Numerical modelling of pump absorption in double-clad active fibers: Overview of recent progress

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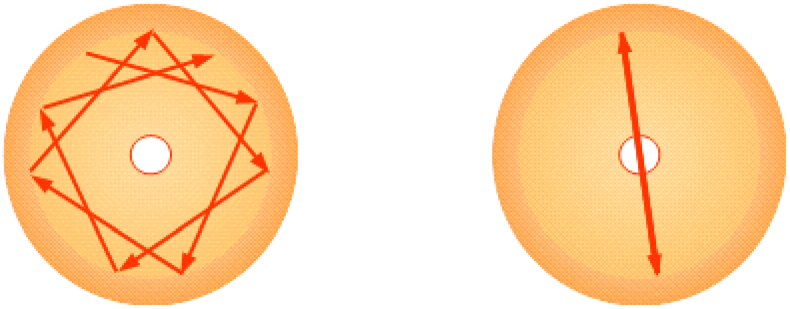
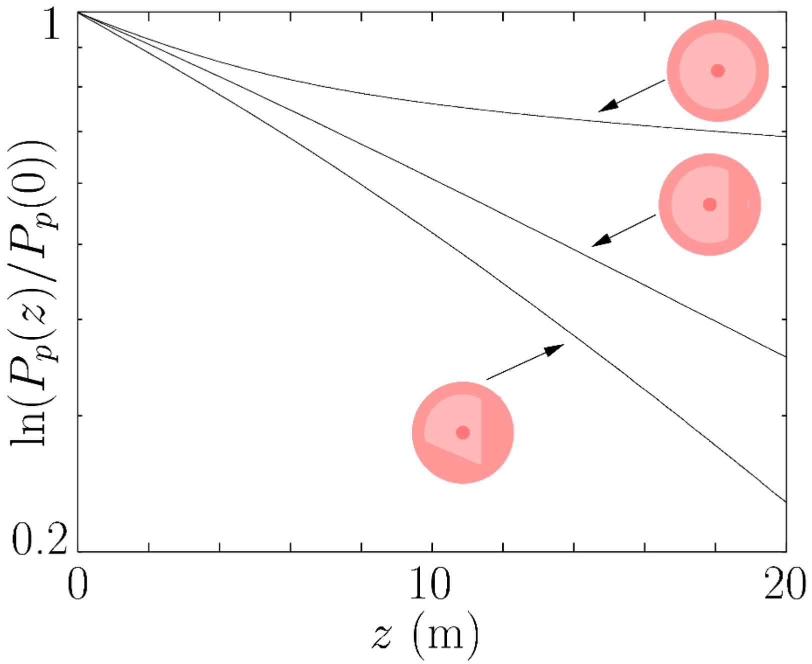
COST, Jena, September 18, 2017

Content

Introduction

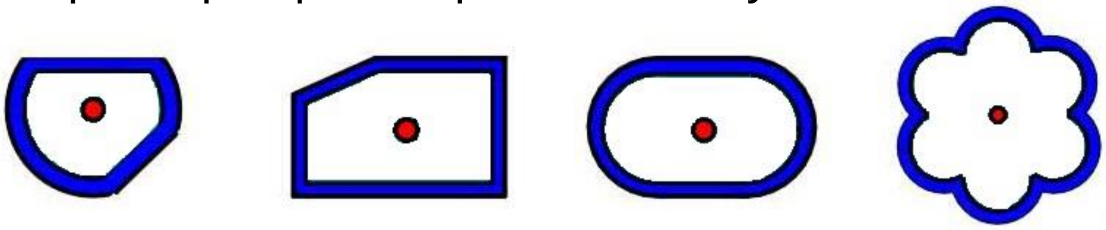
Skew rays limits transfer of pump energy to the active core





Comparison of pump absorption rate for different fiber shapes

Irregular shape of fiber cladding helps to eliminate skew rays and improve pump absorption efficiency



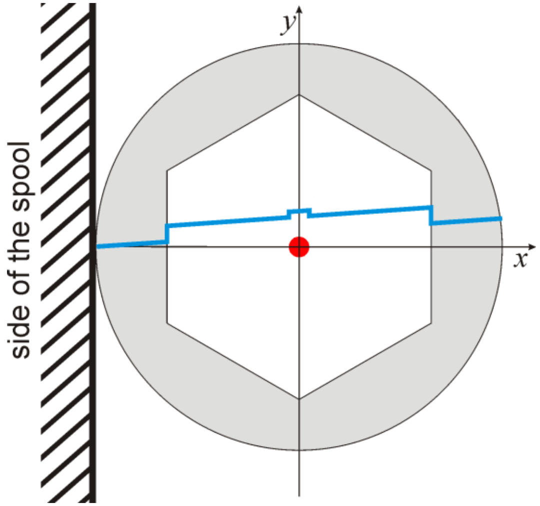
V. Doya et al., Opt. Lett., 26, 872 (2001)

Model of fiber bending

Propagation of pump radiation computed using BPM (FEM and FFT based)

Curvature due to coiling included using modified refractive index profile

$$n_{mod} = n_0 \left(1 + \frac{x}{R}\right)$$



M. Heiblum, J. Harris, *IEEE J. Quantum Electron.,* 11(2), 75 (1975).

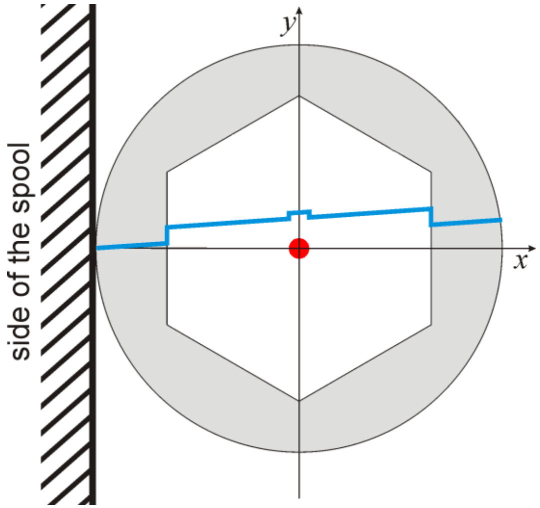
Model of fiber bending and twisting

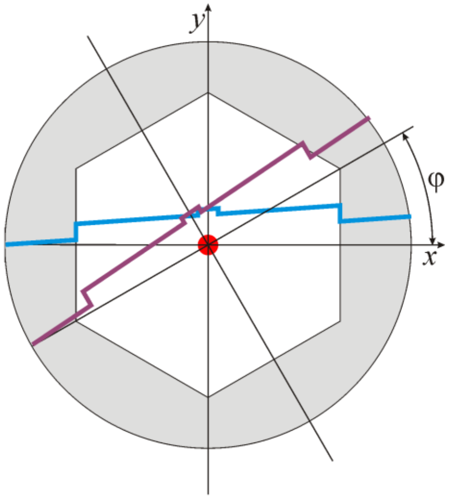
Propagation of pump radiation computed using BPM (FEM and FFT based)

