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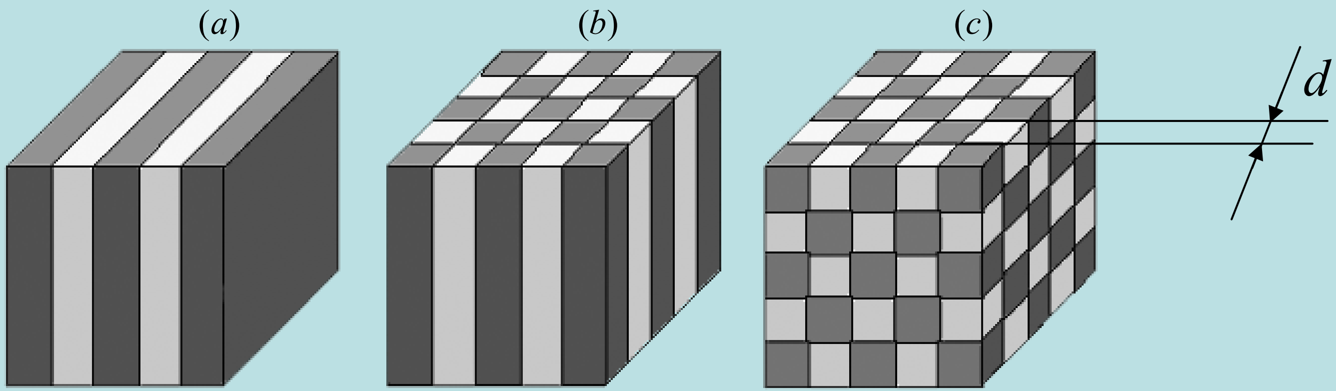
Optical Phenomena in Photonic Crystals

Introduction

- Historical Review
- Opal-like photonic crystals
- Applications

Photonic crystals



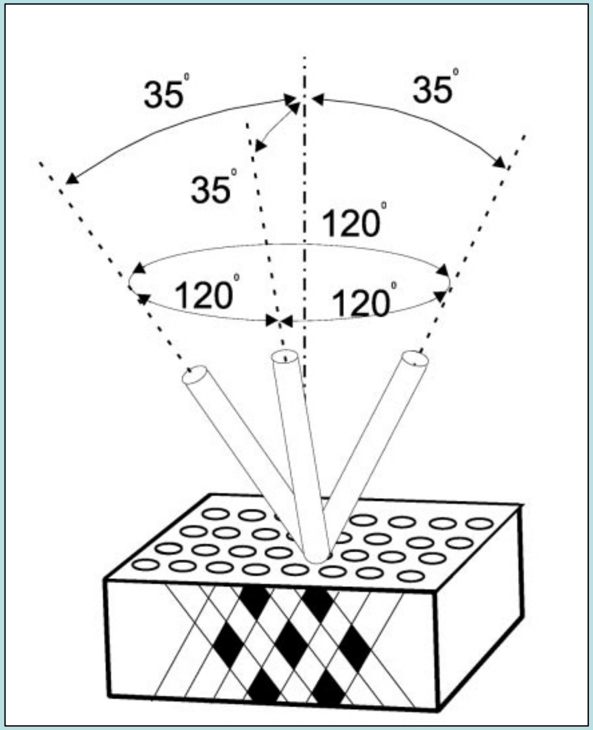
1-D (a), 2-D (b) и 3-D (c) photonic crystals

$$d \sim \lambda$$

$$\lambda = 400..700nm$$

Historical review

Photonic crystals for microwave radiation:



$$d \sim 1mm$$

- *E. Yablonovich*. **Inhibited spontaneous emission in solid-state physics and electronics**.

  Phys. Rev. Lett., Vol. 58, 2059 (1987).
- *S. John*. **Strong localization of photons in certain disordered dielectric superlattices**.

  Phys. Rev. Lett., Vol. 58, 2486 (1987).

Historical review

- *V. P. Bykov*. **Spontaneous emission in a periodic structure**.

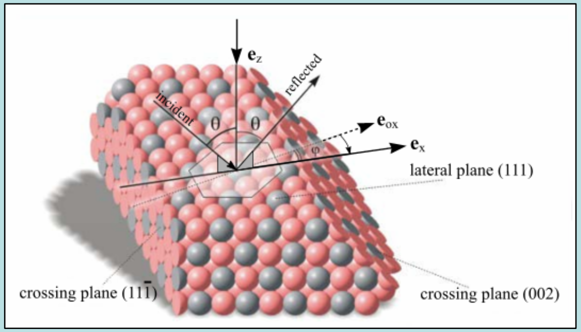
  Sov. Phys. JETP, Vol. 35, 269-273 (1972).
- *V. P. Bykov*. **Spontaneous emission from a medium with a band spectrum**.

  Sov. J. Quant. Electron., Vol. 4, 861-871 (1975).

