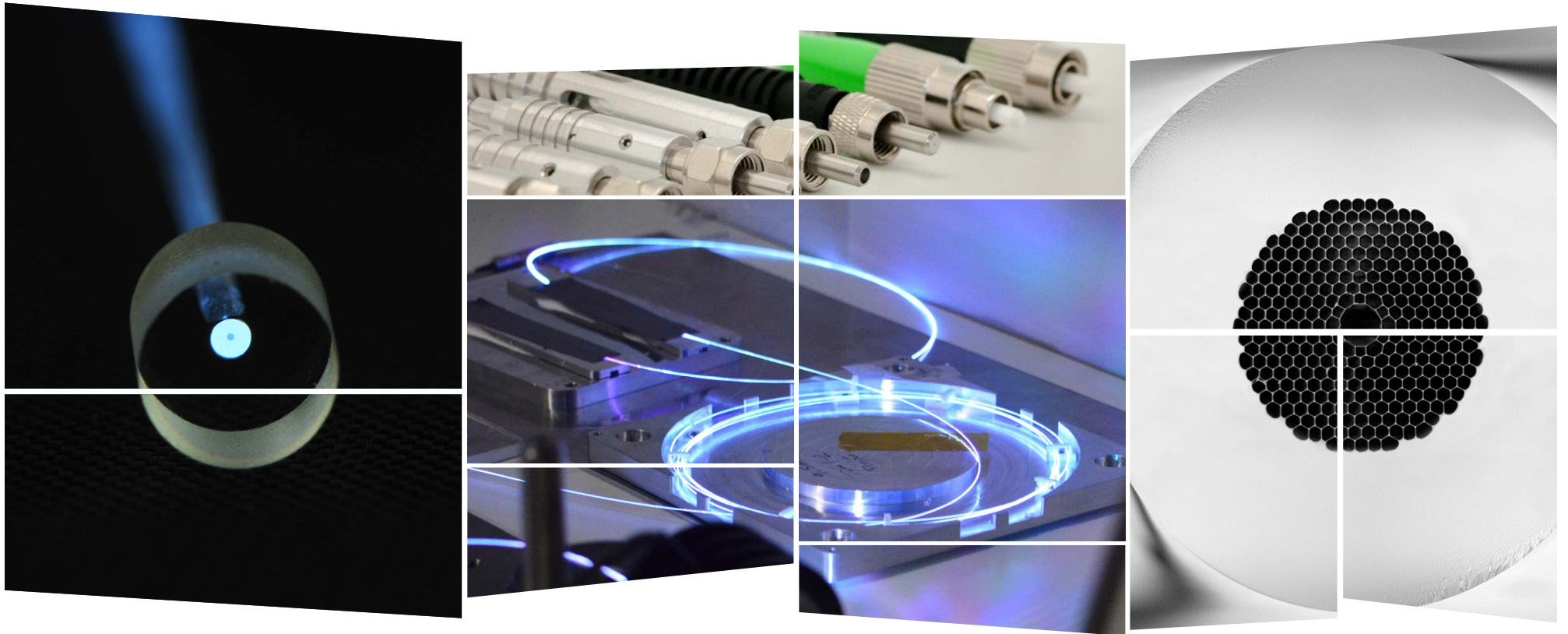


# ALPhA NOV

Optics & Lasers Technology Center



## PHOTONIC CRYSTAL FIBER INTERFACING

In partnership with







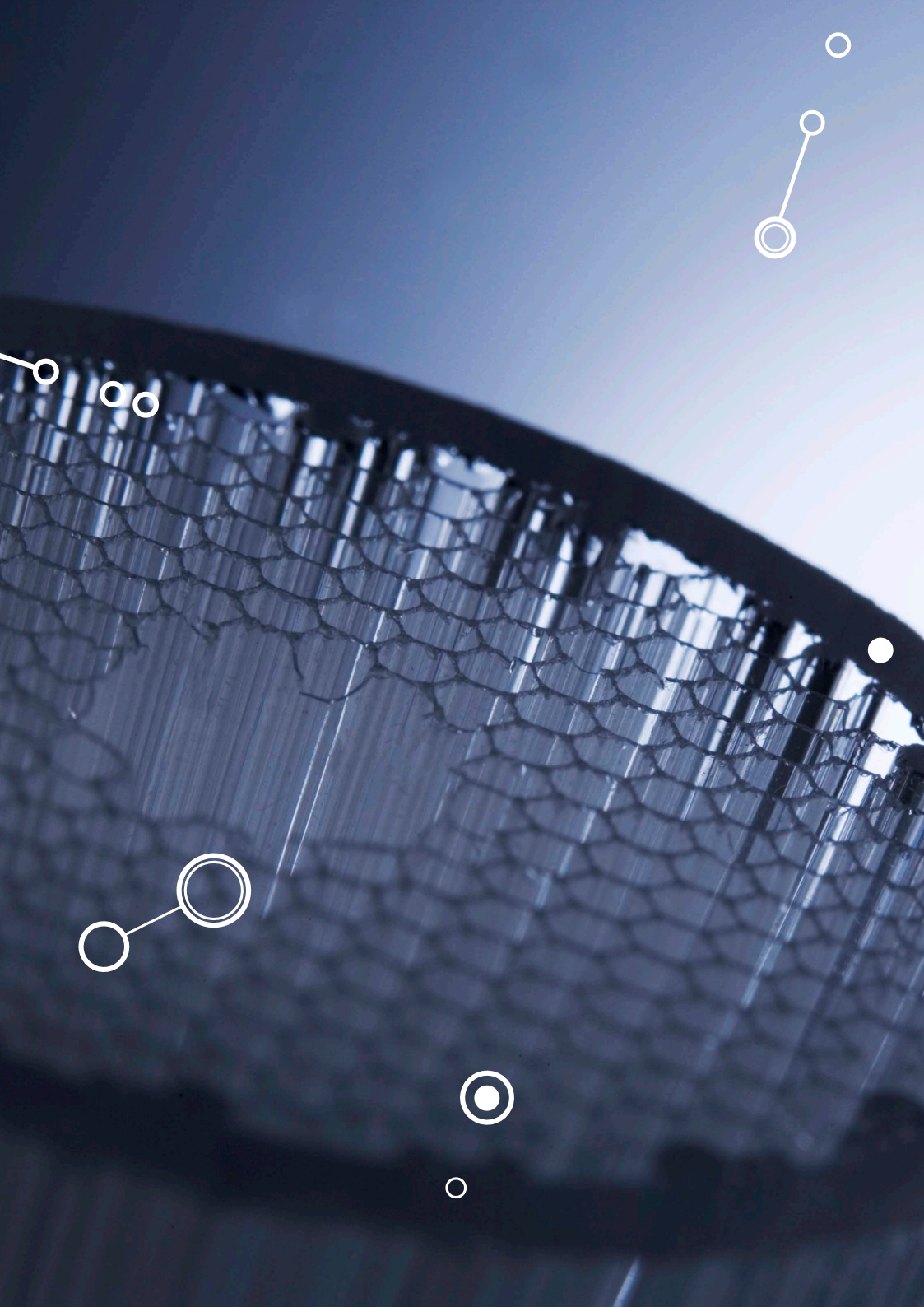
With strong expertise in designing fiber lasers and fused fiber components, ALPhANOV, the Technology Center in Optics and Lasers, entered a partnership with NKT Photonics for supplying end-treatment solutions to Photonics Crystal Fibers (PCF). Such fiber preparation includes PCF connectors, sealed and 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

