Czech Technical University in Prague
Faculty of Electrical Engineering
Department of Telecommunication Engineering

Negative dispersion generated by introducing the curvature into the microstructured fiber

Michal Lucki
Department of Telecommunication Engineering
Faculty of Electrical Engineering
Czech Technical University in Prague
luckim1@fel.cvut.cz

INTRODUCTION

GOALS OF THIS PAPER

- To present a **modeling work** on negative dispersion
- To propose a **new method** of generating negative dispersion - done **by introducing** the controlled **curvature**
- To provide the **study** of a problem **of bending** the fiber
- To **optimize** proposed method to obtain high value of negative dispersion
- To provide the study of the **sensitivity** of negative dispersion **to the deviation** on parameters (imprecision of hole diameter or bend radius)
- To study the **bending losses**
- To propose a unique **detection method** for finding the combination with negative dispersion
- To decide about the **viability** of **applying the study of a problem** of bending the fiber into **a new dispersion compensating method**
- To **compare** my method with existing ones

KEYWORDS

- **Negative dispersion**, Photonic Crystal Fiber, radius of **curvature**, normalized hole diameter, bending losses

THE METHOD

1. **Generation the negative dispersion in Index Guiding PCFs**

   1.1 Modeling the PCF with negative dispersion caused by introducing curvature

   -study of a problem of the bend represented by the curvature radius

   - adjustment of a scientific problem to application in engineering

   -a full-vectorial finite-difference frequency-domain (FDFD) technique have been used

   -for approximation of curved interface, an index averaging technique is used for the cells

2. **Study of dispersion with respect to controlled curvature**

   2.1 Sensitivity of negative dispersion with respect to the deviation from a reference configuration

   2.2 Sensitivity of negative dispersion to the deviation of the radius of curvature

   2.3 Sensitivity of negative dispersion to the deviation of the hole diameter

   2.4 Sensitivity of negative dispersion to broken symmetry and at 1.55 µm

3. **The analysis of bending losses**

4 **Investigation of possibility of dispersion compensation by bending-induced negative dispersion**

$$\beta = \frac{2\pi n_{eff}}{\lambda_0}$$

$$v_G = \frac{d\omega}{dk}$$

$$\tau = \frac{1}{v_G}$$

$$D = \frac{d\tau}{d\lambda}$$

FDFD [11]:

$$ik_0 H_y = i\beta E_x - \frac{\partial E_z}{\partial x}$$

$$ik_0 H_z = \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y}$$

$$ik_0 H_x = \frac{\partial E_z}{\partial y} - i\beta E_y$$

$$-ik_0 \varepsilon_r E_x = \frac{\partial H_z}{\partial y} - i\beta H_y$$

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$$-ik_0 \varepsilon_r E_z = \frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}$$

$$-ik_0 \begin{bmatrix} \varepsilon_{rx} & 0 & 0 \\ 0 & \varepsilon_{ry} & 0 \\ 0 & 0 & \varepsilon_{rz} \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = \begin{bmatrix} 0 & -i\beta I & V_y \\ i\beta I & 0 & -V_x \\ -V_y & V_x & 0 \end{bmatrix} \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix}$$

$$ik_0 \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix} = \begin{bmatrix} 0 & -i\beta I & U_y \\ i\beta I & 0 & -U_x \\ -U_y & U_x & 0 \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix}$$

Update of RIP to satisfy selective reflection [13]:

$$m \cdot \lambda_B = 2 \cdot n_{eff} \cdot \Lambda \cdot \sin\theta$$

$$n_{eff1} - n_{eff2} = \left| n_{eff1} - n_{eff2} \right| = 0$$

The theory of coupling modes [6, 7]:

$$\varepsilon_1 = \psi_1 \exp^{-j\beta_1 z}$$

$$\varepsilon_2 = \psi_2 \exp^{-j\beta_2 z}$$

$$\Psi_I = b_{I1}\Psi_1 + b_{I2}\Psi_2$$

$$\Psi_{II} = b_{II1}\Psi_1 + b_{II2}\Psi_2$$

$$b_{I1} = \frac{\frac{\beta_1}{2\mu_0\omega} 2\pi \int_0^\infty \psi_I \psi_1 r dr}{P_{m1} = 1} = \frac{\int_0^\infty \psi_I \psi_1 r dr}{\int_0^\infty \psi_1^2 r dr}$$

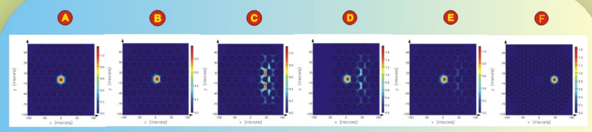
$$b_{I1} = -b_{II2} = \frac{1}{\sqrt{2}} \sqrt{1 - \frac{\Delta\beta}{2S}}$$

$$2b_{I1}b_{II1} = -2b_{I2}b_{II2} = \frac{1}{\sqrt{1 + \left(\frac{\Delta\beta}{2K}\right)^2}}$$