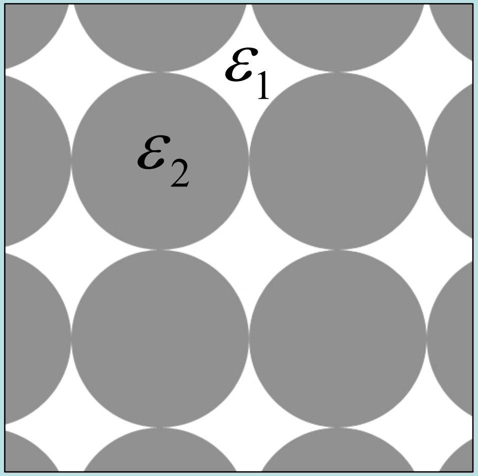
Objects under study

3-D two-component photonic crystals
with FCC lattice

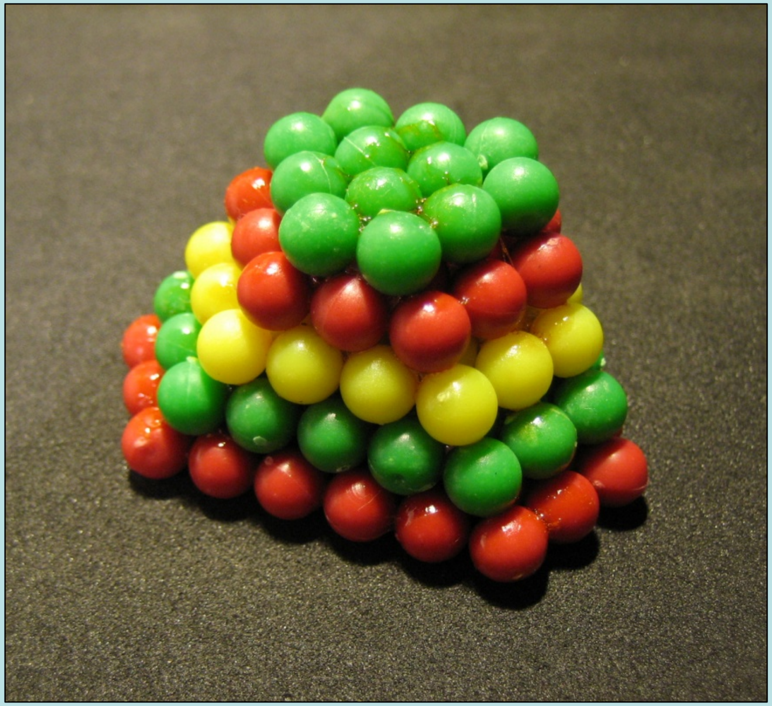
- Opals – SiO_2
- Polymer opal-like photonic crystals