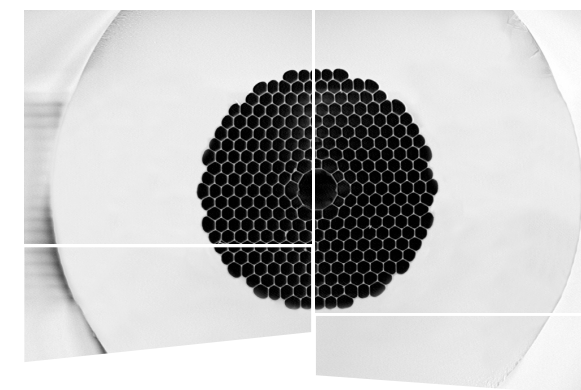
4	Photonics Crystal Fibers
6	End-capping
8	PCF connectors
12	Industrial PCF cables
14	Special termination
16	Special pump and signal combiner
18	High-power femtosecond pulses fiber delivery cable





# PHOTONIC CRYSTAL FIBERS

## HOLLOW-CORE FIBERS

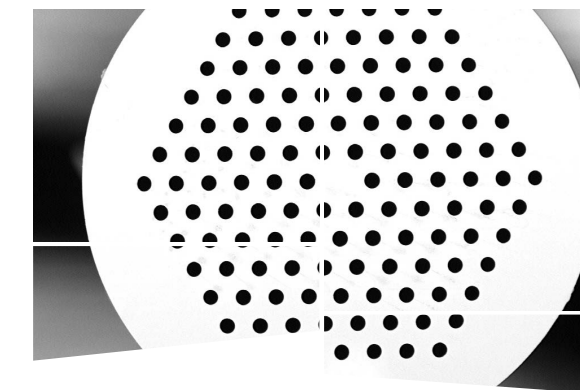


Hollow-core photonic bandgap fibers use a micro-structured cladding region with air holes to guide light in a hollow core. The photonic bandgap guiding mechanism is fundamentally different from the traditional total internal reflection guiding principle.

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

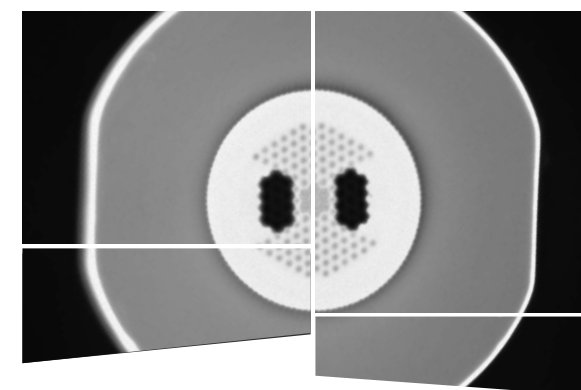
## LARGE MODE AREA FIBERS



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

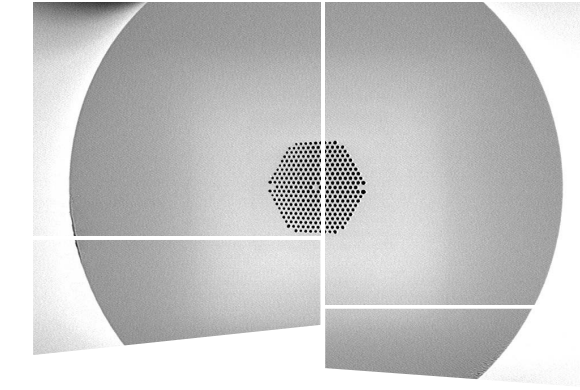
## YTTERBIUM DOPED DOUBLE CLAD FIBERS



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.

