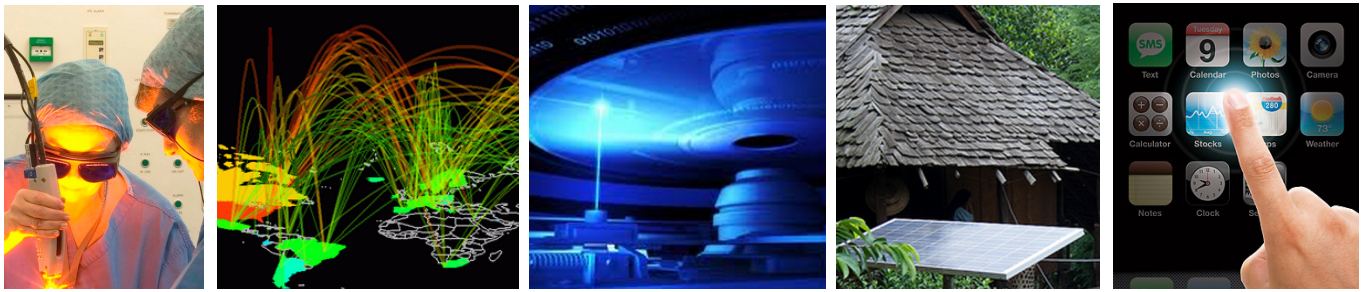
DEMETRA

Sezioni afferenti:
INFN-LNS, INFN-LNF, INFN-Roma1, INFN-TO
Responsabile nazionale: Prof. Gino Sorbello (UniCT & INFN-LNS)

Fabio Baronio, Costantino De Angelis, **Andrea Locatelli**
INFN–"Gruppo collegato di Brescia".
University of Brescia

Pavia – 10 Novembre 2015



Electromagnetic Fields and Photonics Group

http://nora.ing.unibs.it

Dipartimento di Ingegneria dell'Informazione
Università degli Studi di Brescia

Fabio Baronio, Costantino De Angelis, Andrea Locatelli,

Umberto Minoni, Daniele Modotto, Stefan Wabnitz

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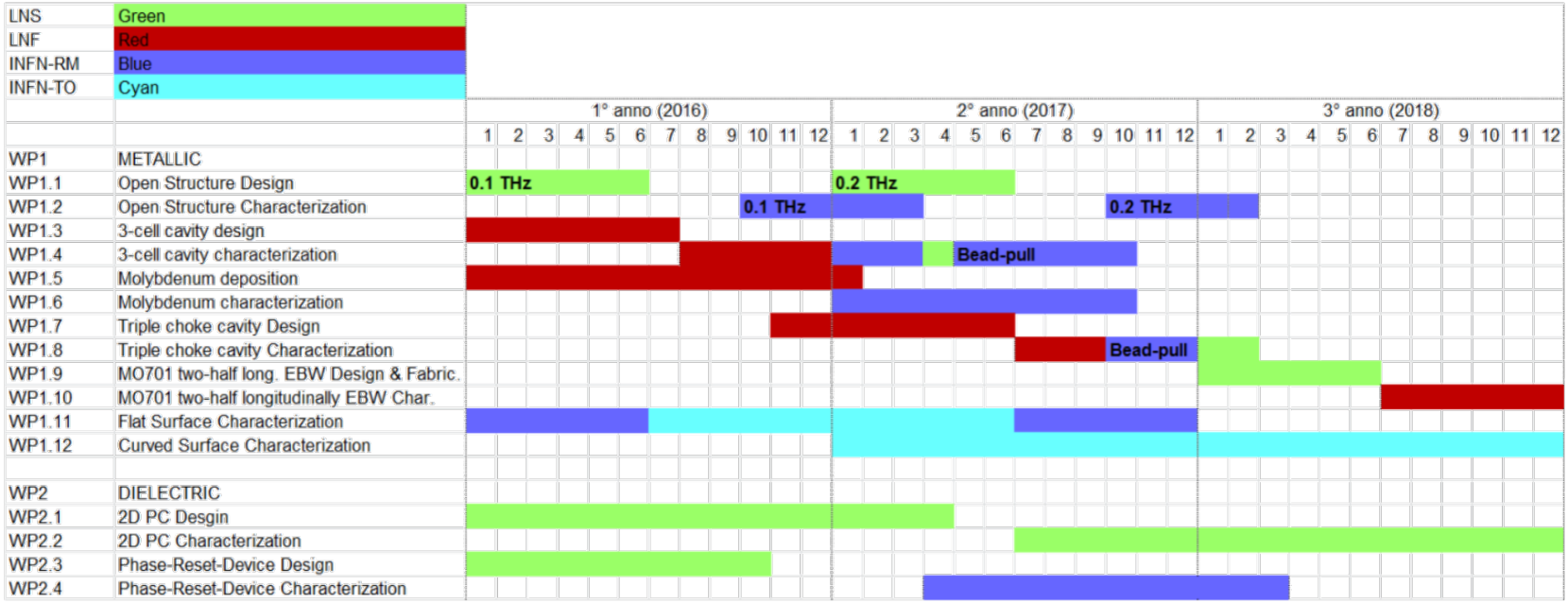
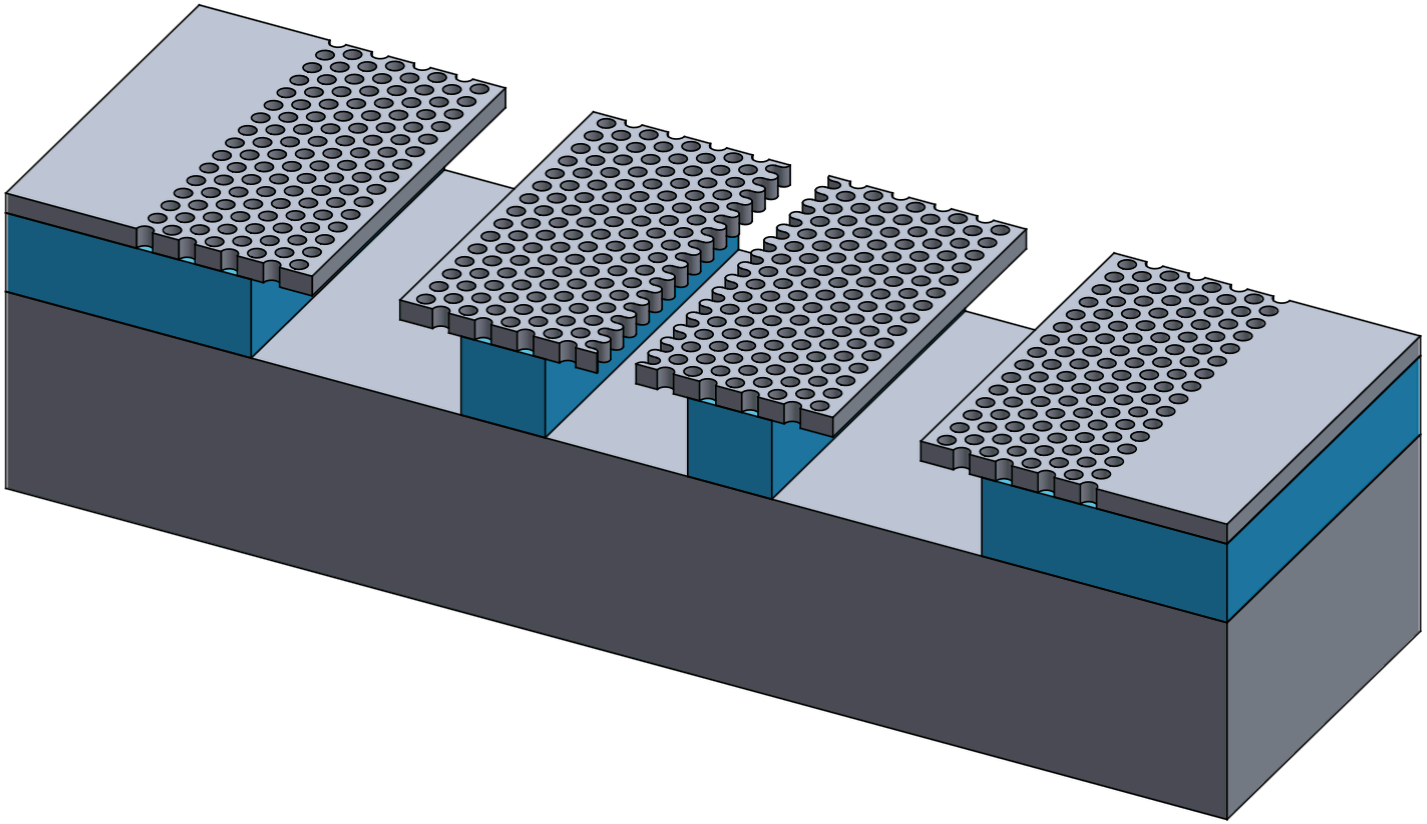


Gennaio 2016 – Aprile 2017

WP2	DIELECTRIC
WP2.1	2D PC Design. INFN–“Gruppo collegato di Brescia”

Photonic LASER driven accelerator

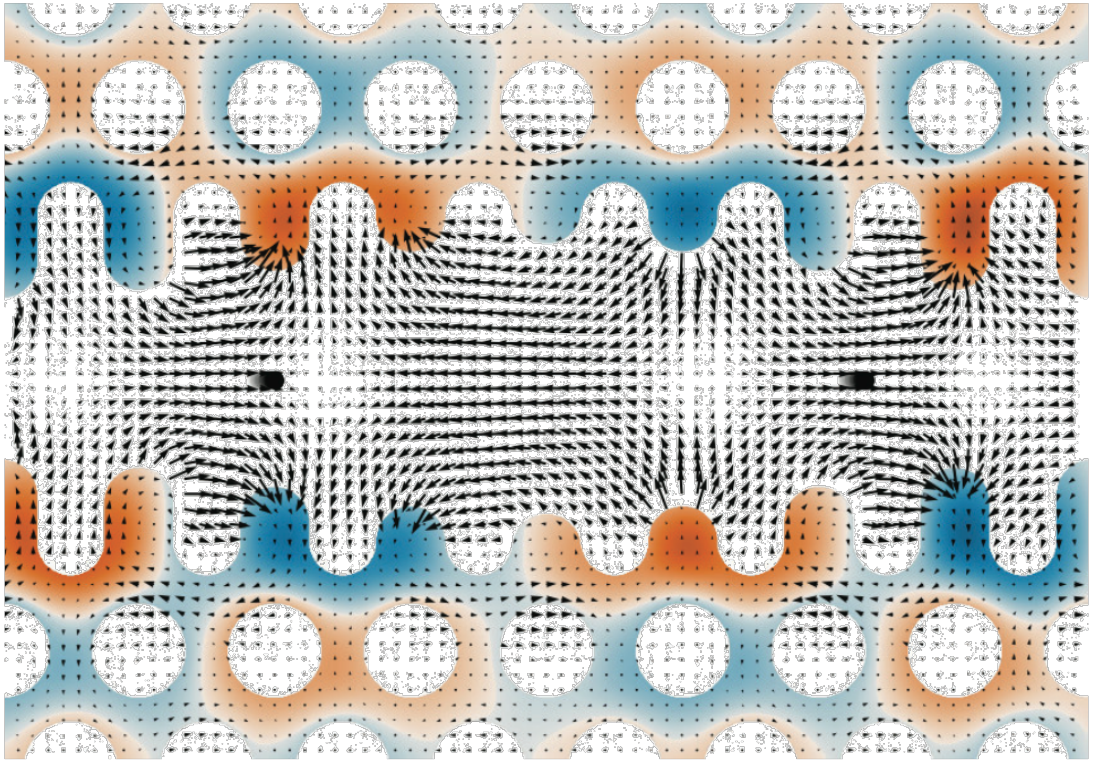


Single-layer accelerator. Gray material is silicon and blue material is a low dielectric material.

B. Naranjo, M. Ho, P. Hoang, S. Putterman, A. Valloni and J. B. Rosenzweig

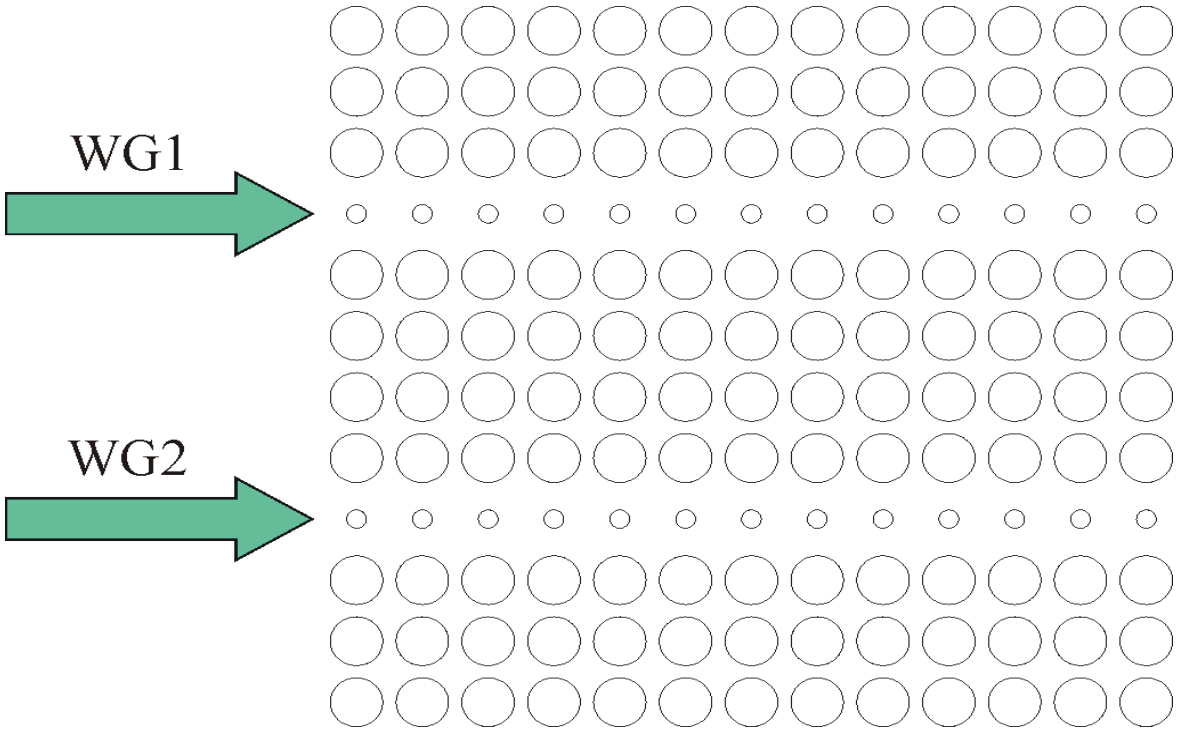
UCLA Dept. of Physics and Astronomy
Los Angeles, CA 90095-1547, USA

Photonic LASER driven accelerator



Accelerator eigenmode having both transverse focusing and longitudinal acceleration. Arrows indicate electric field and shades indicate magnetic field in silicon.

