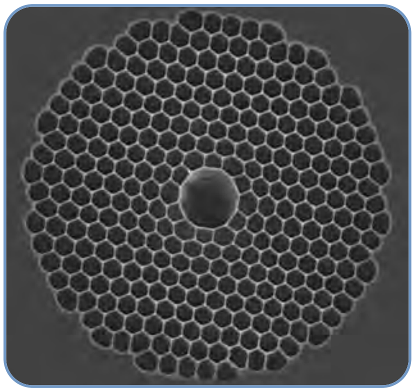
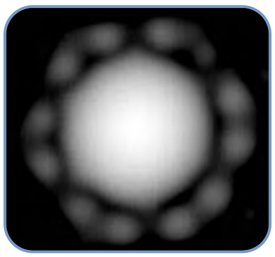
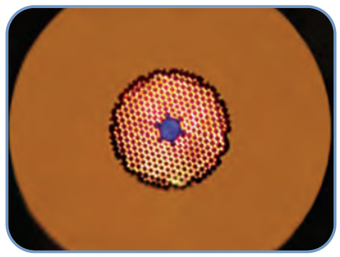
Hollow-Core, Photonic Crystal Fibers (Page 1 of 3)



SEM cross section of a hollow-core photonic crystal fiber (left). Typical output intensity profile measured in the near field (bottom left). Close-up photograph of the fiber while under illumination makes the structure of the fiber clearly visible (below).





The operating principle behind hollow-core photonic bandgap fibers is very different from that of conventional fibers that guide light by total internal reflection; they are related more to that of a multi-layer mirror. For certain incident angles and optical frequencies, the reflection from each layer of holes can add up coherently, transforming the dielectric cladding into an almost perfect two-dimensional mirror, which keeps the light in the core of the fiber.

Key Properties

- Available in a Wide Range of Design Wavelengths
- Available with 7-Cell and 19-Cell Cores
- Operating Bandwidth is ±10% of Design Wavelength
- Attenuation from 20 dB/km (1550 nm) to 300 dB/km (830 nm)
- Zero Dispersion Occurs at a Wavelength in the Operating Band
- Near-Gaussian Fundamental Mode
- Virtually Free of Optical Nonlinearity
- Virtually Immune to Bend Loss
- No Fresnel Reflection from the Endfaces (Modal Index=1)

Optical Properties

- **Modal Properties**

  As with conventional single mode fibers, the favored mode in hollow-core PFC has a quasi-Gaussian intensity distribution. In the case of the 19-cell hollow-core fiber with a 1550 nm operating wavelength (HC19-1550), the measured shape overlap with the fundamental mode of an all-solid step-index fiber is >97%, facilitating coupling to high-mode-quality lasers or conventional fiber. Even though hollow-core PCFs are intended to be used like other single mode fibers, no low-loss, hollow-core PCF demonstrated to date is a true single mode waveguide; typically, they support several higher order core modes, and in some cases, they support additional surface modes located at the core/cladding boundary. All of these modes have higher loss than the fundamental mode and generally decay rapidly, but their presence needs to be taken into account when designing input and output coupling optics.

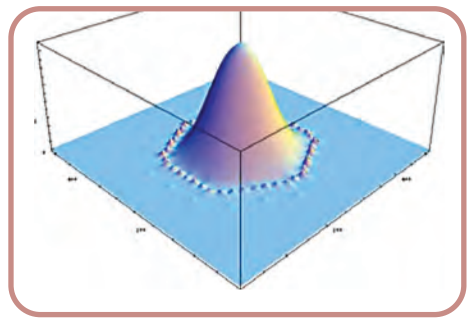
- **Chromatic Dispersion**

  Unlike in conventional fiber where material dispersion plays a major role, Group-Velocity Dispersion (GVD) in hollow-core PCF is dominated by waveguide dispersion. For any design wavelength, including those where the dispersion of silica makes it impossible to achieve zero dispersion in conventional fiber, dispersion is upward sloping and crosses zero at a wavelength close to the center of the operating wavelength band (see box on the next page).

