splice is different and ALPhANOV cannot guarantee a specific loss. Nevertheless this kind of splicing job is done on a best effort basis.

### Optimized splices

ALPhANOV offers you the possibility to optimize any kind of splice. Losses are not guaranteed, but through a short feasibility study, we are able to develop a specific process to minimize them.

Examples : Splice of 40/200 fiber to Kagome fiber with < 0.7 dB loss.

## LENSES

### GRIN lenses

ALPhANOV has developed a process to splice and control Grin Lenses for micro-structured fibers. The behavior of the lens can be simulated ; the focal length and the beam waist can be controlled.

Example: Spot size of 20 µm at a distance of 150 µm starting from a non-linear fiber.

*Grin lenses on PCF*

### Ball lenses

Example: By splicing a ball lens at the end of a Kagome fiber with 15 µm core size, we obtained a spot size of 7 µm at a focal distance of 500 µm.

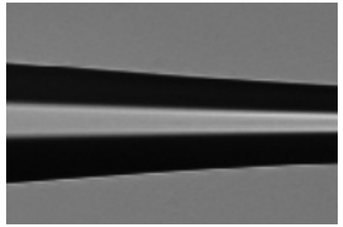
*Ball lens on PCF*

## MODE FIELD ADAPTER & TAPERS

### Mode field adaptation

- For fiber with different MFD
- Up to 40 µm fiber core size
- PM alignment

**The mode field adapter (MFA) is a component that reduces connection loss between fibers with different mode field diameters. The most extreme MFA from our standard product range connects 6 µm and 40 µm core fibers.**



### Benefit of MFA component

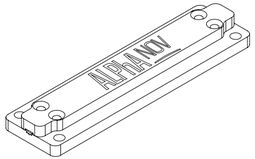
- Optimized signal transmission
- Improved stability
- Improved efficiency in fiber lasers

### Principle of a MFA

Fiber 1 with small MFD

Fiber 2 with bigger MFD

### Dimensions





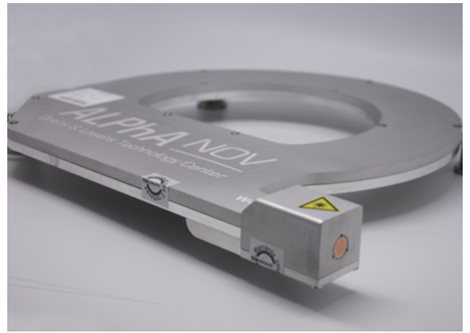
### Tapering

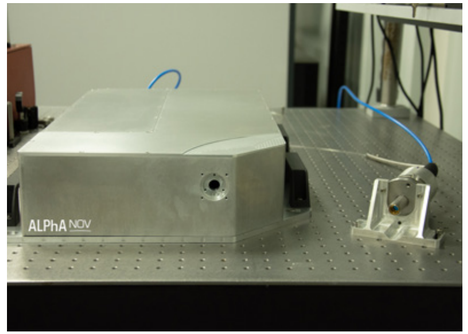
ALPhANOV's expertise allows us to taper micro-structured fibers without collapsing the air holes, in order to maintain the ratio of the structure inside the fiber during the tapering process.

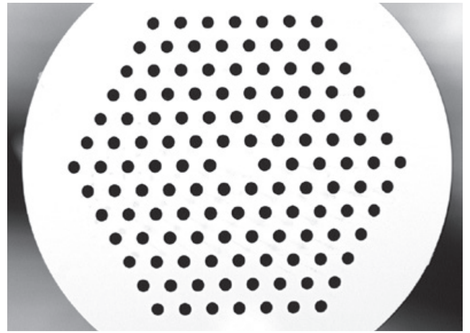
Example: Tapering of a ROD fiber: reduction of the outer diameter of a ROD fiber from 1 mm to 600 µm without any loss.