High dielectric contrast $\frac{\varepsilon_1}{\varepsilon_2}$

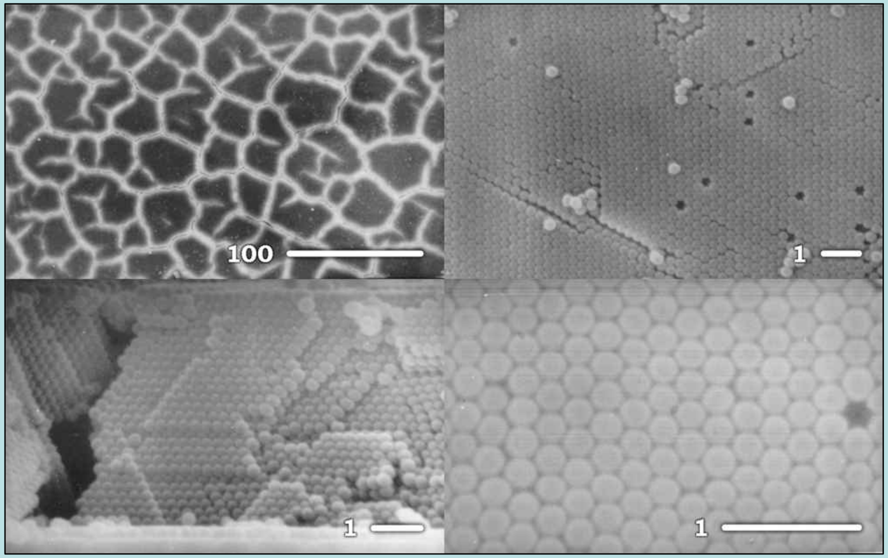


Objects under study

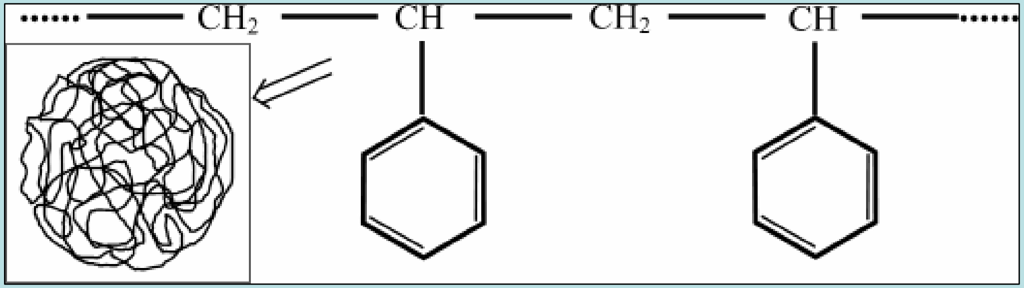


10.000 times magnified model
of photonic crystal with FCC lattice

Objects under study

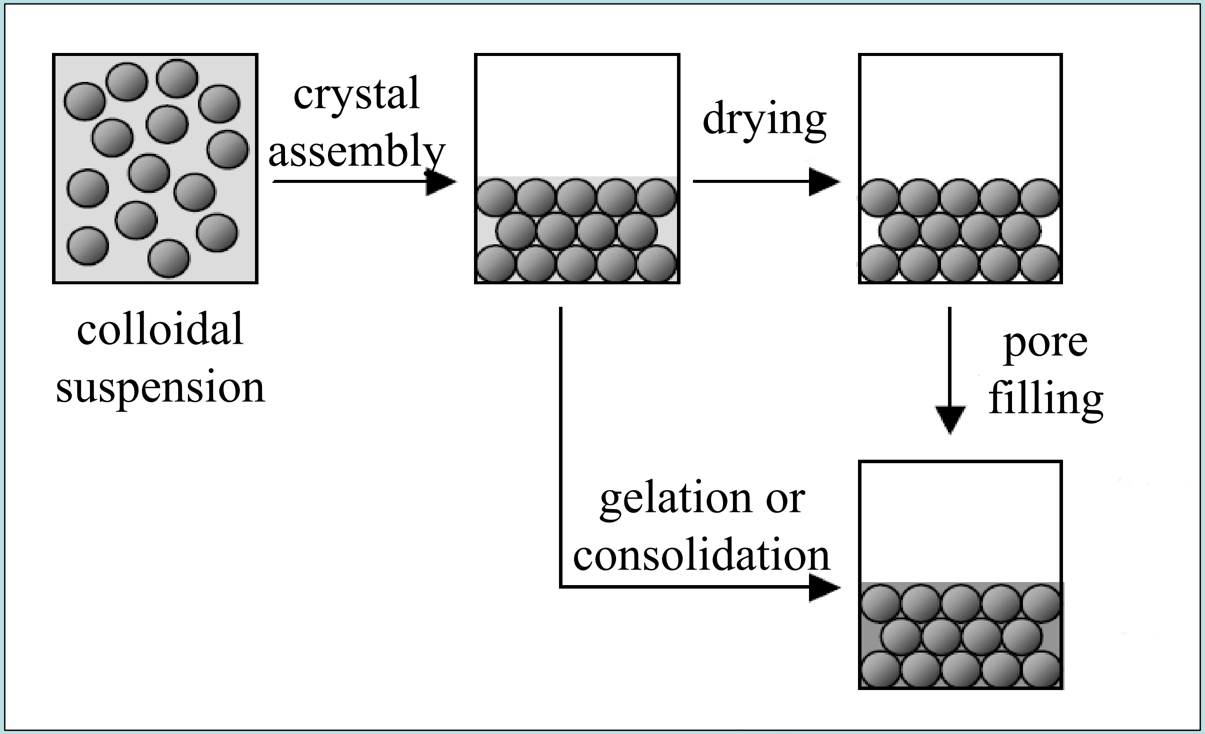


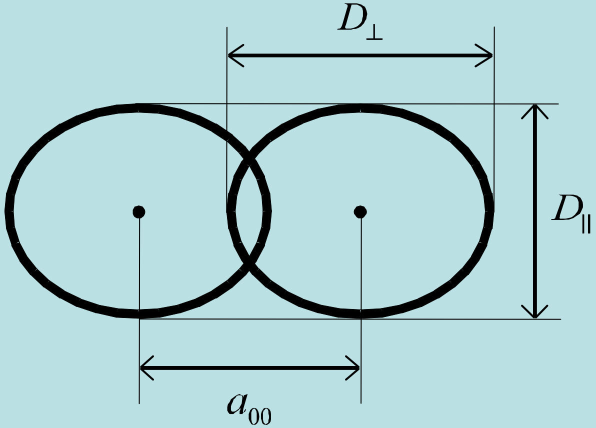
SEM micrographs of polystyrene opal-like photonic crystal



