Photonic Crystal Fiber

Technology, Termination & Examples of Industrial Usage

Nicolai Granzow

123 years of industrial history

1891

NKT

A/S NORDISKE KABEL- OG TRAADFABRIKER
KØBENHAVN.







~9,000 employees

2014

Ownership

NKT

Nilfisk Advance
setting standards

nkt cables

Photonics Group

- Europe
- North America
- Oceania
- Asia

- Northern Europe
- Central Europe
- Eastern Europe
- China

- **NKT Photonics**
- LIOS Technology
- Vytran

Our products

Crystal Fibre

Specialty fibers and modules

SuperK

Supercontinuum lasers

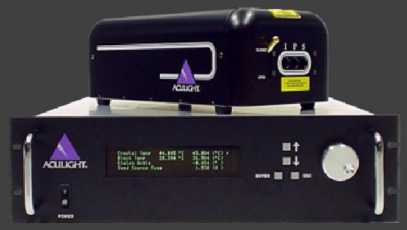
Koheras

Industrial low noise DFB lasers

Argos

LOCKHEED MARTIN

High Power OPOs



Overview

Technology

Termination

Industrial Usage

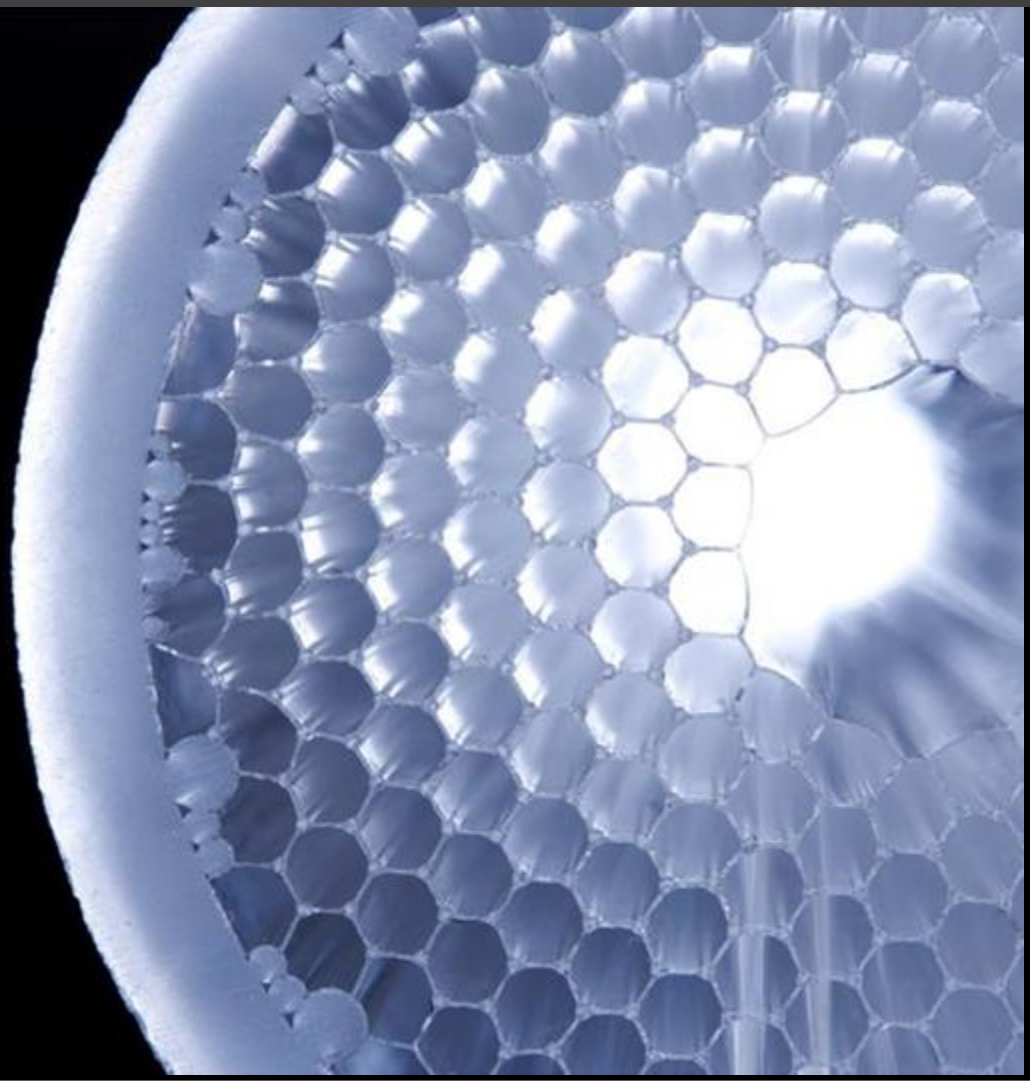
Our platform: photonic crystal fibers

Gain modules & fibers

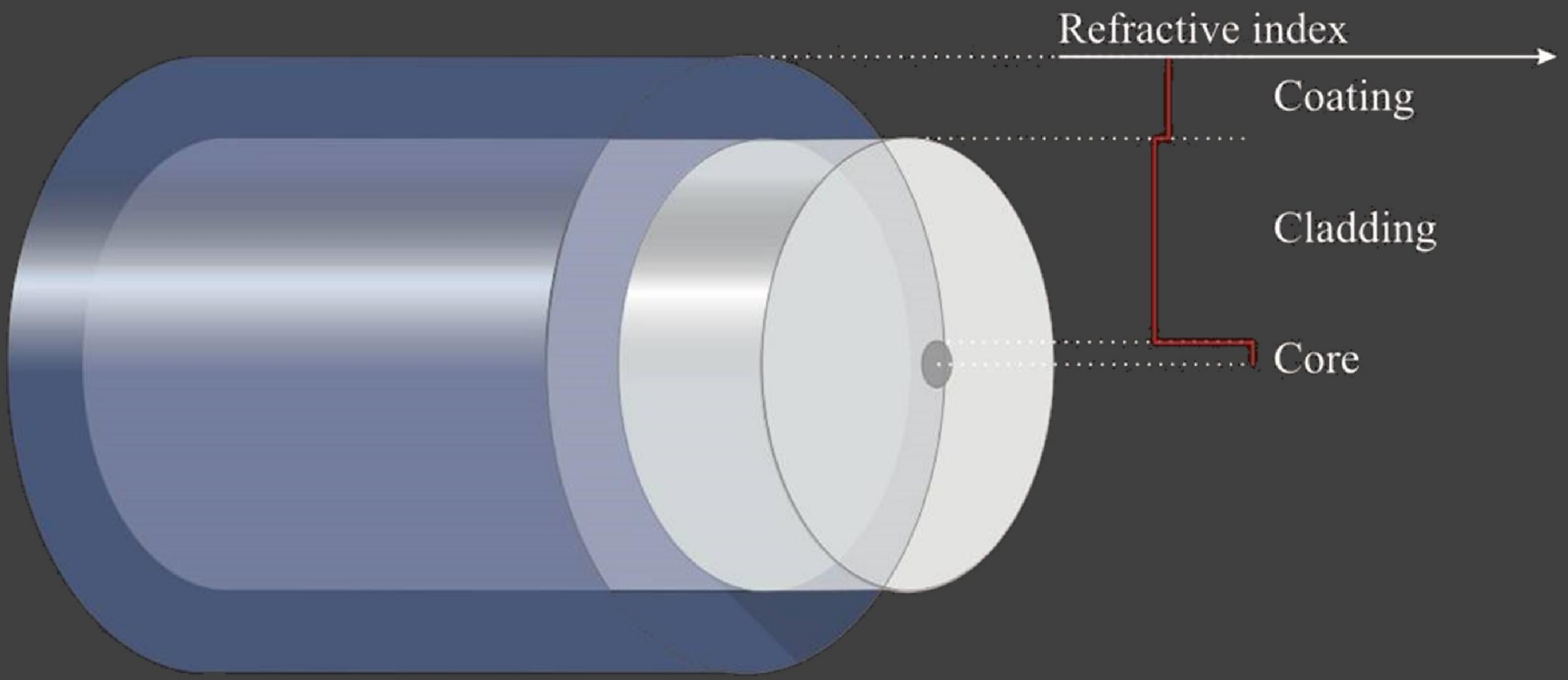
Nonlinear fibers

Fiber delivery systems

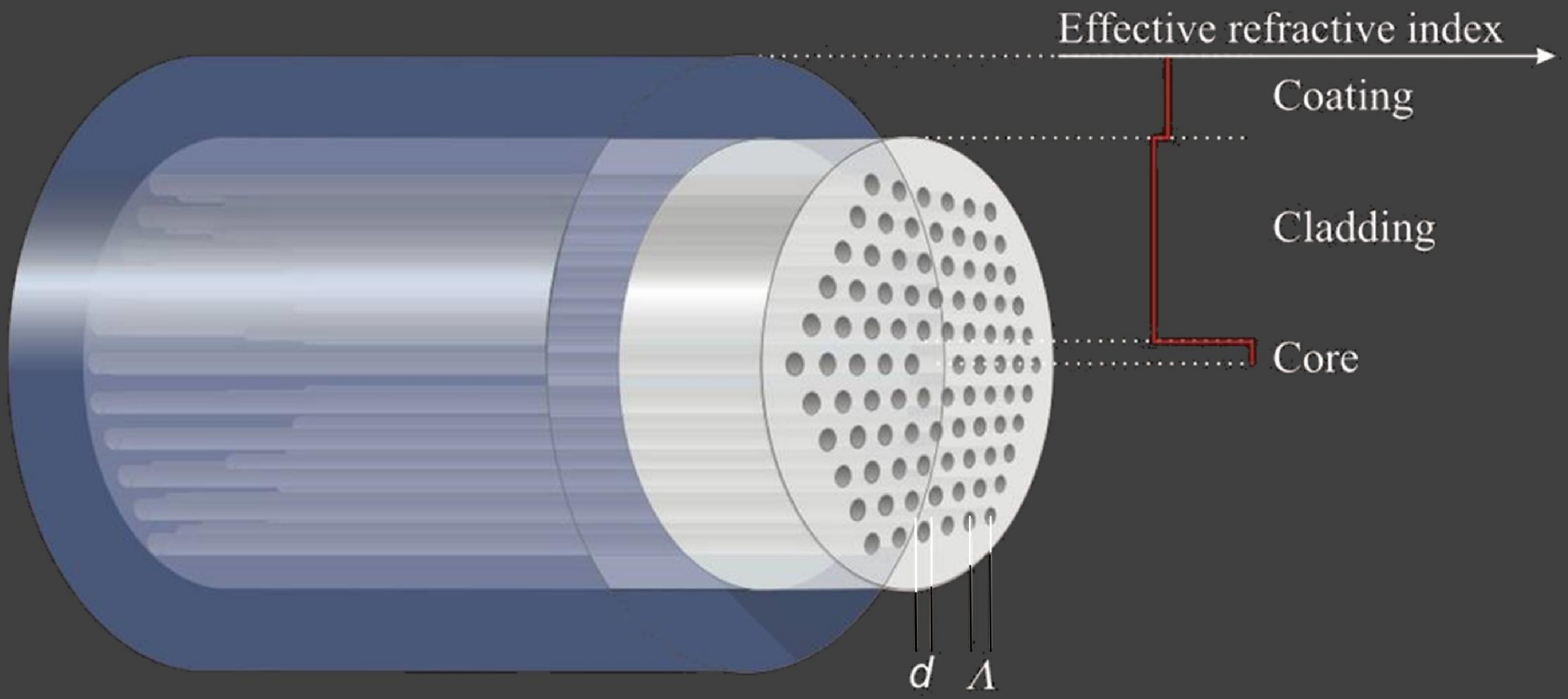
Hollow core PBG fibers



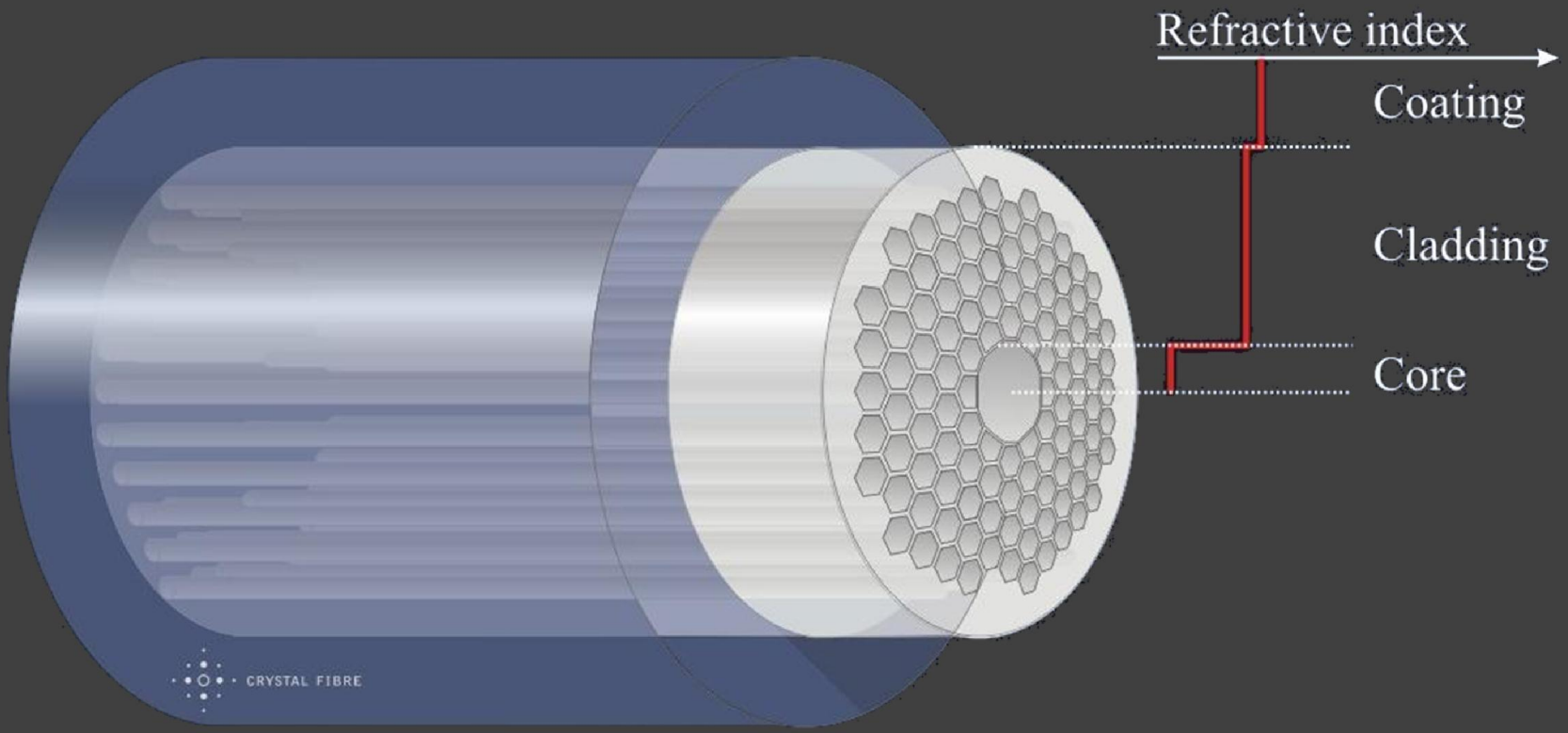
Step index fiber



Solid-core photonic crystal fiber

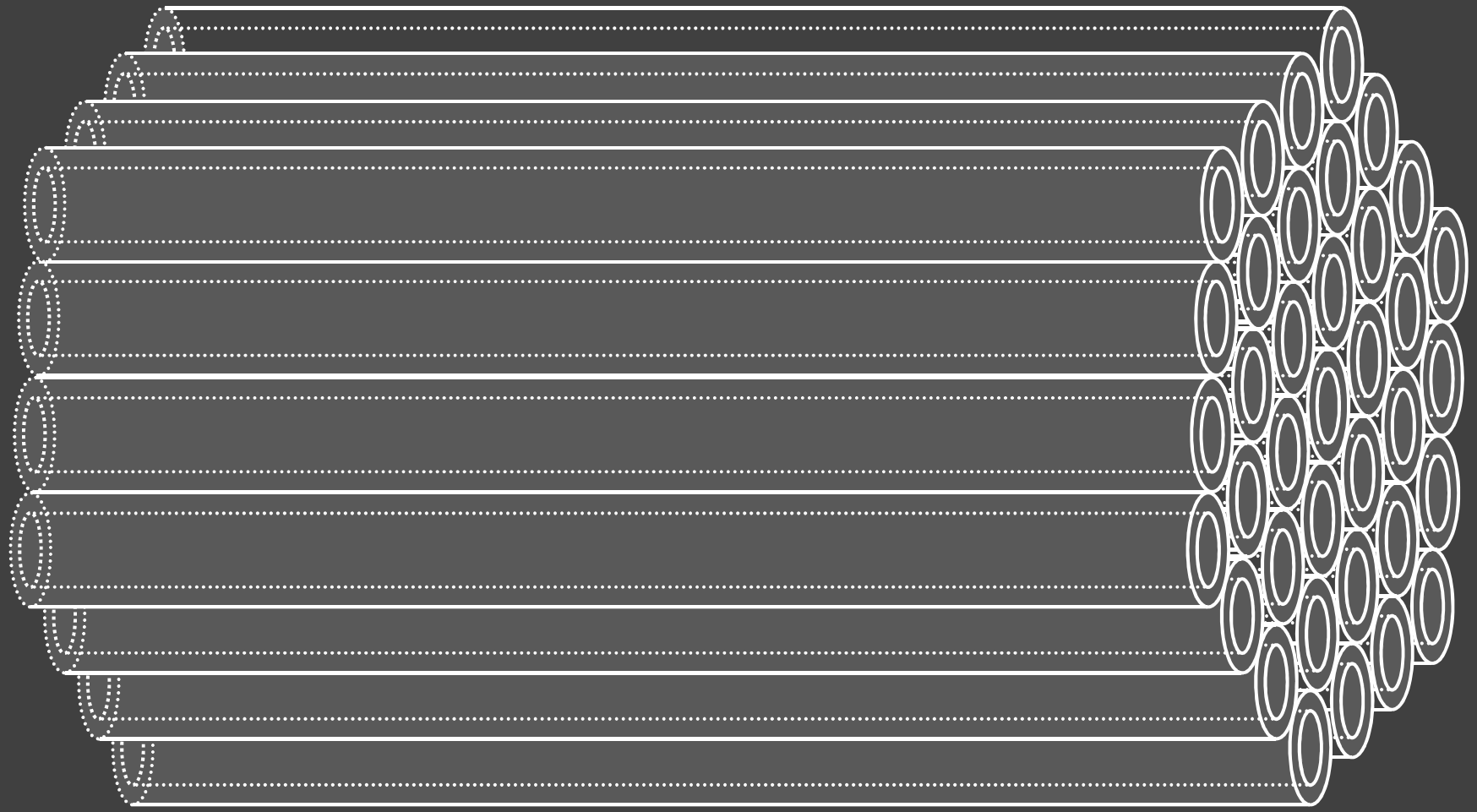


Hollow-core photonic crystal fiber

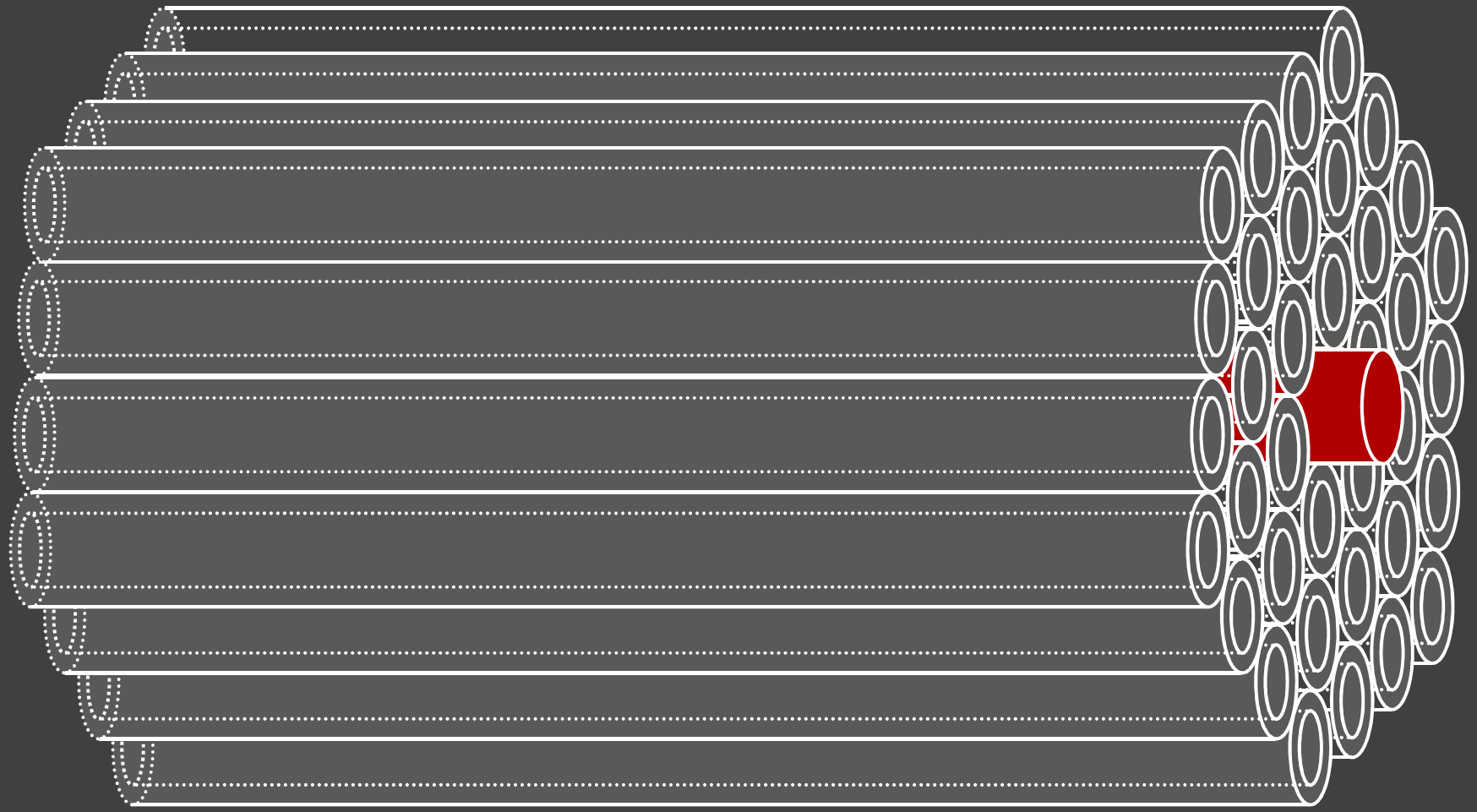


How to make photonic crystal fibers

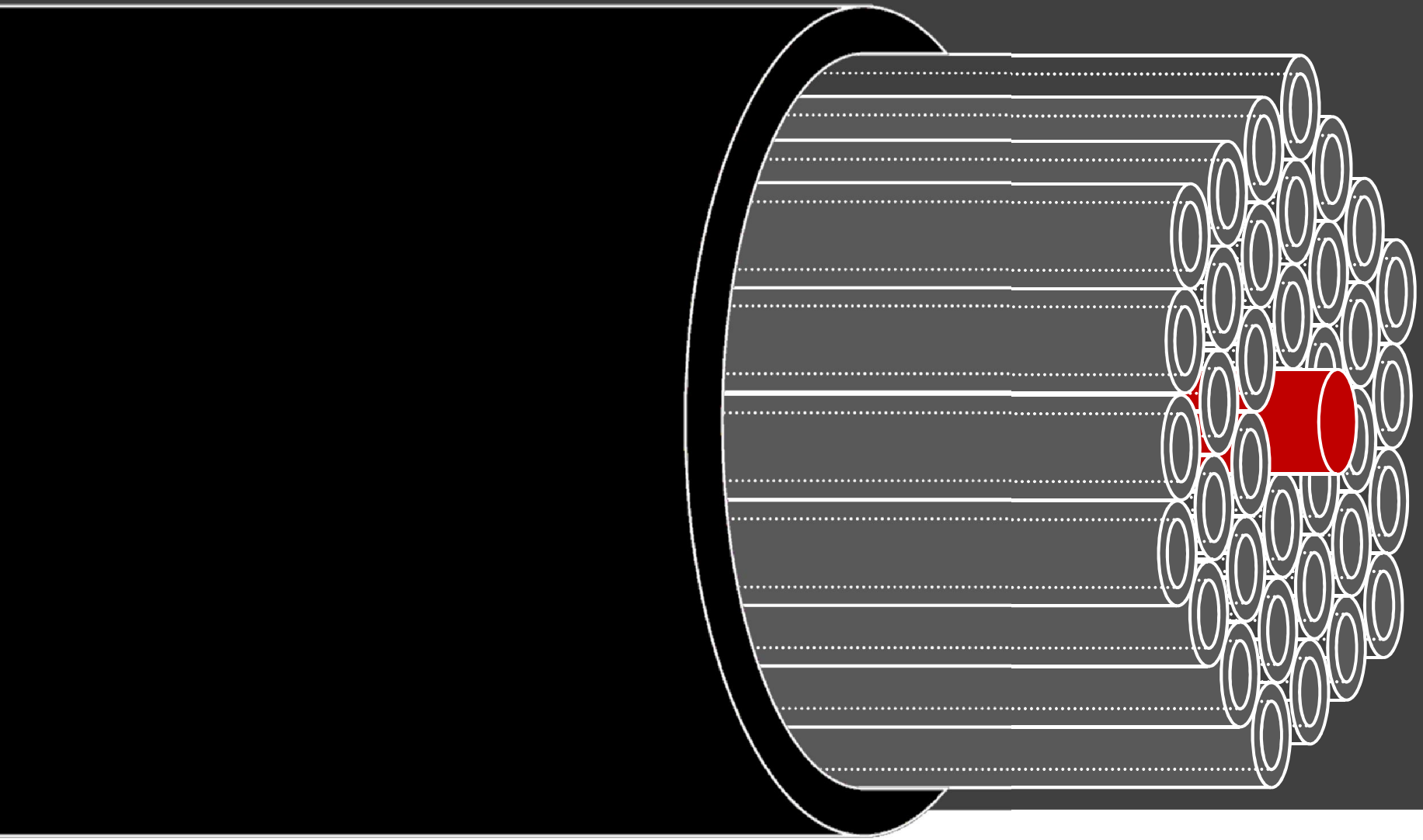