Curvature due to coiling included using modified refractive index profile

$$n_{mod} = n_0 \left(1 + \frac{x}{R}\right)$$

$$n_{mod} = n_0 \left(1 + \frac{x\cos\varphi + y\sin\varphi}{R}\right)$$

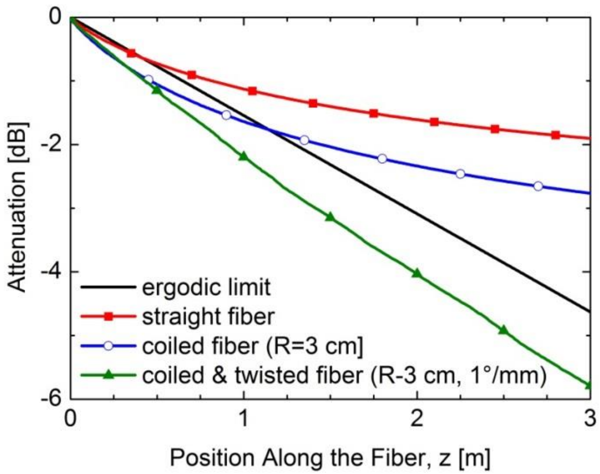




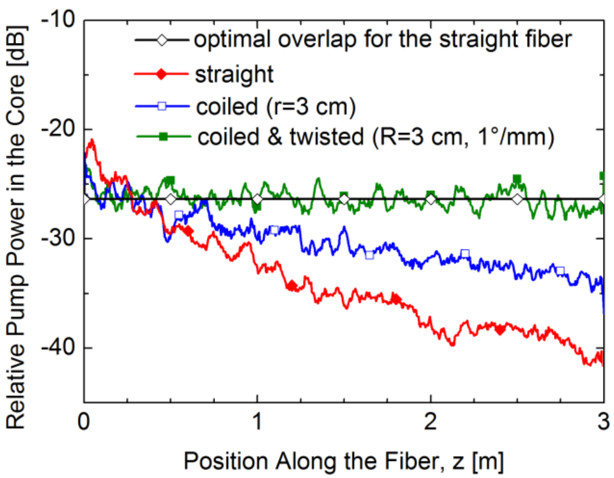
M. Heiblum, J. Harris, *IEEE J. Quantum Electron.,* 11(2), 75 (1975).

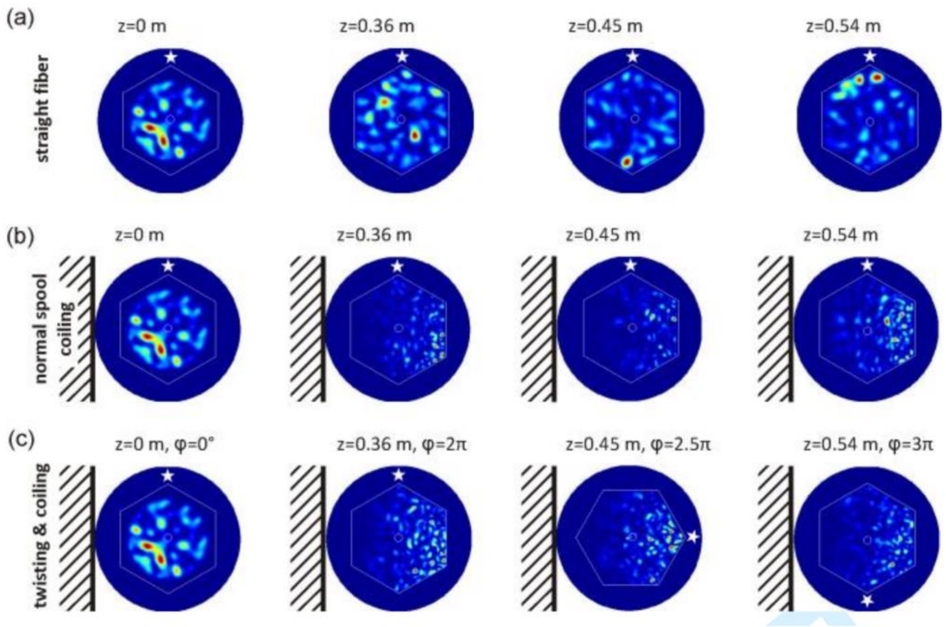
Pump absorption rate enhancement by bending and twisting