Macromolecule of polystyrene

Opal-like photonic crystals production

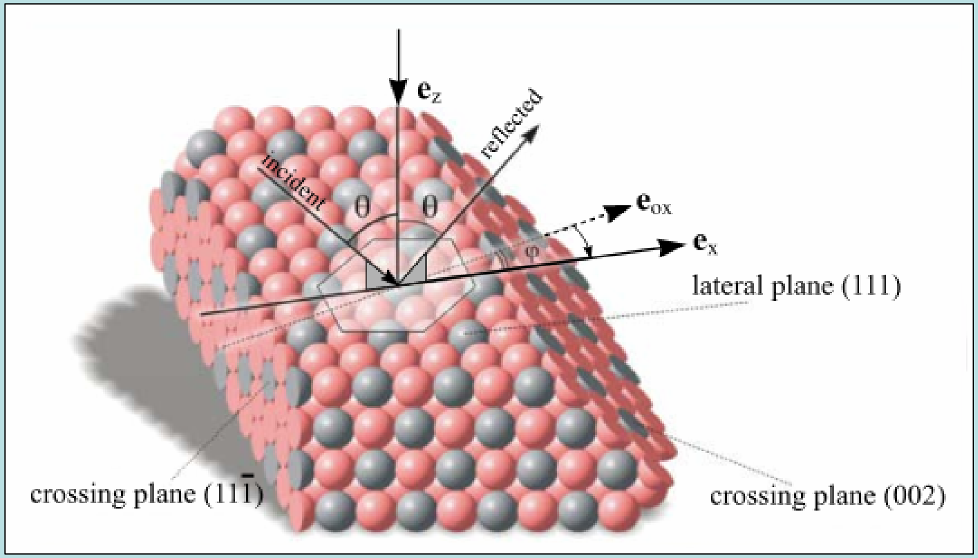


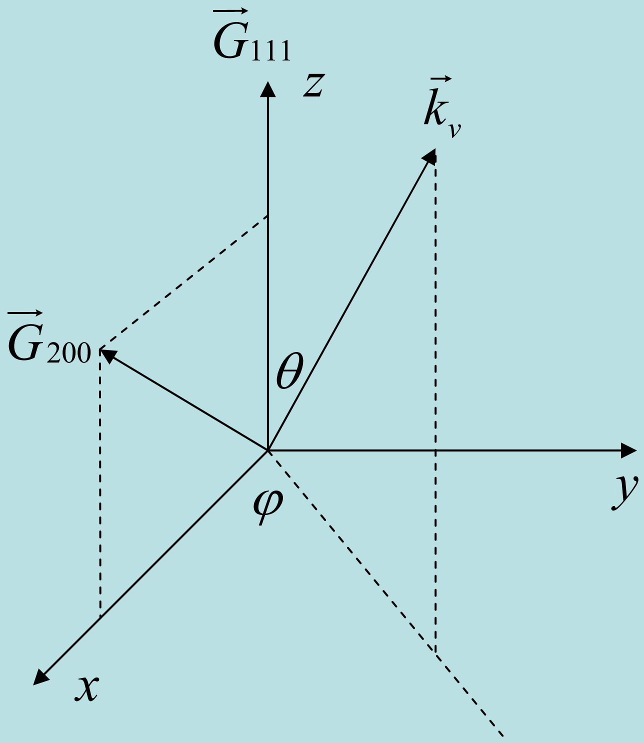


$$\chi = 1 - \frac{a_{00}}{D_\perp}$$ – coefficient of the isotropic sintering

$$\eta = \frac{D_\parallel}{D_\perp}$$ – coefficient of the axial compression along the (111) direction

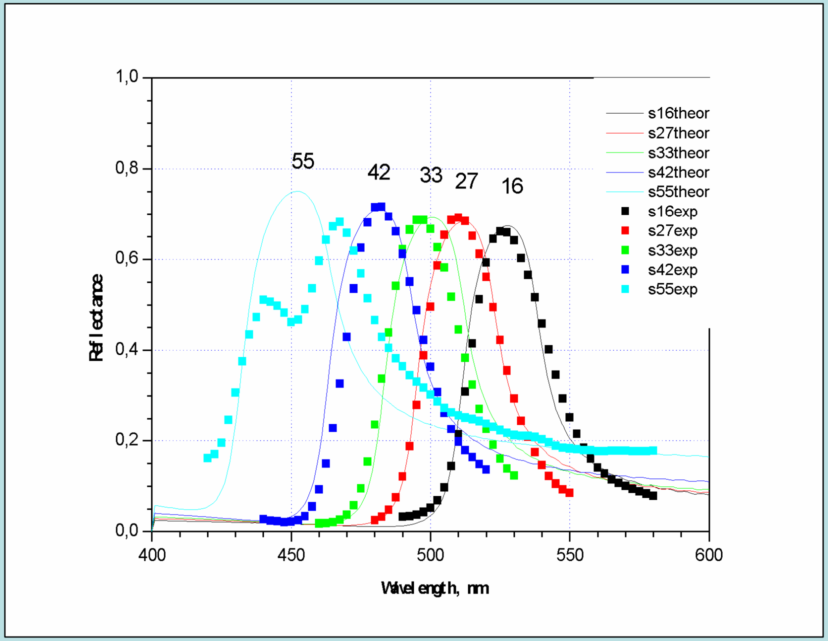
Light propagation geometry

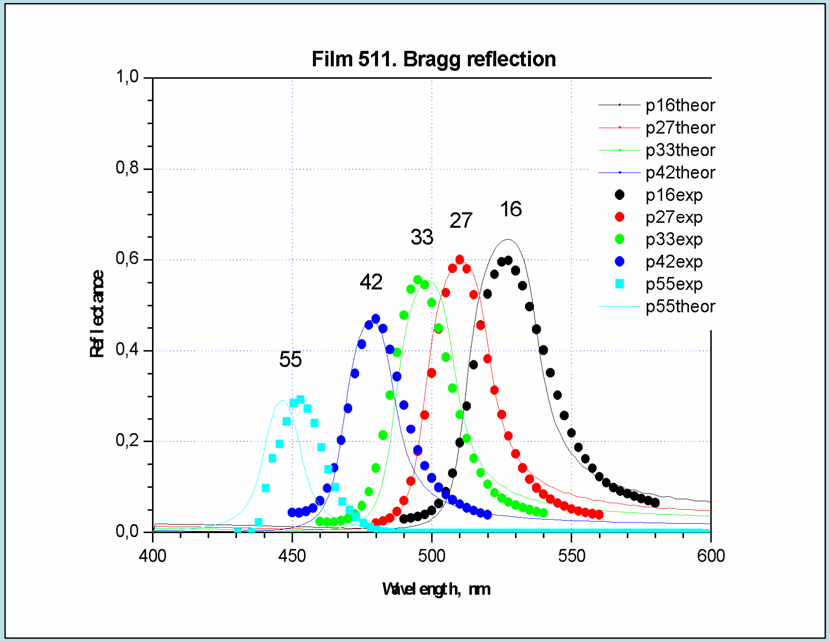




Experimental reflection spectra

$$\varphi = 0°$$





s-polarization

p-polarization

Computing photonic band structure

- Plane wave expansion method
- Korringa-Kohn-Rostoker (KKR) method
- Finite Difference Time Domain (FDTD) method