How to make photonic crystal fibers



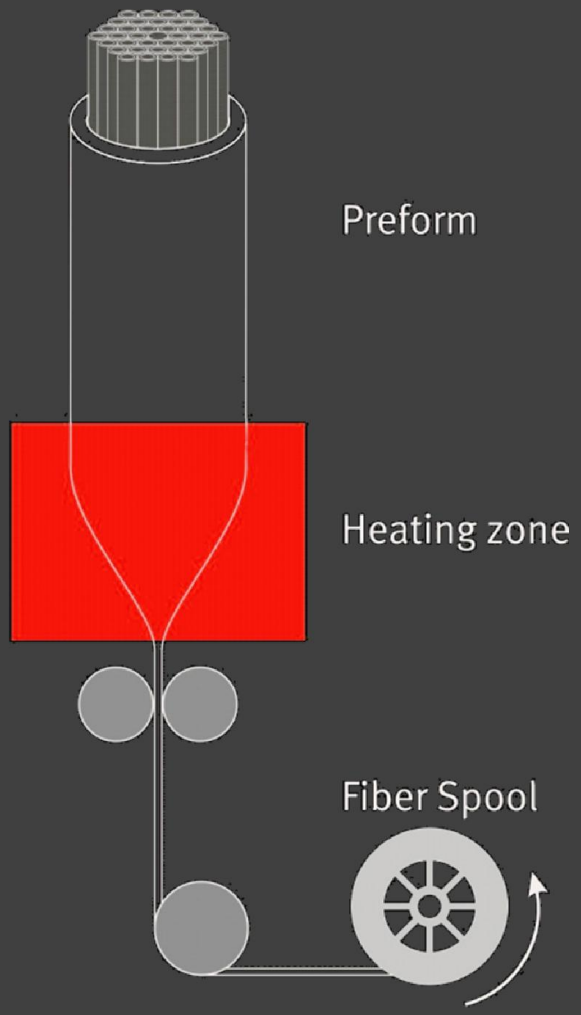
How to make photonic crystal fibers



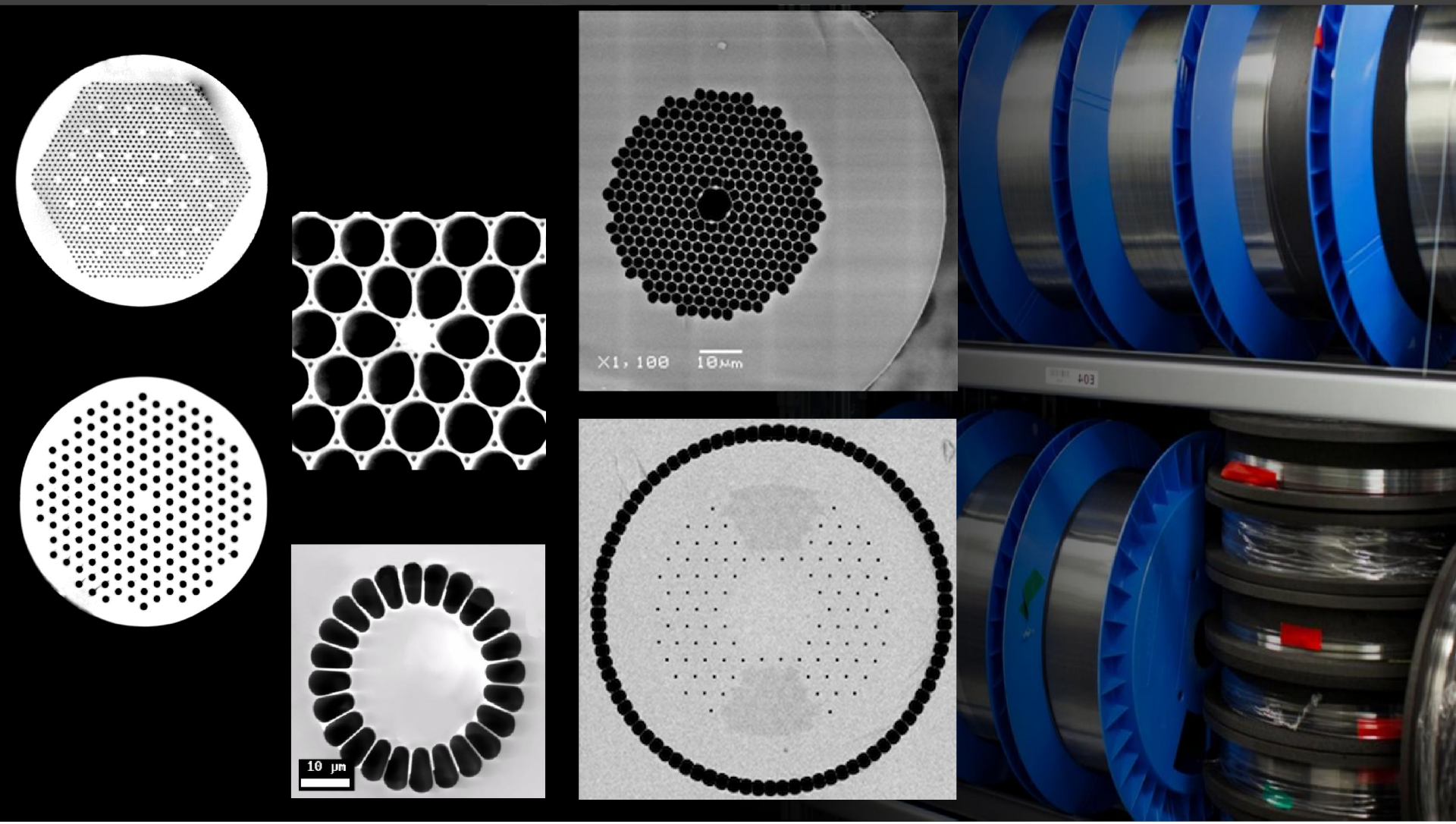
How to make photonic crystal fibers



How to make photonic crystal fibers



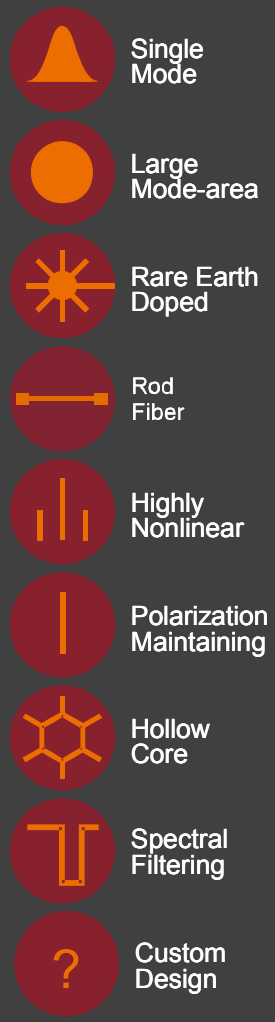
Different fiber structures



NKT Photonics
the power of light

The NKT Photonics PCF line

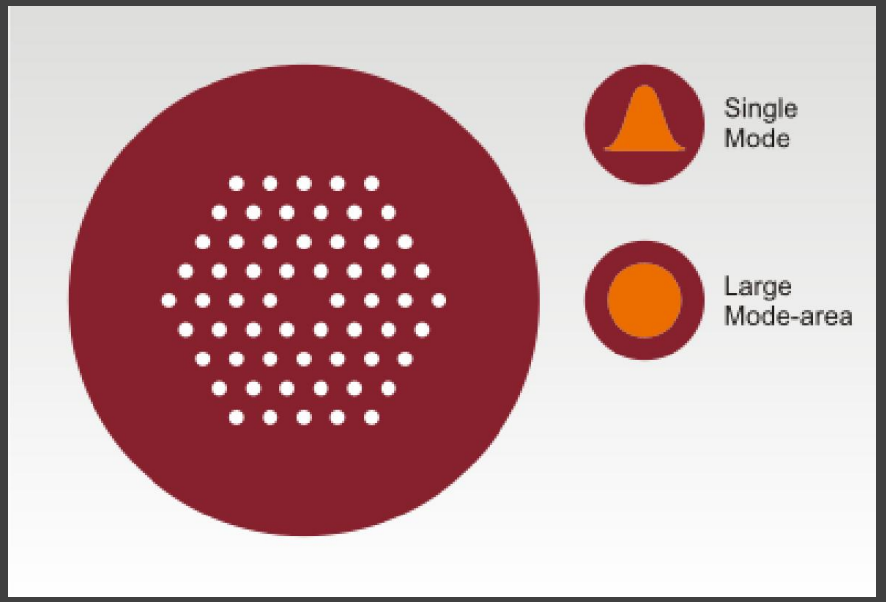
- Single mode fibers
- Large mode area fibers
- Active fibers
- Rod fibers
- Highly nonlinear fibers
- Polarization maintaining fibers
- Hollow core fibers (photonic bandgap fibers)
- Fibers for spectral filtering
- Custom design



