Electromagnetic Wave Guidance Mechanisms in Photonic Crystal Fibers

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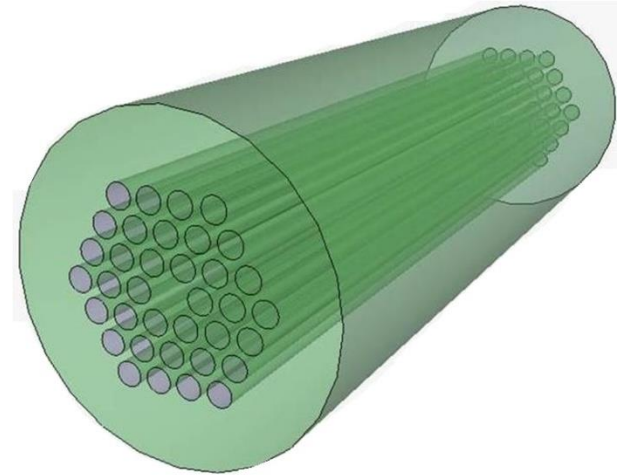
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Outline

- **Introduction**
- **Wave guidance mechanisms in PCF**
  - ➢ **Index guidance**
  - ➢ **Photonic band gap guidance**
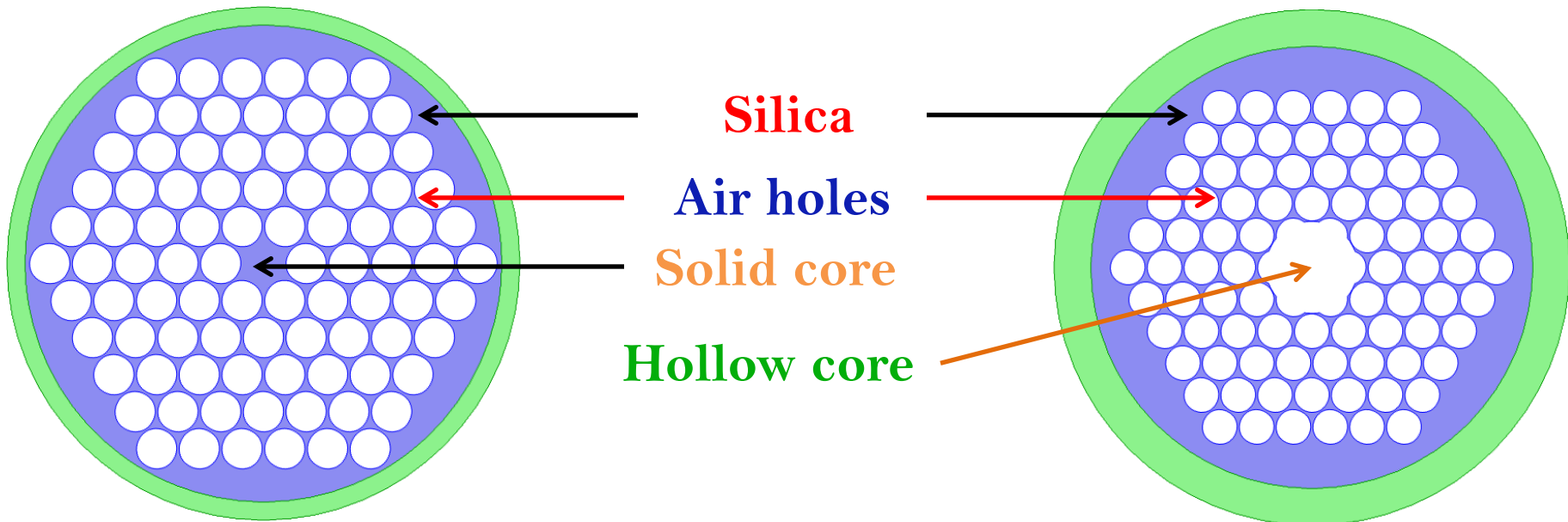 - ➢ **Trapping of Dirac mode**
- **Summary**

Photonic Crystal Fibers(PCFs)