Cristalli Fotonici



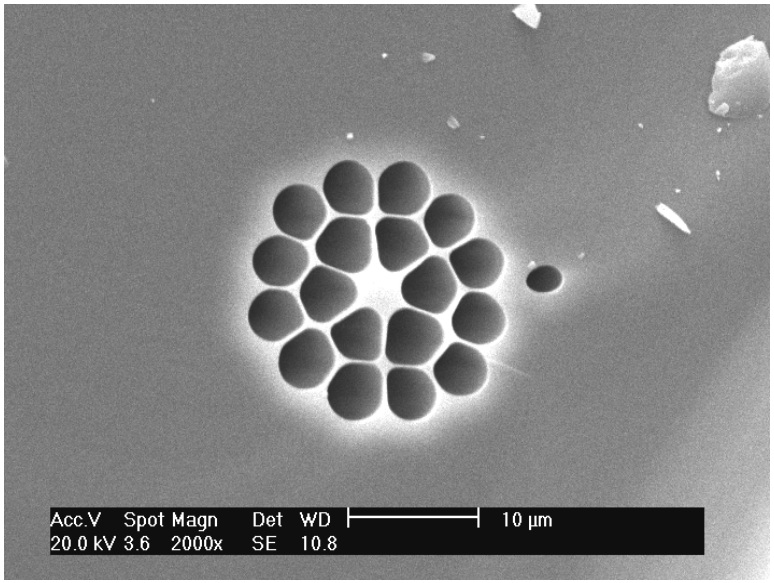
La periodicità induce bande di frequenza proibite

L'inserimento di difetti nel reticolo localizza il campo nei pressi degli stessi

Strutture complesse: necessità di metodi numerici

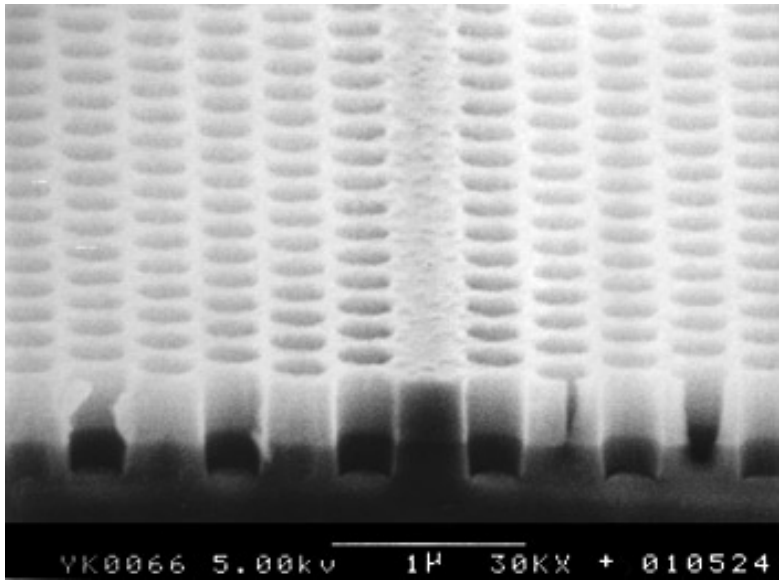
Cristalli Fotonici

Fibra a cristallo fotonico



- Confinamento maggiore
- Dispersione arbitraria

Guida a cristallo fotonico

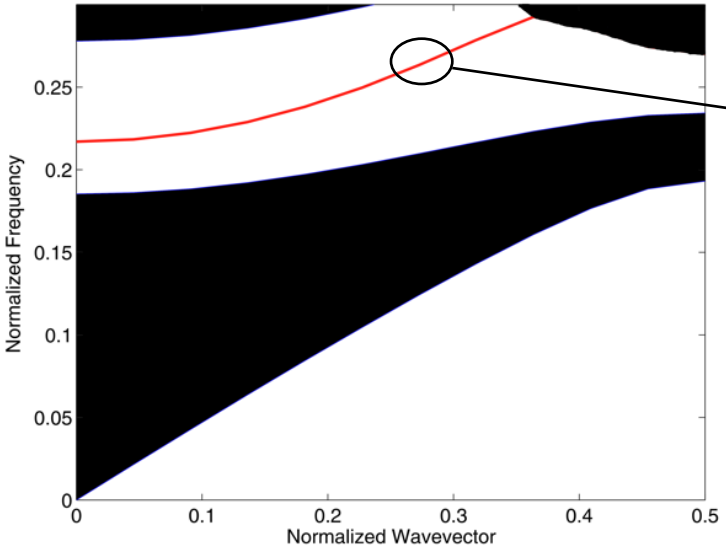


- Raggi di curvatura minori
- Dispositivi fotonici integrati

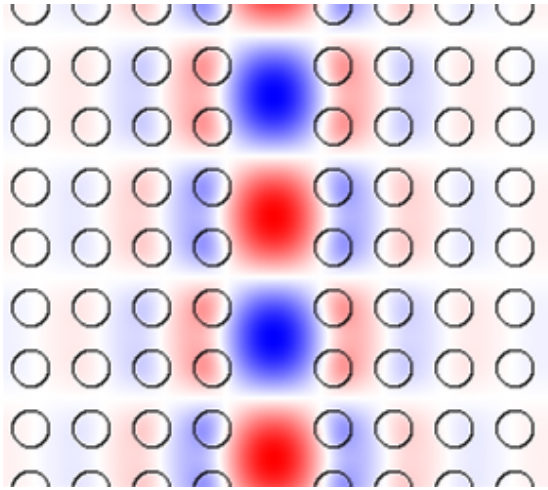
Cristalli Fotonici: Funzionamento

- La periodicità induce bande di frequenza proibite
- L'inserimento di difetti nel reticolo localizza il campo nei pressi degli stessi
- Strutture complesse: necessità di metodi numerici

Diagramma a bande



Modo guidato (Ez)

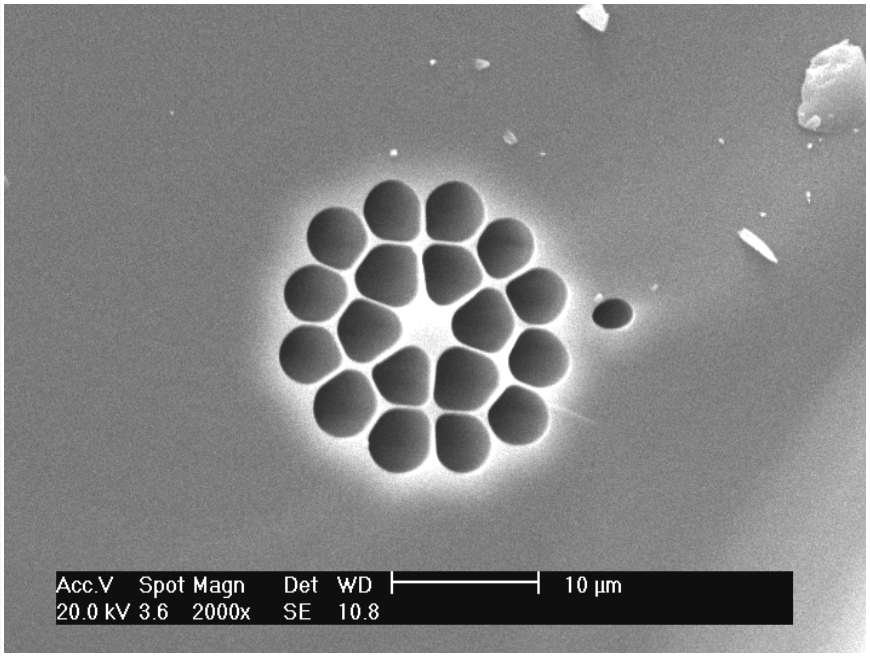


Introduzione

- Le guide a cristallo fotonico consentono di ingegnerizzare la relazione di dispersione dei modi guidati
- Velocità di fase e velocità di gruppo “accordabili”
- Concetto chiave nelle interazioni a più onde e nel phase matching (ottica non lineare e amplificatori parametrici)
- I metodi numerici sono strumento insostituibile
  - MIT Photonic Bands package (MPB)
  - COMSOL
  - CST
  - In house developed codes (FEM)

Esempio: PCF COST exercise (1)

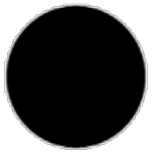
SEM photo



Extracted profile

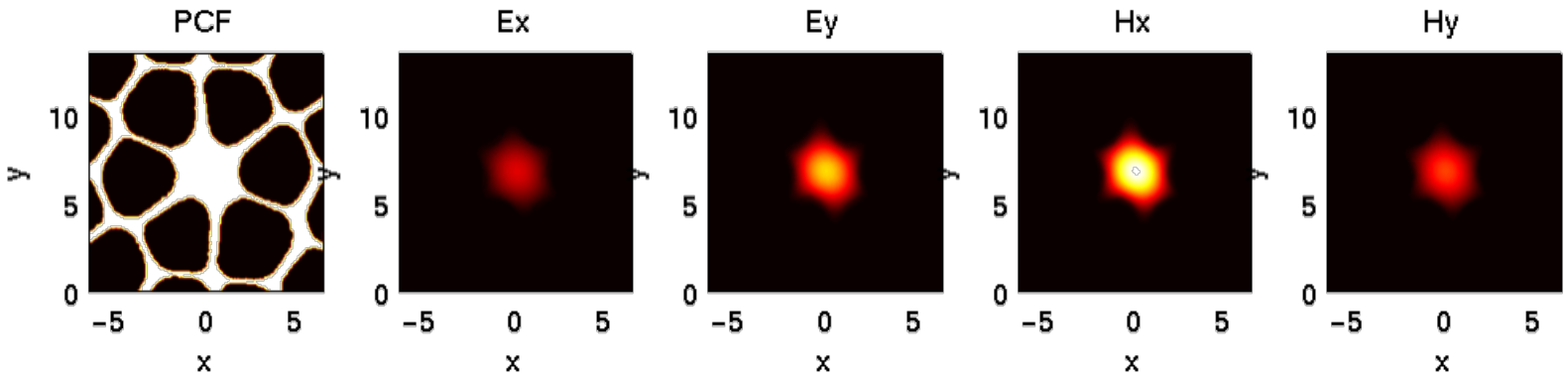
Rough model

D ~ 3.4 µm

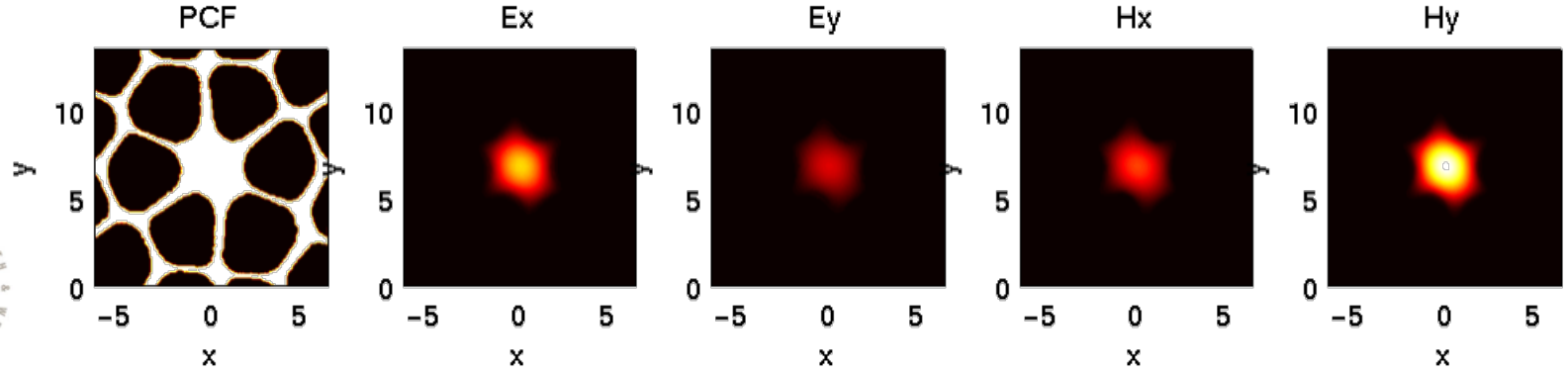


PCF COST exercise (2)

1st mode

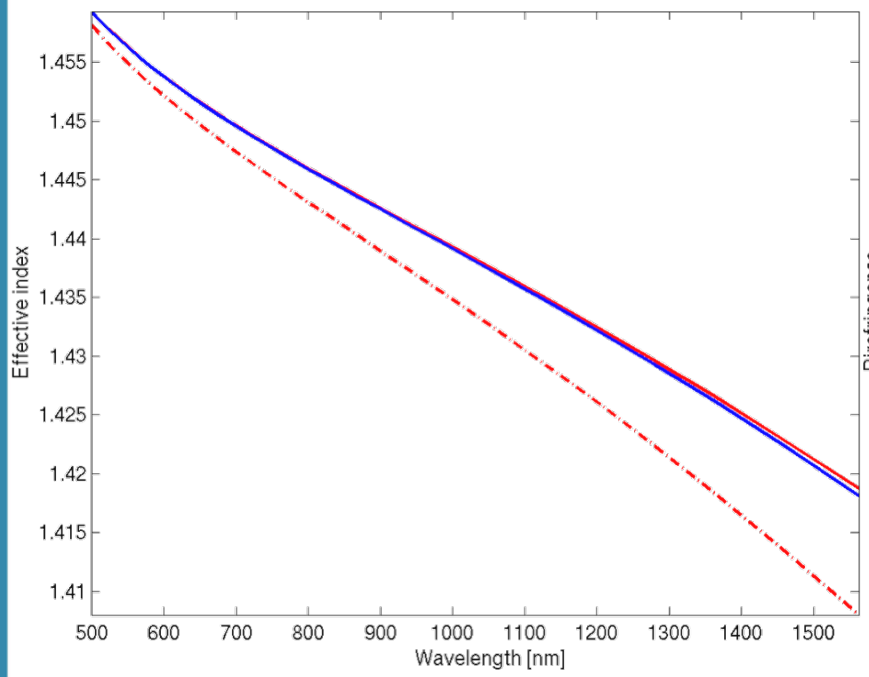


2nd mode



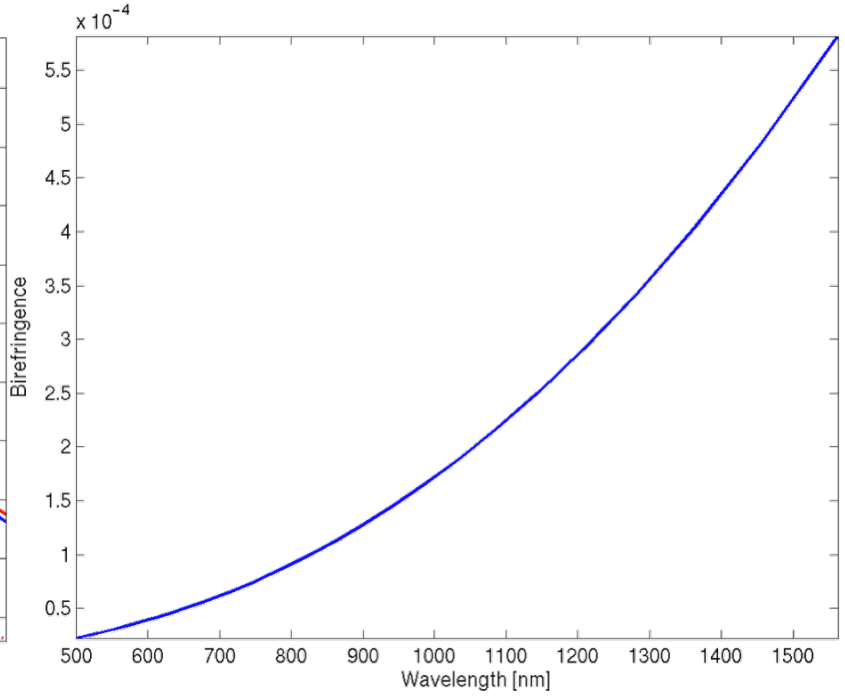
PCF COST exercise (3)

Effective indices



Solid: 1st mode, real PCF
Dash-dotted: 1st mode, rough model
Solid: 2nd mode, real PCF

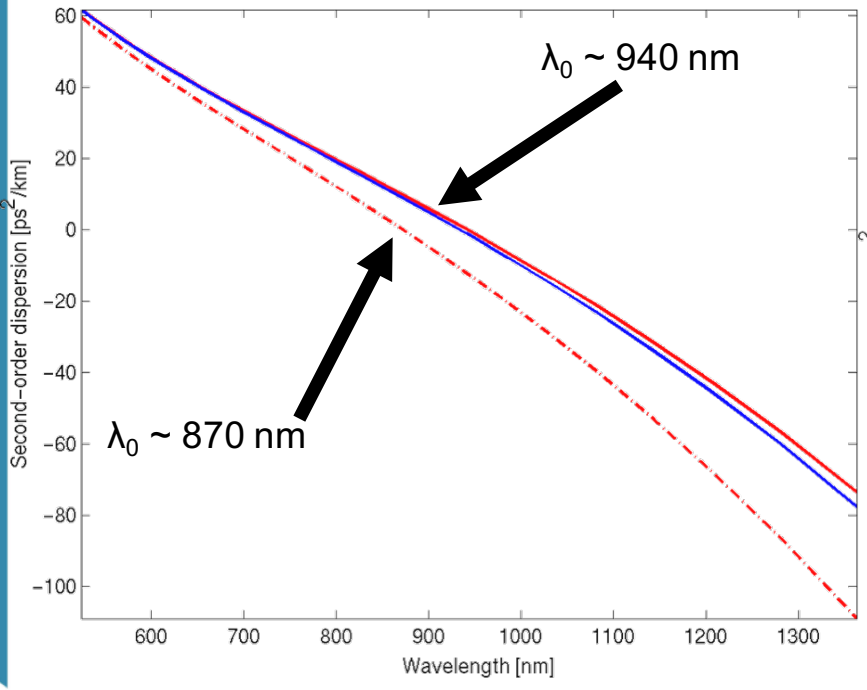
Birefringence



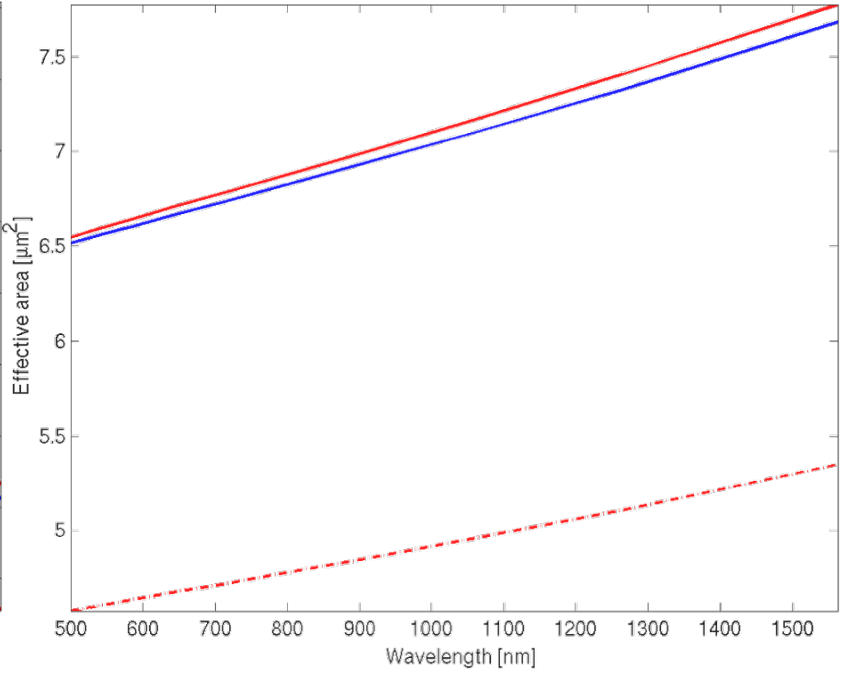
Solid: real PCF

PCF COST exercise (4)