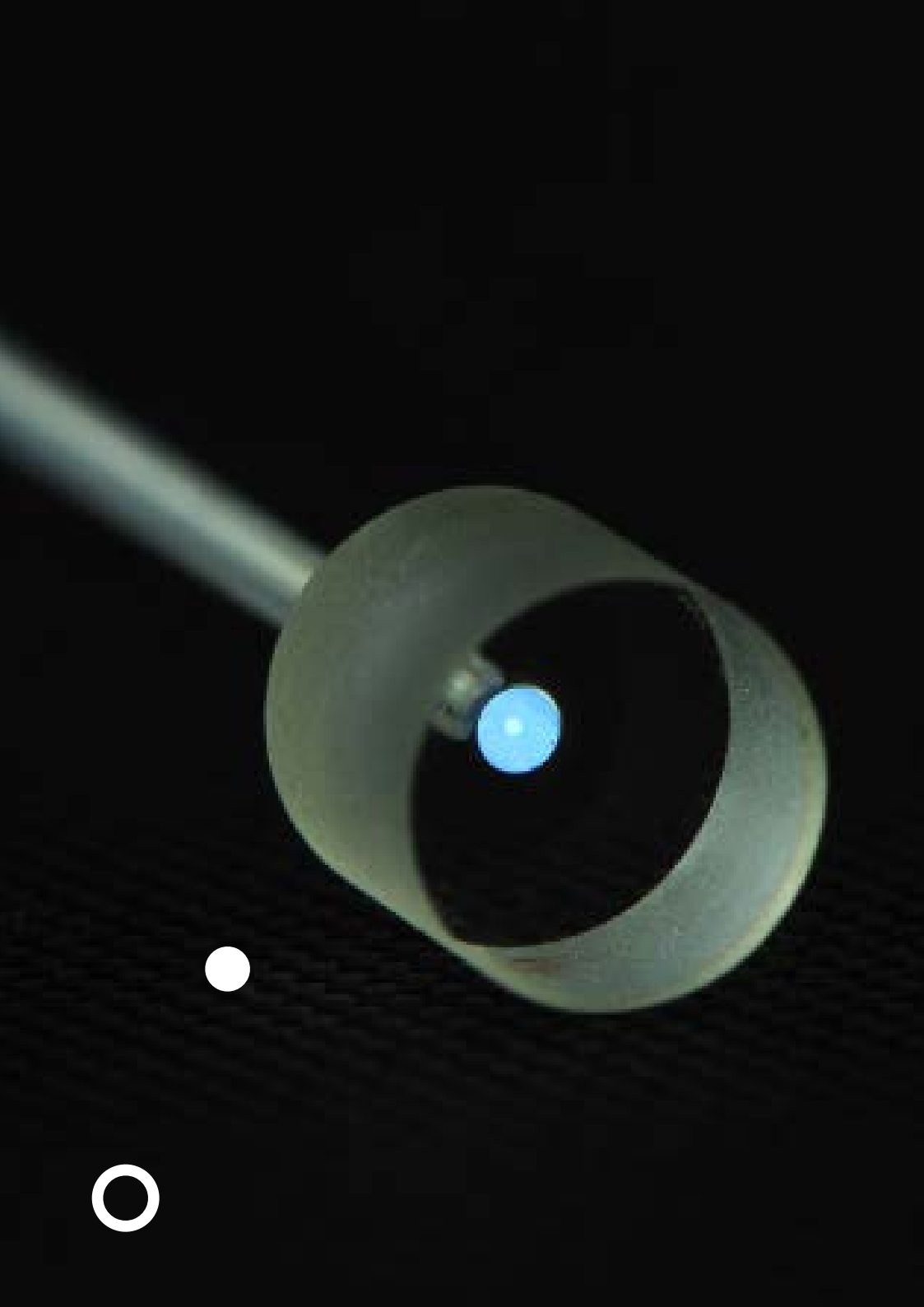
Fiber example: DC-135-14-PM-Yb; DC-200/40-PZ-Yb

## 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.

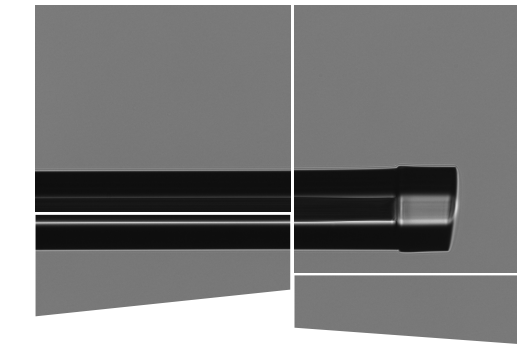
Fiber example: NL-PM-750; SC-5.0-1040 (PM)



# END-CAPPING

## SMALL END-CAPS

- 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 fluence at the input or output interface without modification of the N.A.

### S-end-cap

- End-cap diameter: 125  $\mu\text{m}$
- End-cap length:  $\leq 100 \mu\text{m}$
- Polished angle:  $0^\circ$
- Material: Pure silica

### M-end-cap

- End-cap diameter: from 125  $\mu\text{m}$  to 400  $\mu\text{m}$
- End-cap length:  $\leq 400 \mu\text{m}$
- Polished angle:  $0^\circ$
- Material: Pure silica

### L-end-cap

- End-cap diameter: from 400  $\mu\text{m}$  to 1.5 mm
- End-cap length:  $\leq 1.5 \text{ mm}$
- Polished angle:  $0^\circ$
- Material: Pure silica

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

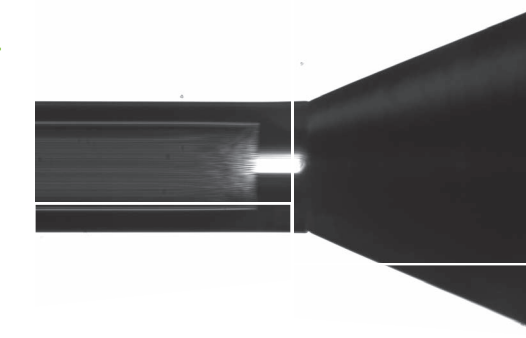
- Custom polished angle (up to  $12^\circ$ )
- Custom length
- AR coating



## 5X5 MM END-CAPS

for high-energy laser beams

- For LMA or DC fiber
- Conical geometry
- Pure silica
- $0^\circ$  or  $5^\circ$  polished angle with AR coating



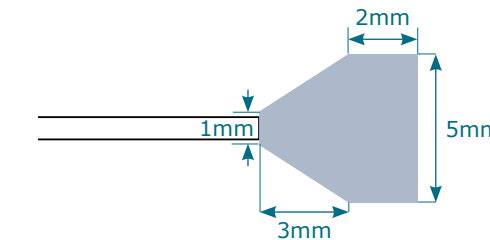
These end-caps are used for high-energy systems. Their unique geometry allows for a strong bond with the fiber, providing the possibility to attach them easily in a mount.