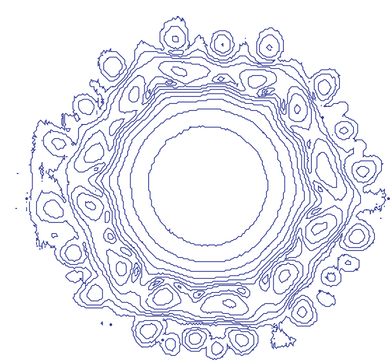
- **Attenuation**

  Hollow core fibers only guide over a wavelength range covered by the photonic bandgap in the cladding. Outside this range (typically about ±10% of the design wavelength) loss increases sharply.

Measured Near-Field Intensity Profile



19-Cell Core, 3 dB/Contour



Applications

- Delivery of Ultra-Short High-Power Optical Pulses
- Pulse Compression and Pulse Shaping
- Sensors and Spectroscopy

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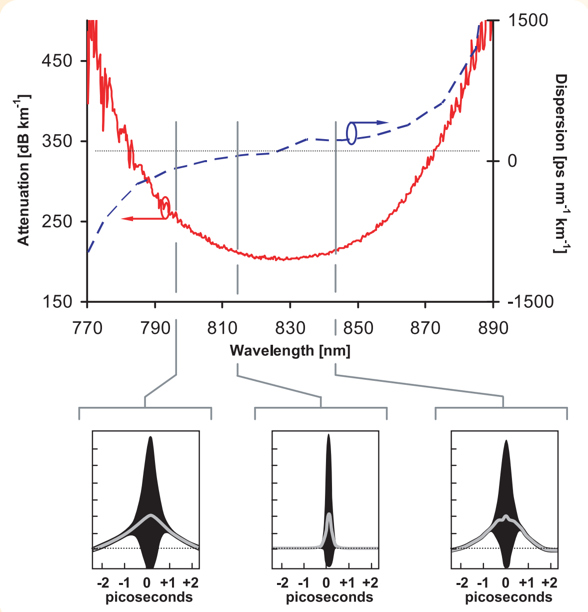
Application Example – Delivery of Femtosecond Pulses from a Ti:Sapphire Laser



Since most of the optical power is located in the core and cladding holes and not in the glass, the nonlinearity of hollow-core fibers can be 2 to 3 orders of magnitude smaller than that of conventional fibers. These characteristics, along with the fact that dispersion crosses zero within the operating waveband, make these fibers ideally suited for the delivery of ultra-short, high-power optical pulses.

This is demonstrated here for the delivery of 150 fs, 8 nJ pulses from a Ti:Sapphire laser over a 1.5 m long fiber. Around the zero dispersion wavelength, the pulses leave the fiber virtually undistorted, despite the fact that the peak power exceeds 100 kW.

Low nonlinearity and anomalous dispersion at any wavelength also make it possible to transmit more powerful pulses in a soliton regime.[*,**] Peak powers of up to 2 mW have been transmitted without causing damage to the fiber.

* Ouzounov *et al.*, Science, **301**, 2003
** Luan *et al.*, Opt. Express, **12**, 2004

7- and 19-Cell Cores

Core Size:
Hollow core fibers are available in two core sizes, which are optimized for different application requirements.

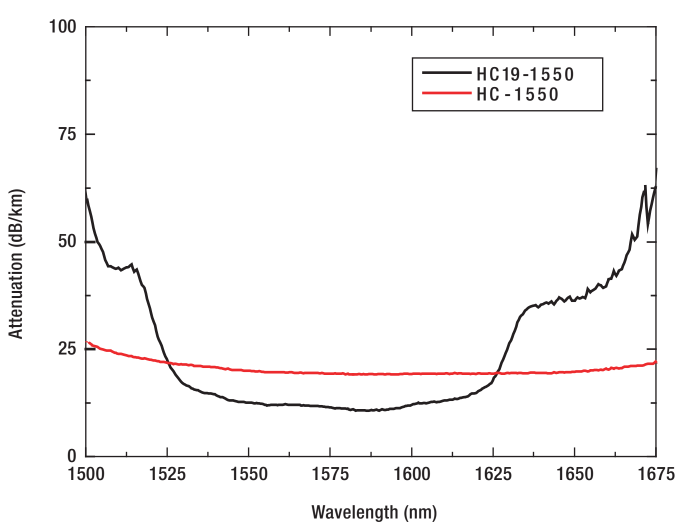
7-Cell Core

- Larger Continuous Operating Bandwidth
- Smaller Number of Core Modes and Parasitic Surface Modes