LMA fibers

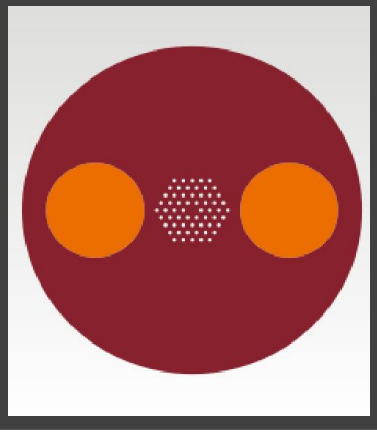
Applications:

Delivery of single mode and high power light over a range of wavelengths



Key Features and Benefits

- Endlessly single mode
- High power handling
- Low nonlinearities
- High beam quality
- Terminations and patch-cord options

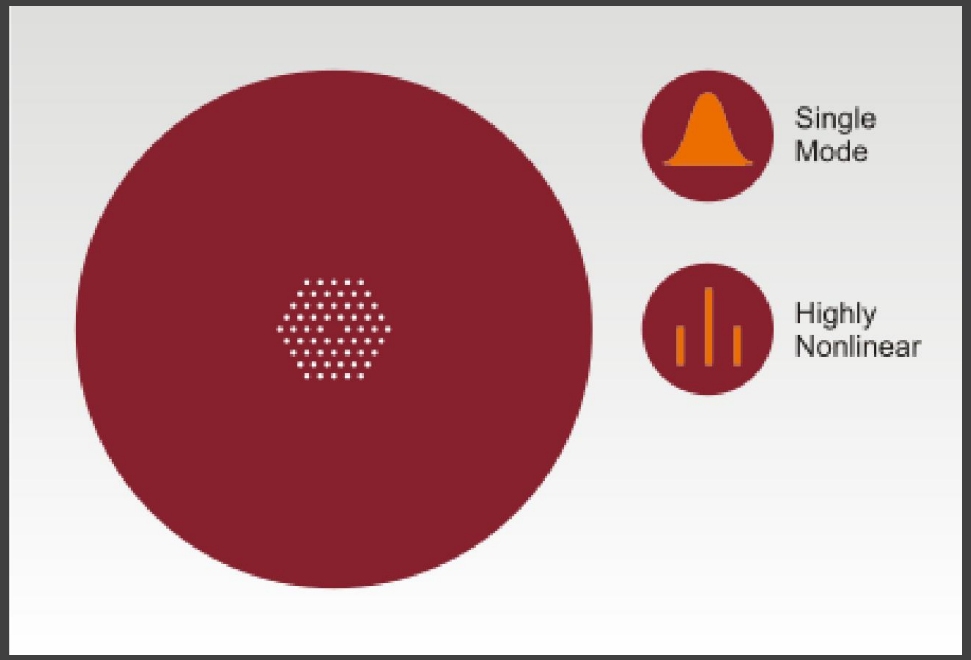


LMA-PM

Nonlinear fibers

Applications:

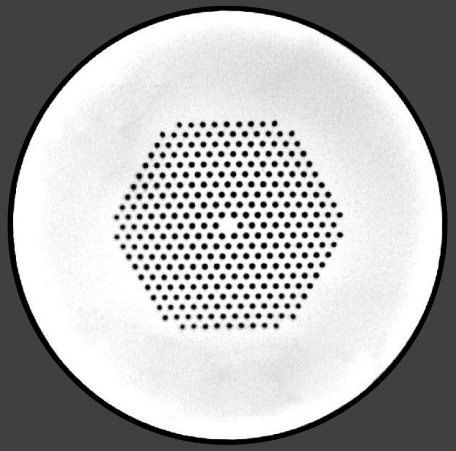
- Supercontinuum generation
- Frequency conversion
- Optical parametric amplification
- Four-wave mixing



Key Features and Benefits

- High nonlinear coefficients
- Single mode
- Zero dispersion at various wavelengths

Common pump wavelengths



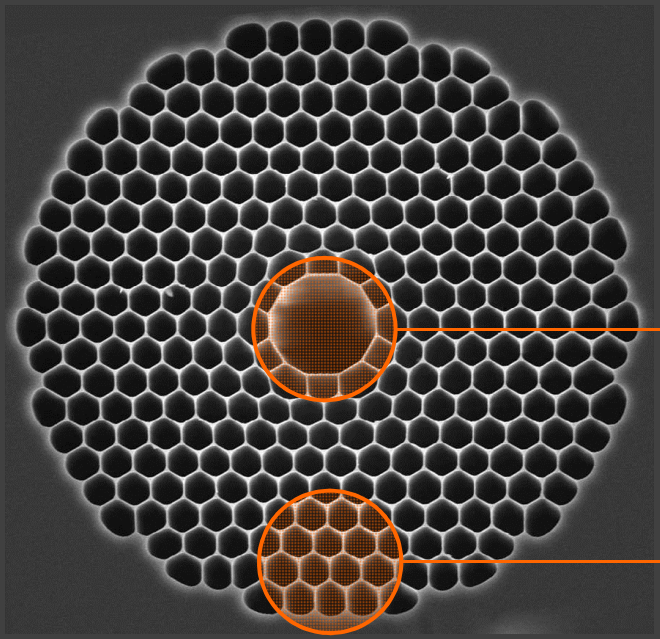
Most fibers are optimized for pumping at major laser wavelengths