Equation for eigenmodes in photonic crystal

$$\vec{E}(\vec{r}) = \sum_{\vec{k}} \vec{E}_{\vec{k}}(\vec{r}) \qquad \varepsilon(\vec{r}) = \sum_{\vec{G}} \varepsilon_{\vec{G}} e^{i\vec{G}\cdot\vec{r}}$$

$$\vec{E}_{\vec{k}}(\vec{r}) = \sum_{\vec{G}} \vec{A}(\vec{k} - \vec{G}) e^{i\cdot(\vec{k}-\vec{G})\cdot\vec{r}}$$

$$(\vec{k}^2 - \varepsilon_0 k_0^2)\vec{A}(\vec{k}) - \vec{k}(\vec{k}\cdot\vec{A}(\vec{k})) = k_0^2 \sum_{\vec{G}\neq 0} \varepsilon_{\vec{G}} \vec{A}(\vec{k} - \vec{G})$$

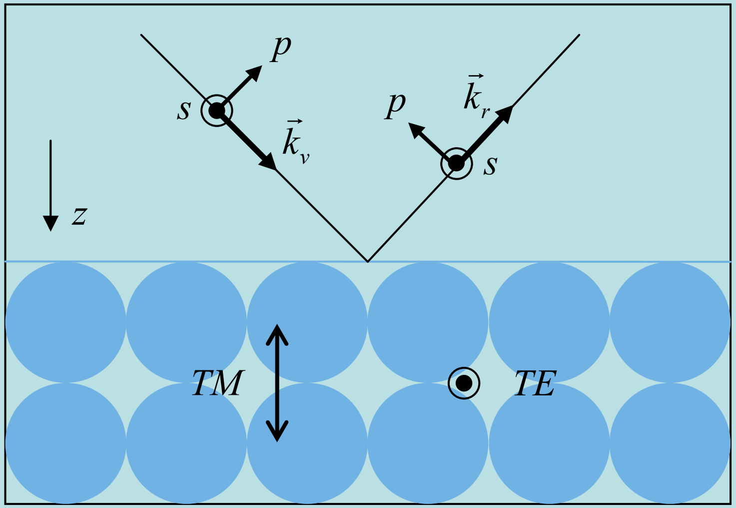
Symbols: $k_0 \equiv \dfrac{\omega}{c}$

Dispersion curves

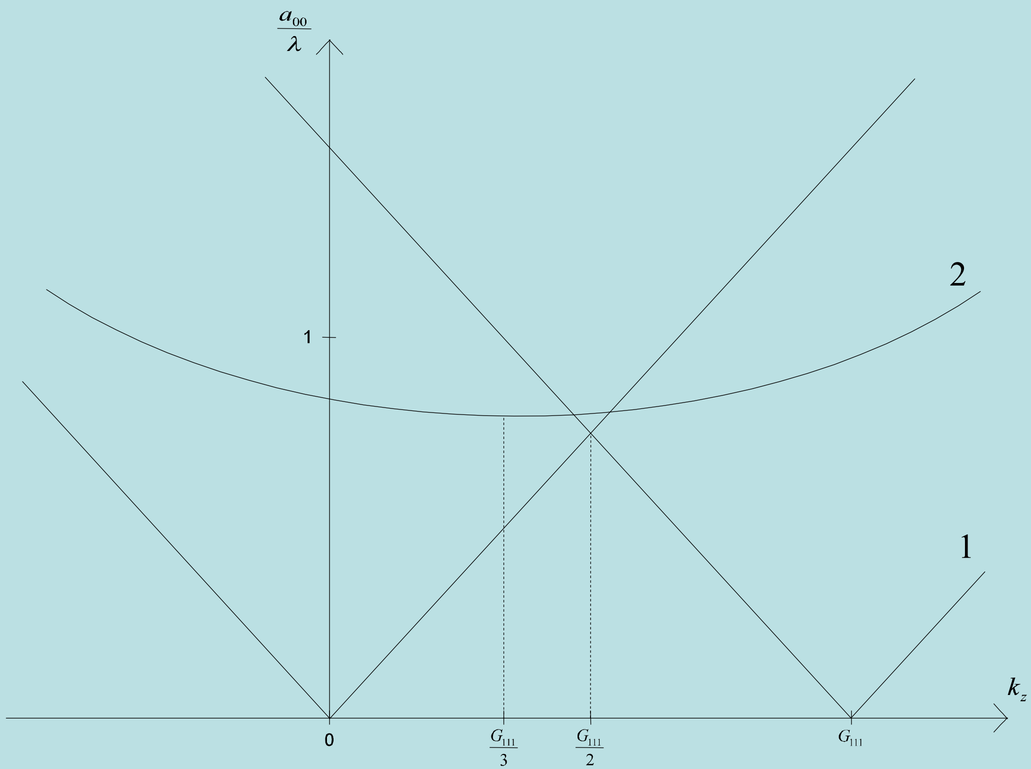
$$\varphi = 0$$

TE-modes – s-polarization

TM-modes – p-polarization



Dispersion curves of eigenmodes in photonic crystal in empty lattice approximation