Pump absorption along the fiber



Pump power fraction in the core

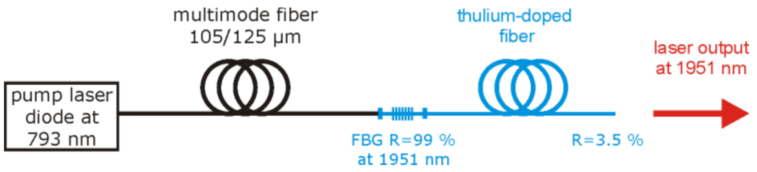


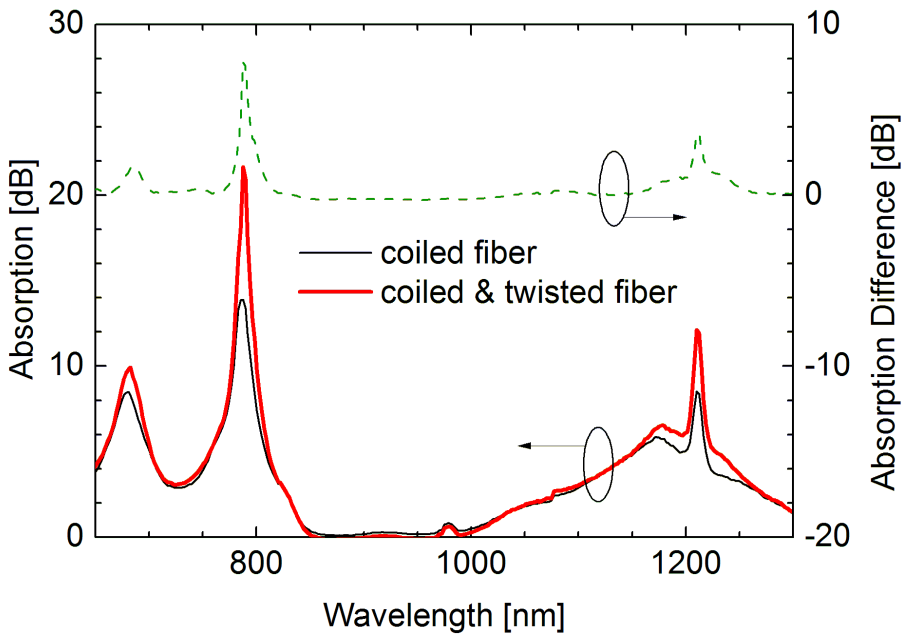


Pump field distribution in straight, bended (coiled), and simultaneously bended and twisted fiber

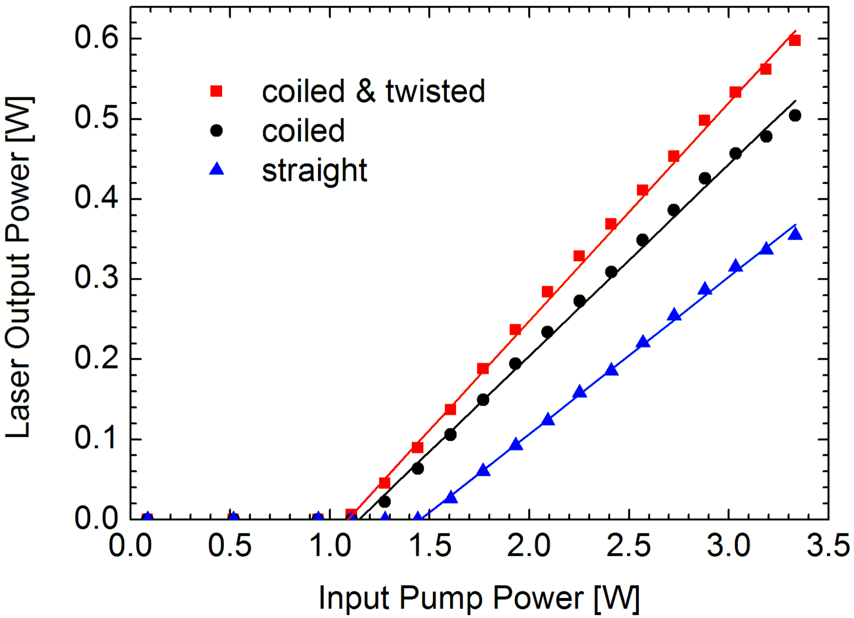
P. Koška et al., IEEE J. Sel. Top. Quantum Electron. 22(2), 55-62 (2016)

Experimental verification of enhanced pump absorption





Difference of the pump absorption between the simultaneously coiled and twisted fiber and coiled only fiber for 3 m long hexagonal fiber.



Slope Efficiency: 19.6 < 24 < 29.4 %

50 % increase of SE

Pavel Koška et al, *Optics Express,* 24(1):102 (2016) special issue of the ASSL 2015

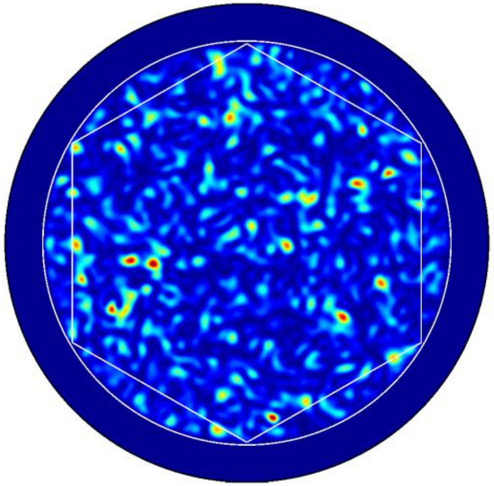
Modal spectra analysis

$$E_r(x,y) = \sum_n B_n\, u_n(x,y)$$

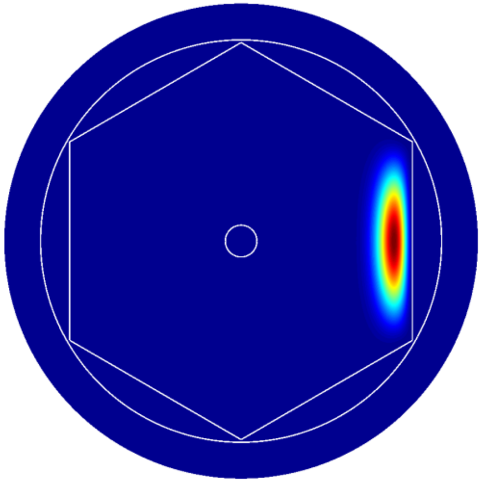
$$E(x,y,z) = \sum_m A_m\, u_m(x,y) e^{-i\beta_m z}$$