Second-order dispersion



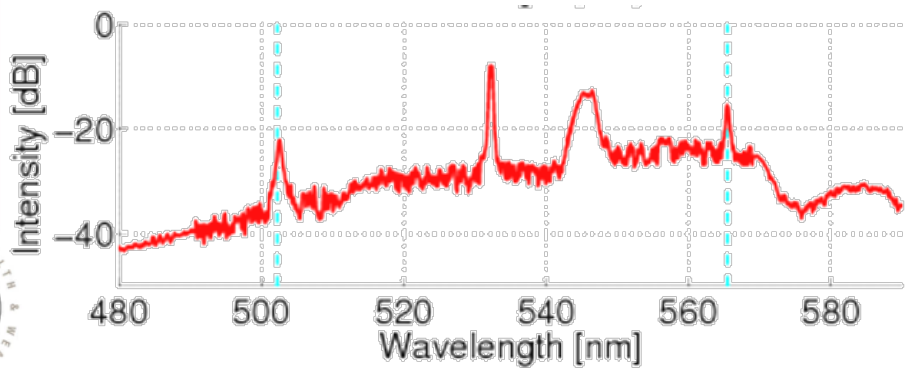
Effective area

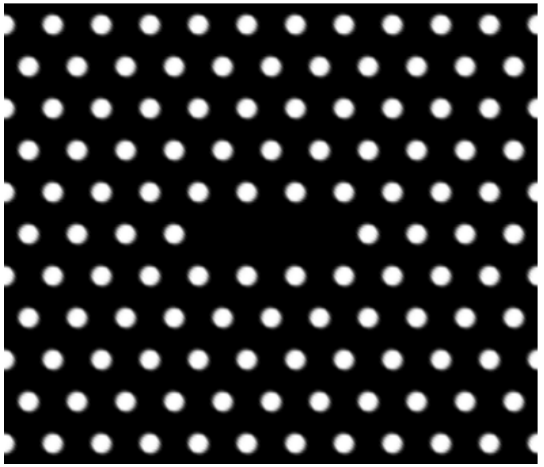


Solid: 1st mode, real PCF
Dash-dotted: 1st mode, rough model
Solid: 2nd mode, real PCF

High-birefringent fiber (1)

- Triangular lattice, pitch 1.04 µm, holes diameter 0.42 µm, 3 removed holes
  - LPUB group: experimental and numerical study of modulational instability in PCFs
    - Key parameters: β_2 and β_4

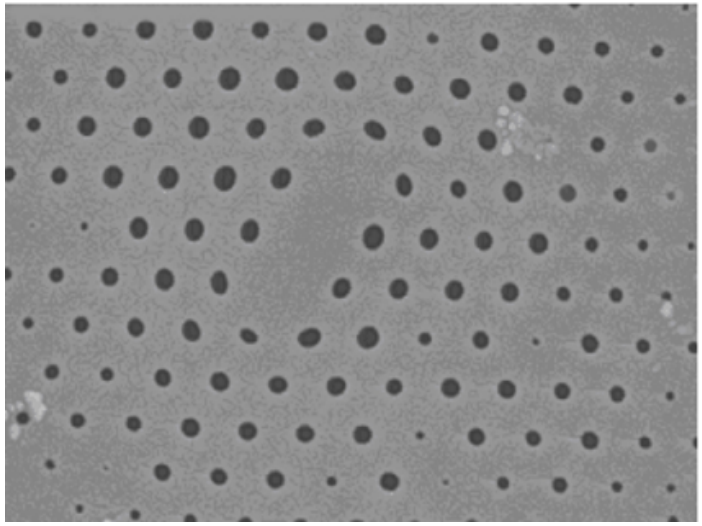




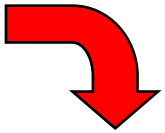
High-birefringent fiber (2)

- Extracted refractive index profile

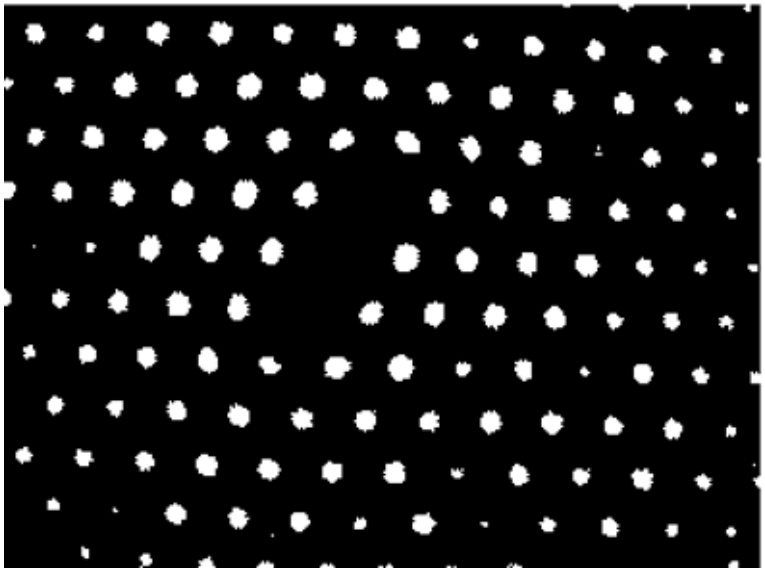
SEM photo



(Fabricated by Lublin University, SEM image from Wroclaw University)

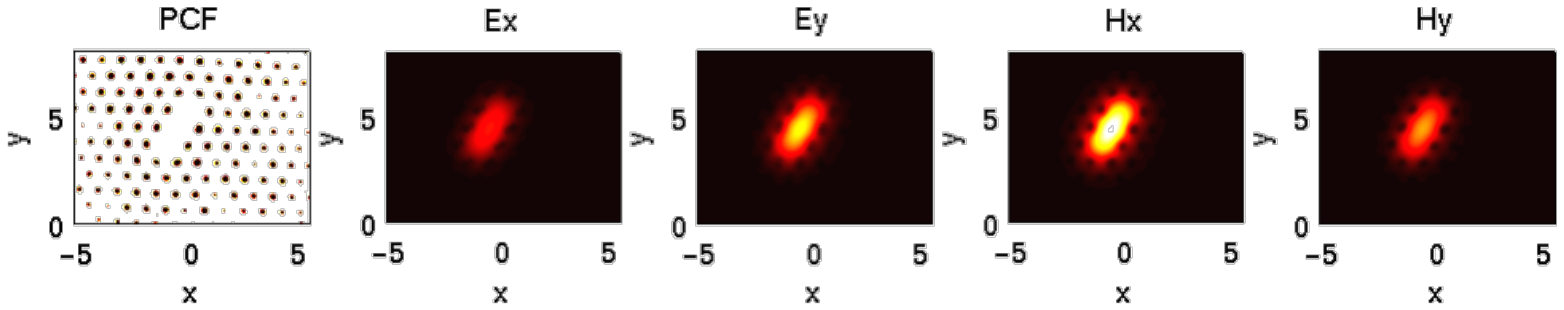


MPB input profile

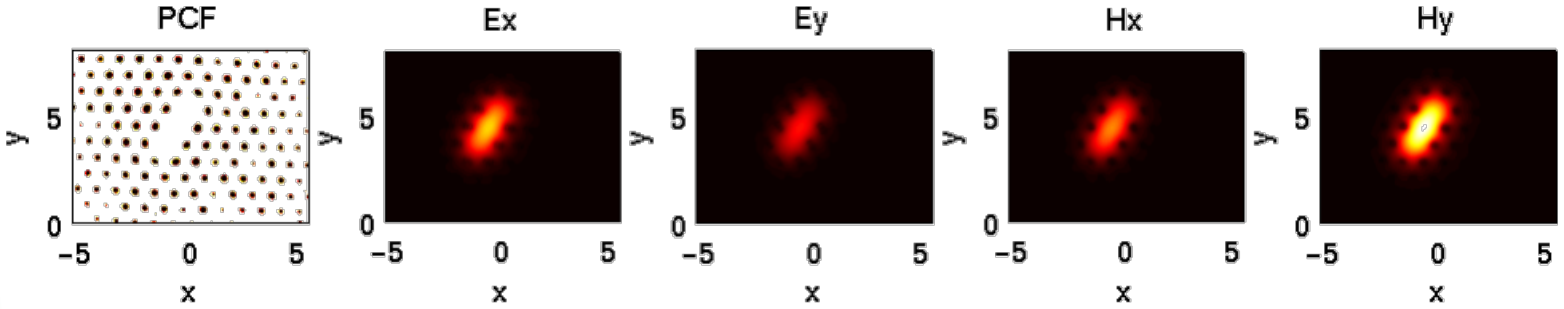


High-birefringent fiber (3)

1st mode

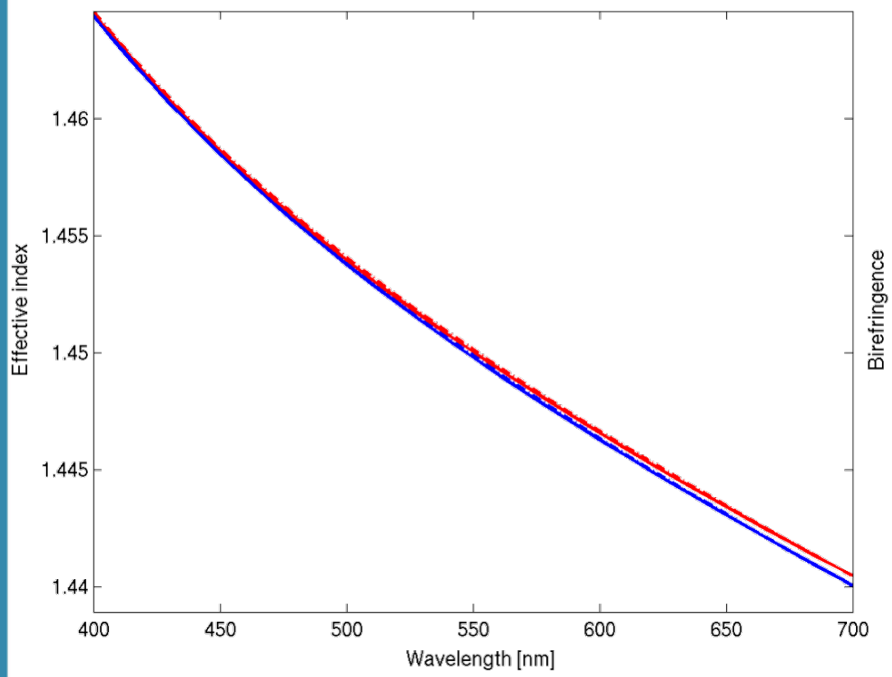


2nd mode



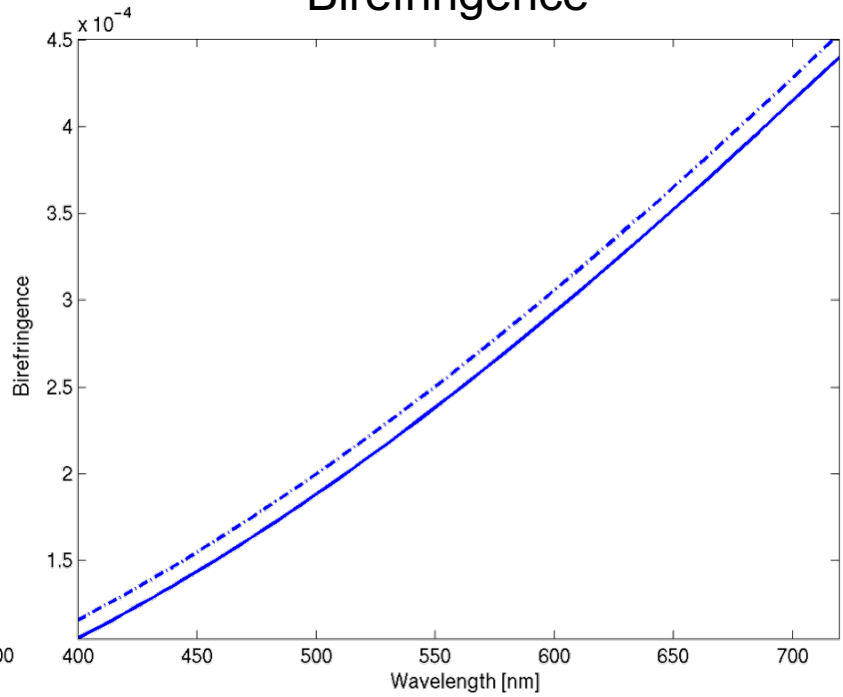
High-birefringent fiber (4)

Effective indices



Solid: 1st mode, real PCF
Dash-dotted: 1st mode, ideal PCF
Solid: 2nd mode, real PCF
Dash-dotted: 2nd mode, ideal PCF

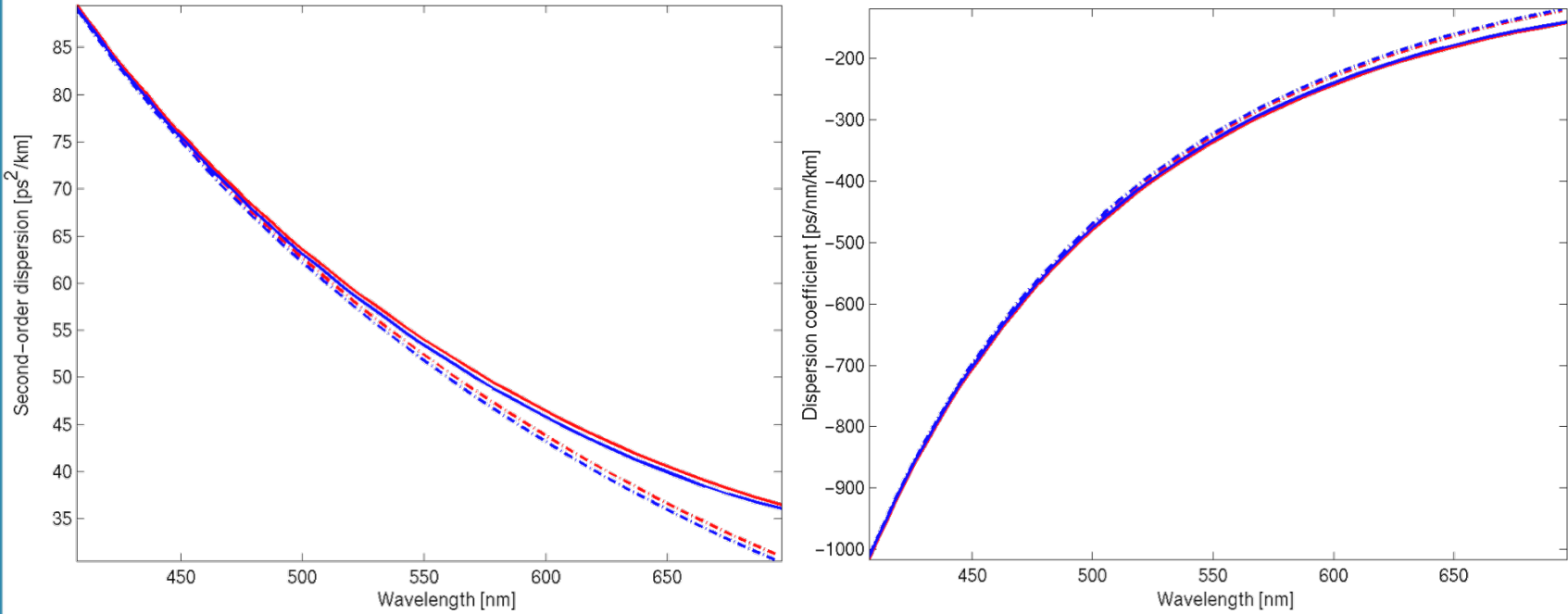
Birefringence



Solid: real PCF
Dash-dotted: ideal PCF

High-birefringent fiber (5)