### Specifications

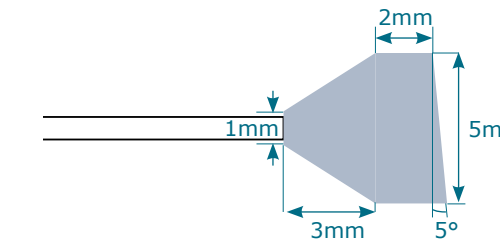
- End-cap diameter: 5 mm
- End-cap length: 5 mm
- Polished angle:  $5^\circ$  or  $0^\circ$  with AR@800-1300 nm
- Material: Pure silica

*[Other AR coating on-demand]*

### Dimensions

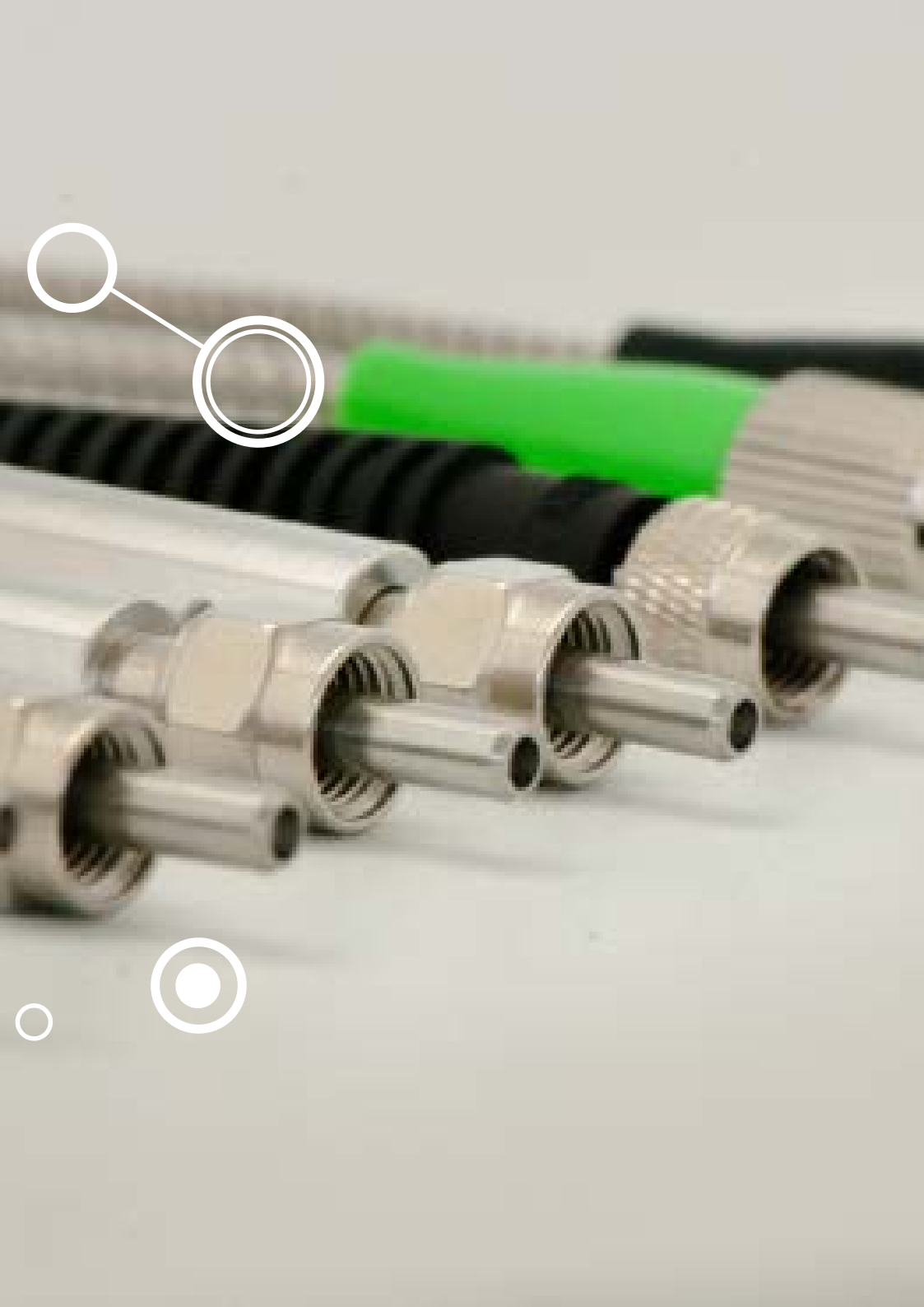


Conical end-cap polished at  $0^\circ$  with 800 nm - 1300 nm AR coating

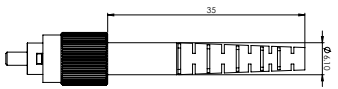
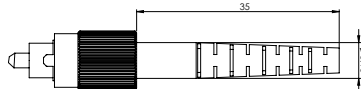



Conical end-cap polished at  $5^\circ$

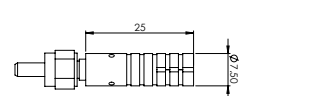
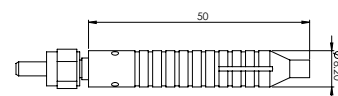
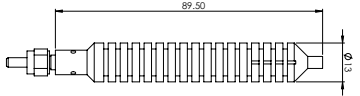
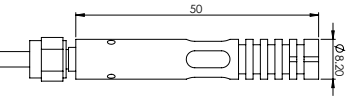