$$P(z) = \int E_r^{\,*}(x,y)\, E(x,y,z) \mathrm{d}\Omega$$

$$\Im\{P\}_{(\beta)} = \sum_m B_m^{\,*}\, A_m \delta(\beta - \beta_m)$$



Reference field

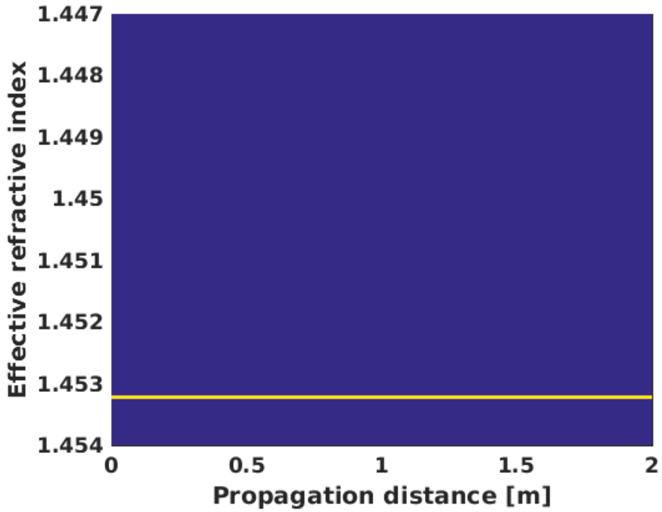


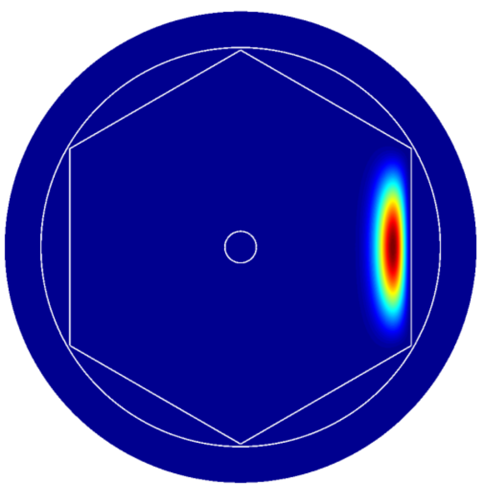
Fundamental mode field

M. D. Feit, J. A. Fleck, Applied Optics 19(7), 1154-1164 (1980).

Spectra evolution in hexagonal fiber

Modal spectra evolution in bended hexagonal fiber

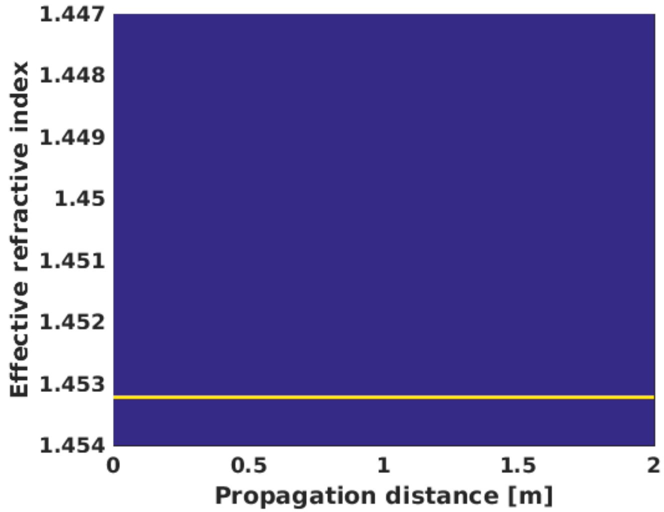




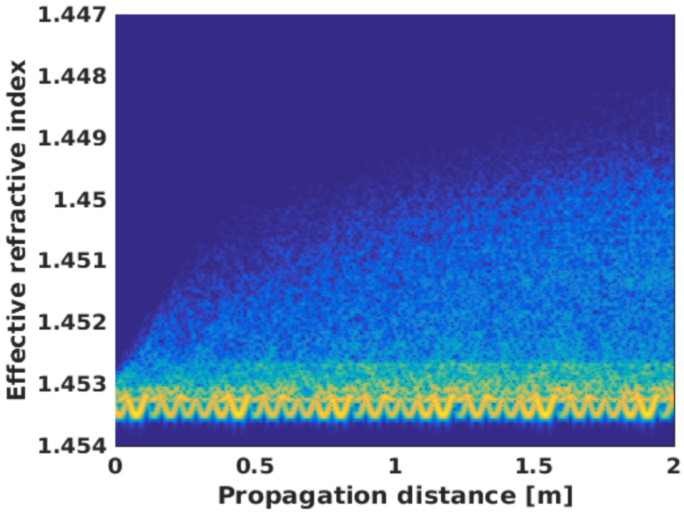
Initial fundamental mode field

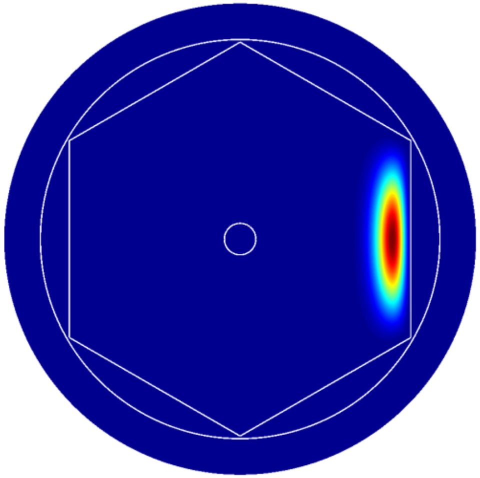
Spectra evolution in hexagonal fiber

Modal spectra evolution in bended hexagonal fiber