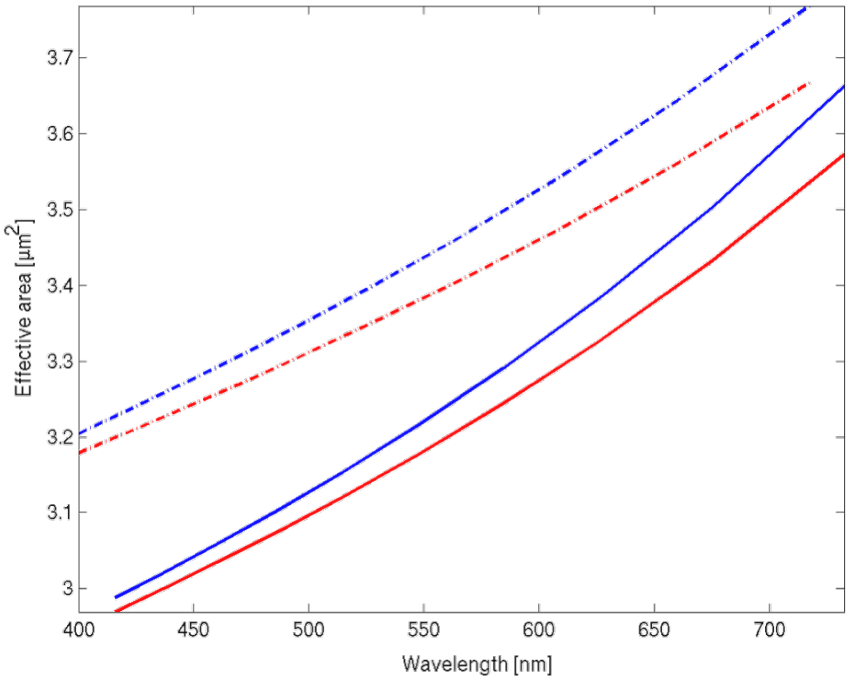
Second-order dispersion



Solid: 1st mode, real PCF
Dash-dotted: 1st mode, ideal PCF
Solid: 2nd mode, real PCF
Dash-dotted: 2nd mode, ideal PCF

High-birefringent fiber (6)

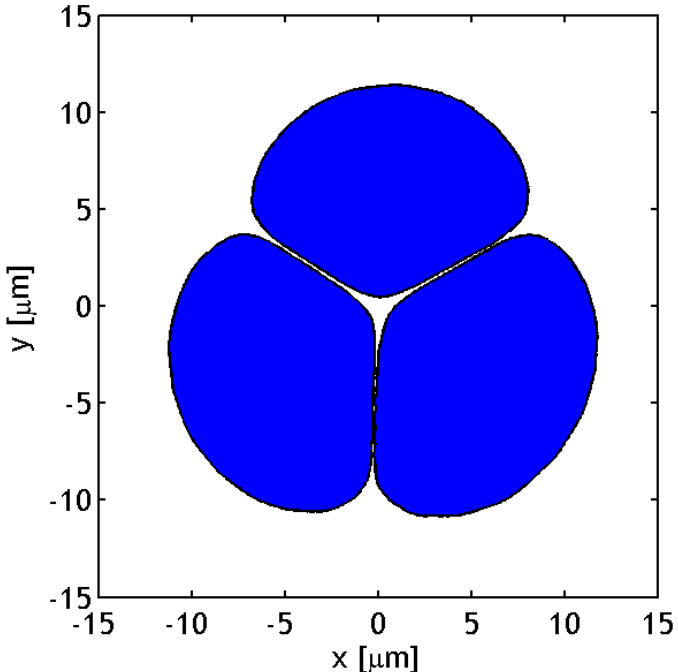
Effective area

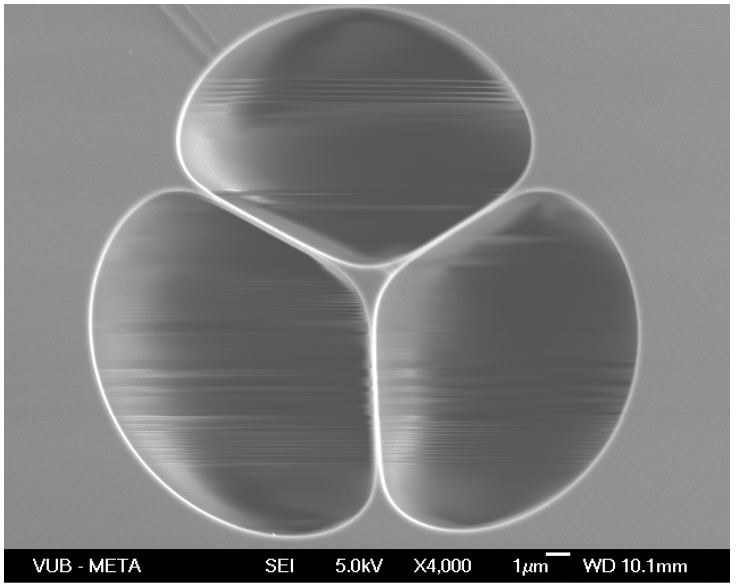


Solid: 1st mode, real PCF
Dash-dotted: 1st mode, ideal PCF
Solid: 2nd mode, real PCF
Dash-dotted: 2nd mode, ideal PCF

Exercise definition

- Starting point: thresholding of SEM images, edge detection, spline fit
  - Black lines: edges of the air holes
  - Blue regions: air
  - White regions: silica

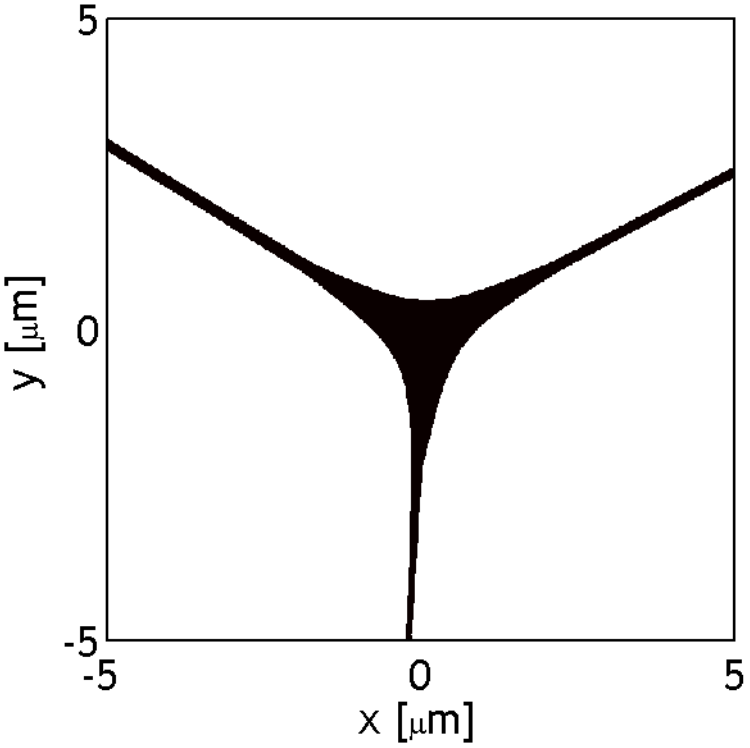




Numerical method

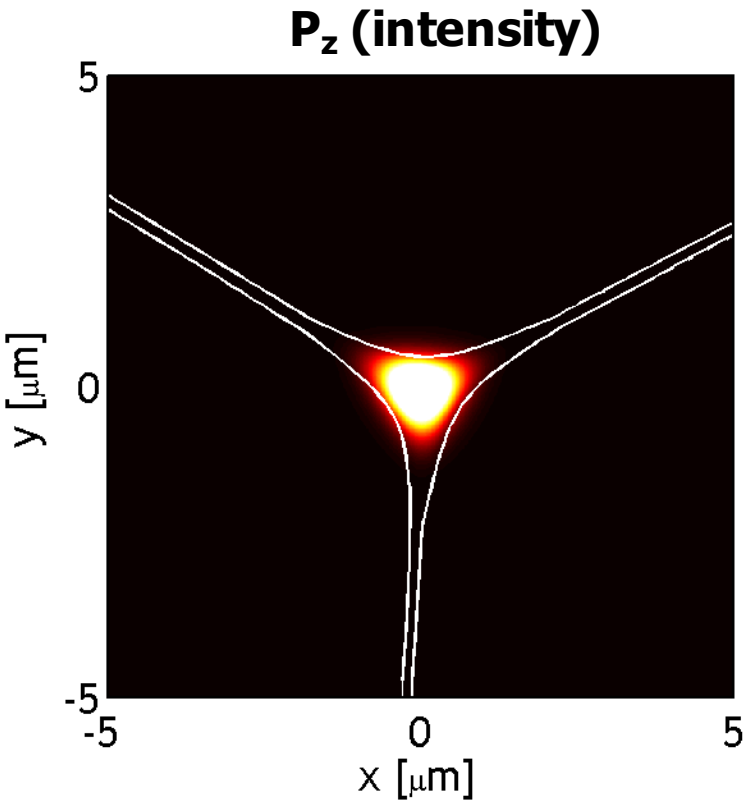
- Plane-wave expansion method
  - MPB (MIT Photonic Bands package)

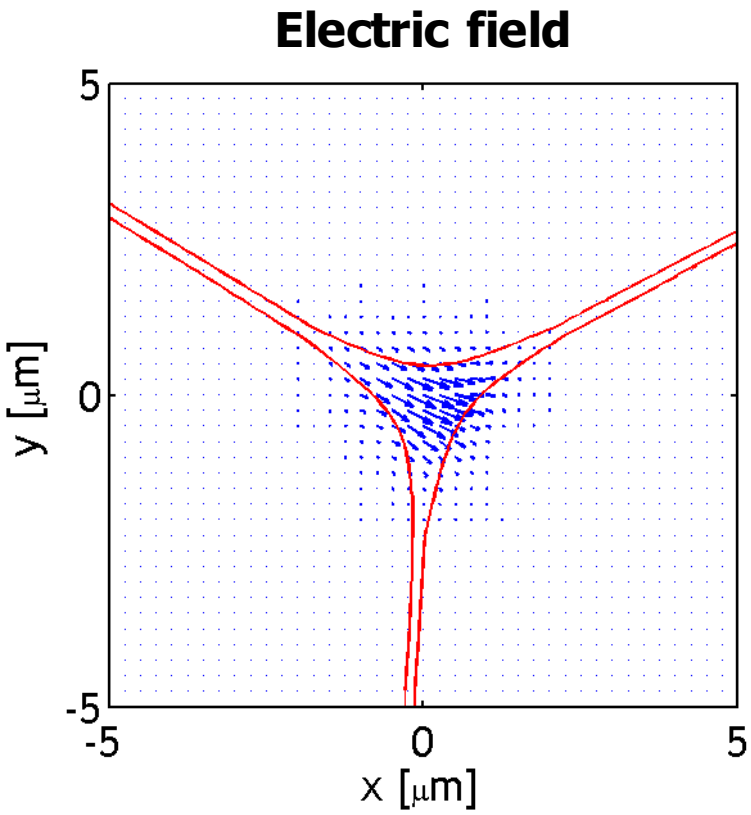
- Computational window: 10 μm x 10 μm
- Grid size: 640 x 640
- Resolution: 64 pixels/μm, uniform grid
- Sellmeier model for silica



Propagating mode shapes (1)

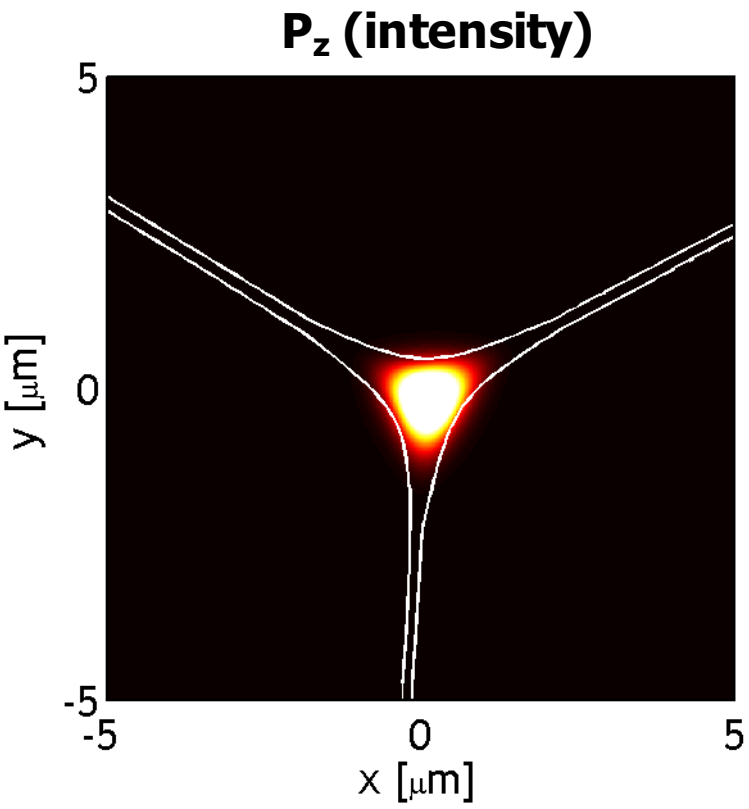
- Mode 1, "HE_{11}-like", λ = 1550 nm
  - n_{eff} = 1.30534, A_{eff} = 1.826 μm^2

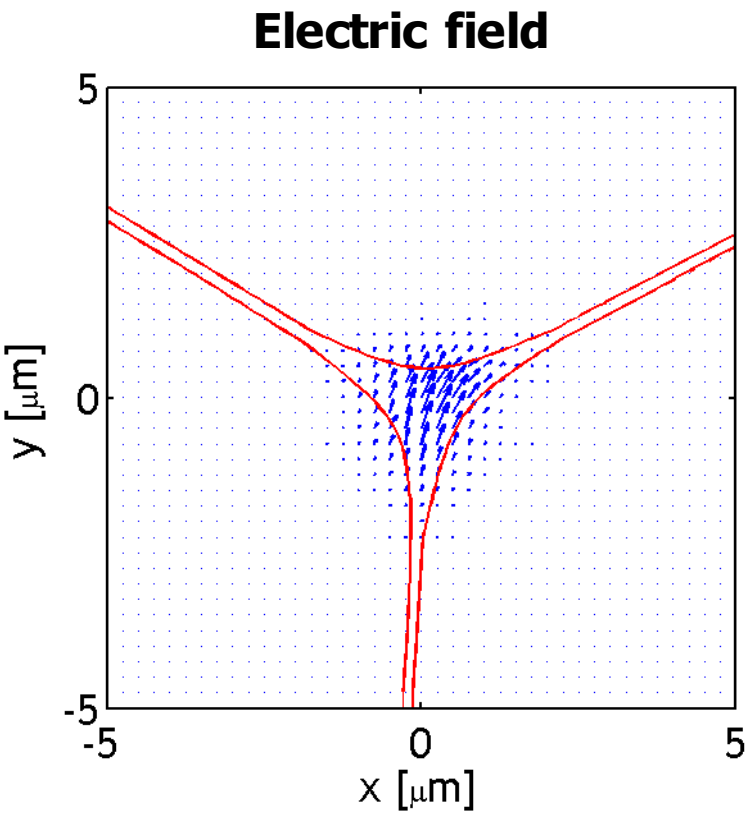




Propagating mode shapes (2)

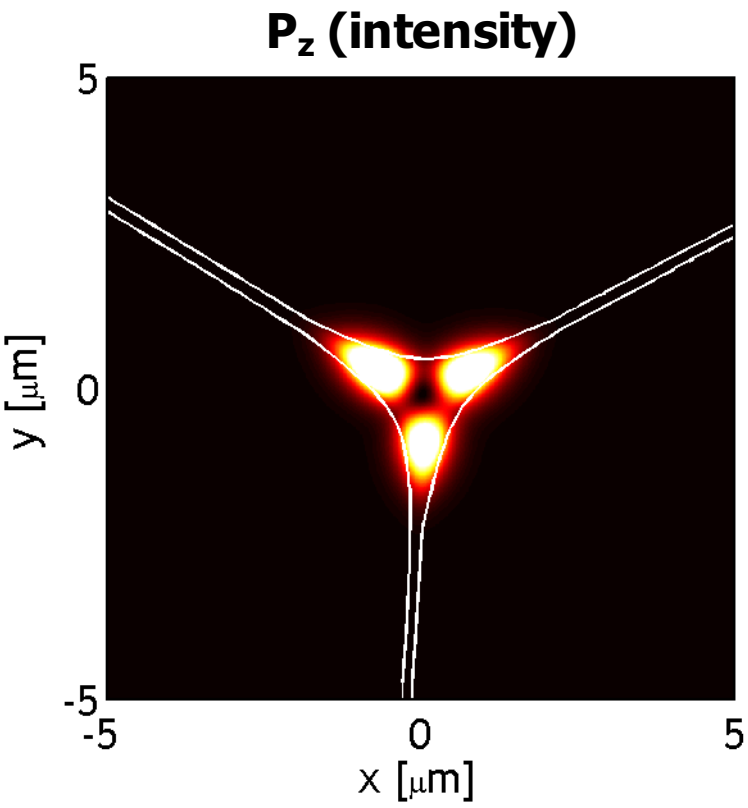
- Mode 2, "HE_{11}-like", λ = 1550 nm
  - n_{eff} = 1.30454, A_{eff} = 1.8135 μm^2