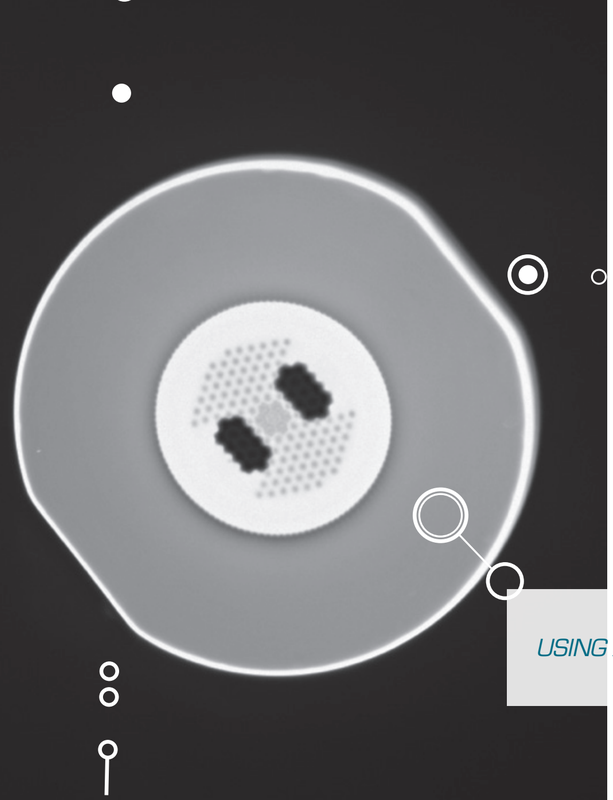
# EXAMPLES OF REALIZATION

- *High power laser amplifier using active microstructured fiber*
- *Beam delivery & shaping based on hollow-core fiber*
- *Beam delivery for quantum experiments based on large mode area fibers*
- *LC cables for low-latency communications based on hollow-core fiber*





# HIGH-POWER LASER AMPLIFIER

*USING ACTIVE MICROSTRUCTURED FIBERS*

## 100 W-CLASS PCF AMPLIFIER

ALPhANOV offers solutions to build fully monolithic high performance fiber amplifiers based on active micro-structured fibers.

### Pump specification

| | |
|---|---|
| Number of pump fibers | 2 or 6 |
| Pump fibers core diameter | 105 µm N.A. 0.15 or 0.22 |
| Max pump power | 50 W per port |
| Typical pump loss | < 0.5 dB |

### Signal specification

| | |
|---|---|
| Fiber type available | PM980, PLMA10, PLMA15 |
| Typical insertion loss | < 1.5 dB |
| Regime | Pulsed or CW |

### Output specification

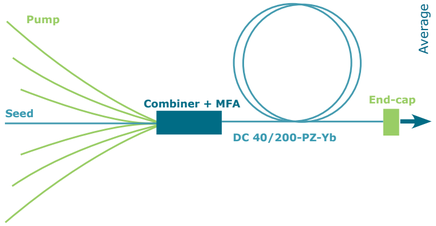
| | |
|---|---|
| Fiber type | Ytterbium doped DC fiber |
| Typical efficiency | > 70 % |

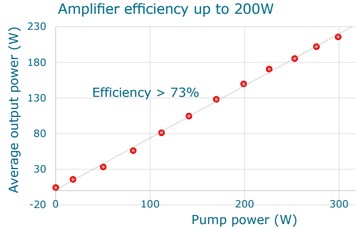
### Options

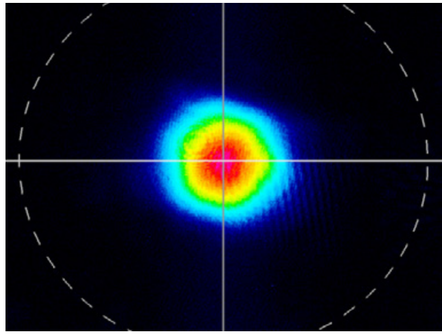
- Collimation/isolation module
- Electronics
- Possibility of contra-propagative waves with micro-optics