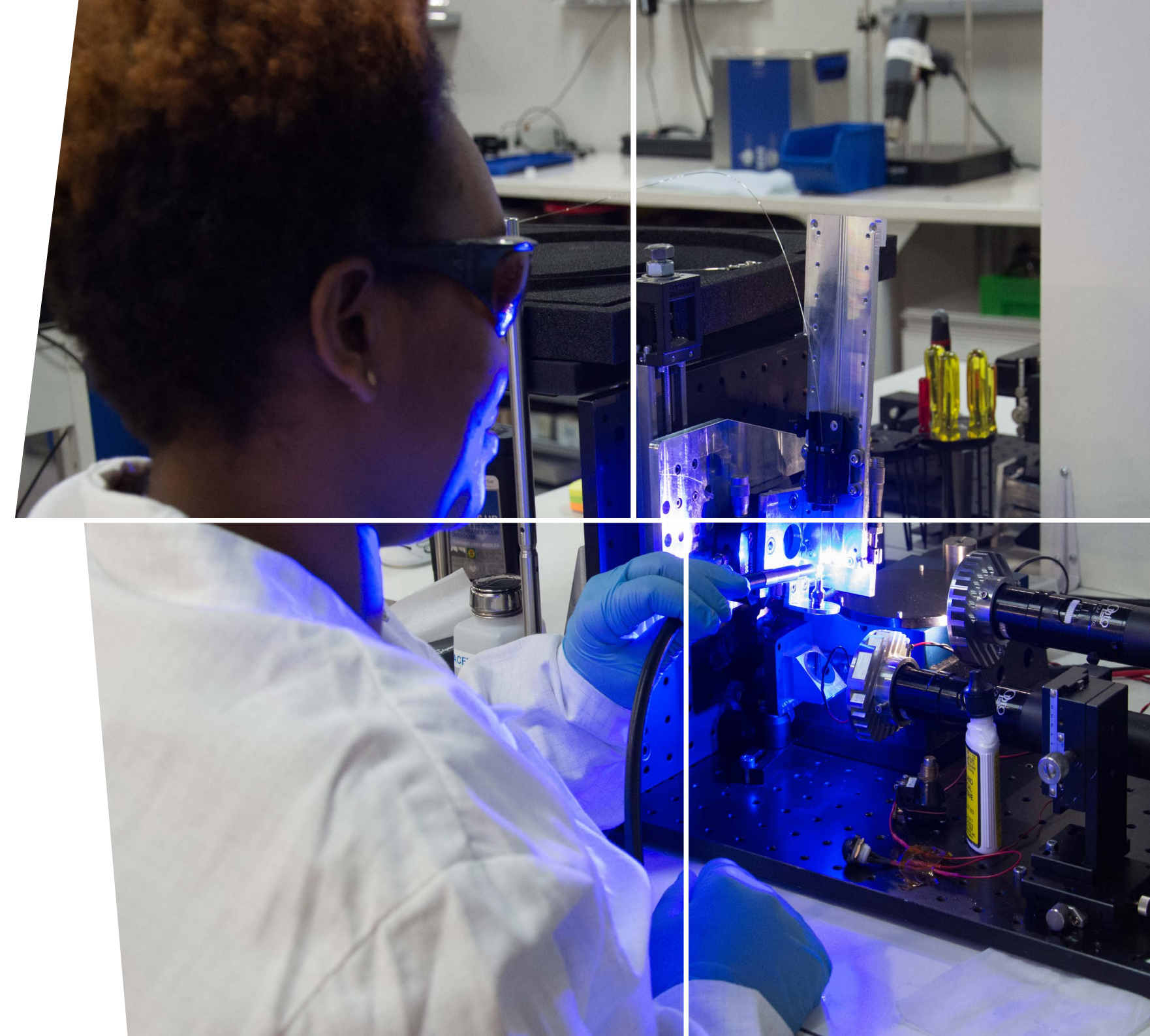


# PCF CONNECTORS

	FC/PC connectors	FC/APC connectors	SMA connectors
<b>Specifications</b>			
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	500 mW injection loss	500 mW injection loss	500 mW injection loss
Ferrule type	Ceramic	Ceramic	Metallic
Ferrule diameter	2.5 mm	2.5 mm	3.2 mm
Polished angle	0°	8°	0-12°
<b>Options</b>			
On-demand end-cap length	From 20 μm - 400 μm	From 20 μm - 400 μm	From 20 μm - 400 μm
On-demand end-cap diameter	From fiber size to 400 μm	From fiber size to 400 μm	From fiber size to 400 μm
PM alignment	Fast or slow axis	Fast or slow axis	Fast or slow axis
<b>Dimensions</b>			
			



	SMA-1 connectors	SMA-2 connectors	SMA-6 connectors	SMA-AF connectors
<b>Specifications</b>				
Standard end-cap diameter	Fiber clad diameter	Fiber clad diameter	Fiber clad diameter	Fiber clad diameter
Standard end-cap length	<100 μm	<100 μm	<100 μm	<100 μm
Power limitations	1 W injection loss	2 W injection loss	6 W injection loss	200 W pump limit
Ferrule type	Metallic	Metallic	Metallic	Metallic
Ferrule diameter	3.2 mm	3.2 mm	3.2 mm	3.2 mm
Polished angle	0-12° +/-1	0-12° +/-1	0-12° +/-1	0-12° +/-1
<b>Options</b>				
On-demand end-cap length	From 20 μm - 1.5 mm	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	From fiber size to 1.5 mm
PM alignment	Fast or slow axis	Fast or slow axis	Fast or slow axis	Fast or slow axis
<b>Dimensions</b>				
				







## INDUSTRIAL PCF CABLES

**A**LPhANOV can meet demanding requests to carry Photonic Crystal Fibers at an industrial level.

### TUBING

to protect your fibers

- Available for all kinds of fibers
- Different materials available
- Waterproofness (optional)

Different kinds of jackets can be proposed in option to protect your fibers depending on the power.

#### Hytrell 900 $\mu\text{m}$ jacket

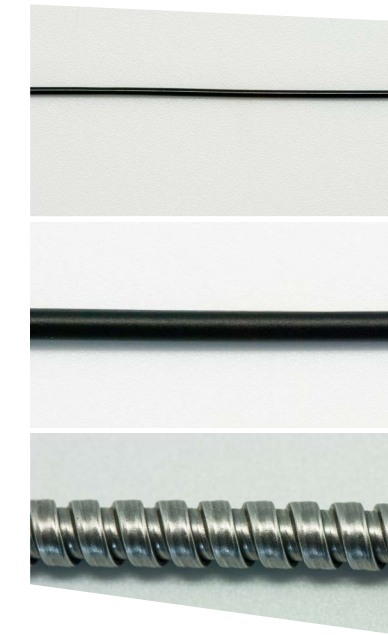
The Hytrell 900  $\mu\text{m}$  jacket is the smaller jacket available for PCF fiber. It can only be used for low power, typically below 1 W average power injected.

#### 3 mm PVC jacket

The 3 mm PVC jacket is used to protect the fiber up to 3 W average power injected.

#### Steel jackets

Adapted for high-power, steel jackets are available for all connectors. These jackets are implemented as depicted in the figure below.