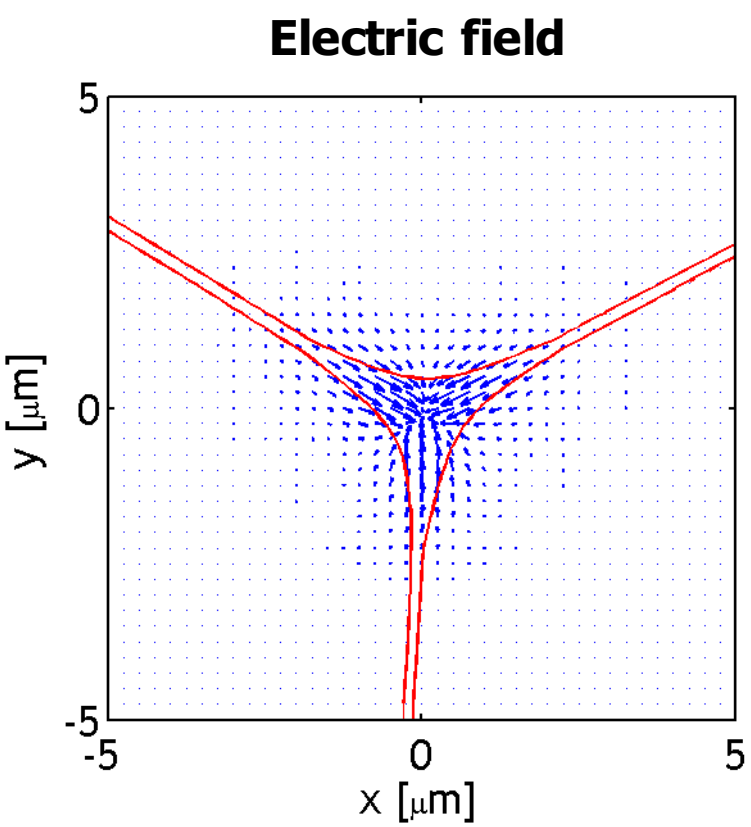




Propagating mode shapes (3)

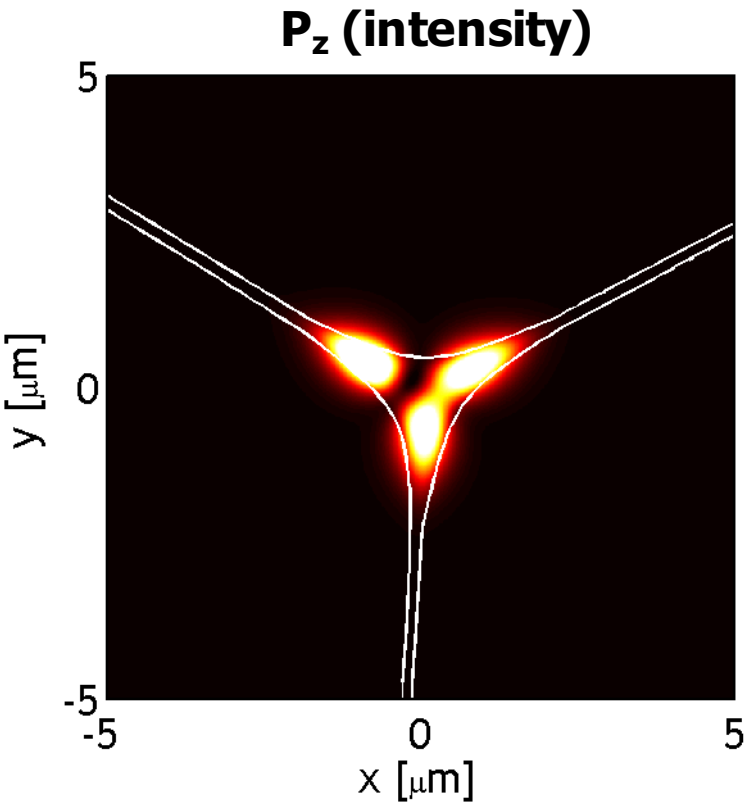
- Mode 3, "TM_{01}-like", $\lambda = 1550$ nm
  - $n_{eff} = 1.19253$, $A_{eff} = 3.7598\ \mu m^2$

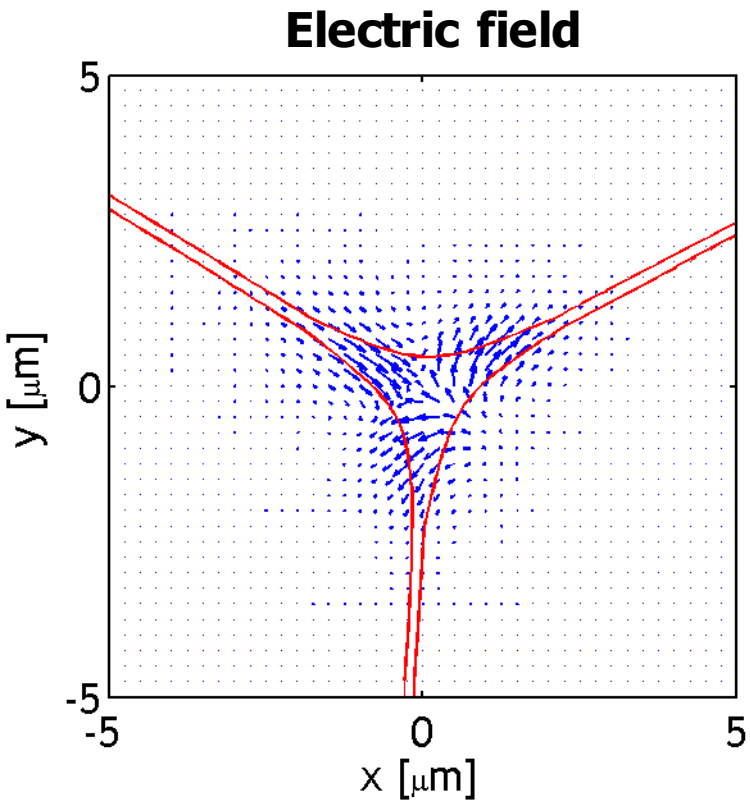




Propagating mode shapes (4)

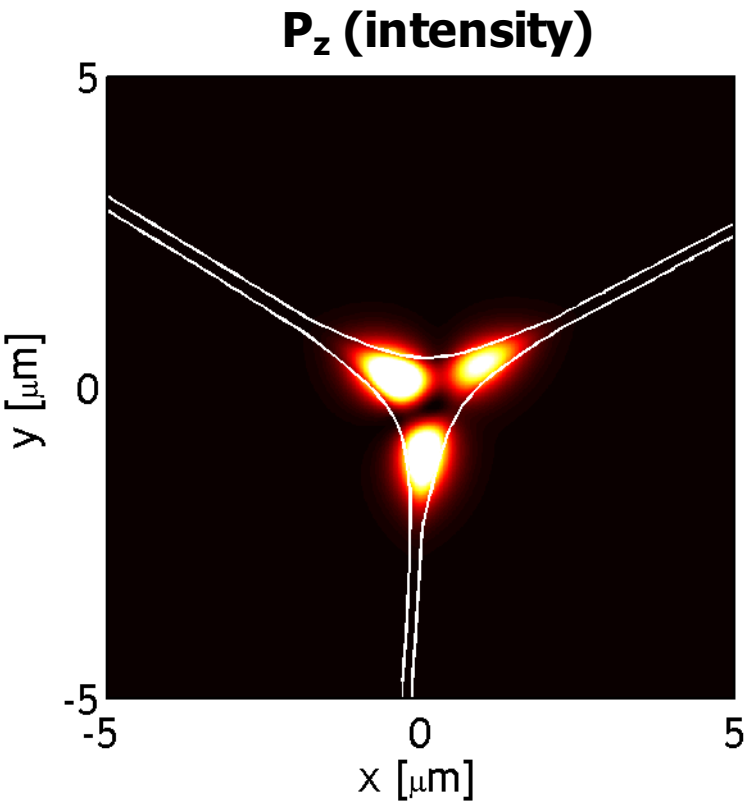
- Mode 4, "HE_{21}-like", λ = 1550 nm
  - n_{eff} = 1.15643, A_{eff} = 4.0219 μm^2

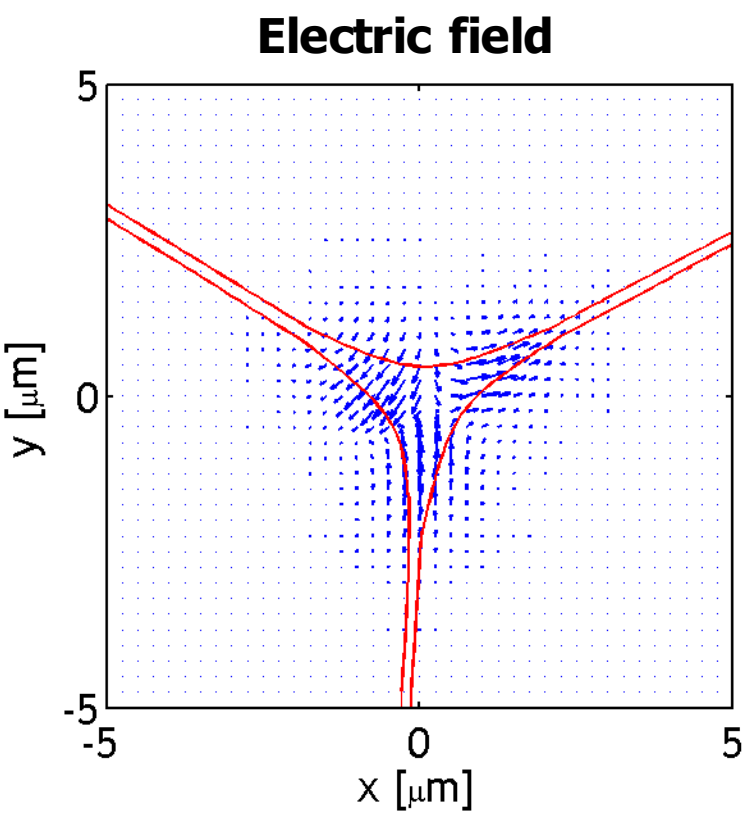




Propagating mode shapes (5)

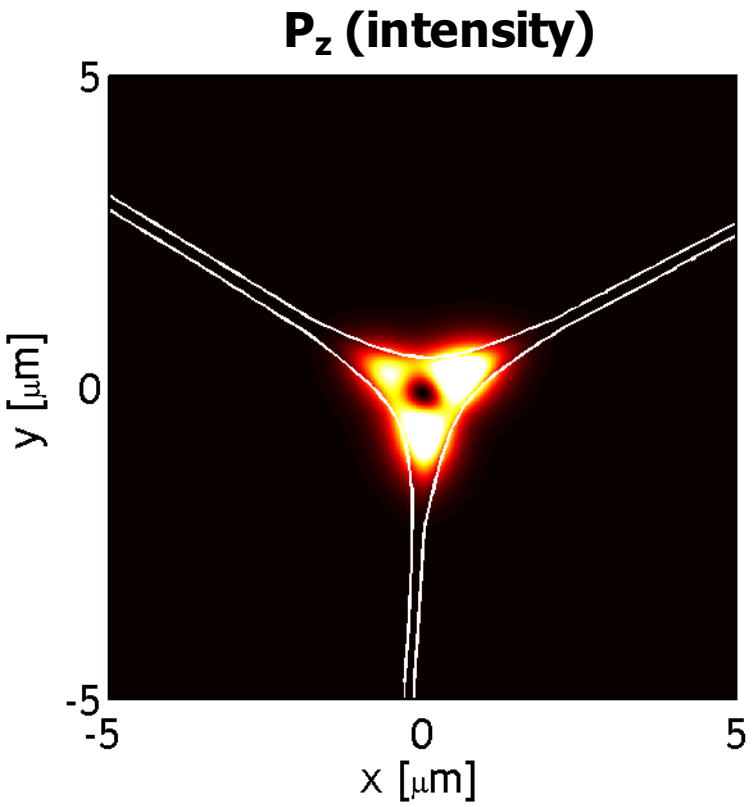
- Mode 5, "HE_{21}-like", λ = 1550 nm
  - n_{eff} = 1.15252, A_{eff} = 3.6320 μm^2

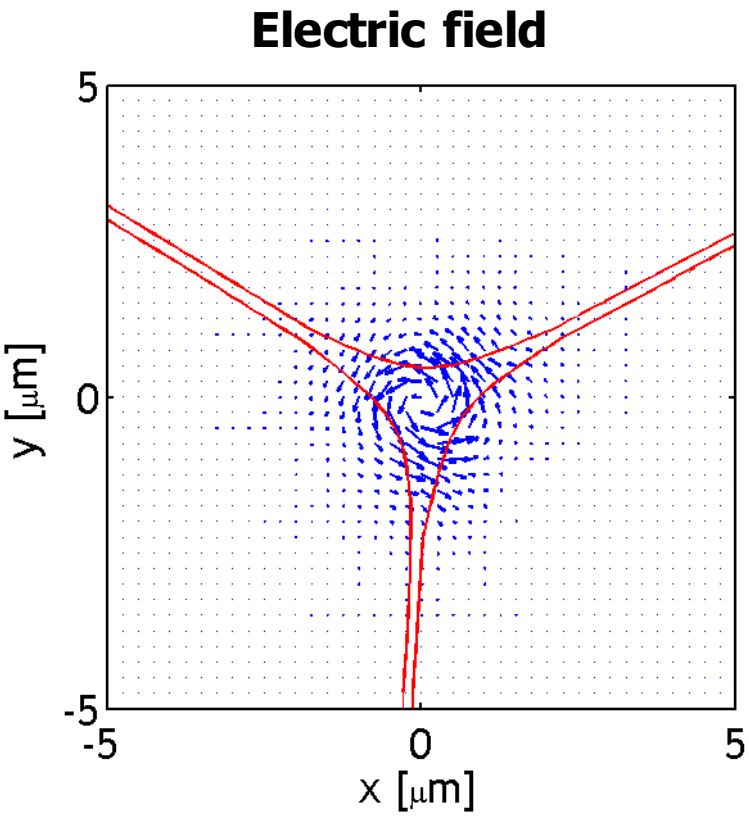




Propagating mode shapes (6)

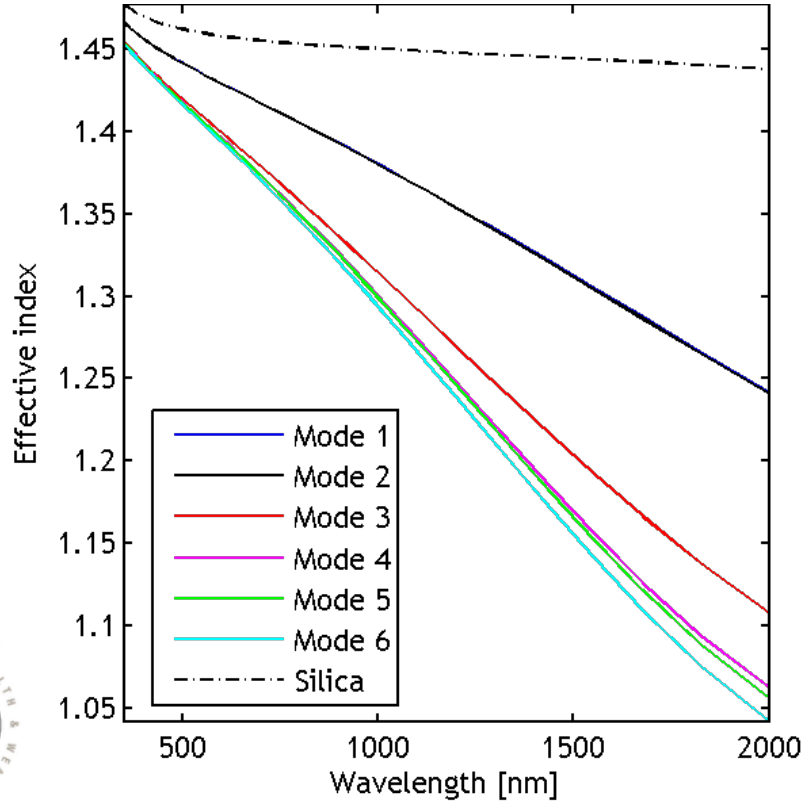
- Mode 6, "TE_{01}-like", λ = 1550 nm
  - n_{eff} = 1.14160, A_{eff} = 3.8150 μm^2