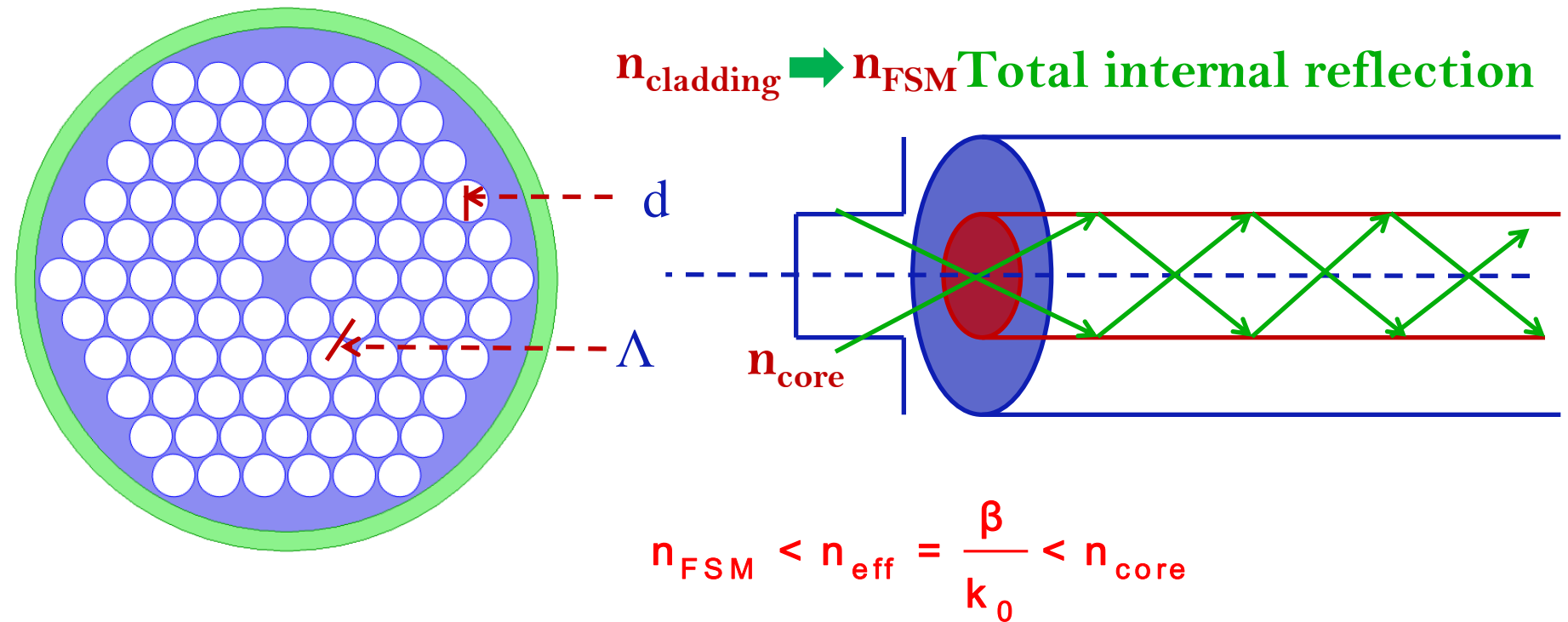PCF is a new class of *optical waveguide* which consists of either a solid or hollow core and crystal like cladding

SC-PCF

HC-PCF

Silica

Air holes

Solid core

Hollow core

Index guidance

Equivalent step index model

$n_{cladding}$ ➡ n_{FSM} Total internal reflection

d

Λ

n_{core}

$$n_{FSM} < n_{eff} = \frac{\beta}{k_0} < n_{core}$$

d= diameter of air hole, Λ=pitch (centre to centre distance between two consecutive air holes), n_{core}

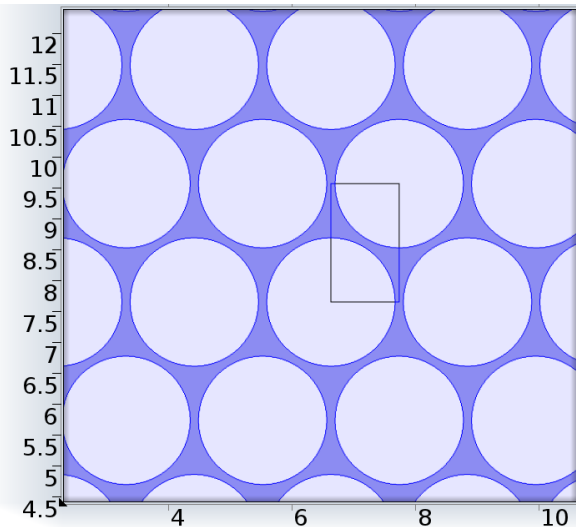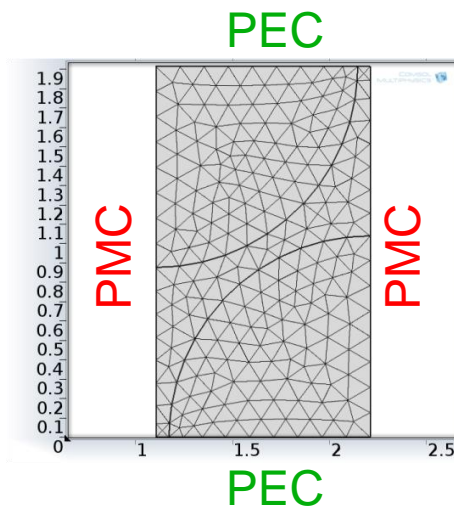# Calculation of n_{FSM} and n_{eff}

