Photonic Crystal Fiber

Technology, Termination & Examples of Industrial Usage

Nicolai Granzow
123 years of industrial history

1891

~9,000 employees

2014

SuperK • Koheras • Crystal Fibre • aeroPULSE

Proprietary and Confidential

NKT

Photonics
the power of light
Ownership

› Europe  › Northern Europe  › NKT Photonics
› North America  › Central Europe  › LIOS Technology
› Oceania  › Eastern Europe  › Vytran
› Asia  › China
Our products

- Crystal Fibre: Specialty fibers and modules
- SuperK: Supercontinuum lasers
- Koheras: Industrial low noise DFB lasers
- Argos: 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

- Effective refractive index
  - Coating
  - Cladding
  - Core

- d, A
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

Diagram showing the process of making photonic crystal fibers.
Different fiber structures
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
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
• 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-1060-02  HC-1550-02  HC-2000-01
HC-800-01  HC-1550-04  HC-1550-PM-01  HC19-1550-01
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

- Technology
- Termination
- Industrial Usage
Industrial usage: gain modules for lasers

- aeroGAIN-ROD-PM85
- aeroGAIN-ROD-PM55
- aeroGAIN-FLEX, aeroGAIN-BASE, DC-200/40-PZ-Yb
- DC-135/14-PM-Yb

~50X difference in peak power handling
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

... 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
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

fiber with suitably designed dispersion and nonlinearity
SuperK Series

Fiber based modelocked pico-second oscillator

Pre amp

Booster amp

NL-fiber

Driver and control electronics

SuperK • Koheras • Crystal Fibre • aeroPULSE

Proprietary and Confidential
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

Power [mW/nm] vs. Wavelength [nm]

- EXR-20
- EXW-12
- EXB-6
**SuperK EXTREME – cut-in wavelengths**

<table>
<thead>
<tr>
<th>Model</th>
<th>Min. [nm]</th>
<th>Max. [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EXB-series</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXB-1</td>
<td>~435</td>
<td>~2200</td>
</tr>
<tr>
<td>EXB-4</td>
<td>~415</td>
<td>~2300</td>
</tr>
<tr>
<td>EXB-6</td>
<td>~405</td>
<td>~2300</td>
</tr>
<tr>
<td><strong>EXW-series</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXW-1</td>
<td>~500</td>
<td>~2200</td>
</tr>
<tr>
<td>EXW-4</td>
<td>~470</td>
<td>~2300</td>
</tr>
<tr>
<td>EXW-6</td>
<td>~465</td>
<td>~2350</td>
</tr>
<tr>
<td>EXW-12</td>
<td>~455</td>
<td>~2400</td>
</tr>
<tr>
<td><strong>EXR-series</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXR-1</td>
<td>~615</td>
<td>~1750</td>
</tr>
<tr>
<td>EXR-4</td>
<td>~535</td>
<td>~2050</td>
</tr>
<tr>
<td>EXR-15</td>
<td>~475</td>
<td>~2350</td>
</tr>
<tr>
<td>EXR-20</td>
<td>~470</td>
<td>~2400</td>
</tr>
</tbody>
</table>
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
Test & measurement / characterization

SuperK COMPACT

SuperK Split

OR

SuperK EXTREME

Passive optical device (WDM, fiber,..)

Plug & Play

OSA 350-1750nm

OSA 1200-2400nm
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

- NIST
- MIT Massachusetts Institute of Technology
- Stanford University
- Caltech
- Harvard University
- Fraunhofer IOF
- GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN
- Technische Universität Braunschweig
- JKU Johannes Kepler Universität Linz
- Tsinghua University
- Fudan University
- Osaka University
- INSP Institut des NanoSciences de Paris
- CNRS
- ESCP EUROPE
- l'Observatoire de Paris
- Institut Fresnel Marseille
- IPCMS

Proprietary and Confidential
Questions?

ngr@nktphotonics.com