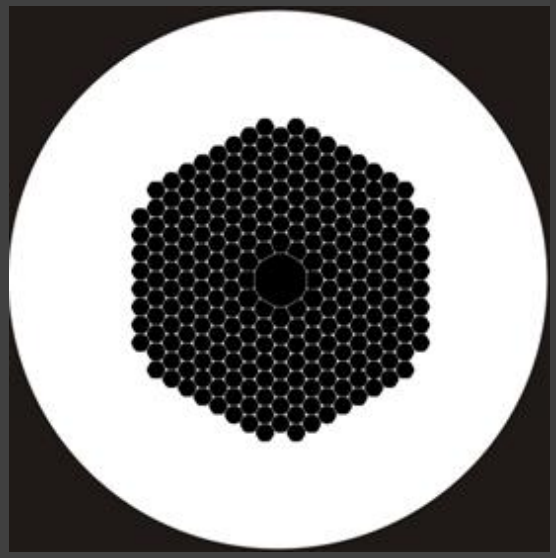
800 nm

1060 nm

1550 nm

Hollow core fibers



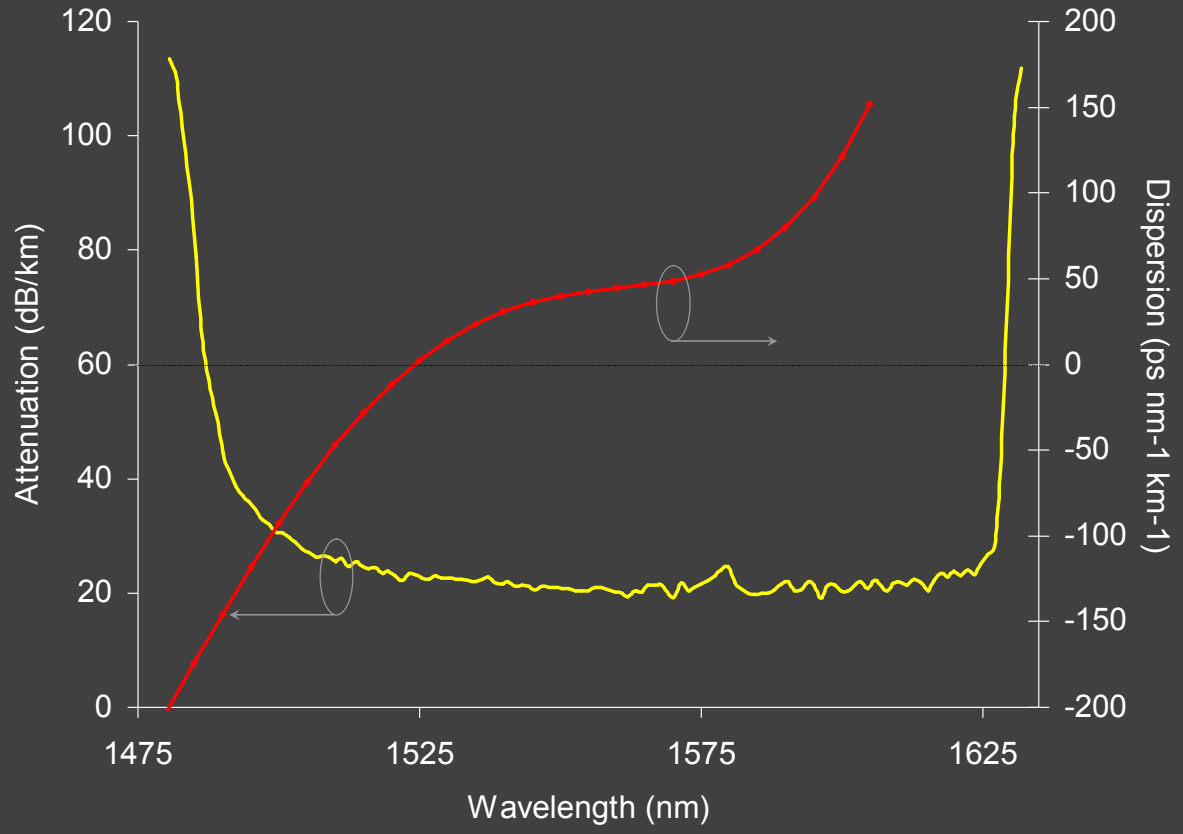


Hollow core guides light

⇒ Light matter interaction dramatically reduced

Propagation in the cladding is inhibited by photonic bandgap effect

Photonic bandgap guidance

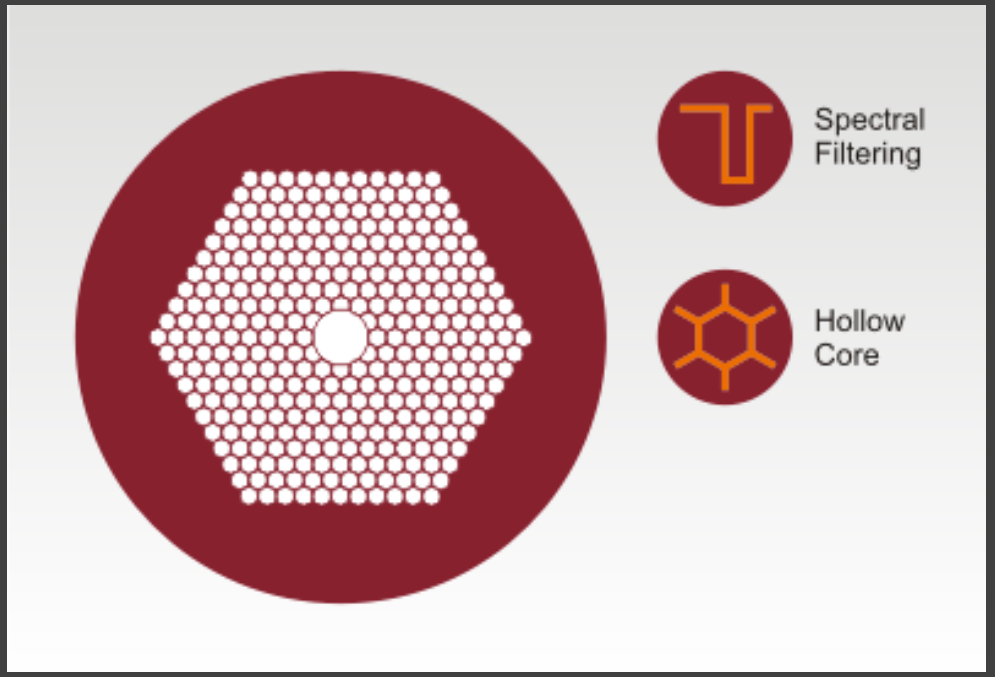


- Transmission band well-defined; like a notch filter.
- Dispersion follows similar trend for all fibers as shown in this example

Hollow core fibers

Applications

- Pulse delivery
- Spectral filtering
- Sensors, gyroscopes



Key Features and Benefits

- Reduced interaction with silica
- Low nonlinearity
- Insensitivity to bending, radiation, magnetic fields, and thermal fluctuations
- Unique dispersion properties
- Long interaction length with gases

Hollow core fibers

Visible wavelength fibers

HC-440-02 HC-532-02 HC-580-02 HC-633-02

Near Infrared fibers

AIR-6-800
HC-800-01

HC-1060-02

HC-1550-02
HC-1550-04
HC-1550-PM-01
HC19-1550-01

HC-2000-01

Overview

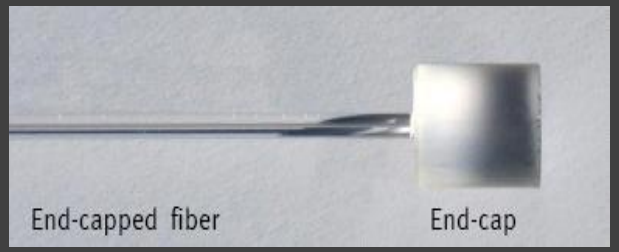
Technology

Termination

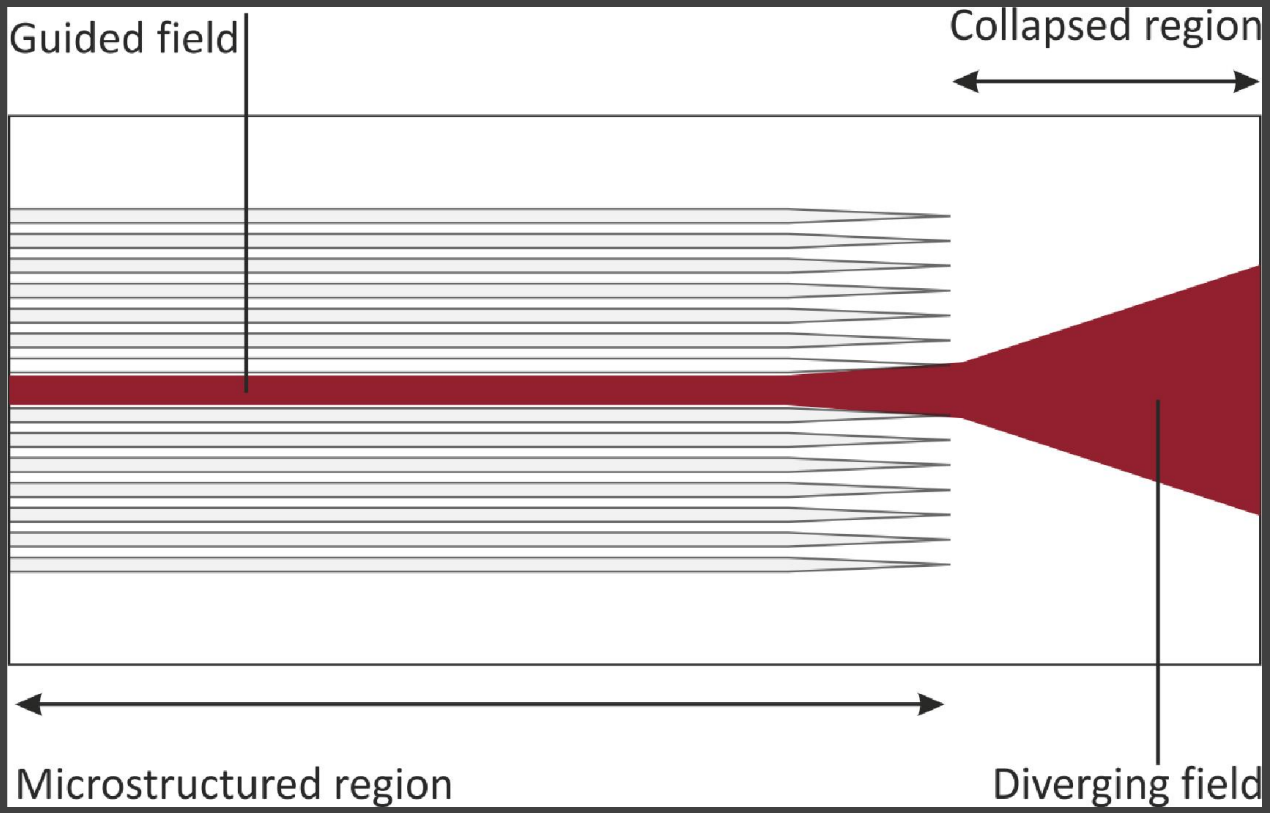
Industrial Usage

Termination

- End seal and cleave / end caps
- Connectorization
  - FC/PC, FC/APC, PM
  - SMA-905
- Splicing to standard pigtails
- Tubing (up to 5 meters)
  - 3 mm PVC / 900 micron loose tube
  - Flexible steel tube
- Standard assemblies



End-sealing (solid core fibers)



Overview

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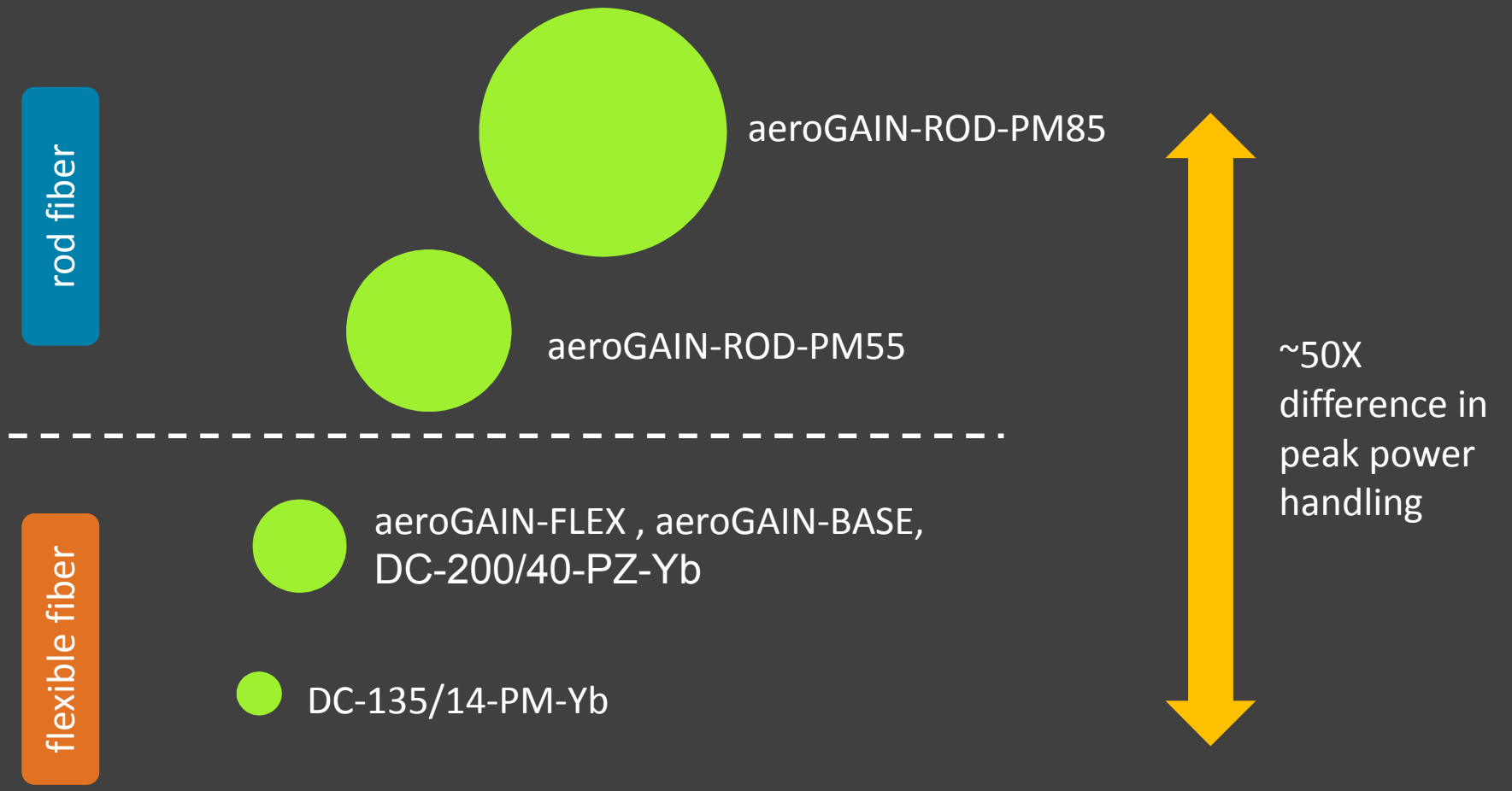
Industrial Usage