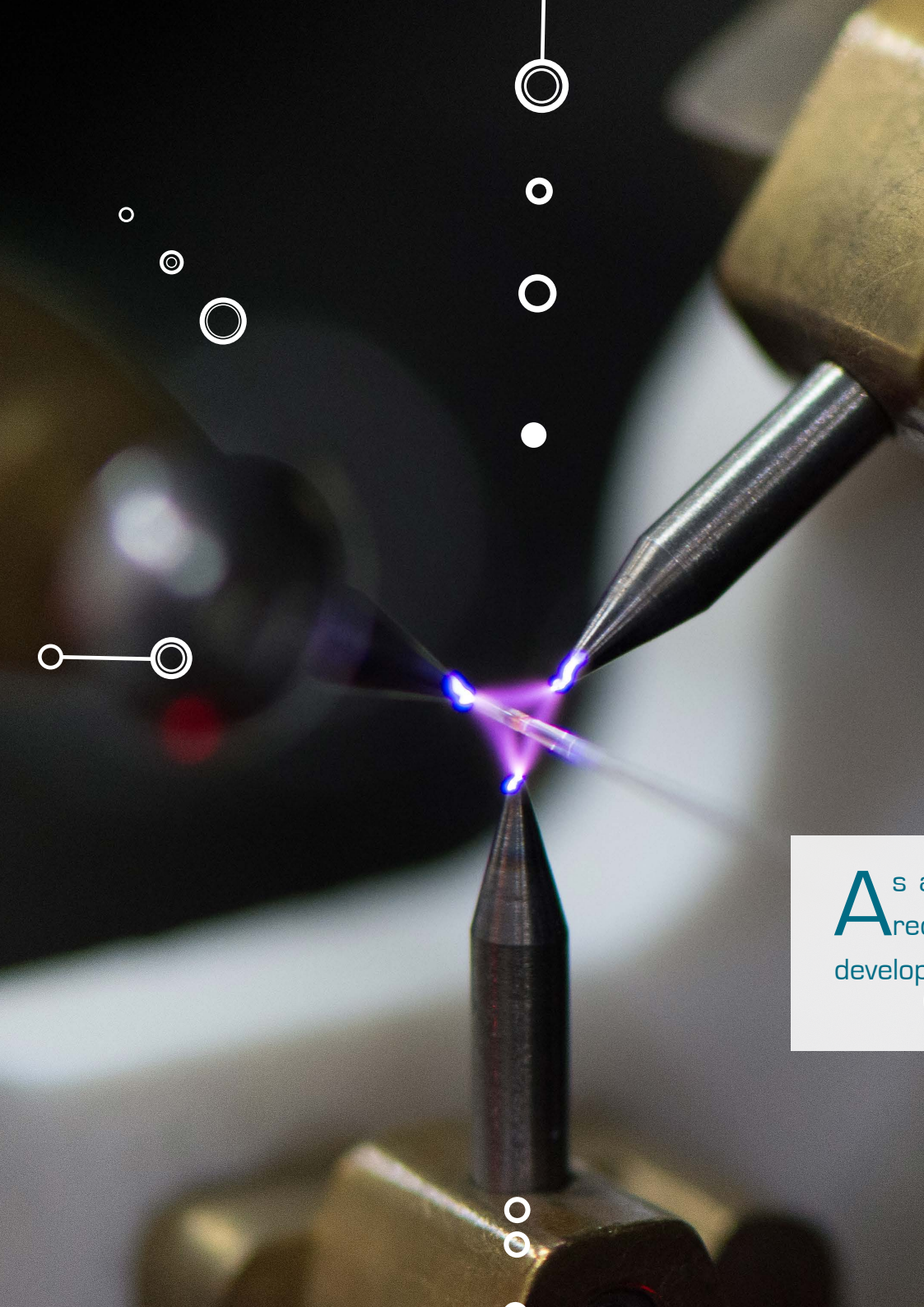
### EXAMPLE OF REALIZATION



Industrial HC-1550 patch-cable, using LC connectors and waterproof sheathing.



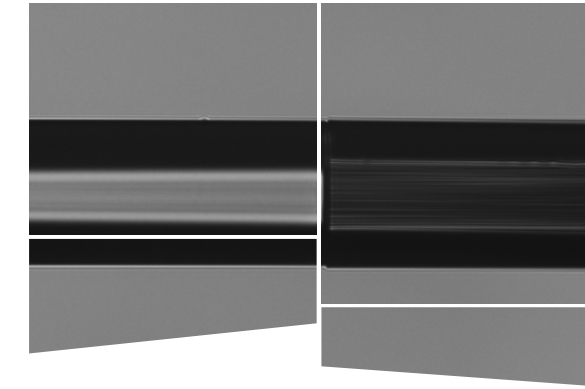




# SPECIAL TERMINATION

As a technology center, ALPhANOV is able to address special requests on PCF interfacing through feasibility studies or developments.

## SPLICES



- 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.

### 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

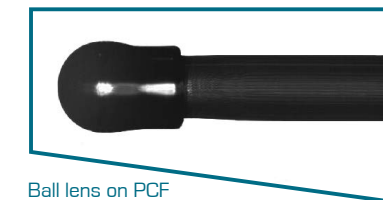


Grin lenses on PCF

### 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.



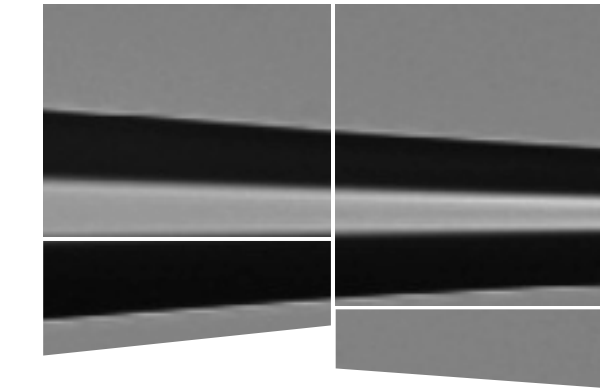
Ball lens on PCF

### 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.

## MODE FIELD ADAPTER & TAPERS

### MODE FIELD ADAPTATION



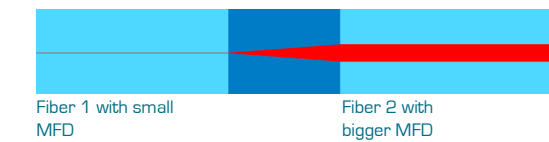
- For fiber with different MFD
- Up to 40 μm fiber core size
- PM alignment

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.