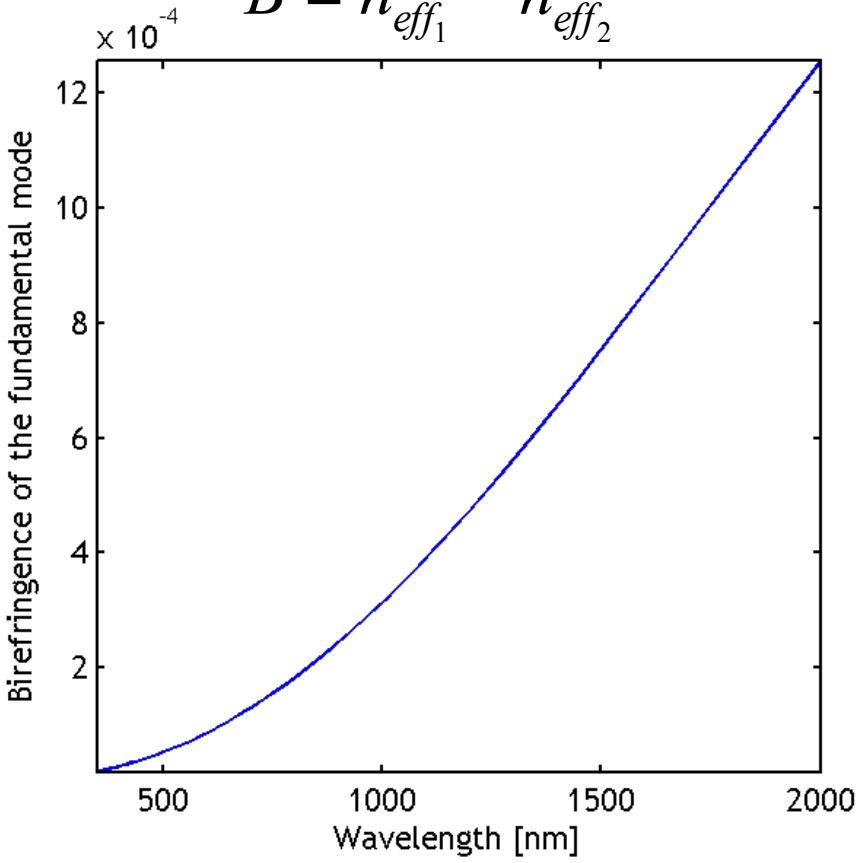


Effective indices

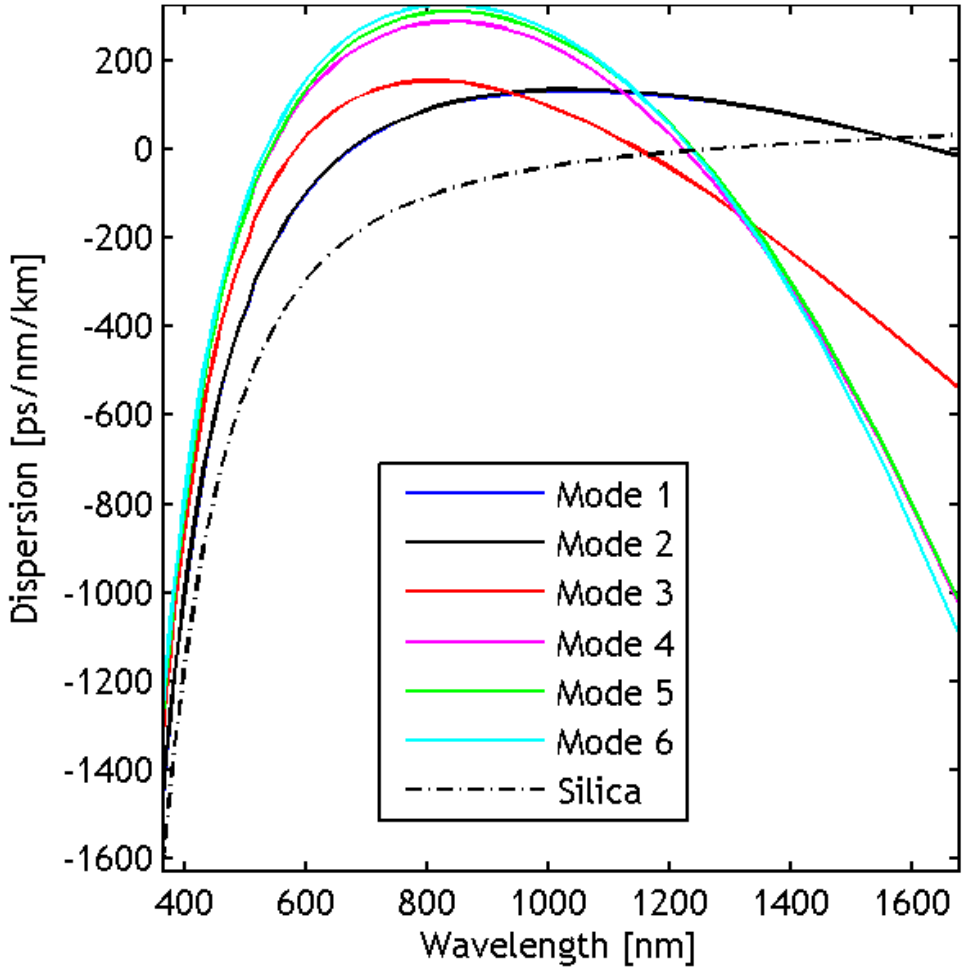
n_{eff}



$B = n_{eff_1} - n_{eff_2}$



Chromatic dispersion



$$D = -\frac{2\pi c}{\lambda^2}\beta_2$$

Mode 1:

λ_{ZD_1} = 674 nm

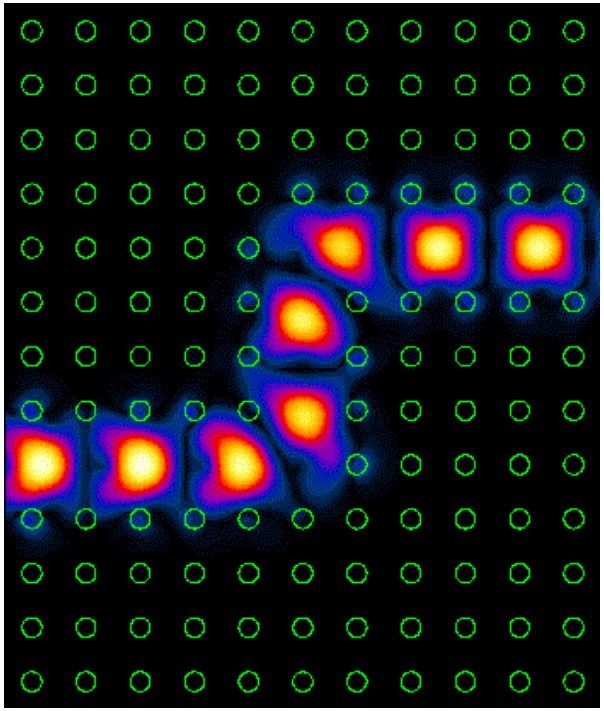
λ_{ZD_2} = 1634 nm

D = 31 ps/nm/km

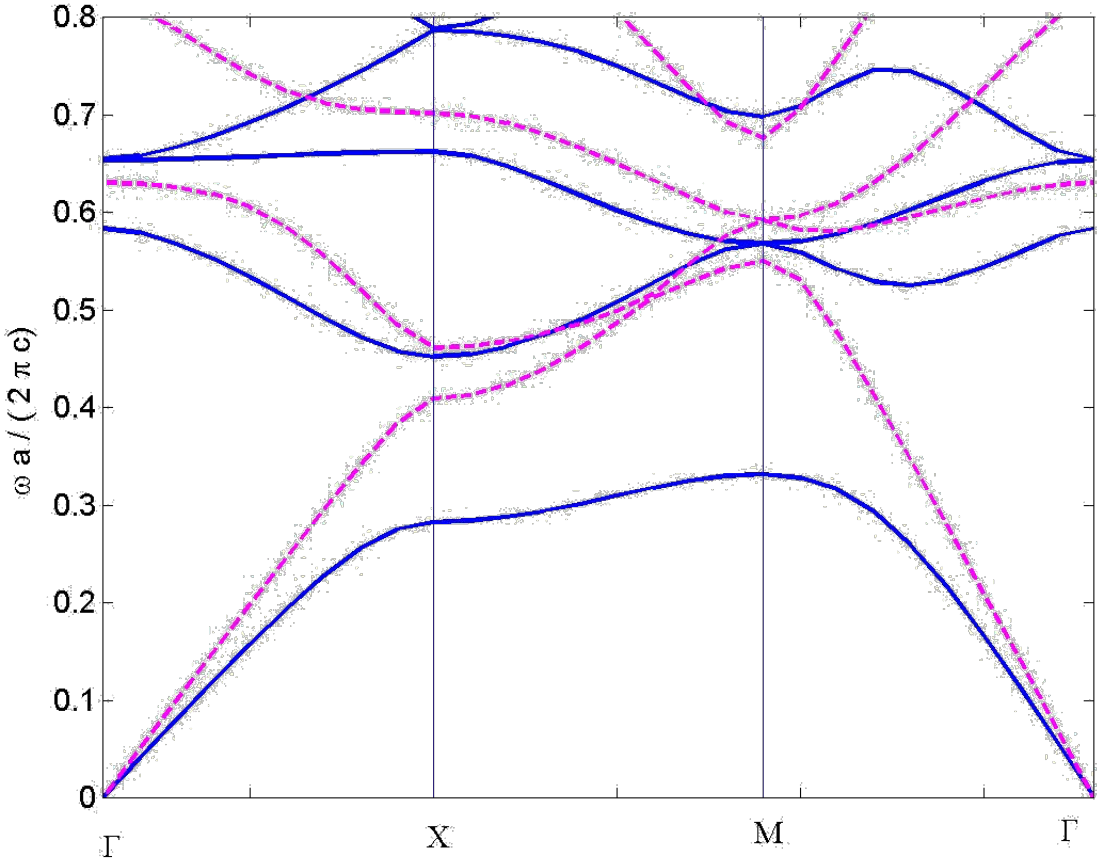
@ 1550 nm

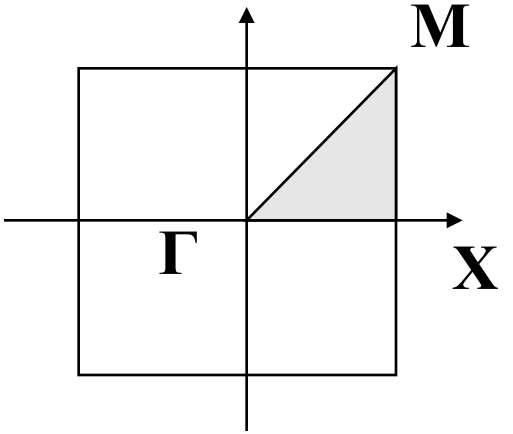
Strutture guidanti

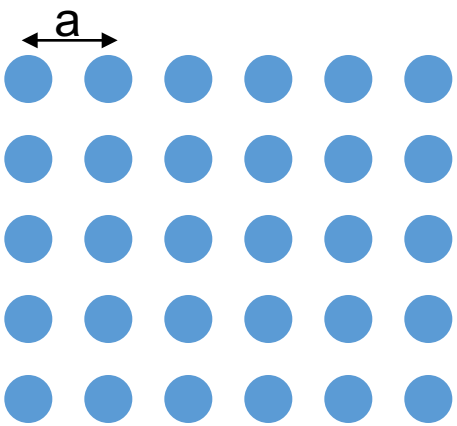
- Inserendo un difetto lineare nella struttura cristallina si crea una guida d'onda.
- Il difetto si crea rimuovendo una linea di colonne o variandone il diametro.