Industrial usage: gain modules for lasers



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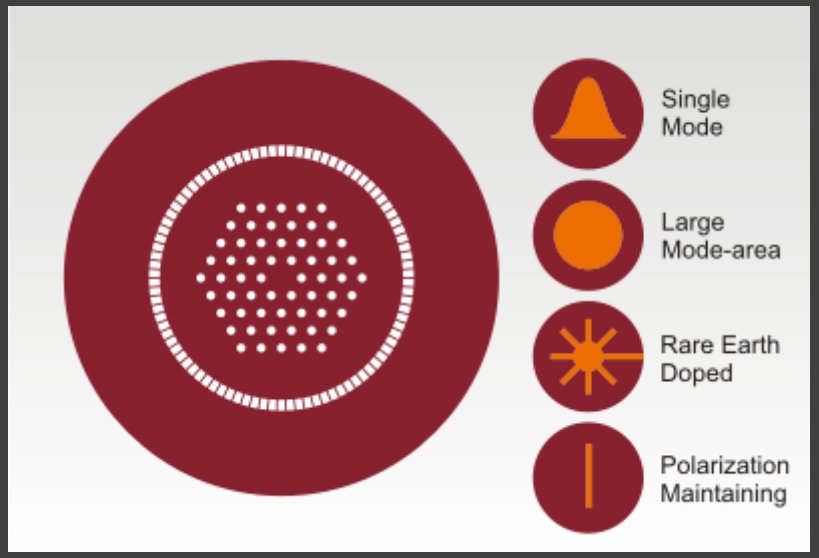
Industrial usage: gain modules for lasers

- **Rods permit larger pulse energy and higher peak power**

- Diffraction limited beam quality
- Large effective area
- Polarization-maintaining
- AR coated end-caps



Industrial usage: gain modules for lasers

COHERENT®

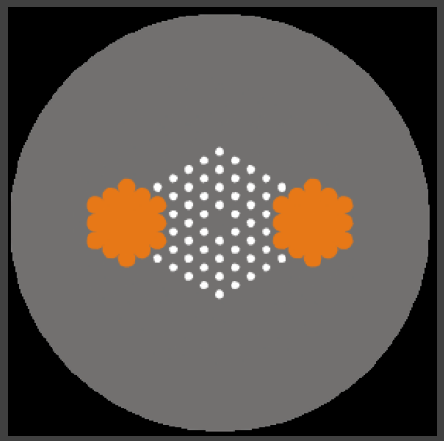
Amplitude SYSTEMES

EOLITE LASERS

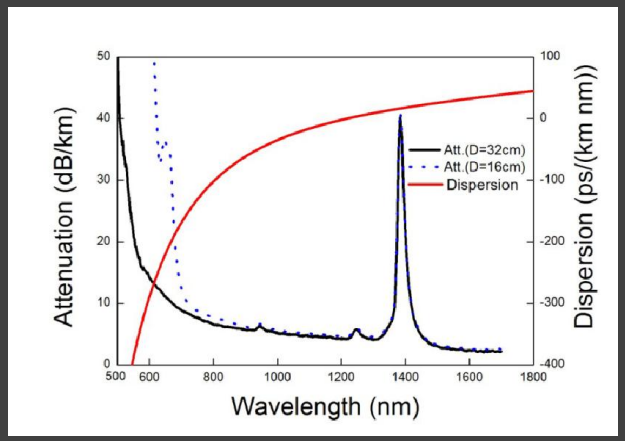
... and many more

Industrial usage: fiber delivery

aeroGUIDE-Power – broadband high power PM fiber delivery



Polarization maintaining



Attenuation < 10 dB/km
Mode field diameter ~ 12.6 µm

SMA high power connector

Hall of fame

1 ns, 4.3 mJ pulses with 4.5 MW peak power

3.8 GW peak femtosecond CPA system

4 kW single mode amplifier chain

167 W cw power at 1178nm

18 W cw at 532 nm (Verdi)

...

Industrial usage: white light lasers

Lamps

Pro: Cheap, compact, robust
Con: Brightness, lifetime

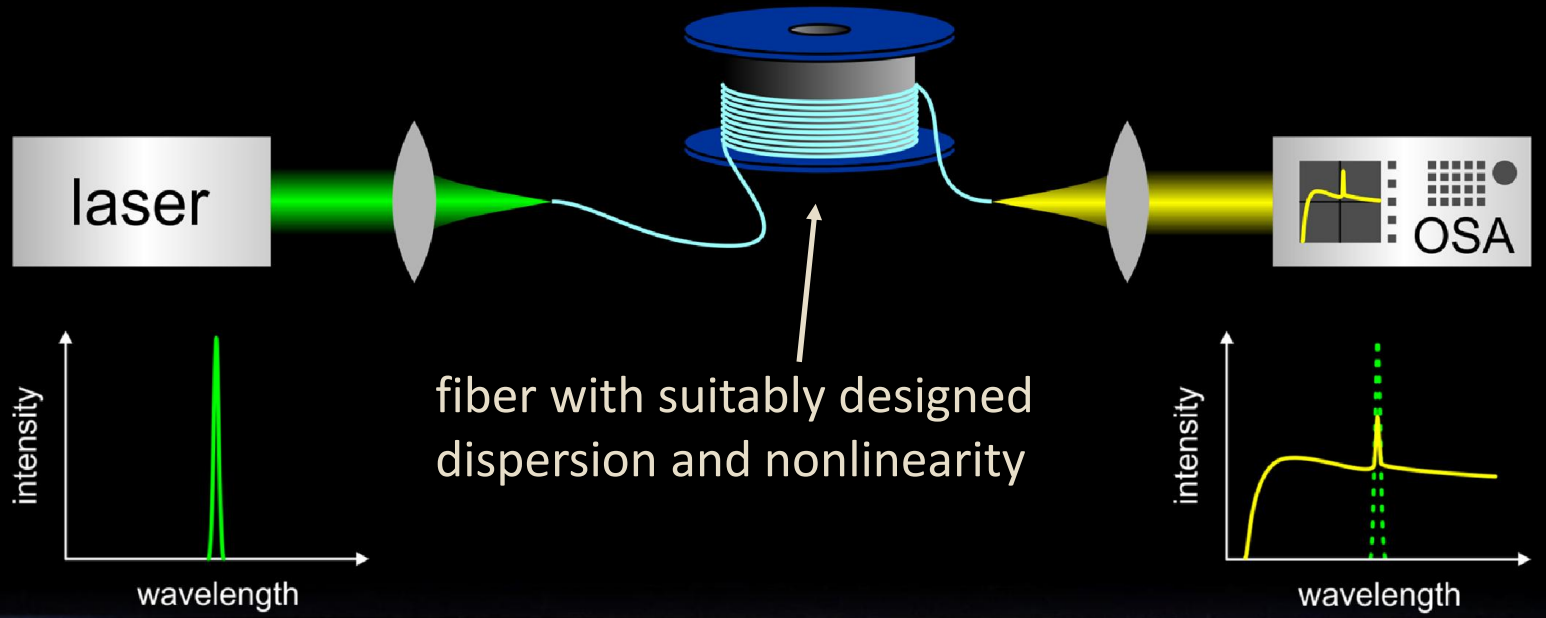
Lasers

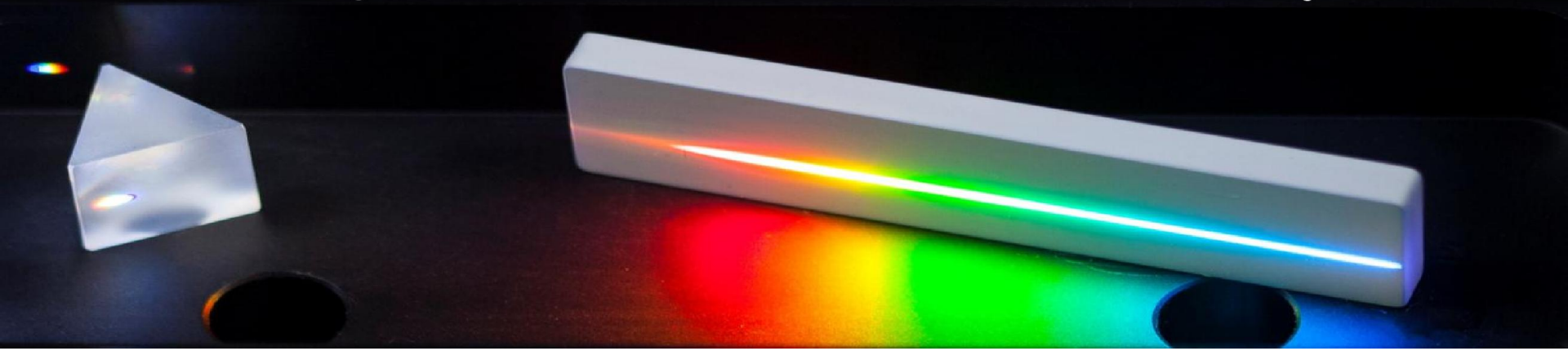
Pro: Bright, single-mode, lifetime
Con: Single line

What is a supercontinuum source?

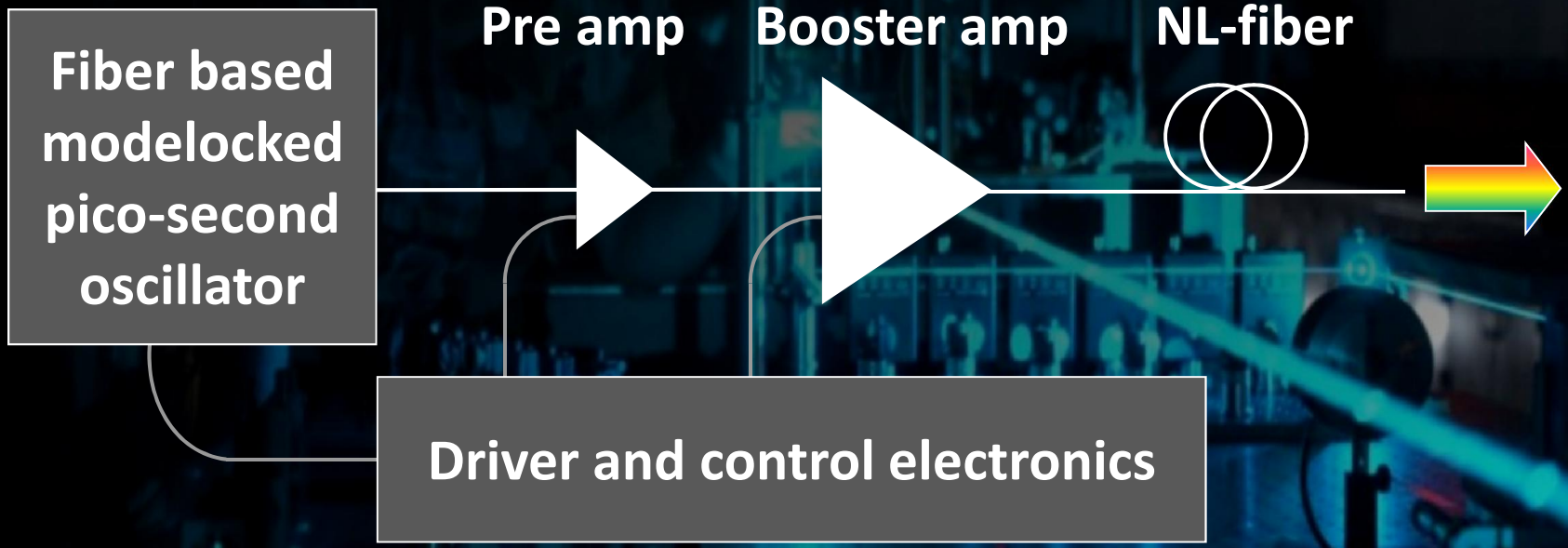
- **Bright** as a laser, **broad** as a lamp
- **Continuous** spectrum in the visible and nIR
- Continuously **tunable** over hundreds of nanometers
- **Fiber** delivered, **diffraction limited** output
- **Stable** and very **reliable** all-fiber system with zero maintenance