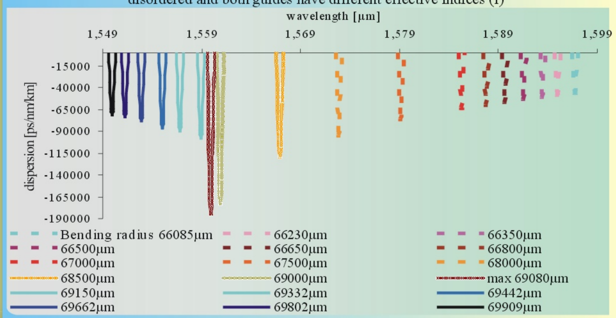
$$b_{I2} = b_{II1} = \frac{1}{\sqrt{2}} \sqrt{1 + \frac{\Delta\beta}{2S}}$$

$$K = \frac{\beta_I - \beta_{II}}{2}$$

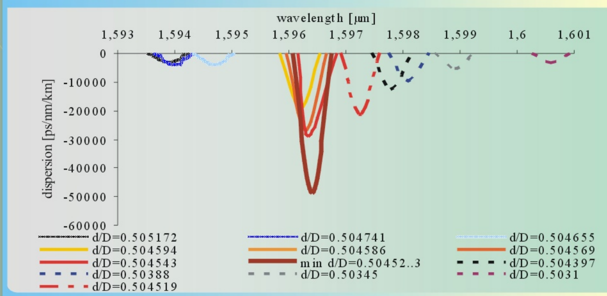
RESULTS



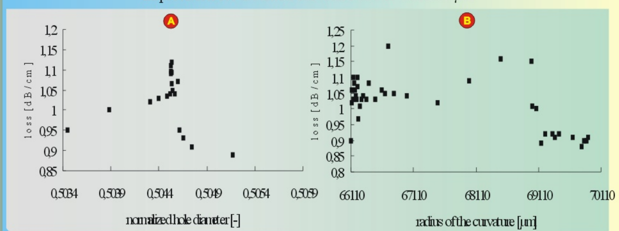
Lp01before bending (a) after bending causing **coupling at the phase-matching λ** in C-Band, core and cladding modes **guided by the same effective index** (b, c) coupling untouched for imprecision or absence of holes in the x < 0 plane, if the bending orientation is 0 rad (d) weak coupling, poor phase matching, wek nonlinearity for even small deviation of hole in the x > 0 plane (e) no possibility to introduce external core for aggregating coupled power and switch by proper bend as the curvature is disordered and both guides have different effective indices (f)



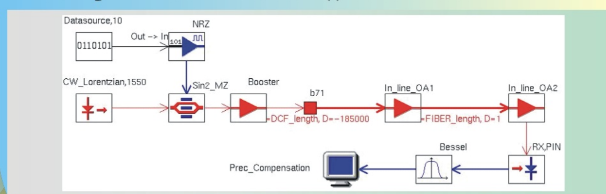
Sensitivity of nonlinear negative chromatic dispersion (CD) to deviation of bending radius with respect to λ, at assumed d/Λ = 0.50453, potential tuning of the phase-matching λ



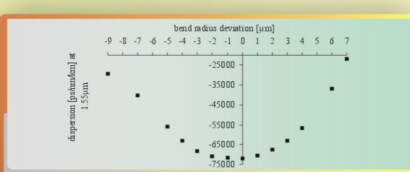
Sensitivity of negative chromatic dispersion to deviation of **normalized hole diameter** imprecision for assumed curvature of RIP 66115.7 µm



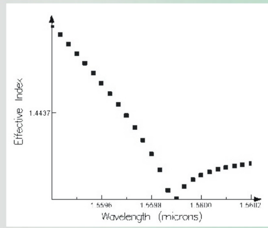
Bending losses vs. Normalized hole diameter (a) or vs. Curvature radius



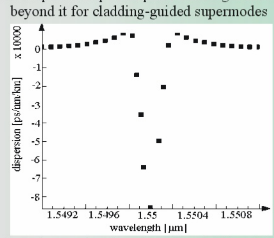
Investigated post-compensation scheme of 175-long link using investigated negative CD by TDSS method



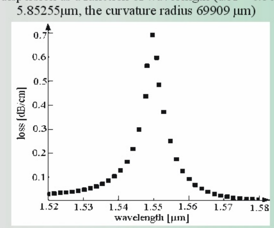
Negative CD at 1550 nm for different bending radii deviation, the minimum negative CD is at different wavelength



Nonlinear behavior of effective index of a PCF bent at radius 69080 µm, for core-guided supermode up to the phase-matching λ 1559.9 nm and beyond it for cladding-guided supermodes



Negative dispersion as a function of wavelength (d/Λ = 0.504530 d = 5.85255µm, the curvature radius 69909 µm)



Bend loss corresponding to the negative dispersion peak vs. Λ

CONCLUSIONS

Advantages

Possibility of **tuning zero-dispersion** wavelength by winding DCF onto a reel

The method does **not** require **doping in the core or** introducing **external cores** or two-step fabrication process to match external cores to existing central doped core

Curvature of the fiber **leads to negative dispersion** at certain λ for defined geometry

The highest value was **-185000 ps/nm/km,** large effective mode area **700 µm^2**

A certain **negative tolerance** is preferred to both: hole diameter deviation and radius of curvature

A **kilometer-long fiber not necessary**, disp. 375 ps/nm of distance **Prague-Brno** could be **compensated with 2 meters** of proposed compensating fiber

Disadvantages

Negative dispersion **sensitive to the hole diameter deviation**, in the area with light (amplitude scaling).

The **position** of a peak **sensitive to the curvature radius** (shifts toward another wavelength)

Loss around **1dB/cm, weak possibility of aggregation coupled power**

Necessity to make a **correction** of mode profile (**by lens**) to match the Gaussian shape for required Numerical Aperture

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