Mode Analysis

Maxwell's EMW Eq.

$$\nabla \times (\nabla \times E) - k_0^2 \varepsilon_r E = 0$$
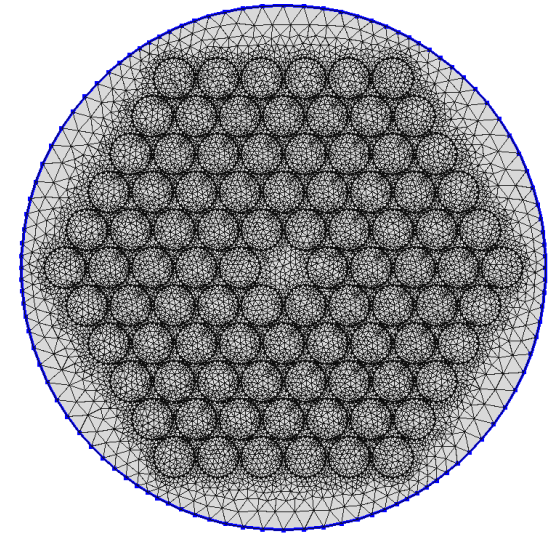
PC cladding   Elementary piece   PCF cross section

Mesh :   Type – physics controlled,
          Element size - normal

Study – Mode Analysis
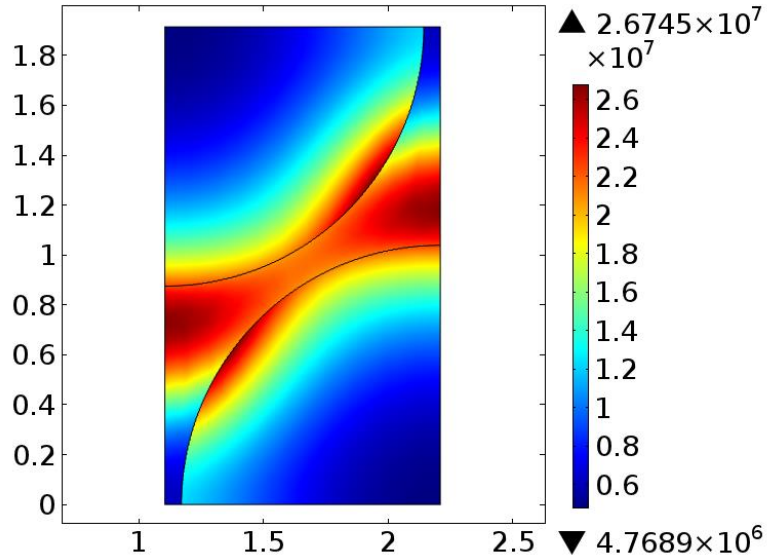Search for mode around-1.45
Mode analysis freq- c_const/Lambda

Results

FSM

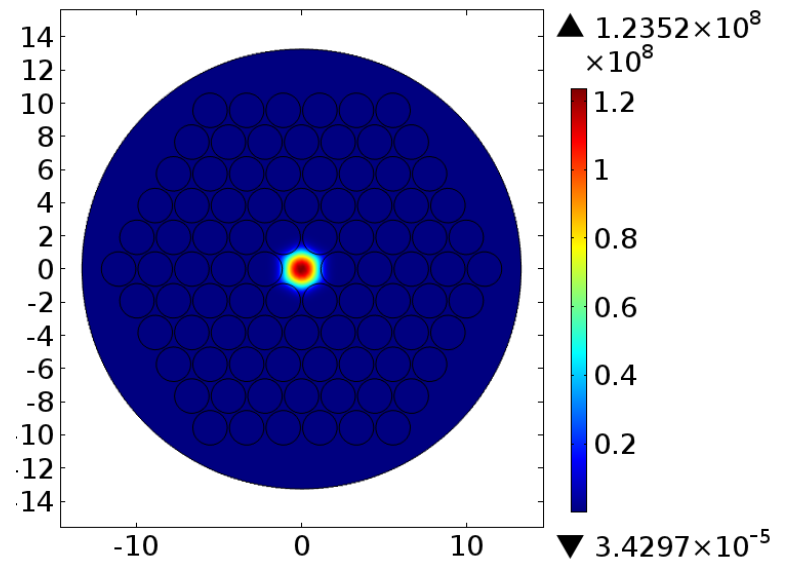Effective mode index=1.149436
Surface: Electric field norm (V/m)