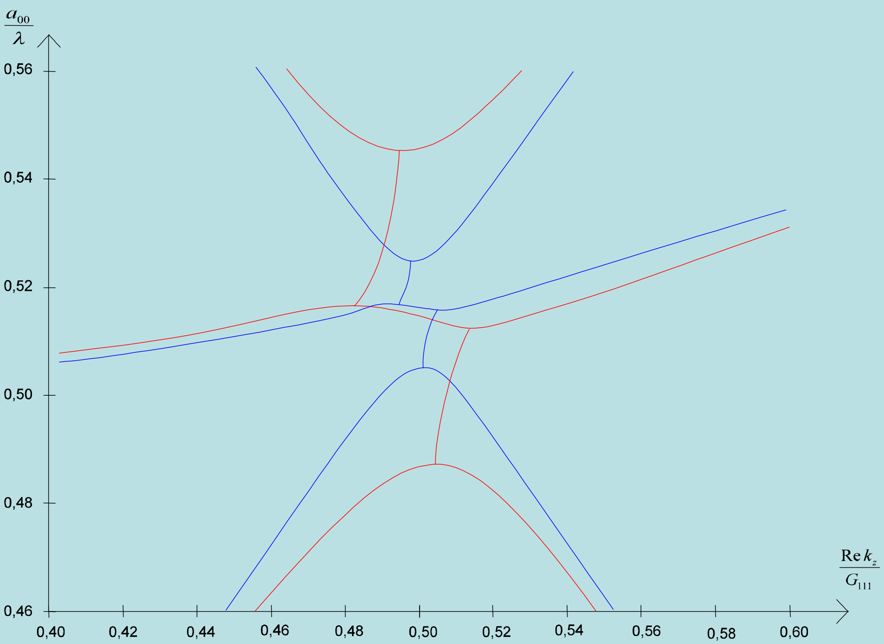


$$\varepsilon_{111} \to 0, \varepsilon_{\bar{1}11} \to 0$$

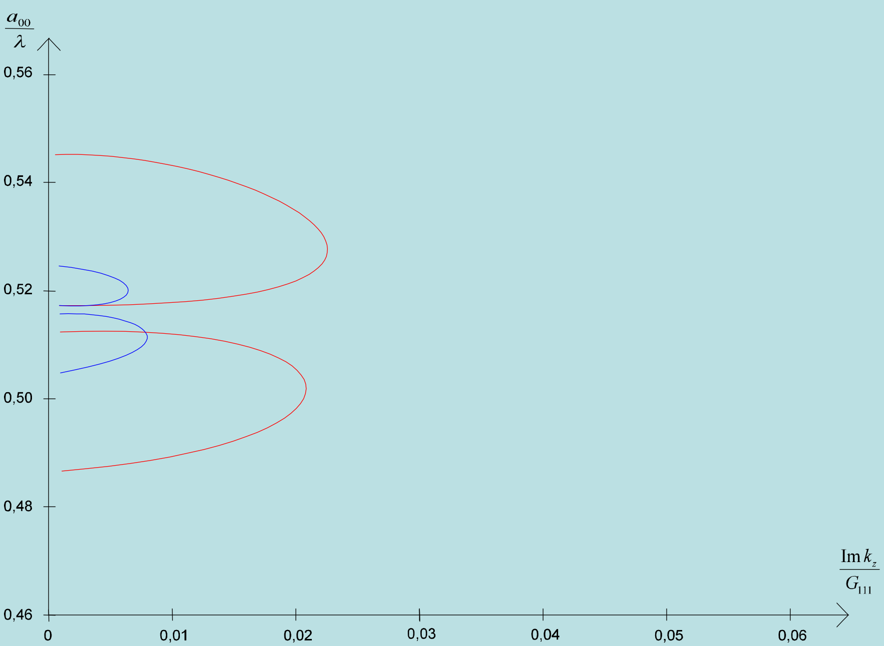
1 – Bragg reflection from (111) plane

2 – Bragg reflection from $(\bar{1}11)$ plane

Dispersion relations



$$\theta = 57°, \varphi = 0°$$