Struttura quadrata di cilindri in aria



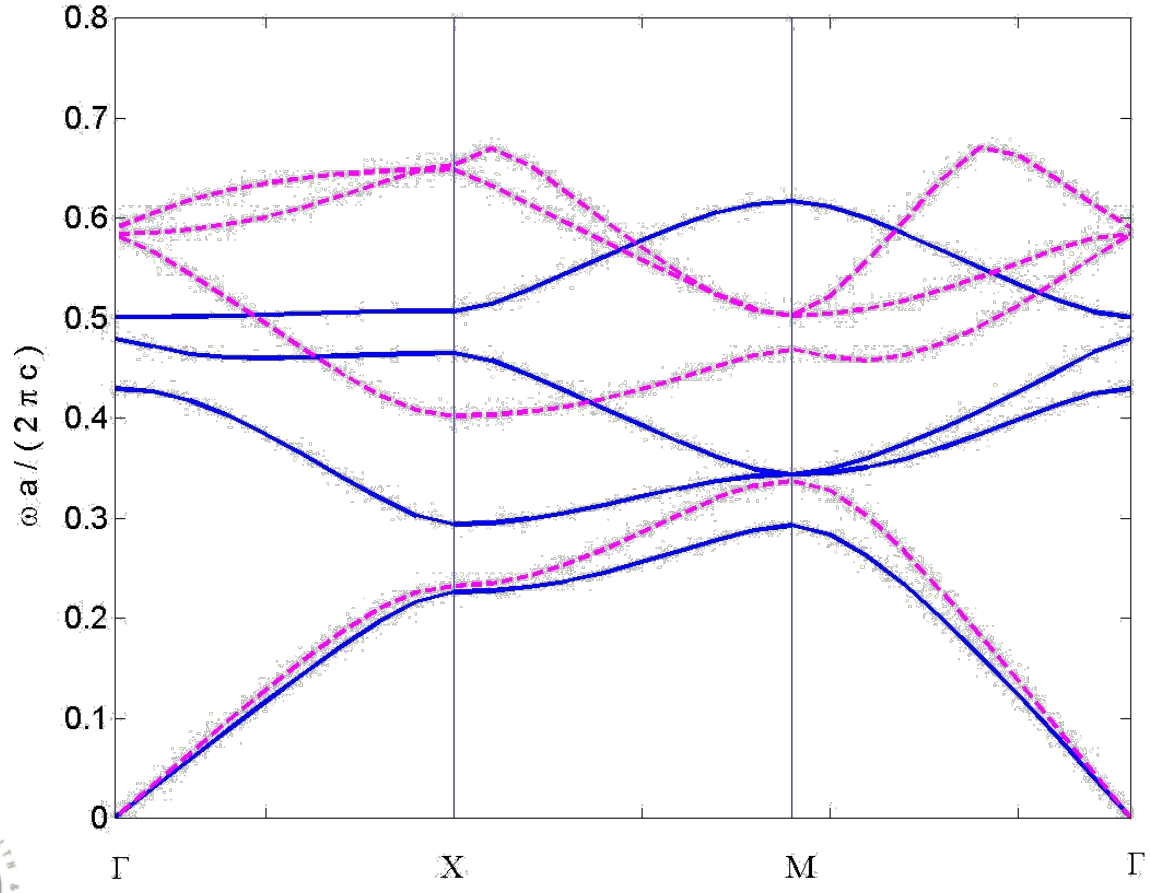


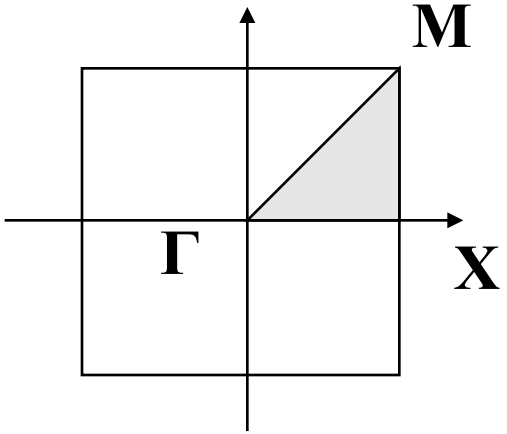


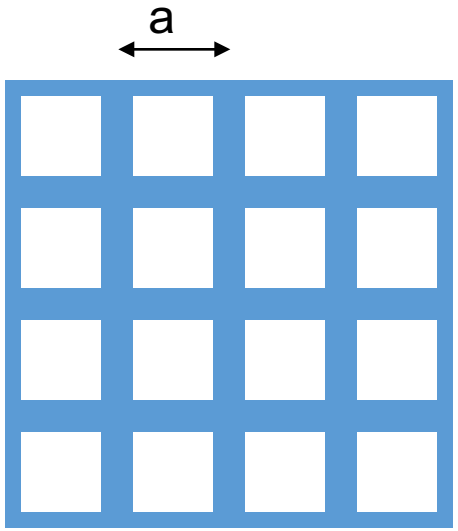
Band-gap per modi TM

$\varepsilon_r = 12$

Struttura quadrata di fori quadrati



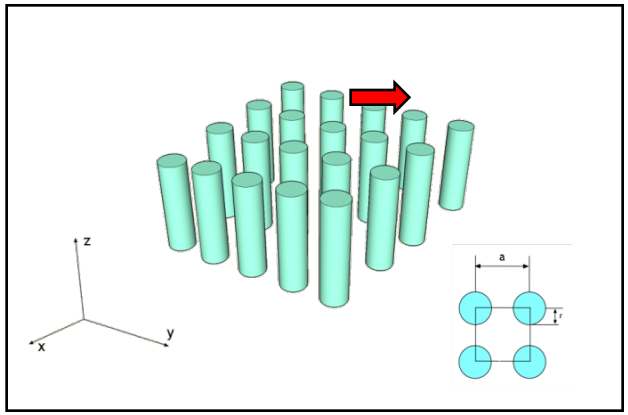


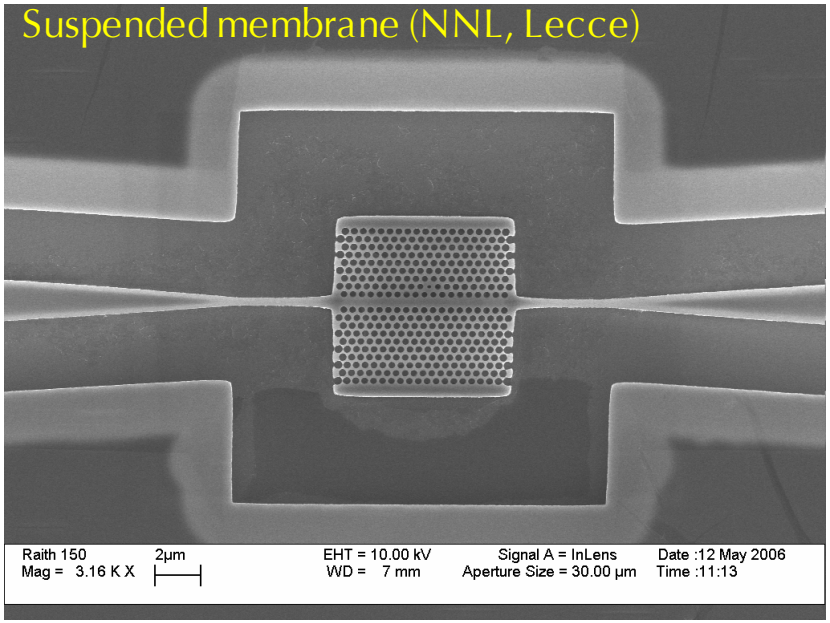


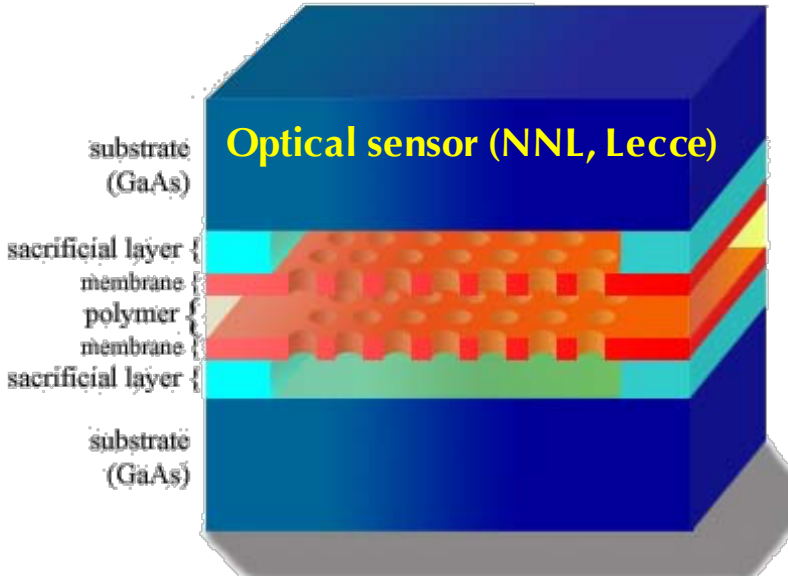
Band-gap per modi TE

$\varepsilon_r = 8.9$

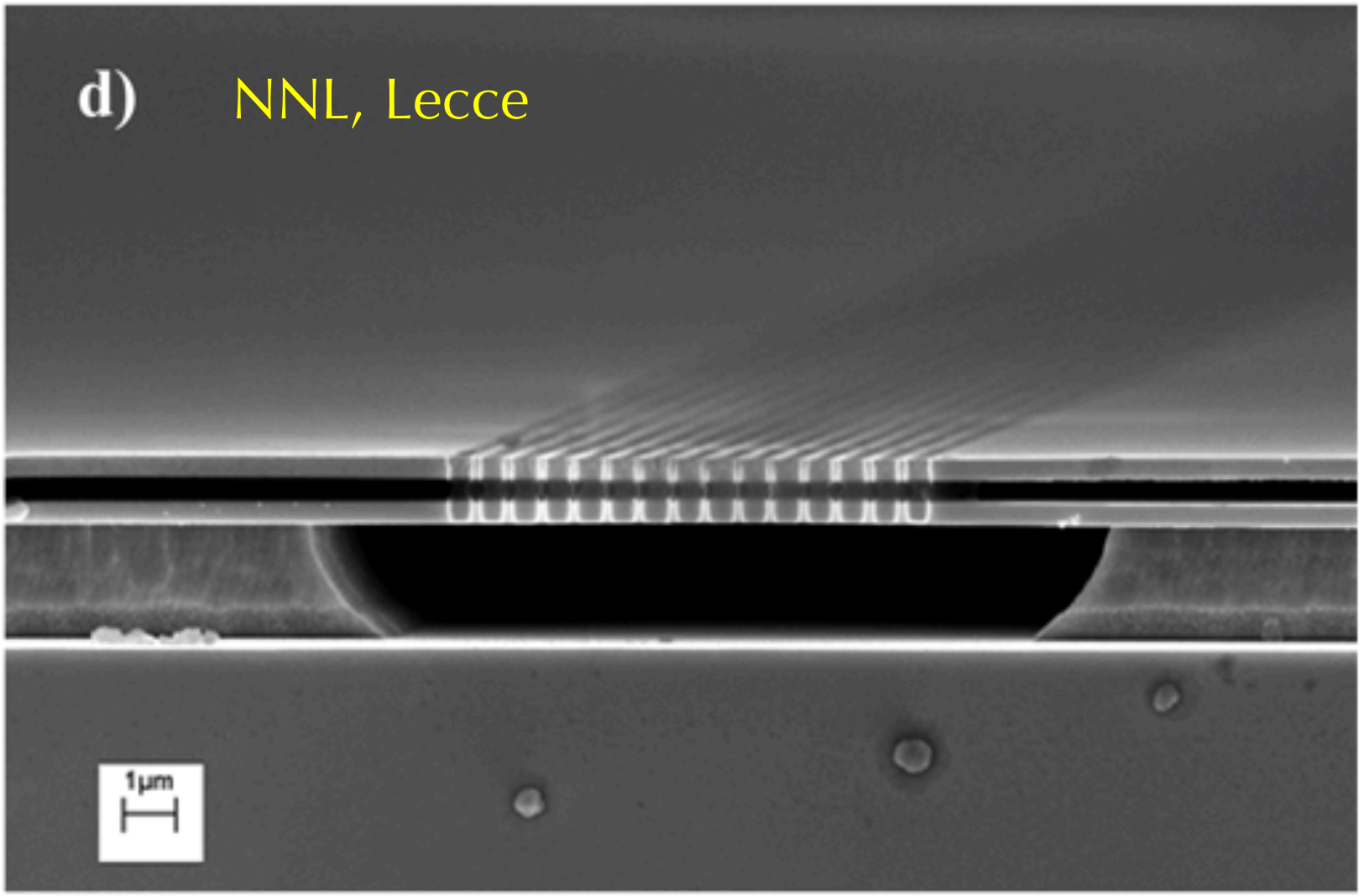
Membrane sospese



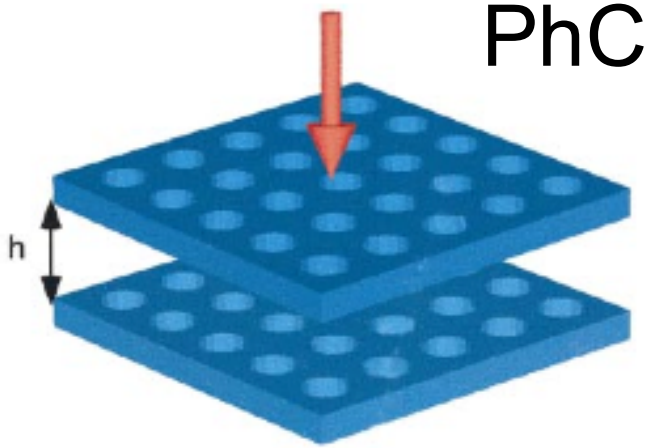


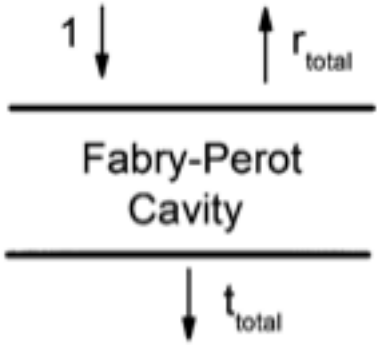


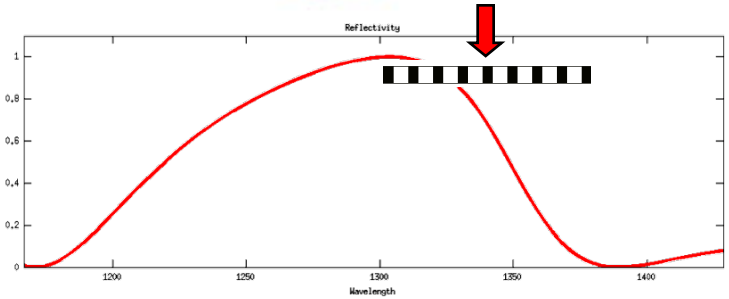
Optical sensor based on coupled double PhC membranes

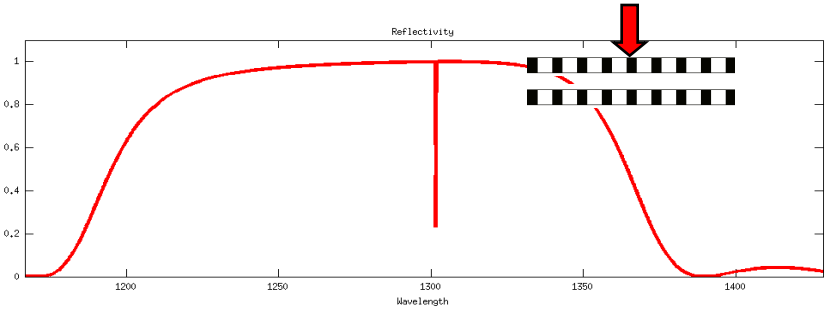


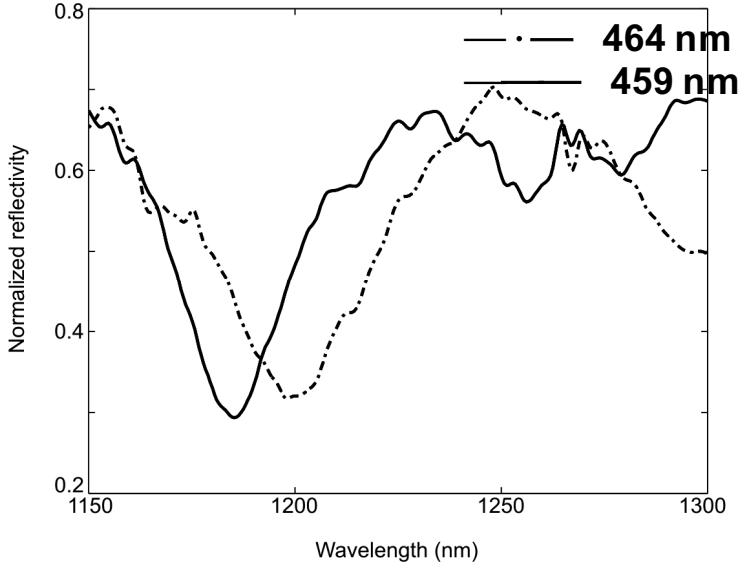
Optical sensor based on coupled double PhC membranes



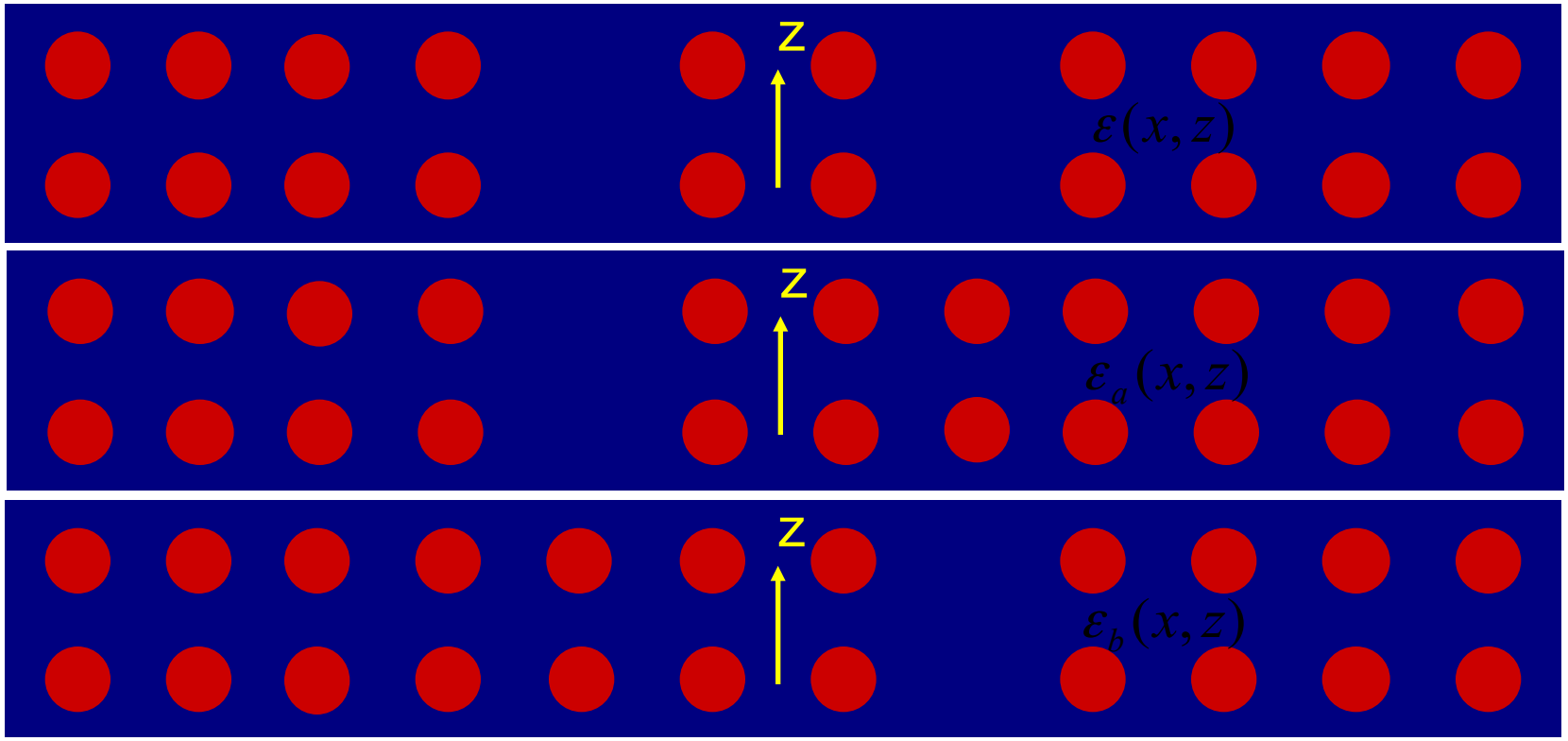








Photonic crystal directional couplers



$$\varepsilon(x,z) = \varepsilon_a(x,z) + \Delta\varepsilon_b(x,z)$$

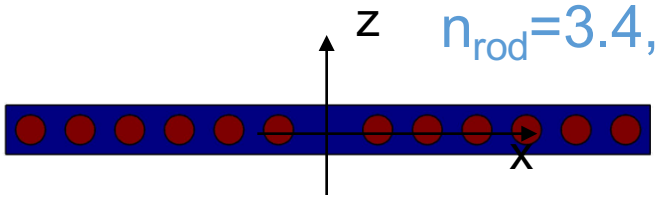
$$\varepsilon(x,z) = \varepsilon_b(x,z) + \Delta\varepsilon_a(x,z)$$