Modal spectra evolution in bended and twisted hexagonal fiber





Initial fundamental mode field

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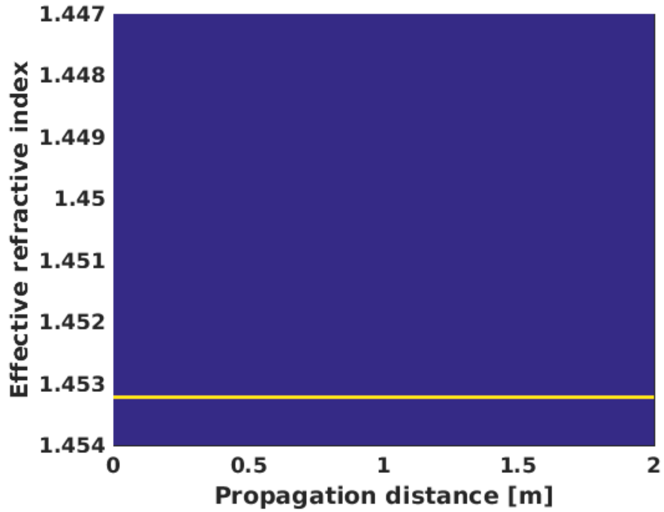
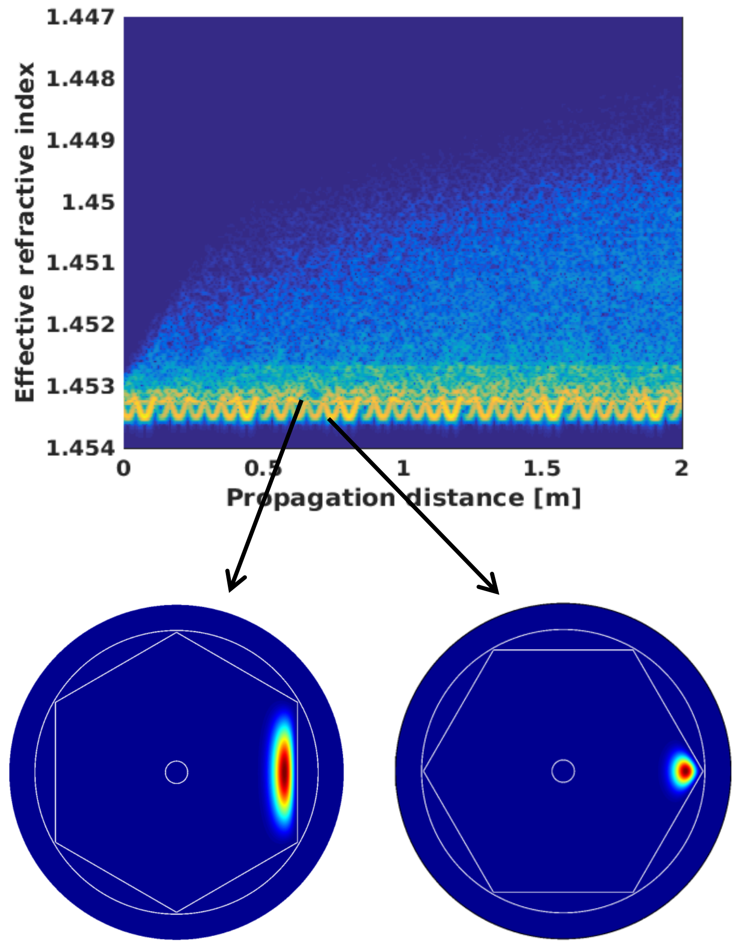
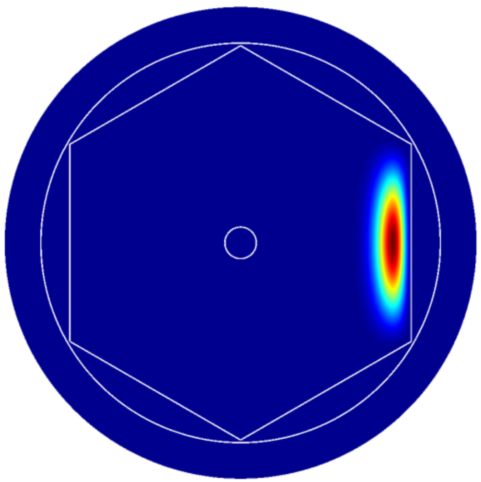
Modal spectra evolution in bended hexagonal fiber



Modal spectra evolution in bended and twisted hexagonal fiber



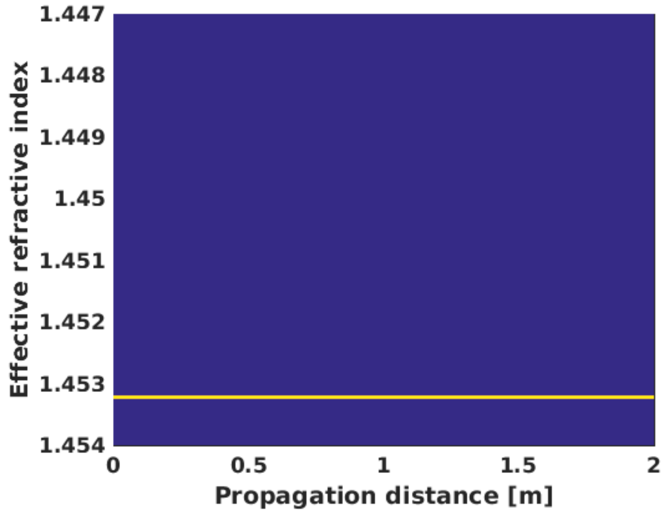
'Edge' mode *'Corner' mode*



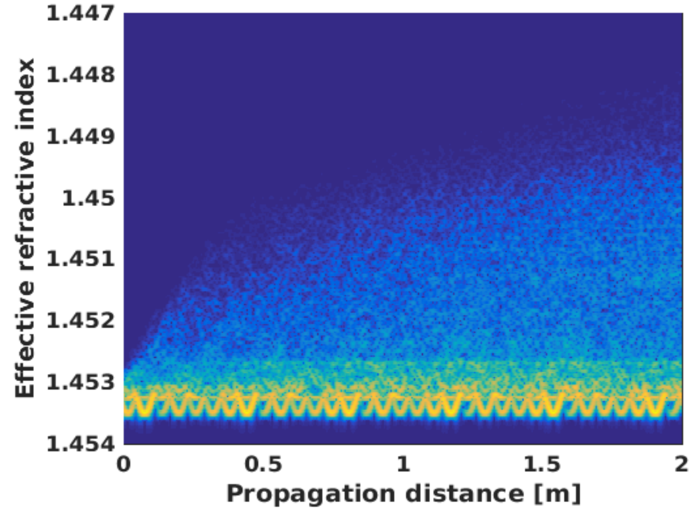
Initial fundamental mode field

Spectra evolution in circular fiber

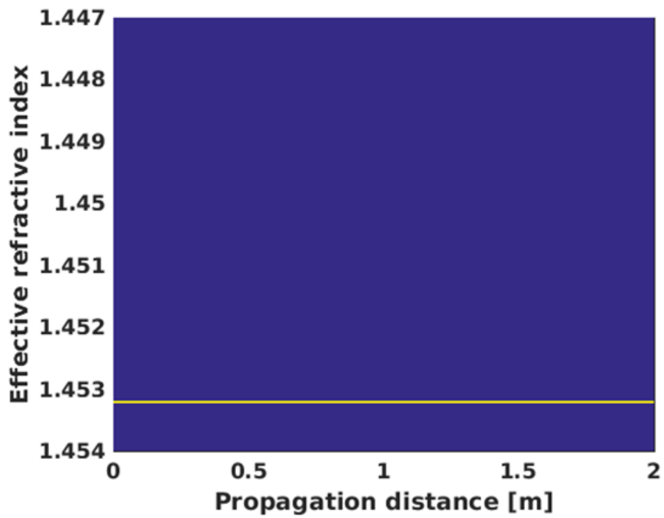
Modal spectra evolution in bended hexagonal fiber