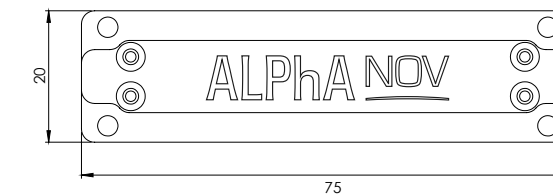
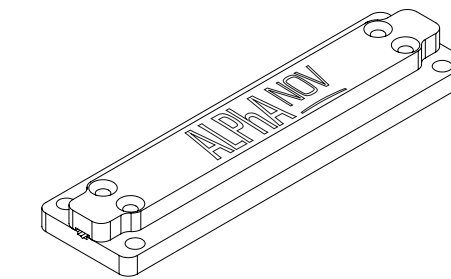
### Benefit of MFA component:

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

### Principle of a MFA



### 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.





# HIGH-POWER SPECIAL FIBER AMPLIFIER FOR ACTIVE MICROSTRUCTURED FIBERS

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  $\mu\text{m}$  N.A. 0.15 or 0.22
- Max pump power: 50 W per port
- Typical pump loss: <0.5 dB

### Output specification

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

### Signal specification

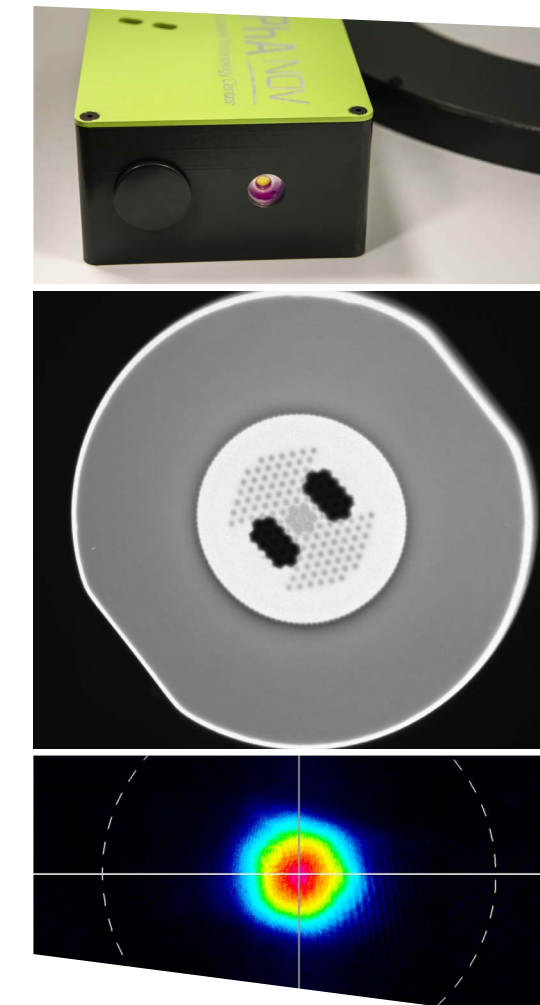
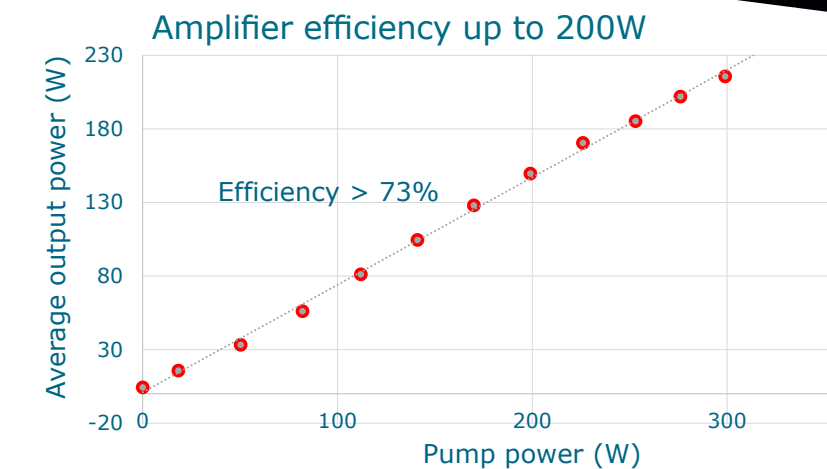
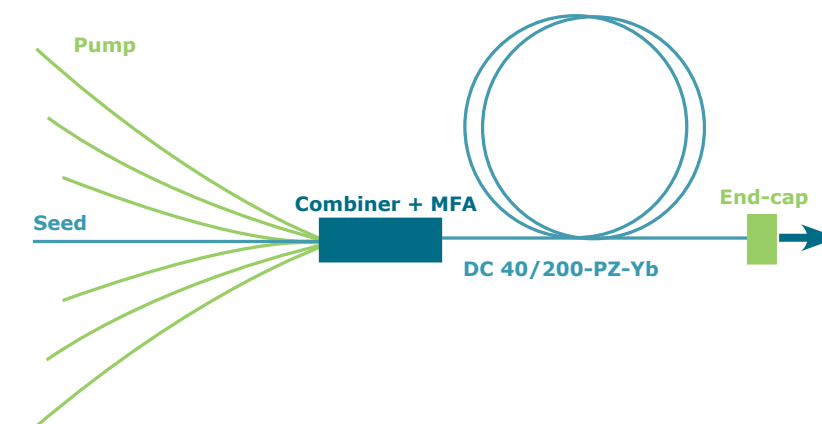
- Fiber type available: PM980, PLMA10, PLMA15
- Typical insertion loss: <1.5 dB
- Regime: Pulsed or CW