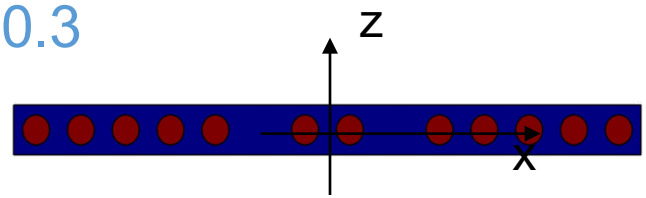
Photonic crystal directional couplers

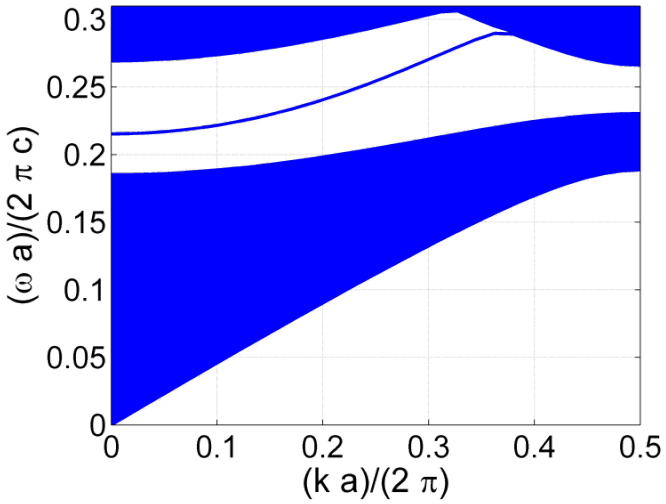
Single waveguide

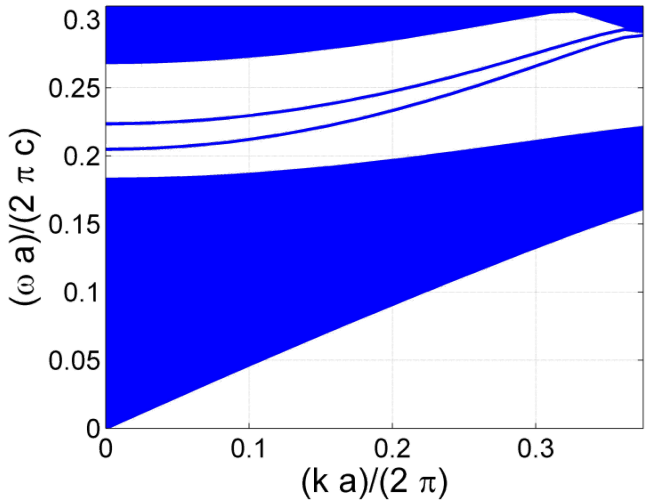
Waveguide coupler

$n_{rod}=3.4,\ n_{sub}=1.5,\ r=0.3$









Photonic crystal waveguides:
the mode shape
is periodic along z

$$\overline{E}(x,z) = \overline{e}(x,z)\exp(-ikz)$$

$$\overline{H}(x,z) = \overline{h}(x,z)\exp(-ikz)$$

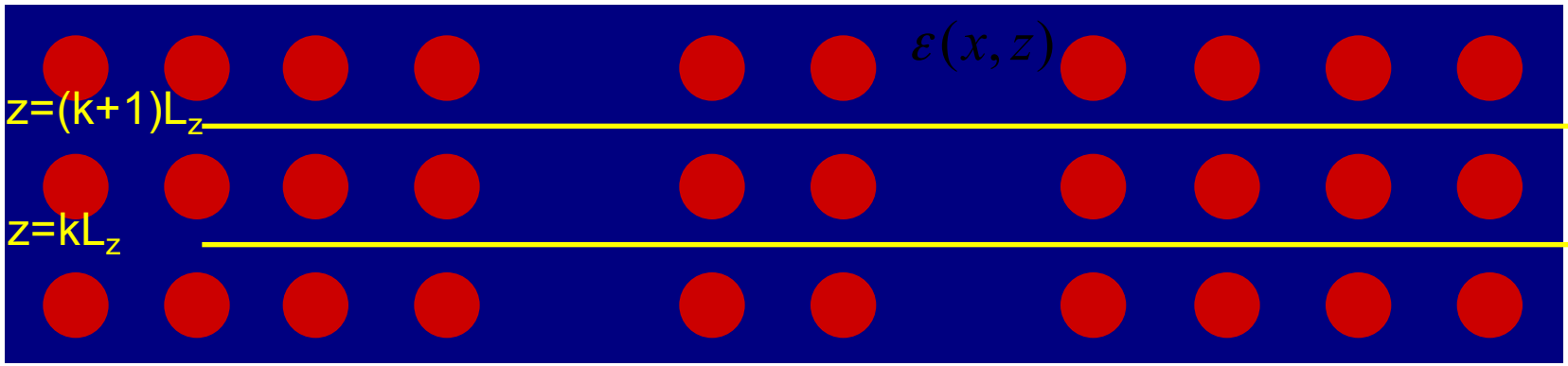
Photonic crystal directional couplers

$$\frac{dA(z)}{dz} + i\gamma\, A(z) = iCB(z)$$

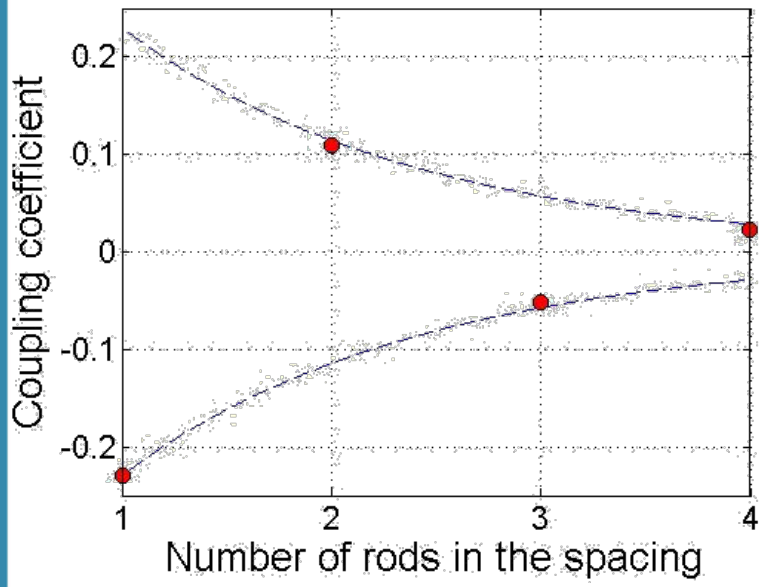
$$\frac{dB(z)}{dz} + i\gamma\, B(z) = iCA(z)$$

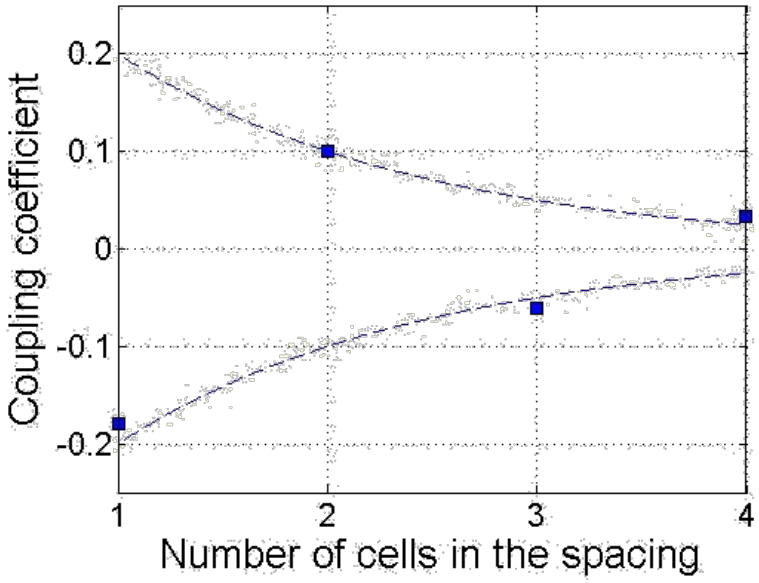
$$C = \frac{\omega}{I_a L_z} \int_{-\infty}^{\infty} dx \int_{kL_z}^{(k+1)L_z} dz\, (\varepsilon - \varepsilon_a) \left\{ \bar{e}_{a\perp}^{*} \cdot \bar{e}_{b\perp} + \frac{\varepsilon_b}{\varepsilon} \bar{e}_{az}^{*} \cdot \bar{e}_{bz} \right\}$$

$$I_a = 2 \int_{-\infty}^{\infty} dx \left(\bar{e}_a^{*} \times \bar{h}_a \right)_z$$



Photonic crystal directional couplers





N **even** $C > 0$ (the fundamental mode of the coupler is **even**)

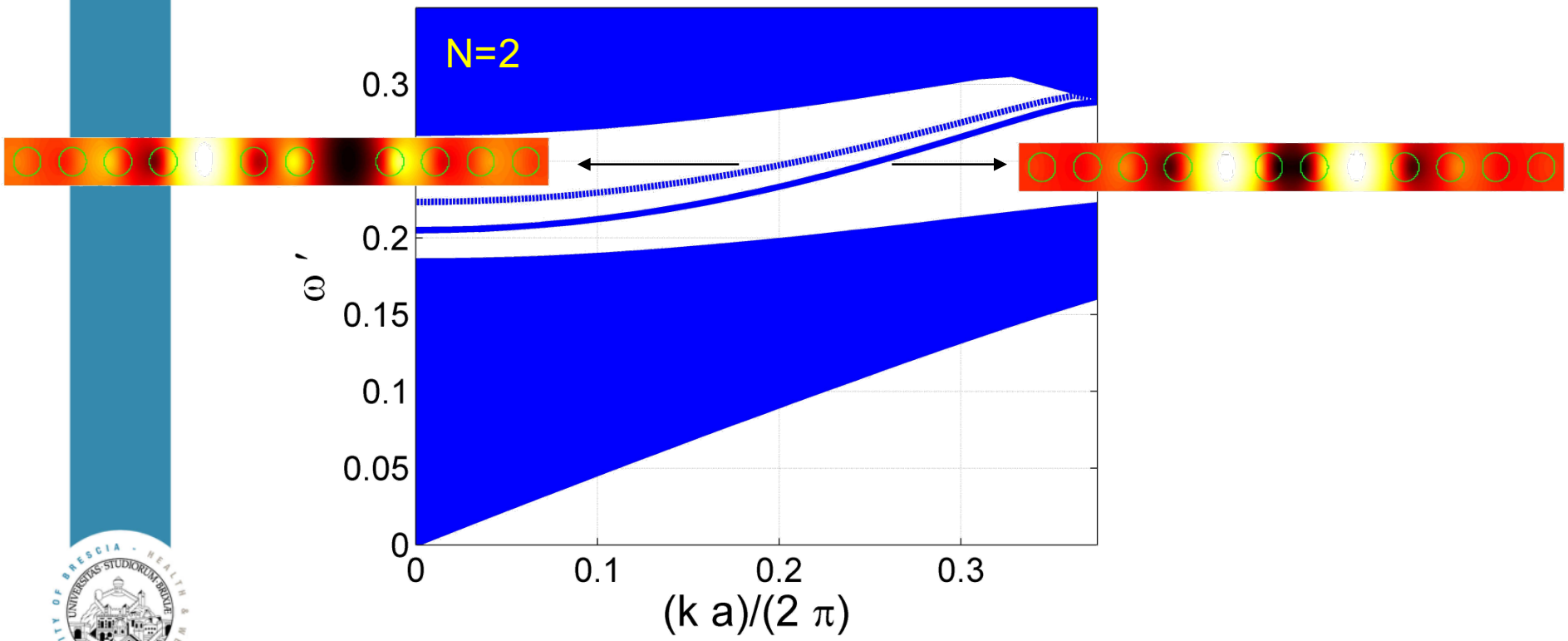
N **odd** $C < 0$ (the fundamental mode of the coupler is **odd**)

Photonic crystal directional couplers

C > 0 (the fundamental mode of the coupler is **even**)

C < 0 (the fundamental mode of the coupler is **odd**)

$$C = \frac{\beta_+ - \beta_-}{2}$$

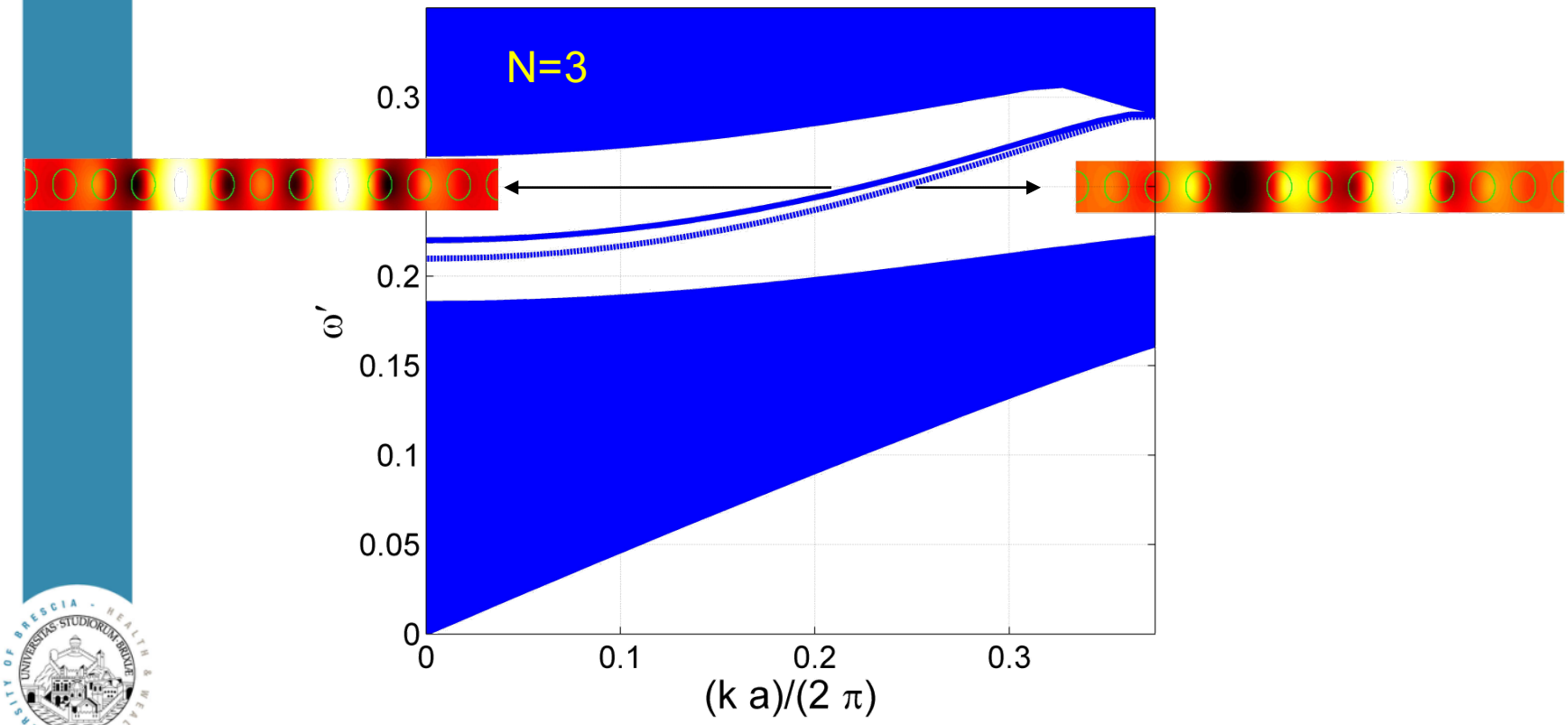


Photonic crystal directional couplers

C > 0 (the fundamental mode of the coupler is **even**)

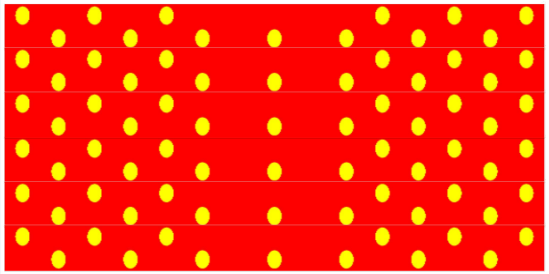
C < 0 (the fundamental mode of the coupler is **odd**)

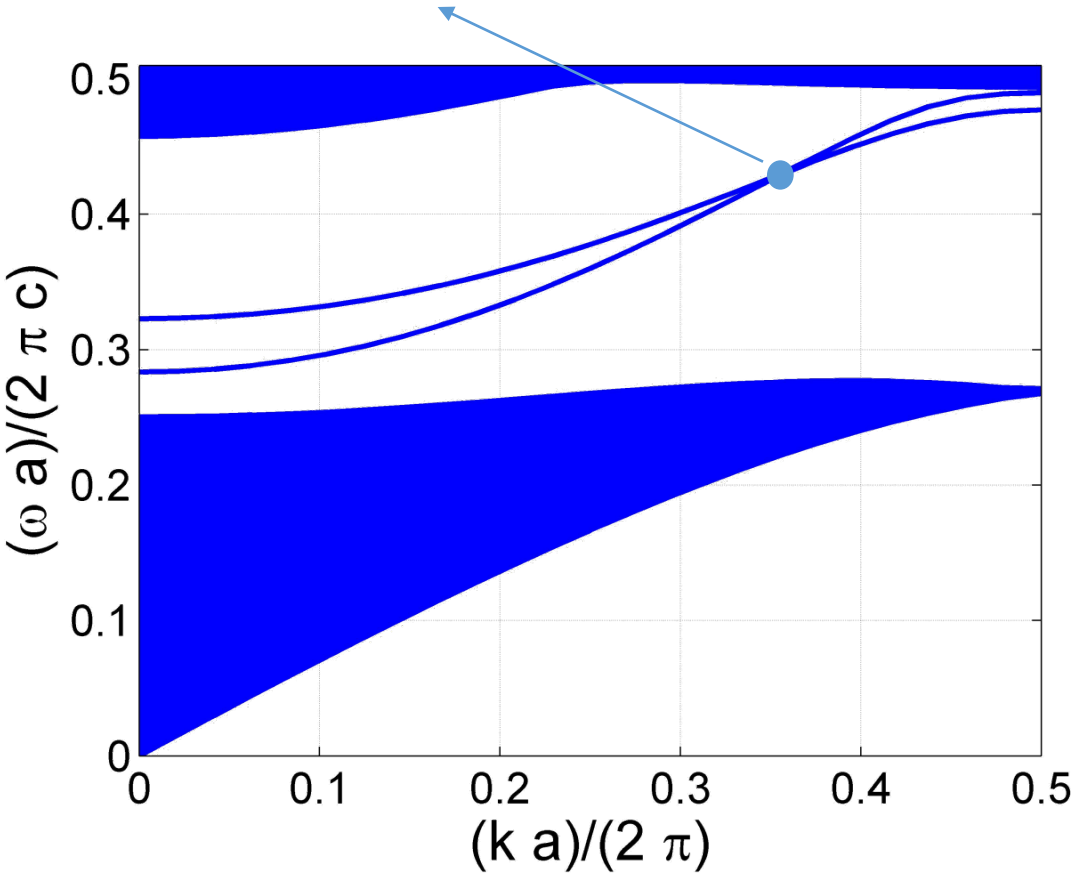
$$C = \frac{\beta_+ - \beta_-}{2}$$



Photonic crystal directional couplers

$C = 0$: zero discrete diffraction





DEMETRA

Sezioni afferenti:
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Responsabile nazionale: Prof. Gino Sorbello (UniCT & INFN-LNS)

Fabio Baronio, Costantino De Angelis, **Andrea Locatelli**
INFN–"Gruppo collegato di Brescia".
University of Brescia

Pavia – 10 Novembre 2015