Supercontinuum generation





SuperK Series

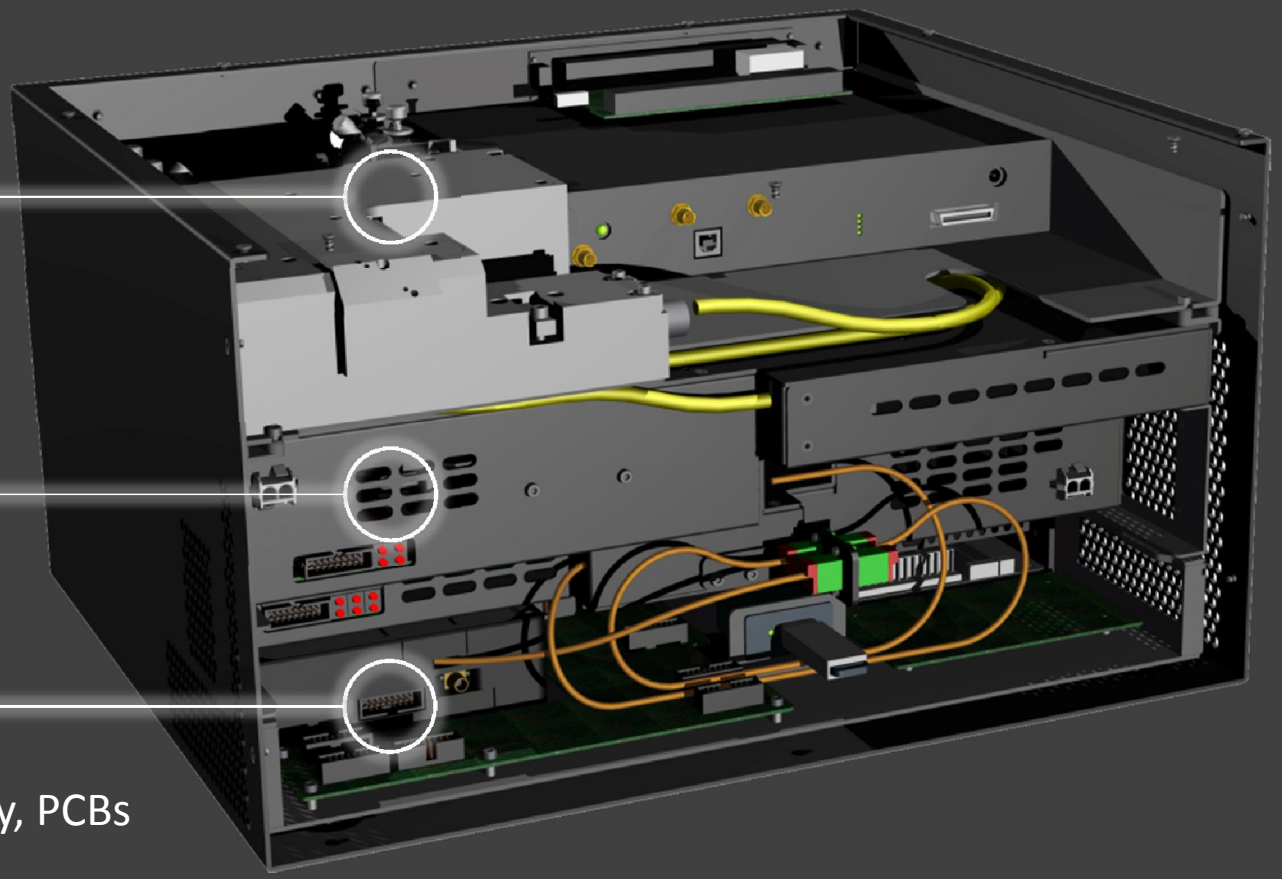


Modular system architecture

top layer
OEM specific
(e.g. SELECT and
integrated RF Driver)

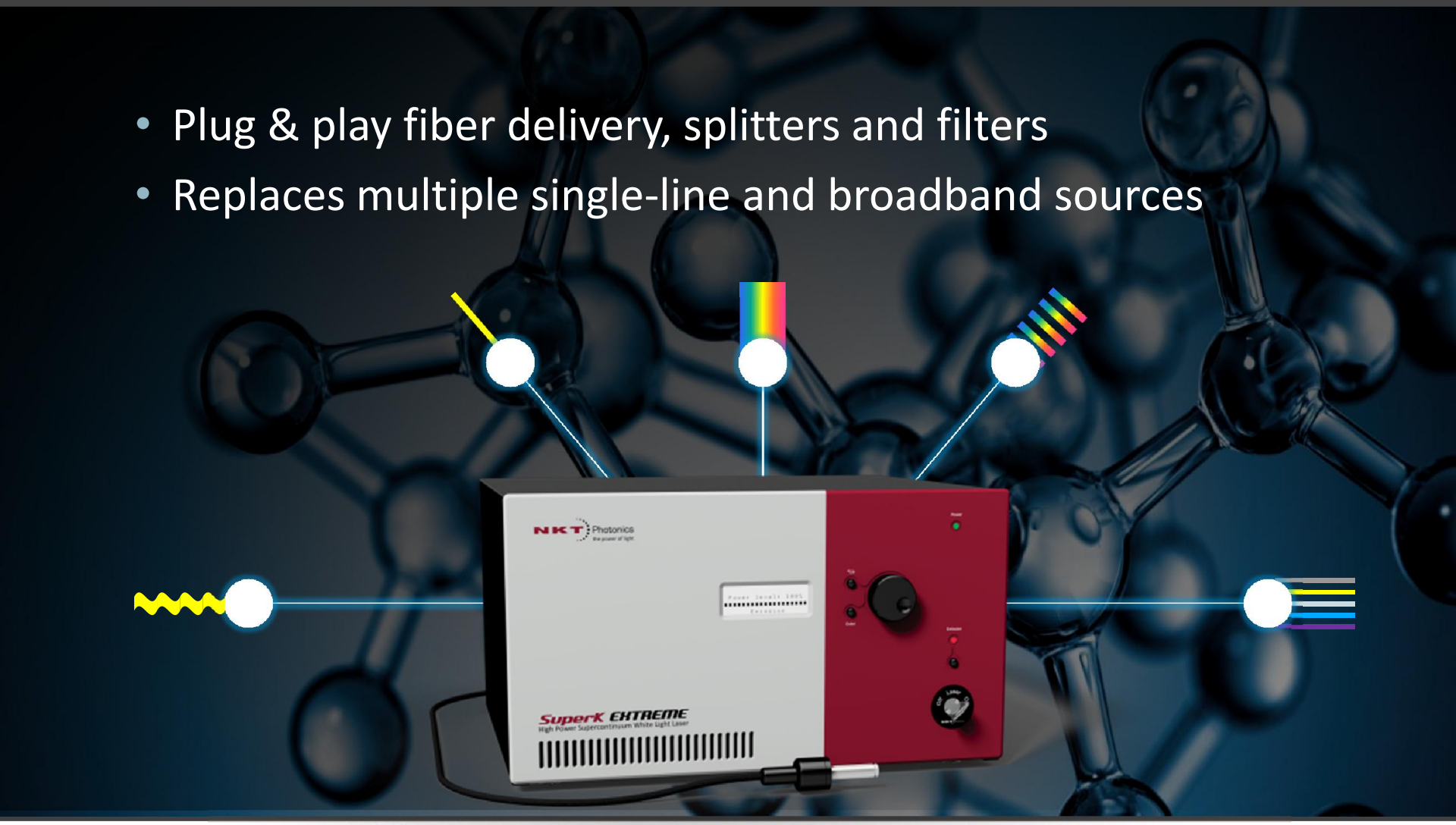
middle layer
booster-amp module
with spliced PCF
(SCG and guide fiber)

ground layer
seeder and pre-amp
modules, power supply, PCBs

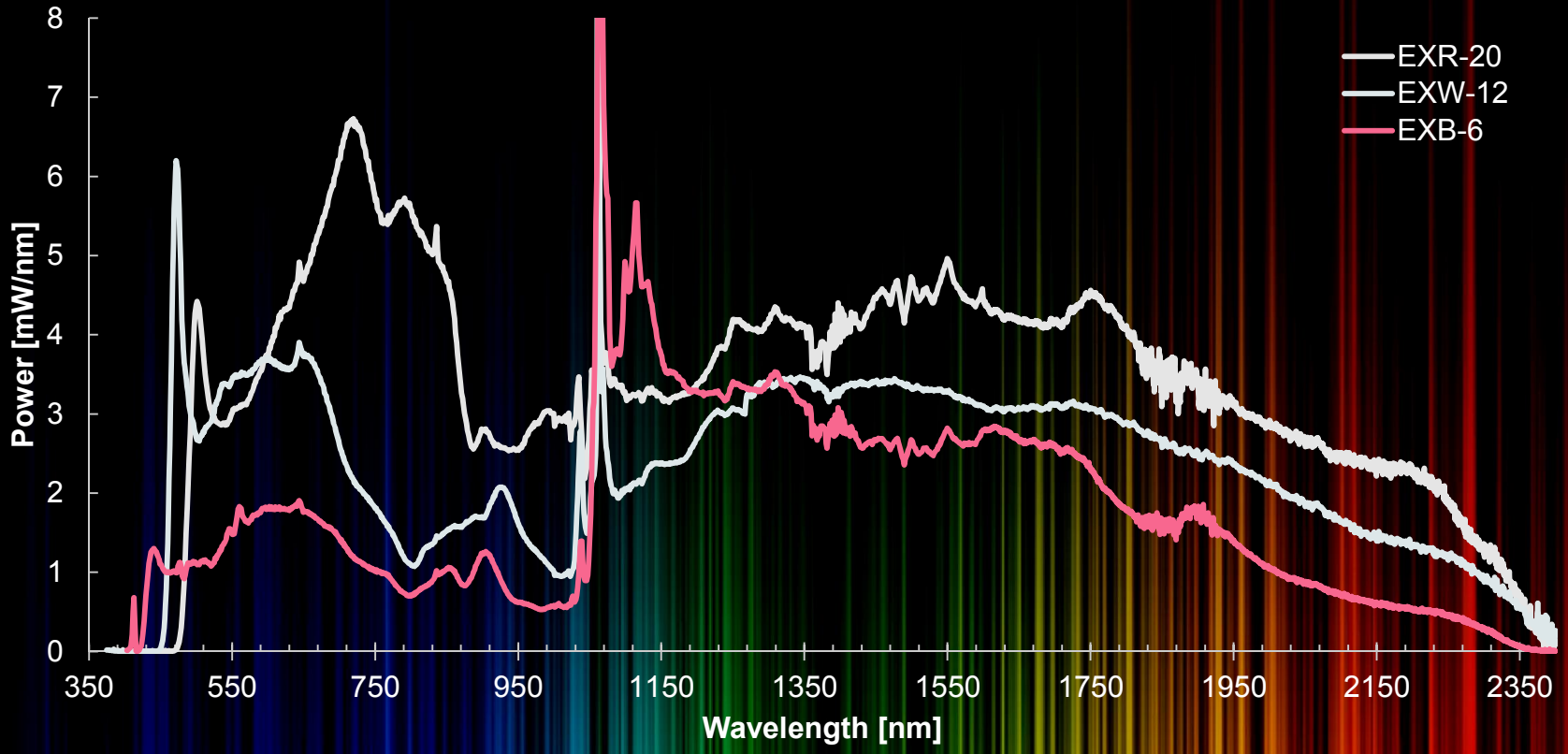


All purpose lab tool

- Plug & play fiber delivery, splitters and filters
- Replaces multiple single-line and broadband sources