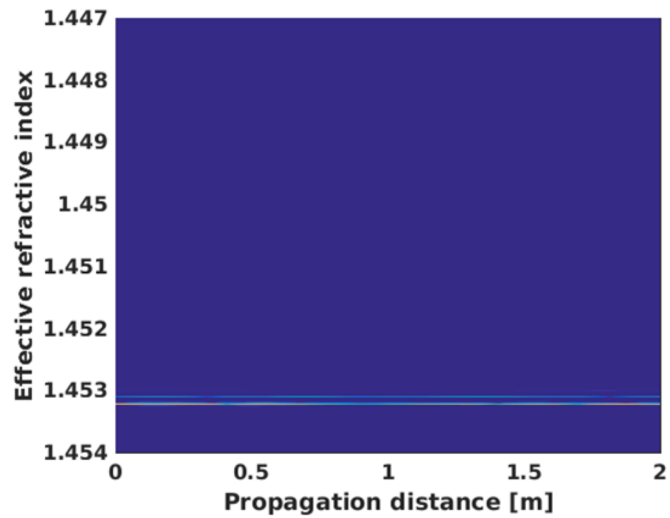
Modal spectra evolution in bended and twisted hexagonal fiber



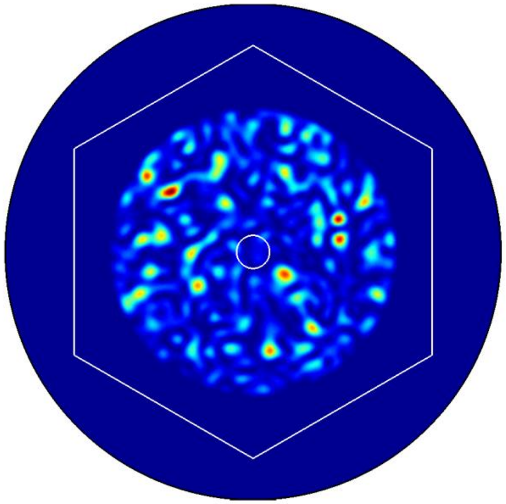
Modal spectra evolution in bended circular fiber



Modal spectra evolution in bended and twisted circular fiber



Active hexagonal Yb doped fiber parameters



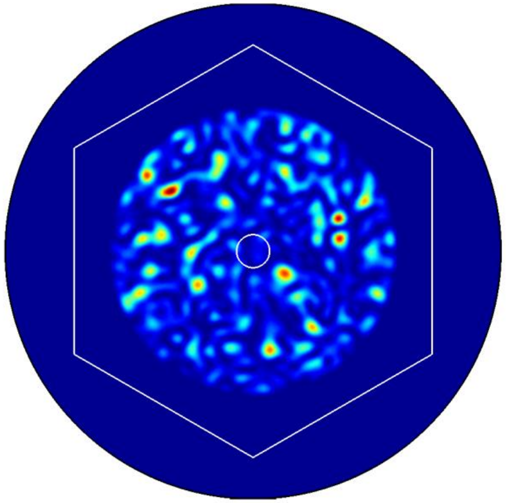
Initial field

Core diameter	12 μm
Cladding diameter (flat to flat)	130 μm
Core refractive index	1.4556
Cladding refractive index	1.4507
Coating refractive index	1.4027
Yb Concentration	4.54×10^{25} m^{-3}
Pump wavelength	975 nm
Signal wavelength	1020 nm

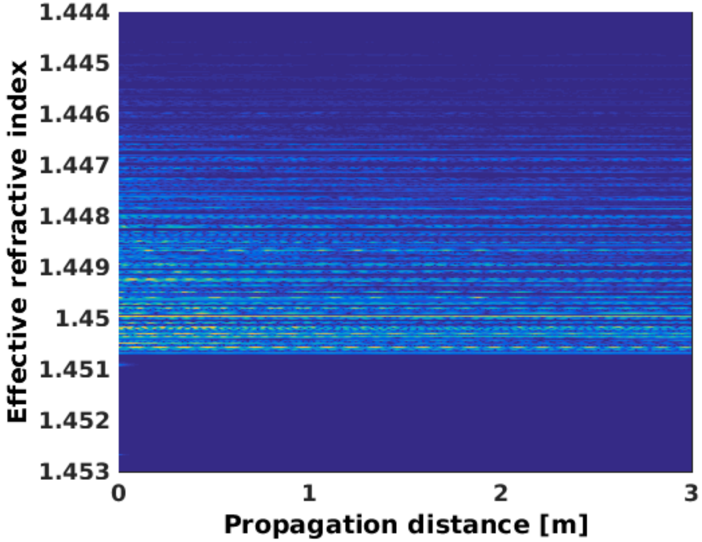
Parameters of Yb doped active hexagonal fiber