▲ 2.6745×10^7

▼ 4.7689×10^6

Fundamental mode

Effective mode index=1.407186
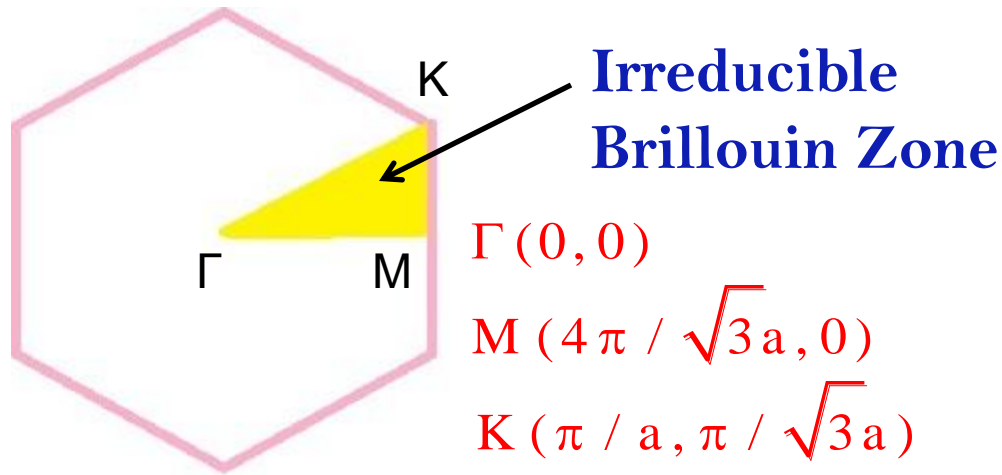Surface: Electric field norm (V/m)

▲ 1.2352×10^8

▼ 3.4297×10^{-5}

Dispersion: n_{FSM} , n_{eff} and n_{core}

Verification of MTIR
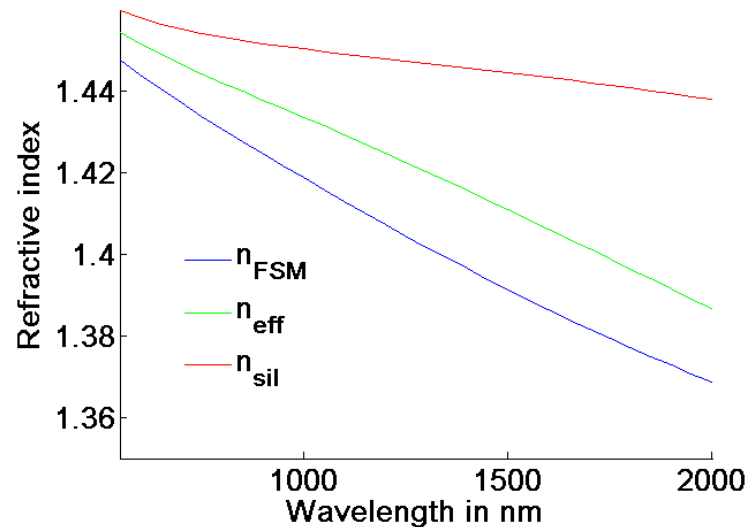
Calculation of PBS for PBG guidance

Eigenfrequency

Unit cell

Irreducible Brillouin Zone

$\Gamma\,(0,0)$

$M\,(4\pi\,/\,\sqrt{3}\,a\,,\,0)$

$K\,(\pi\,/\,a\,,\,\pi\,/\,\sqrt{3}\,a\,)$
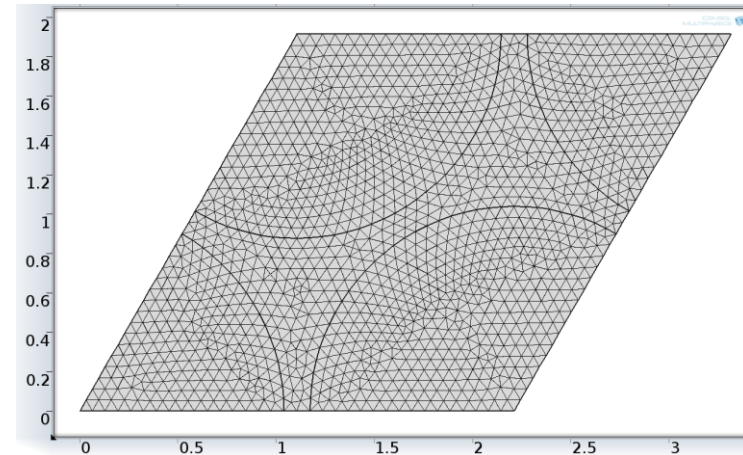
Boundary conditions– **Floquet periodicity**