### Options

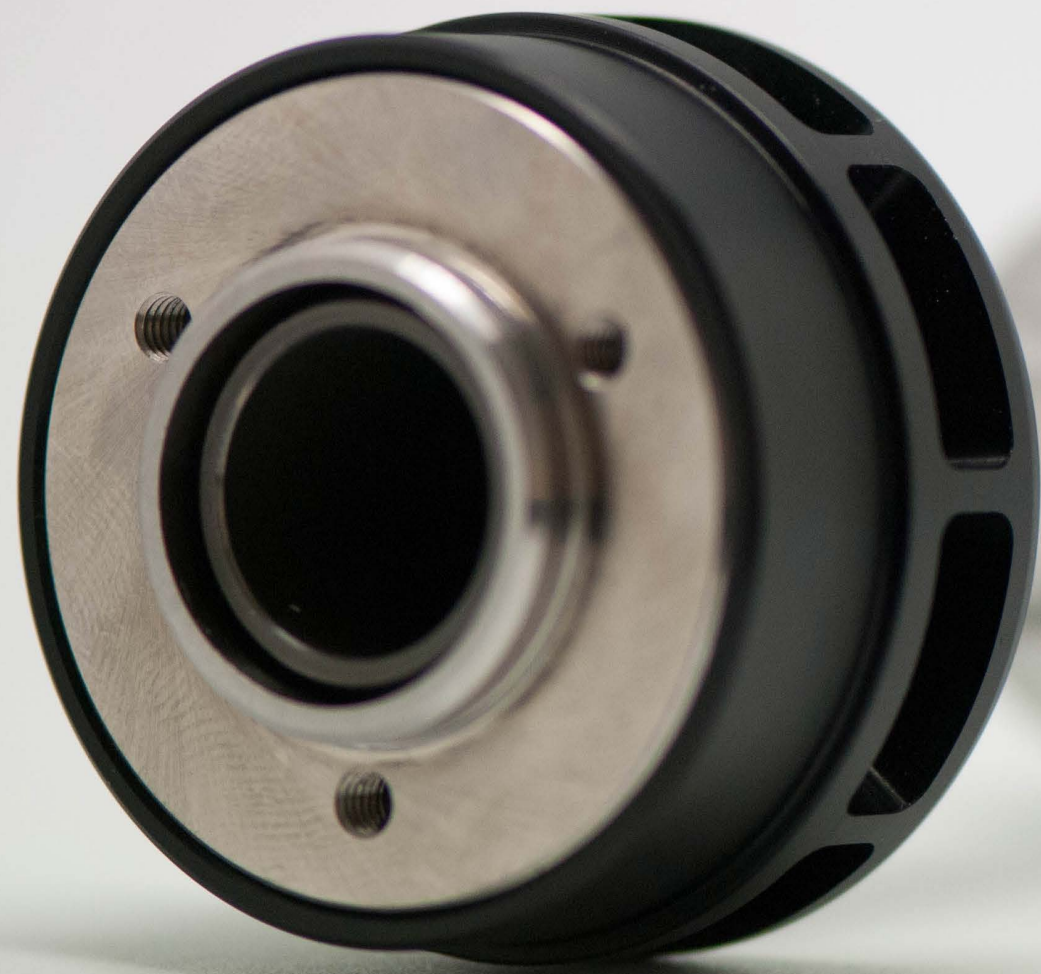
- Collimation/isolation module
- Electronics
- Possibility of contra-propagative waves with micro-optics

### Example

- Fiber type: DC 40/200 fiber (other active fiber on request)
- Input fibers: 15  $\mu\text{m}$  core
- Input signal: ~2 W; 40 MHz; 100 ps
- Output signal: up to 200 W







## HIGH-POWER FEMTOSECOND PULSES FIBER DELIVERY CABLE BASED ON HOLLOW-CORE FIBERS

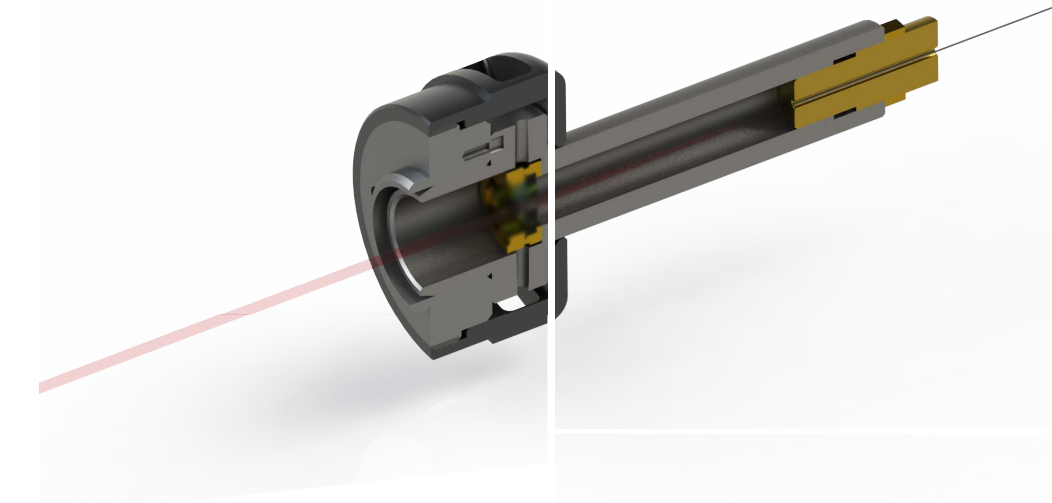
Our PowerPAC connector offers a highly precise connector for single-mode hollow-core fibers (\*). It includes a collimator, which can withstand more than 100 Watts of injected power. It is particularly suitable for beam delivery based on hollow-core fibers, for instance in the femtosecond regime.

### Features:

- 100 W-class in femtosecond regime
- Plug-and-play (high repeatability)
- Passive cooling (active cooling on-demand)

Optical specifications assuming input laser beam with  $M^2=1.1$ :

Wavelength	1000-1100 nm
Max. power input [1]	100 W
Maximum loss [1]	20 W
Collimated beam diameter [2]	2 mm
Divergence	<0.5 mrad
Injection loss	<10 %
Optical return loss	>40 dB
Pointing precision [3;4]	+/-0.1 mrad
Beam location precision [3;4]	<0.3 mm (of the collimator center)



- [1] Considering 80% coupling efficiency in the femtosecond regime  
 [2] MFD measured at  $1/e^2$   
 [3] Depends on the fiber  
 [4] Considering 10% loss of the coupling ratio  
 [\*] This connector is also possible for other large core single-mode PCF (Kagome, LMA PCF,...)



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In partnership with **NKT** Photonics  
the power of light



Photos : ALPhANOV, NKT photonics