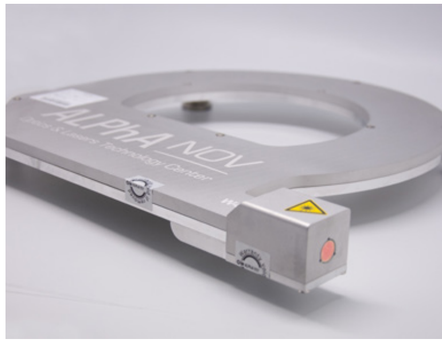
### Example

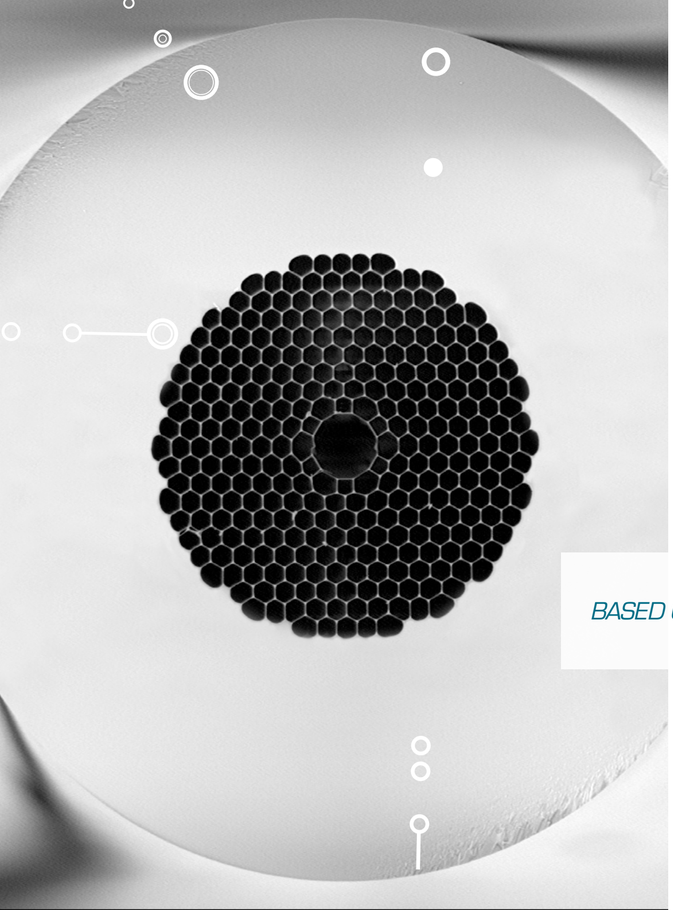
- Fiber type: DC 40/200 fiber (other active fiber on request)
- Input fibers: 15 µm core
- Input signal: ~2 W; 40 MHz; 100 ps
- Output signal: up to 200 W







# BEAM DELIVERY & SHAPING

*BASED ON HOLLOW-CORE FIBER*

## HC FIBER DELIVERY, A PERFECT SOLUTION

It is often necessary in laser applications to have their light output as close as possible to the delivery target. Fiber delivery offers the perfect solution for beam transport with its durability, flexibility and resistance against mechanical bending.

Assembly of a fiber with a high precision mechanical connector requires a tight control of mechanical tolerances, and considerable knowledge of fiber processing.

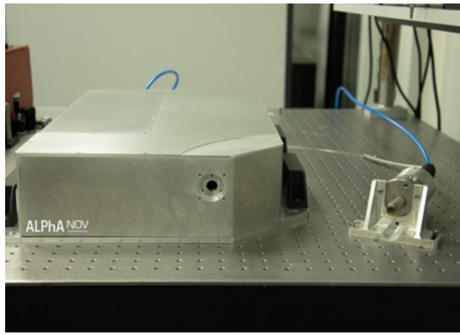
For very high average powers, ALPhANOV can create custom high-power fiber delivery modules using either standard connection output such as LLK, or others on demand. Since our connector design includes collimation optics, we can easily include beam shaping components to obtain specific beam profiles such as flat-top beams, or even squared beams.