k-vector for Floquet periodicity- **User defined**

Example: for M point $k_F \begin{cases} k_x \;=\; 4\pi\,/\,\sqrt{3}\,a \\[6pt] k_y \;=\; 0 \end{cases}$
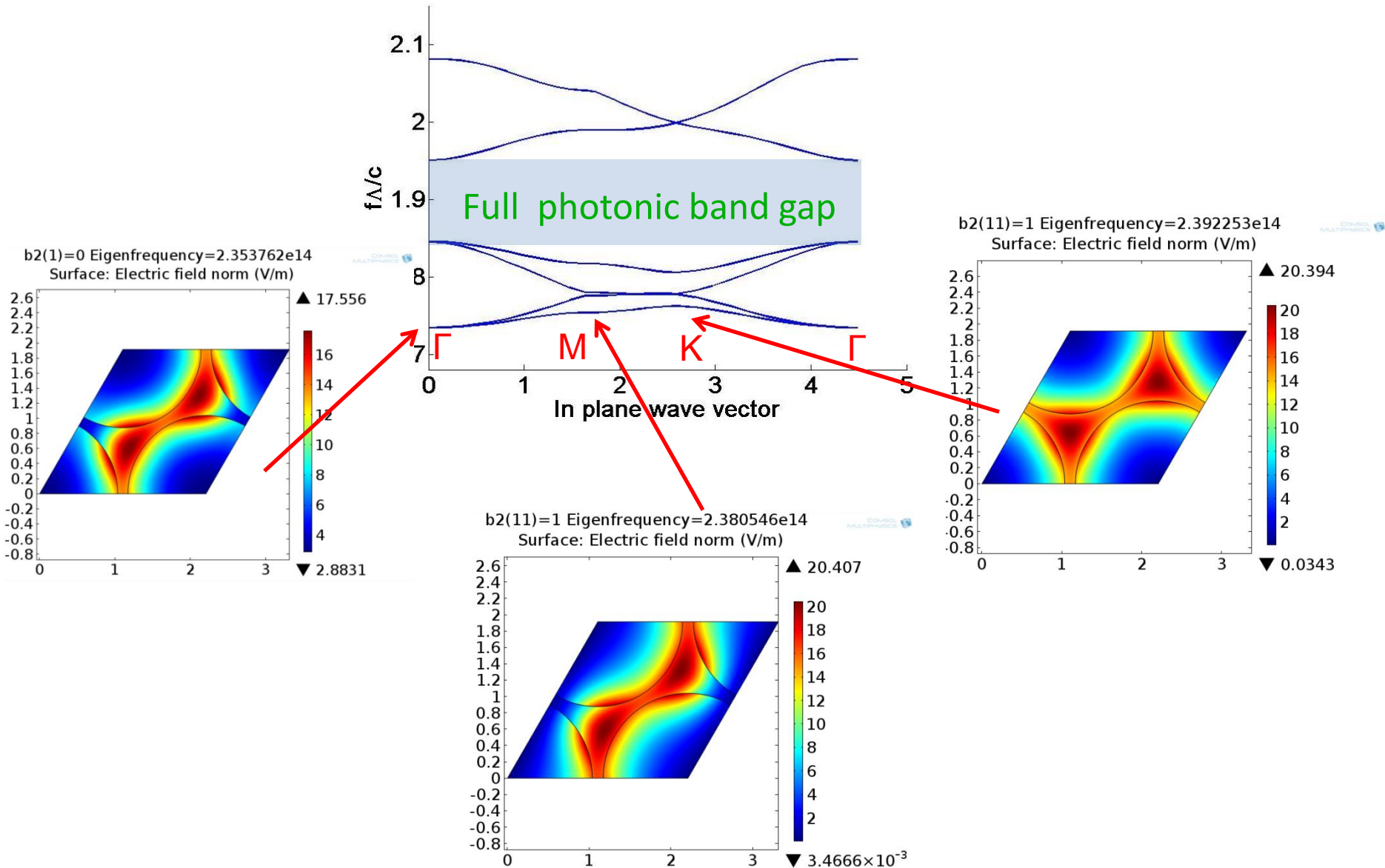
Mesh :

Type – **Physics-controlled**
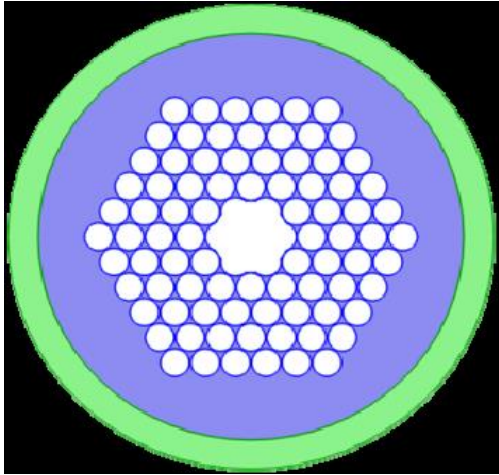
Element size - **Extra fine**