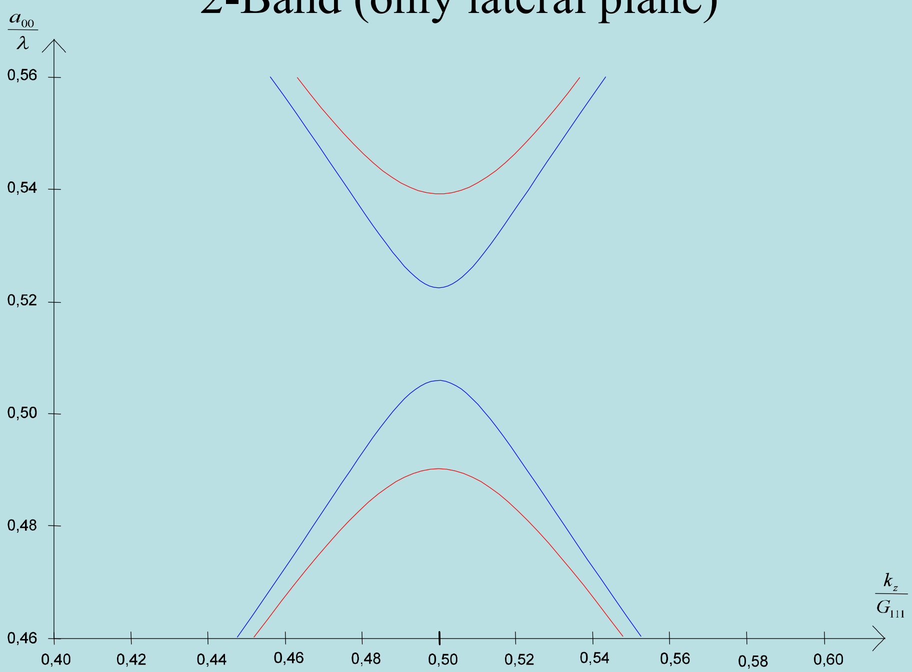
s-polarization

p-polarization

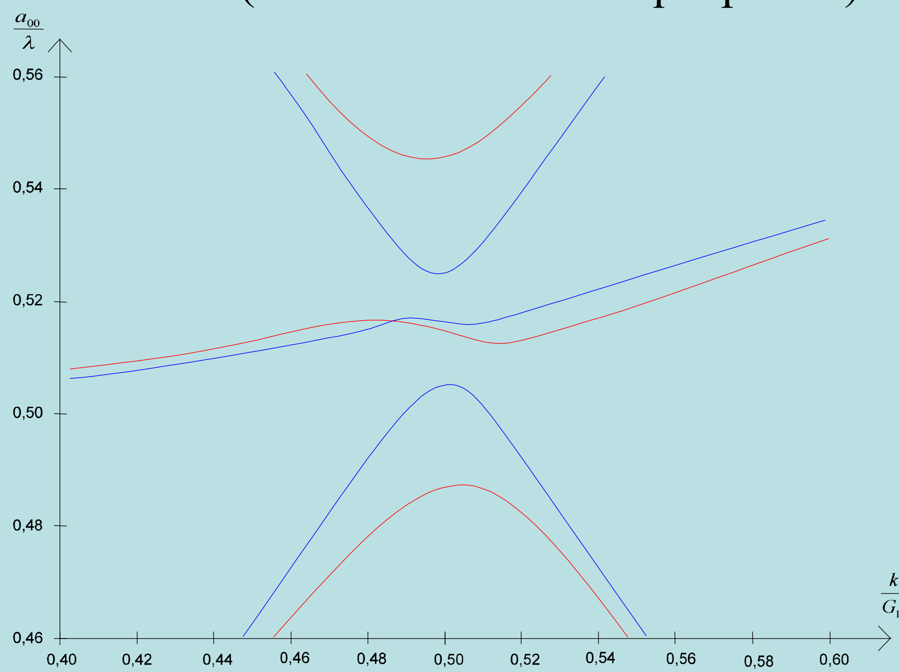
Dispersion relations

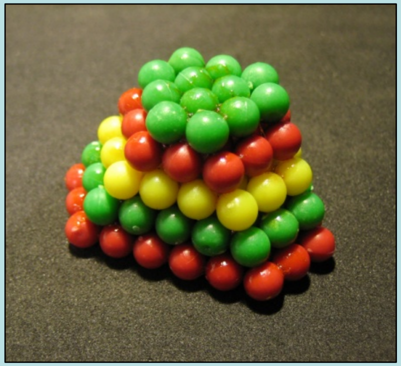
$$\theta = 57°, \varphi = 0°$$

2-Band (only lateral plane)



3-Band (both lateral and oblique planes)