SuperK EXTREME – wavelength range



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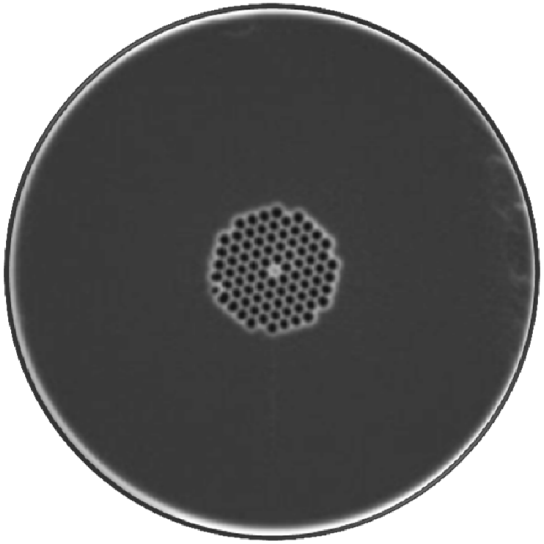
SuperK EXTREME – cut-in wavelengths

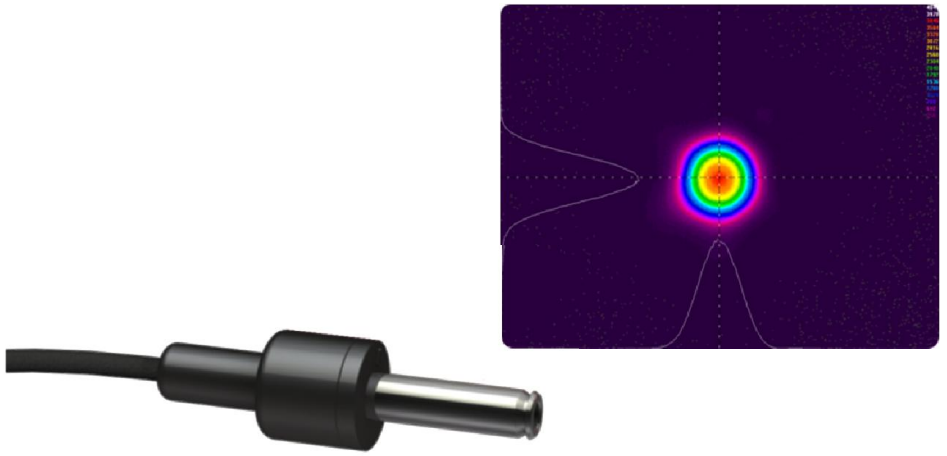
	Model	Min. [nm]	Max. [nm]
EXB-series	EXB-1	~435	~2200
	EXB-4	~415	~2300
	EXB-6	~405	~2300
EXW-series	EXW-1	~500	~2200
	EXW-4	~470	~2300
	EXW-6	~465	~2350
	EXW-12	~455	~2400
EXR-series	EXR-1	~615	~1750
	EXR-4	~535	~2050
	EXR-15	~475	~2350
	EXR-20	~470	~2400

SuperK termination



NKT photonic crystal fiber is the key technology enabling

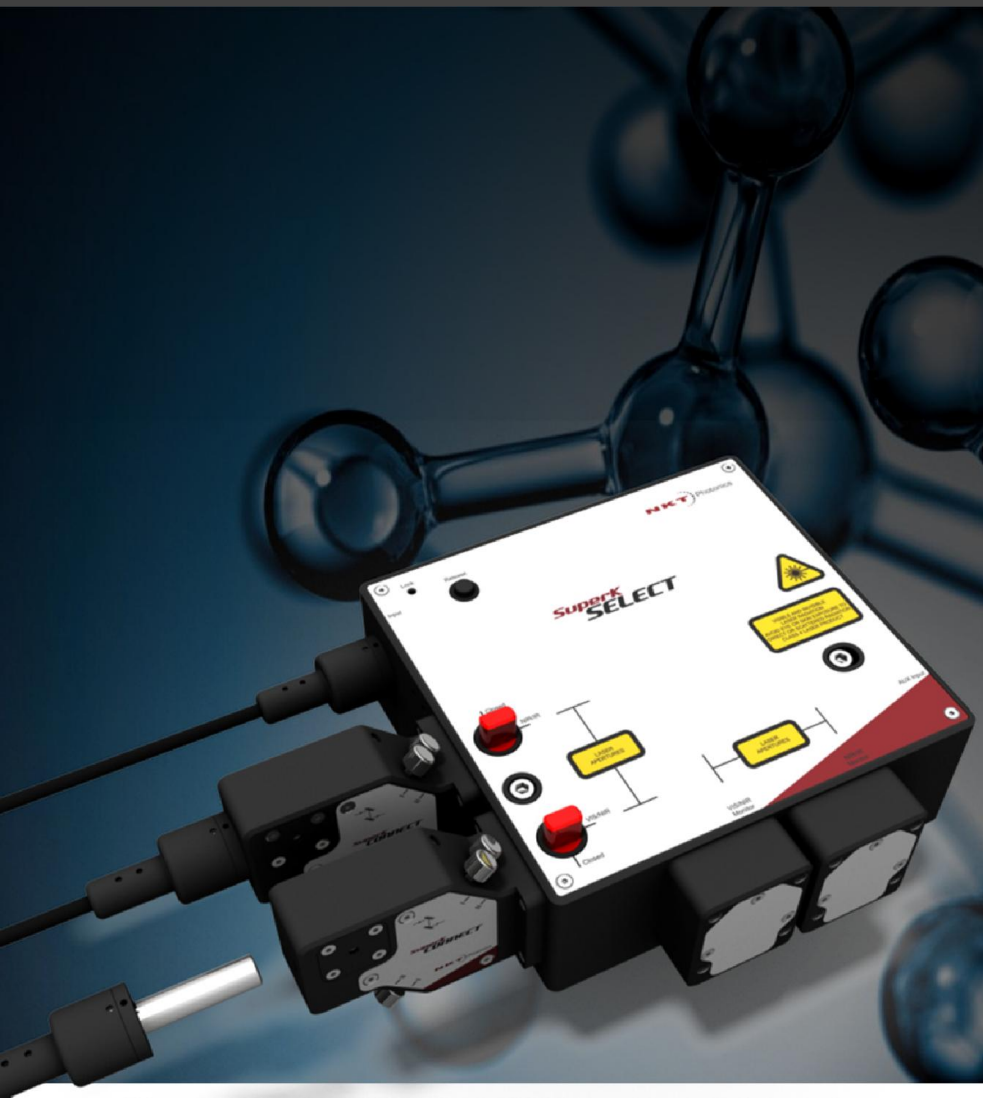
- high brightness SC generation
- efficiency
- reliability, therefore low TCO



Proprietary collimator

- diffraction limited
- achromatic
- highest pointing accuracy
- true single mode
- fiber coupling >70%

Tunable like no other source



Choose between:

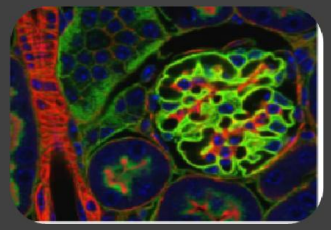
- Full broadband output
- Up to 8 tunable channels simultaneously
- Single line variable bandwidth tunable channel

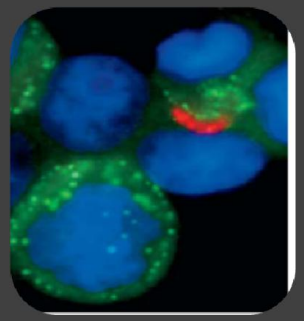
Scientific applications

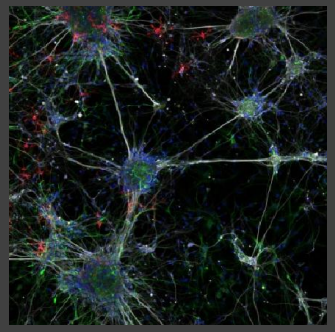
- OCT
- FLUORESCENCE MICROSCOPY
- FLIM / FRET MICROSCOPY, TCSPC
- TRANSIENT SPECTROMETER
- FLOW CYTOMETRY
- SURFACE PLASMON / METAMATERIAL RESEARCH
- BRAGG GRATING / FIBER CHARACTERIZATION
- COMBUSTION MONITORING / FLAME DIAGNOSTICS
- all purpose lab light source

http://www.nktphotonics.com/side5415.html

Leica TCS SP8 X







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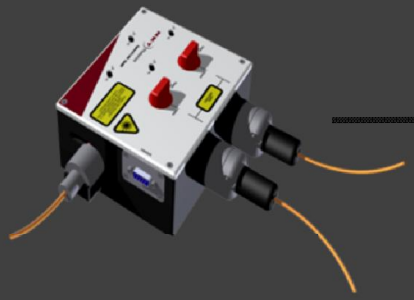
Horiba FluoroCube

Test & measurement / characterization

SuperK COMPACT

OR

SuperK Split



SuperK EXTREME

Passive optical device (WDM, fiber,..)

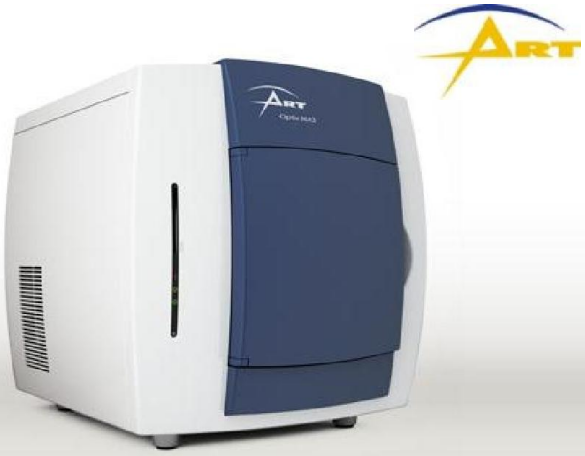
OSA 350-1750nm

OSA 1200-2400nm

Plug & Play

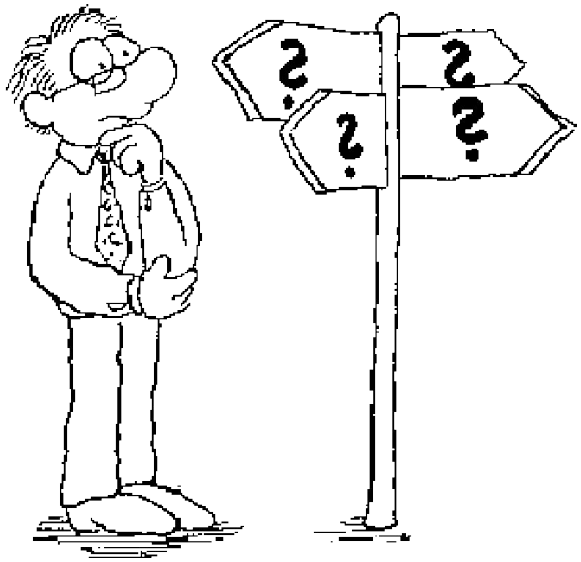
Examples of OEM customers

- Leica confocal microscopes
- LaVision BioTec ultra microscopes
- ART molecular imaging systems
- Hamamatsu streak cameras
- Horiba Scientific FLIM systems



Major scientific customers

Questions?



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