Study – **Eigenfrequency**

Search for *eigenfrequencies* around:

c_const/Lambda

PBG: Transmission window for HCPCF

$f\Lambda/c$

Full photonic band gap

In plane wave vector

Γ   M   K   Γ

b2(1)=0 Eigenfrequency=2.353762e14
Surface: Electric field norm (V/m)

▲ 17.556
▼ 2.8831

b2(11)=1 Eigenfrequency=2.392253e14
Surface: Electric field norm (V/m)

▲ 20.394
▼ 0.0343

b2(11)=1 Eigenfrequency=2.380546e14
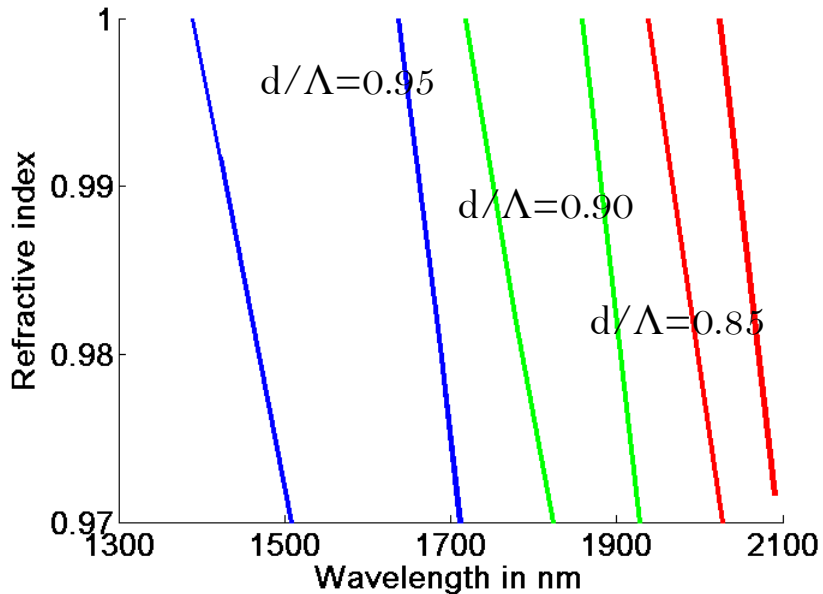Surface: Electric field norm (V/m)