Pump spectra evolution in active hexagonal fiber

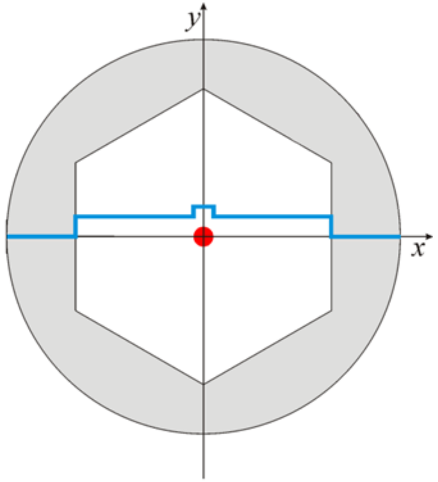
Initial field



Modal spectra evolution in straight hexagonal fiber

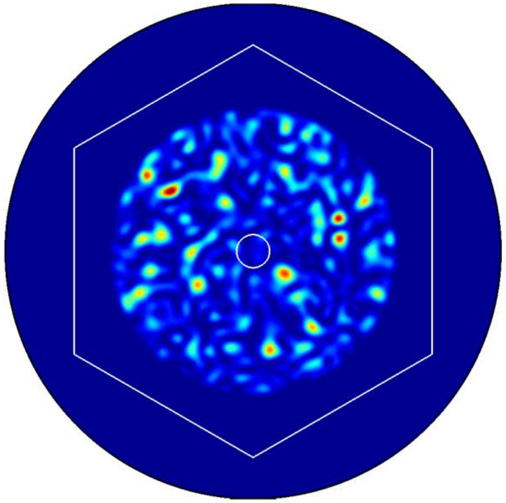


Refractive index profile in straight fiber

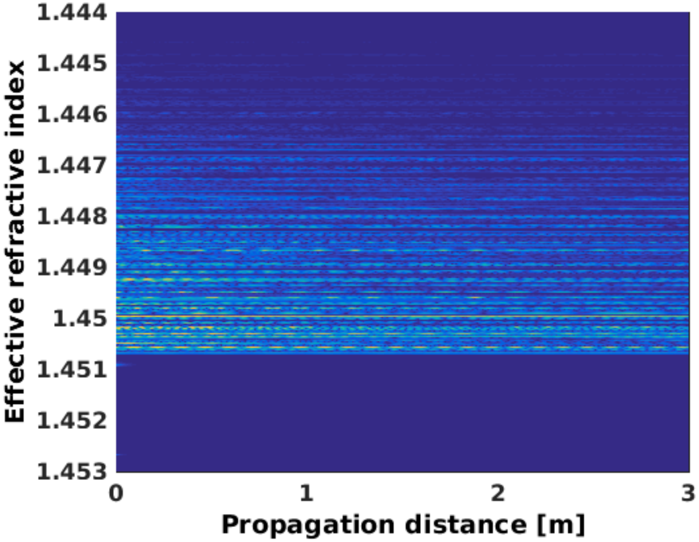


Pump spectra evolution in active hexagonal fiber

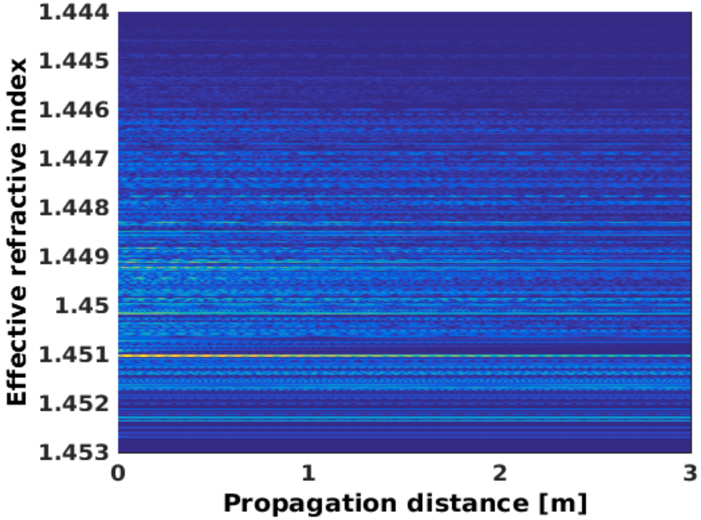
Initial field



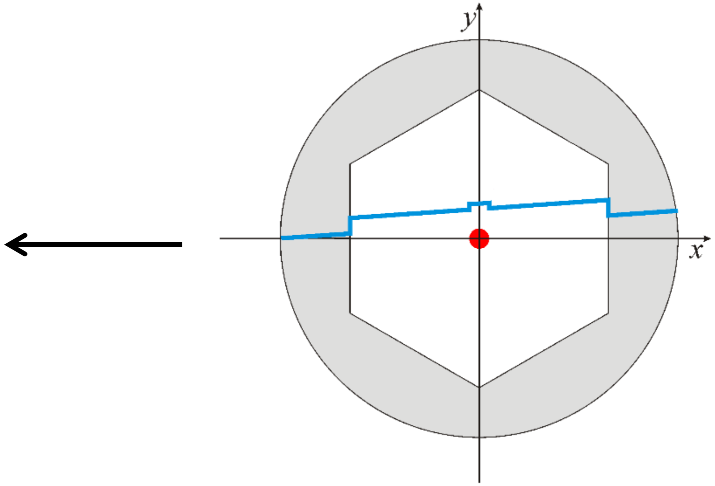
Modal spectra evolution in straight hexagonal fiber