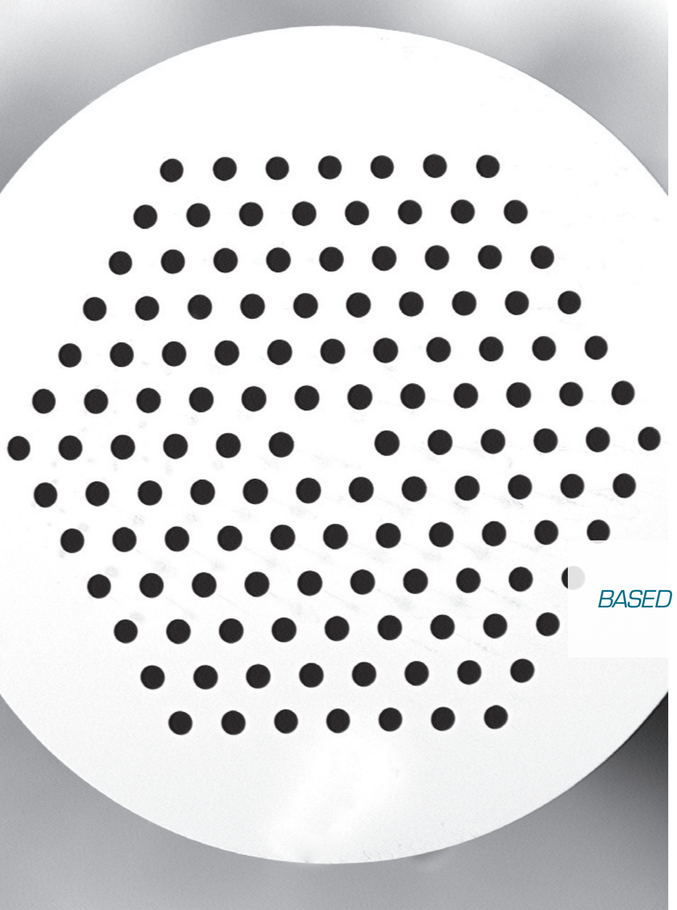
Fiber-based transport is usually not compatible with high peak power, femtosecond pulses. Our PowerPAC connector offers a high precision beam transport solution for femtosecond pulses.

Based on hollow-core fiber technology, our components can withstand more than 100 Watts of injected average power.

### Features

- Custom fiber delivery options
- Compatible with average power >100 W
- PowerPAC for femtosecond laser pulse delivery
- Custom beam shaping possible

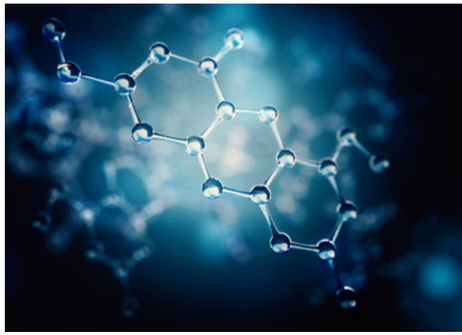



# BEAM DELIVERY FOR QUANTUM EXPERIMENTS

*BASED ON LARGE MODE AREA FIBERS*

## LMA PCF FOR ATOM PHYSICS

Highest power delivery | Truly single-mode | Durability | Limited back-reflections | Customer care



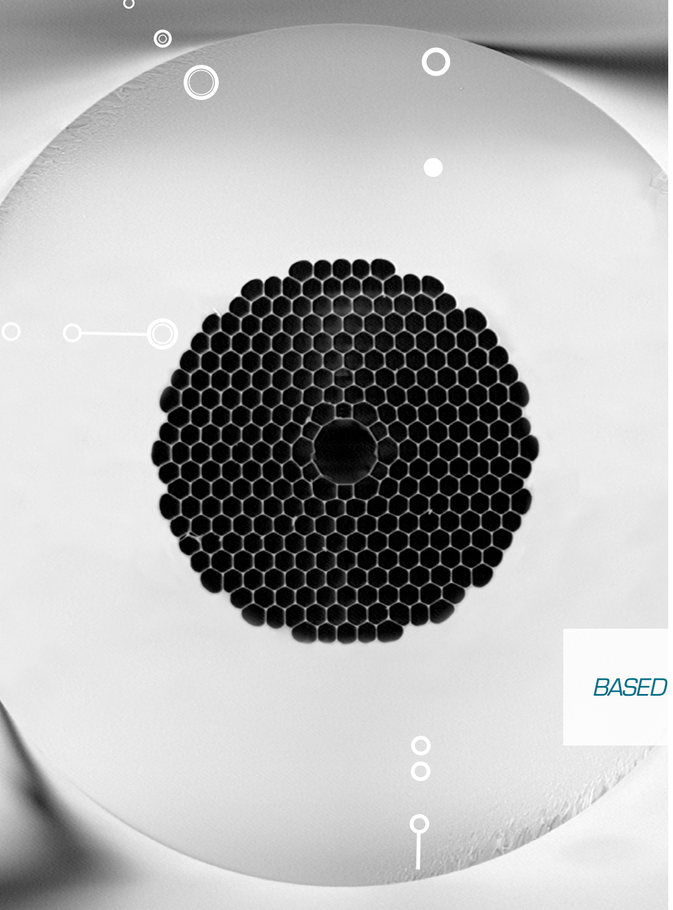
Our fiber delivery solution designed for atom physics relies on the state-of-the-art large mode area photonic crystal fiber, enabling truly single-mode operation over a wide wavelength range. Thanks to the large mode field diameter, which is wavelength independent, power limitations are pushed back and the unwanted Brillouin effect is limited. The fiber can be polarization maintaining.