19-Cell Core

- Larger Mode Field Diameter
- Lower M^2 of Fundamental Mode (More Gaussian-Like), Resulting in Increased Coupling Efficiency to High-Mode-Quality Lasers and Conventional Fibers
- Lower Attenuation
- Lower Dispersion and Dispersion Slope
- Lower Optical Nonlinearity
- Higher Breakdown Power Threshold

Transmission Spectra: 7-Cell and 19-Cell PCFs



The graph above compares typical transmission spectra for a 7-cell (HC-1550) and a 19-cell core fiber (HC19-1550), both designed for operation at 1550 nm. The peaks in the transmission band of the 19-cell fiber are due to surface modes that have a propagation constant that is degenerate with the fundamental mode at certain wavelengths.

Hollow-Core Photonic Crystal Fibers (Page 3 of 3)

Hollow Cores

Photonic bandgap (hollow-core) fibers guide light in a hollow core that is surrounded by a microstructured cladding formed by a periodic arrangement of air holes in silica. Since only a small fraction of the light propagates in glass, the effect of material nonlinearities is significantly reduced, and the fibers do not suffer from the same loss limitations as conventional fibers made from solid material alone. The fiber is protected by a single-layer acrylate coating and can be stripped and cleaved like ordinary solid fibers.

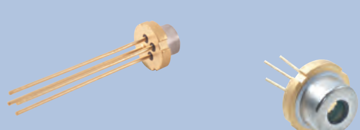
HC-1550

ITEM#	CENTER λ (nm)	CORE DIA. (µm)	MFD* (µm)	NUMERICAL APERTURE	EFFECTIVE MODE INDEX	ATTENUATION (dB/km)	BANDWIDTH (nm)	CLADDING DIA. (µm)	COATING DIA. (µm)
HC-1550	1590	10.9	7.5	~0.2	~0.99	<30	1490 - 1690	120	220
HC19-1550	1570	20 ± 2	13	~0.13 ± 0.03	~0.995	<20	1530 - 1610	115	220
HC-1060	1060	9.7	6.5	~0.2	~0.99	<100	1015 - 1105	123	220
HC-800	830	9.2**	8.8	~0.2	~0.99	<300	780 - 870	135	220

*Full 1/e[2] width of the near field intensity distribution.
** 9.2 µm for long axis, 9.5 µm for short axis.

ITEM#	PRICE/m	$	£	€	RMB	DESCRIPTION
	1 to 9 m	$ 533.00	£ 367.80	€ 474,40	¥ 4,498.60	
HC-1550	10 to 49 m	$ 224.00	£ 154.60	€ 199,40	¥ 1,890.60	Hollow-Core PCF, Center Wavelength 1590 nm, 7-Cell Core
	50 m and Up	$ 122.00	£ 84.20	€ 108,60	¥ 1,029.70	
	1 to 9 m	$ 898.00	£ 619.70	€ 799,30	¥ 7,579.20	
HC19-1550	10 to 49 m	$ 525.00	£ 362.30	€ 467,30	¥ 4,431.00	Hollow-Core PCF, Center Wavelength 1570 nm, 19-Cell Core
	50 m and Up	$ 364.00	£ 251.20	€ 324,00	¥ 3,072.20	
	1 to 9 m	$ 533.00	£ 367.80	€ 474,40	¥ 4,498.60	
HC-1060	10 to 49 m	$ 224.00	£ 154.60	€ 199,40	¥ 1,890.60	Hollow-Core PCF, Center Wavelength 1060 nm, 7-Cell Core
	50 m and Up	$ 122.00	£ 84.20	€ 108,60	¥ 1,029.70	
	1 to 9 m	$ 533.00	£ 367.80	€ 474,40	¥ 4,498.60	
HC-800	10 to 49 m	$ 224.00	£ 154.60	€ 199,40	¥ 1,890.60	Hollow-Core PCF, Center Wavelength 830 nm, 7-Cell Core
	50 m and Up	$ 122.00	£ 84.20	€ 108,60	¥ 1,029.70	

Laser Diodes



- 5.6 mm and 9 mm Packages
- Wavelengths from 405 nm to 1550 nm
- Output Powers Up to 1 W
- Variety of Standard Pin Configurations

See Page 1032

Benchtop Current Controller

- Drive Currents from 20 mA to 4 A Available
- Compatible with All Laser Diode Polarities
- Constant Current and Constant Power Modes

See Page 1176