Modal spectra evolution in bended hexagonal fiber

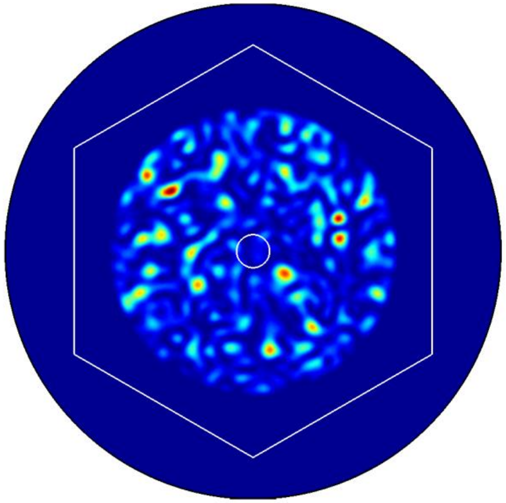


Refractive index profile in bended fiber

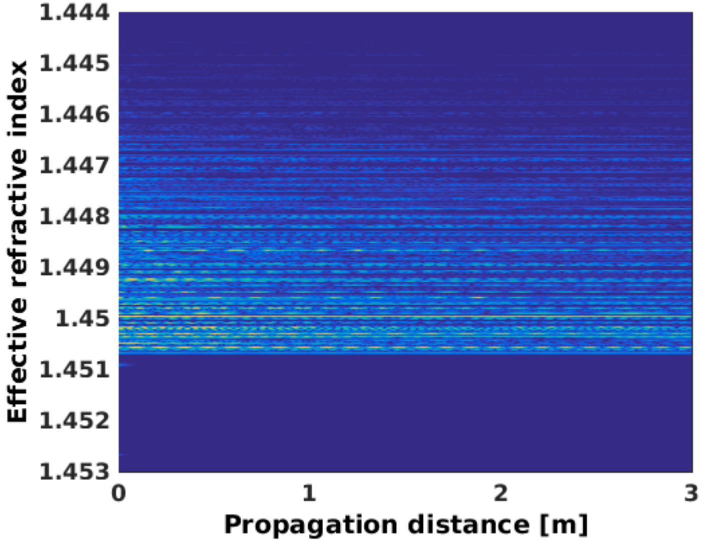


Pump spectra evolution in active hexagonal fiber

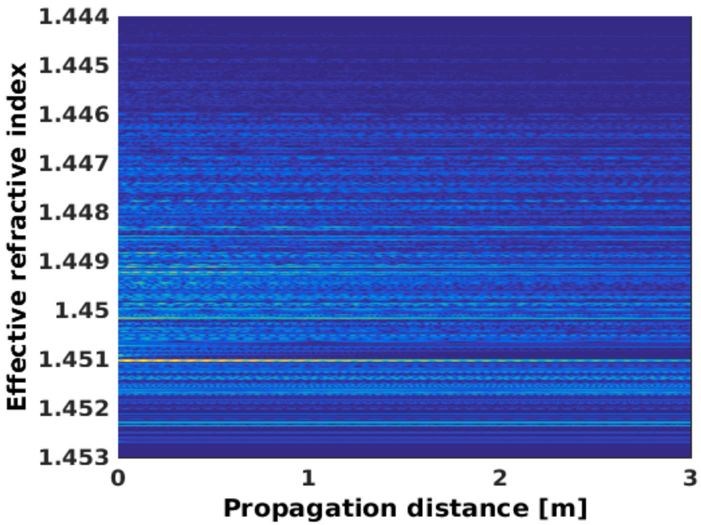
Initial field



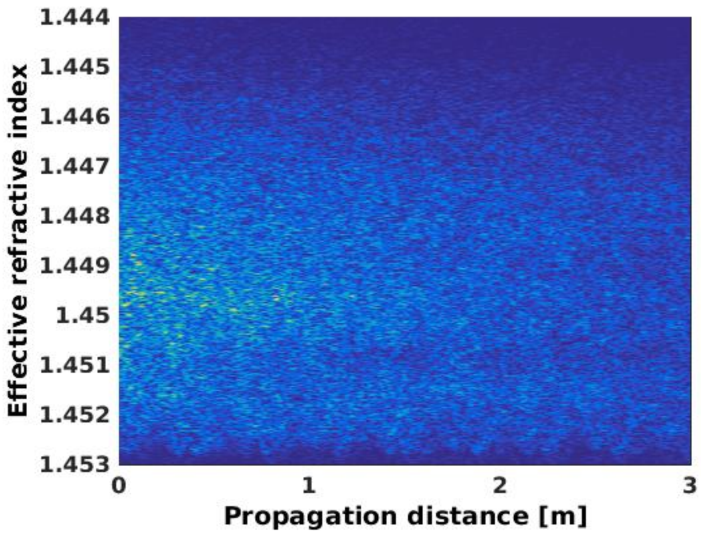
Modal spectra evolution in straight hexagonal fiber



Modal spectra evolution in bended hexagonal fiber



Modal spectra evolution in bended and twisted hexagonal fiber



Conclusions

- The effect of bending and twisting on pump field modal spectra investigated
- Bending extends allowed modal spectra range, but does not provide mode-mixing
- Simultaneous bending and twisting of circularly nonsymmetrical fibers provides mode-mixing and inherently extends modal spectra content
- Modal spectra enrichment improves pump absorption rate in double-clad active fibers

ACKNOWLEDGEMENT

This work was supported by European action COST MP 1401 AFLASER

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Důsledné užití řezů písma

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Grafy pokud možno na bílém podkladu, popisky a osy černě, hodnoty pomocí barev

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Body text Arial bold 18pt

Body text Arial regular 18pt

Důležité sdělení by nemělo být nikdy menší než 18pt

Popiska Georgia Italica 11-16pt

Popiska

[1] Autor Arial regular 10 pt., *Název je v kurzívě,* 9,(101) – číslo regular

Zápis referencí

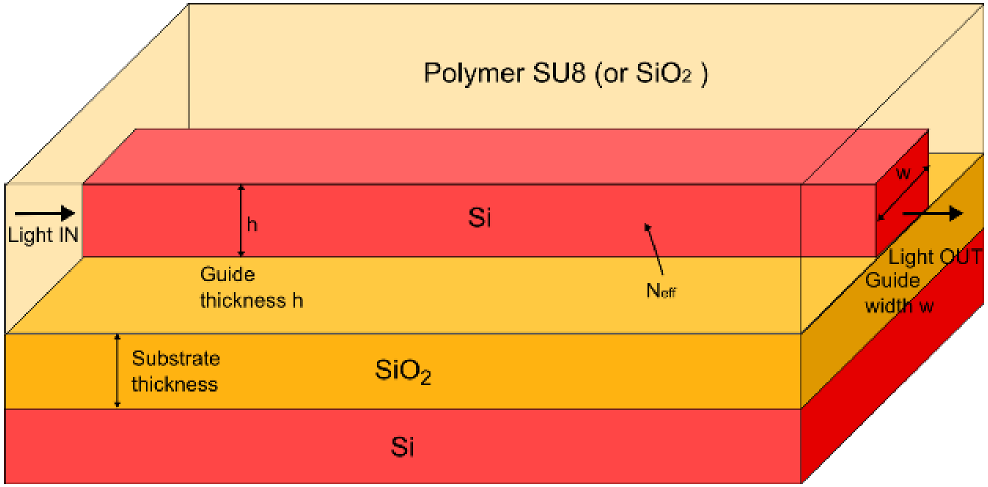
BENEFITS

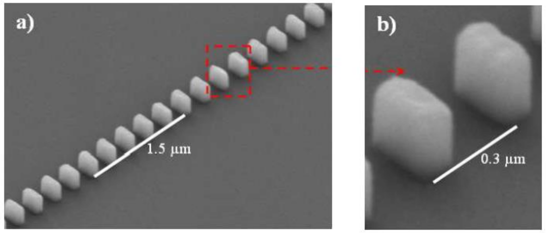
- **Důležité sdělení**

Vzor prezentace

P. Cheben, et al. (NRC Canada): a feasible way to fabricate low-index waveguides with required dispersion properties using ‘standard’ SOI technology

“Standard” photonic SOI nanowire





SEM images of the SWG straight waveguide with a 300 nm period, 250 nm width and a duty cycle of 33%.

P. J. Bock et al., *Optics Express,* 18(19), 20251 (2010).