Thanks to our end-capping expertise on photonic crystal fiber, we manufacture reliable cables that are completely immune to contamination, and with perfect mode quality. Thanks to our end-capping expertise on photonic crystal fiber, we manufacture reliable cables that are completely immune to contamination, and with perfect mode quality. Besides, our unique mode-stripping technology enables us to produce high-power connectors. Every cable can be delivered with a protective jacket over the needed length, keeping the user serene.

Always ready to tailor the cable to the application, ALPhANOV can propose options such as anti-reflective coatings, collimators, and specific treatments depending on the use.

| | Low power version | High power version | Ultra violet version | Supreme power* version |
|---|---|---|---|---|
| Wavelength range | 400 - 2000 nm | 500 - 2000 nm | 300 - 2000 nm | 500 - 2000 nm |
| Length | On demand (> 0.5 m) | < 1.5 dB | On demand (> 0.5 m) | On demand (> 1.5 m) |
| Power handling | Up to 10 W | Up to 50 W | Up to 200 mW | Up to 100 W |
| Connectors ** | FC/PC or APC or SMA-905 | SMA-905 with mode stripper | FC/PC or APC | SMA-905 |
| End-cap | < 100 µm | < 100 µm | < 100 µm | < 100 µm |
| Angle | On demand | On demand (5° typ.) | 0° or 8° | On demand (5° typ.) |
| Tubing | PCV or steel | PCV or steel | PCV (advised) | PCV or steel |
| Options | AR coating/Collimators | AR coating/Collimators | AR coating/Collimators $H^2$ loading | AR coating/Collimators |