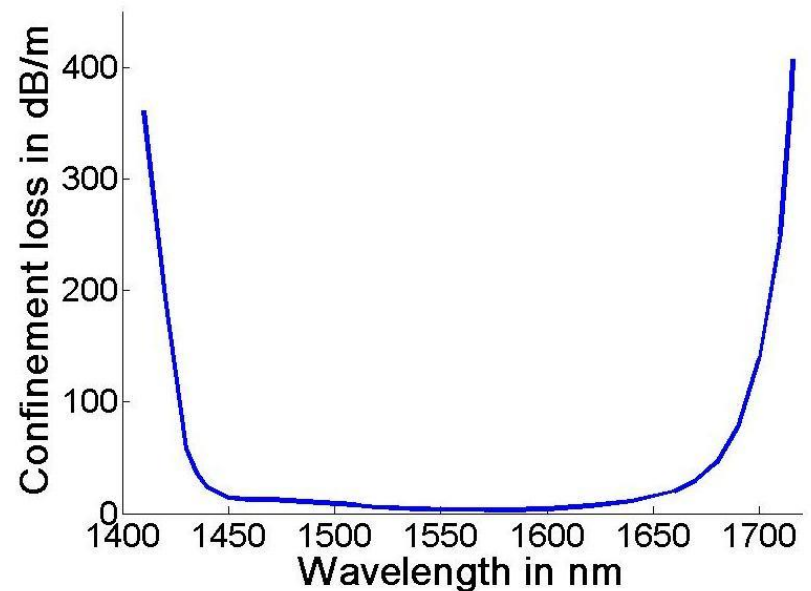▲ 20.407
▼ 3.4666×10⁻³

Hollow Core Photonic Band Gap fiber

✓Useful in ultrafast pulse propagation

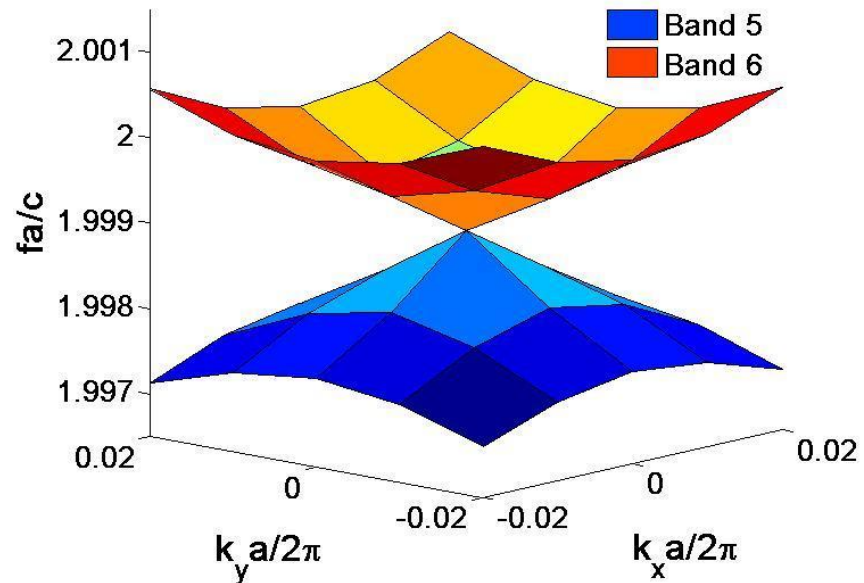✓Core can be filled with gas/liquid for sensing/lasing applications
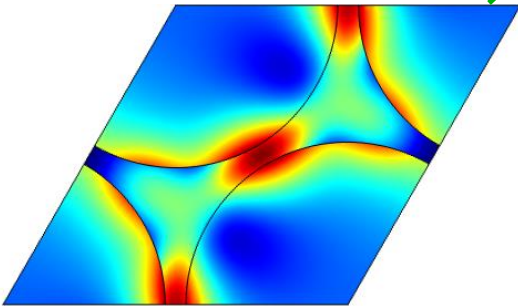

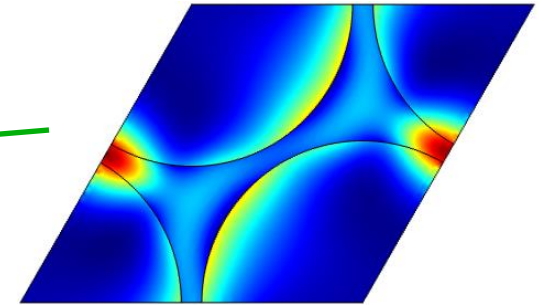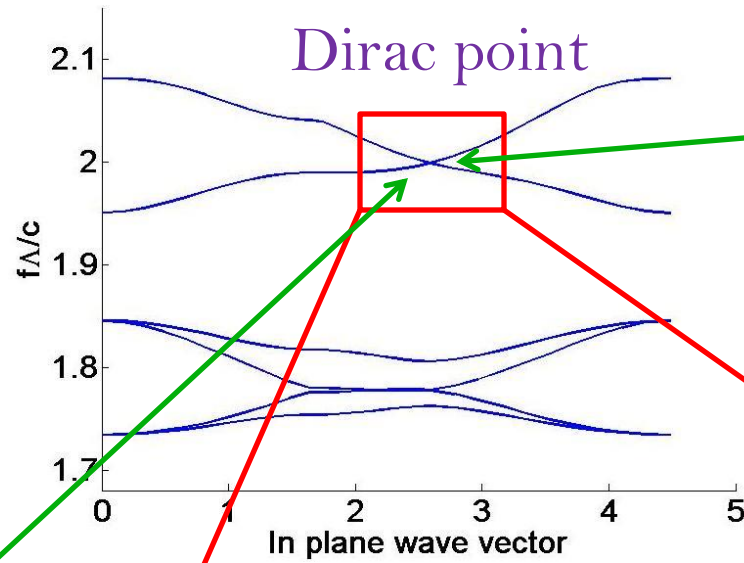Effective mode index=0.990922
Surface: Electric field norm (V/m)
▲ 4.2029×10⁷