* Preliminary
** See P9-10 of our catalog



# LC CABLES FOR LOW-LATENCY COMMUNICATIONS

*BASED ON HOLLOW-CORE FIBER*

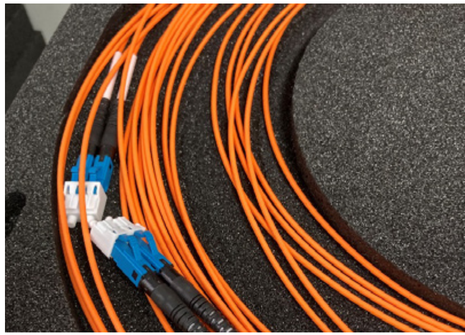
## THE LIGHT SPEED FIBER

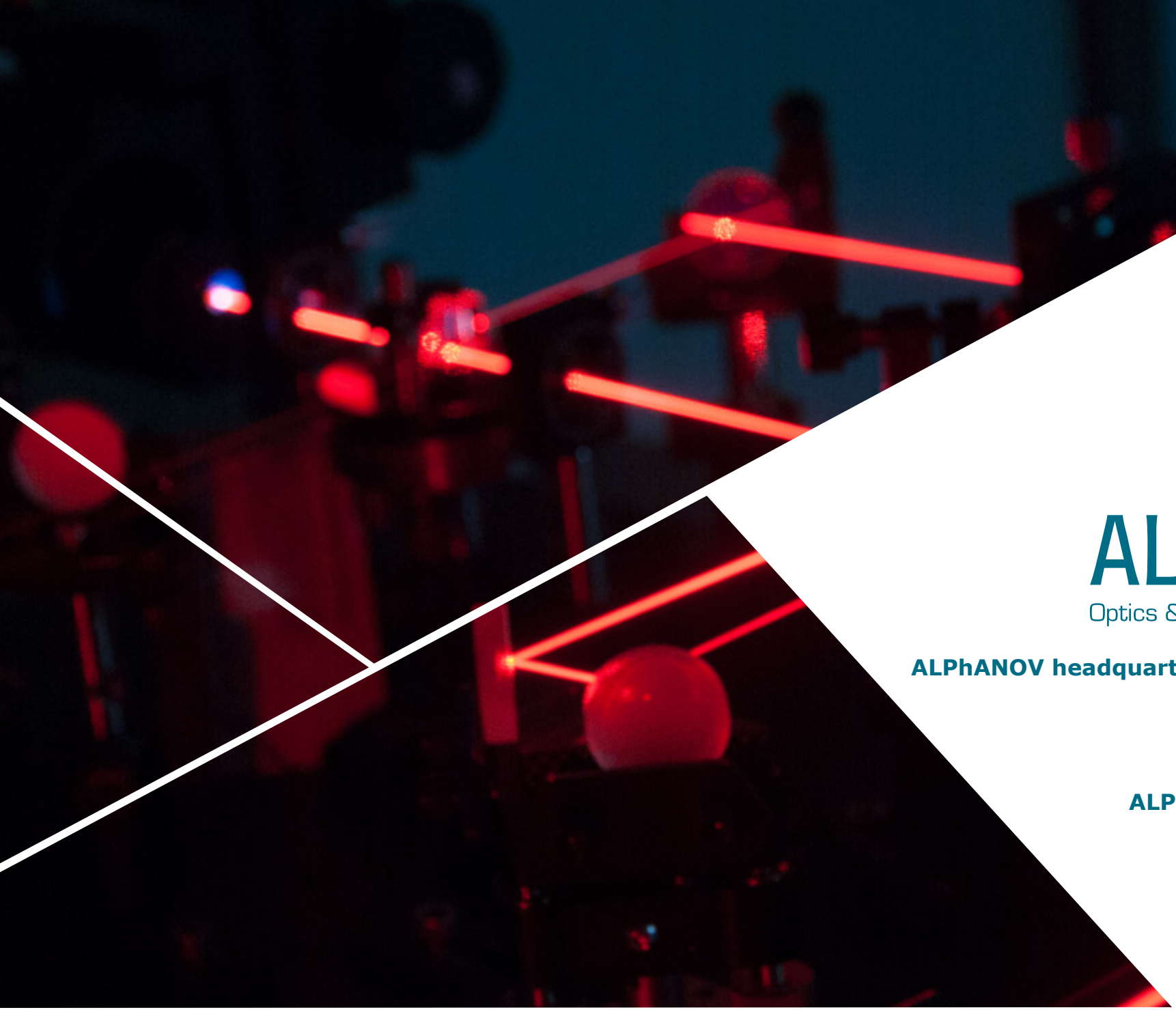
Using state-of-the-art hollow core fibers, this revolutionary cable reduces latency of data transfers by up to 33%.

### Main features

- Latency reduced by 33%
- Length up to 500 m
- Standard telecom connectors
- Lightweight duplex armored cable designed for outdoor install or lightweight sheathing of indoor install
- Improved handling with pulling sack and secured packaging

| | |
|---|---|
| Fiber type | Hollow core |
| Wavelength | Centered @1510 or @1310 nm |
| Attenuation (fiber + connectors) | 3 dB + 30 dB/km |
| Length | Up to 500 m |
| Sheathing | Outdoor use: PVC tubing (inner sheathing) + Armored steel jacket (outer sheathing)<br>Indoor use: PVC tubing |
| Termination type | LC (Straight through or crossover configuration) |
| Handling | Pulling sack |
| Operation temperature | From - 40°C to 50°C |





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