▼ 6835.5
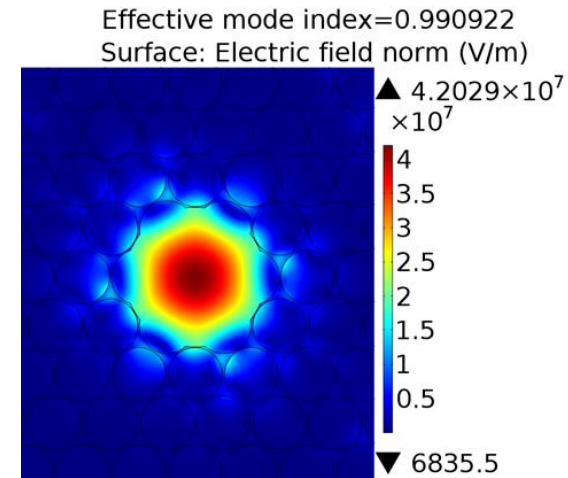
Tuneable operating wavelength

Low loss transmission window

d/Λ=0.95

d/Λ=0.90

d/Λ=0.85

Dirac point in Photonic Crystal
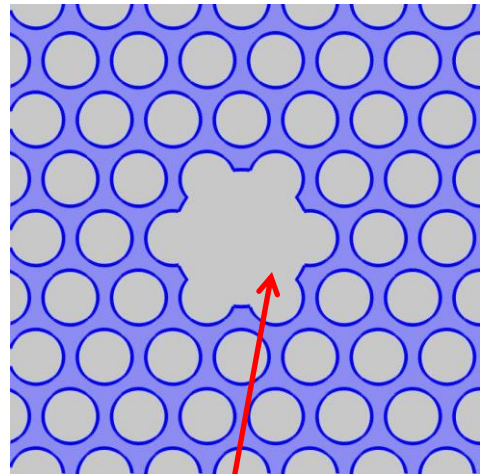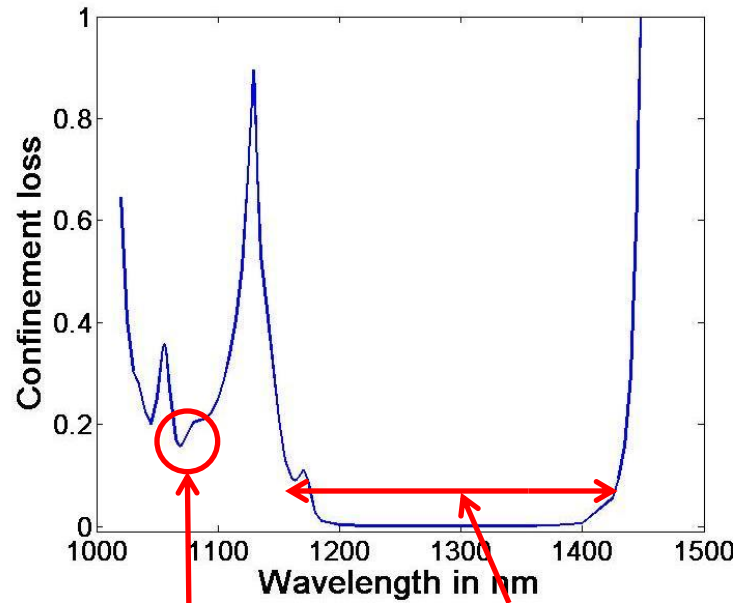

Dirac point
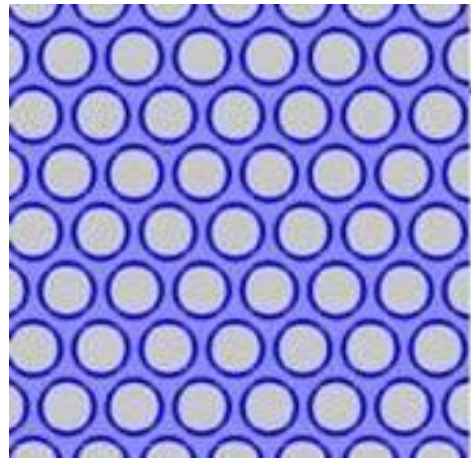
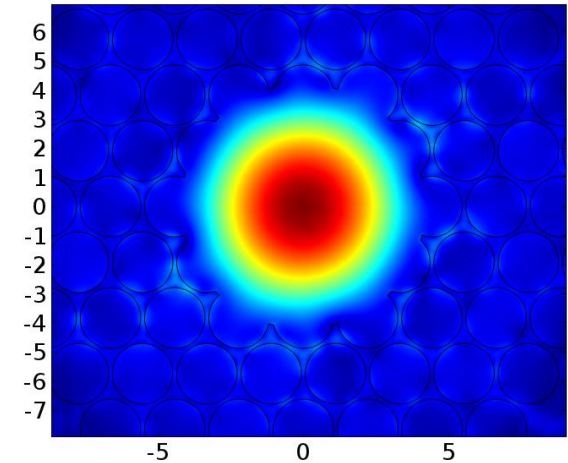# Fiber guiding at Dirac frequency

Defect created for trapping Dirac mode

Dirac mode guidance

PBG guidance

Effective mode index=0.995701-2.42174e-4i
Surface: Magnetic field (V/m)

- Wave guidance is governed neither by TIR nor by PBG

- Shows sharp frequency response

- May find application in sensing/lasing

Summary

✓PCFs having core index higher than cladding guide light by TIR

✓PCFs having core index lower than cladding guide light by trapping either PBG or Dirac mode

✓n_{FSM} and n_{eff} are calculated using **Mode Analysis** study

✓PBS is calculated using **Eigenfrequency study**

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Thank You