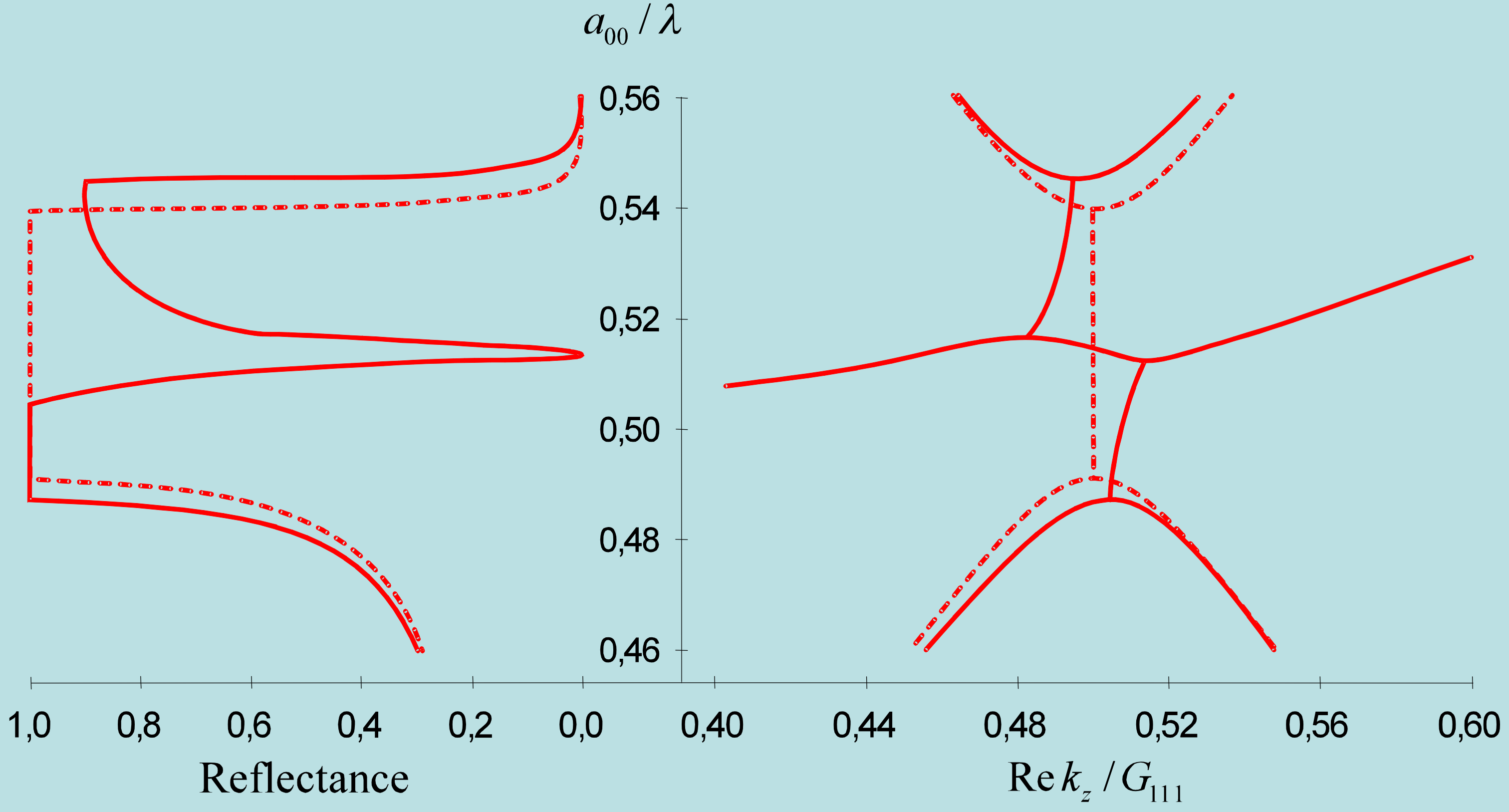


s-polarization

p-polarization

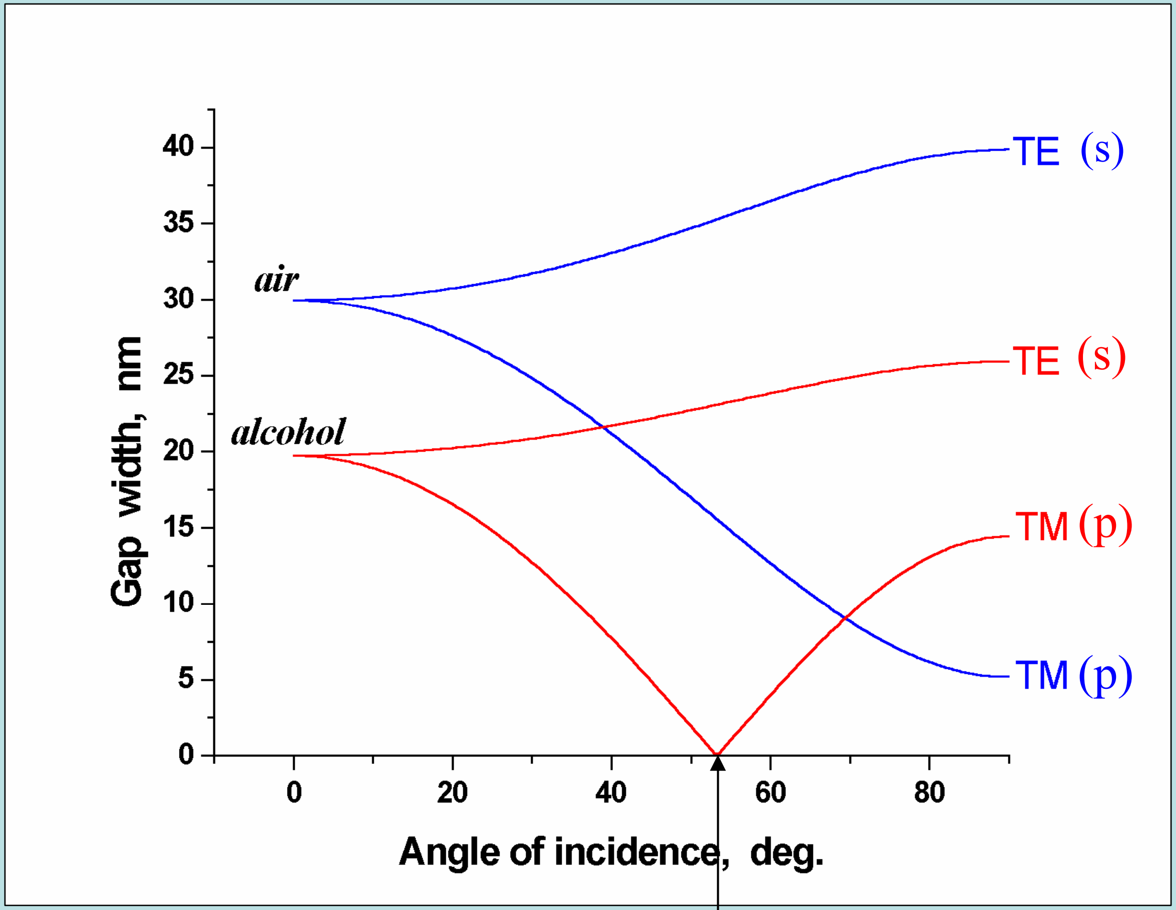
Dispersion relations

$$\theta = 57°, \varphi = 0°$$



s-polarization

Stop-band width



stop-band collapse for p-polarized incident light

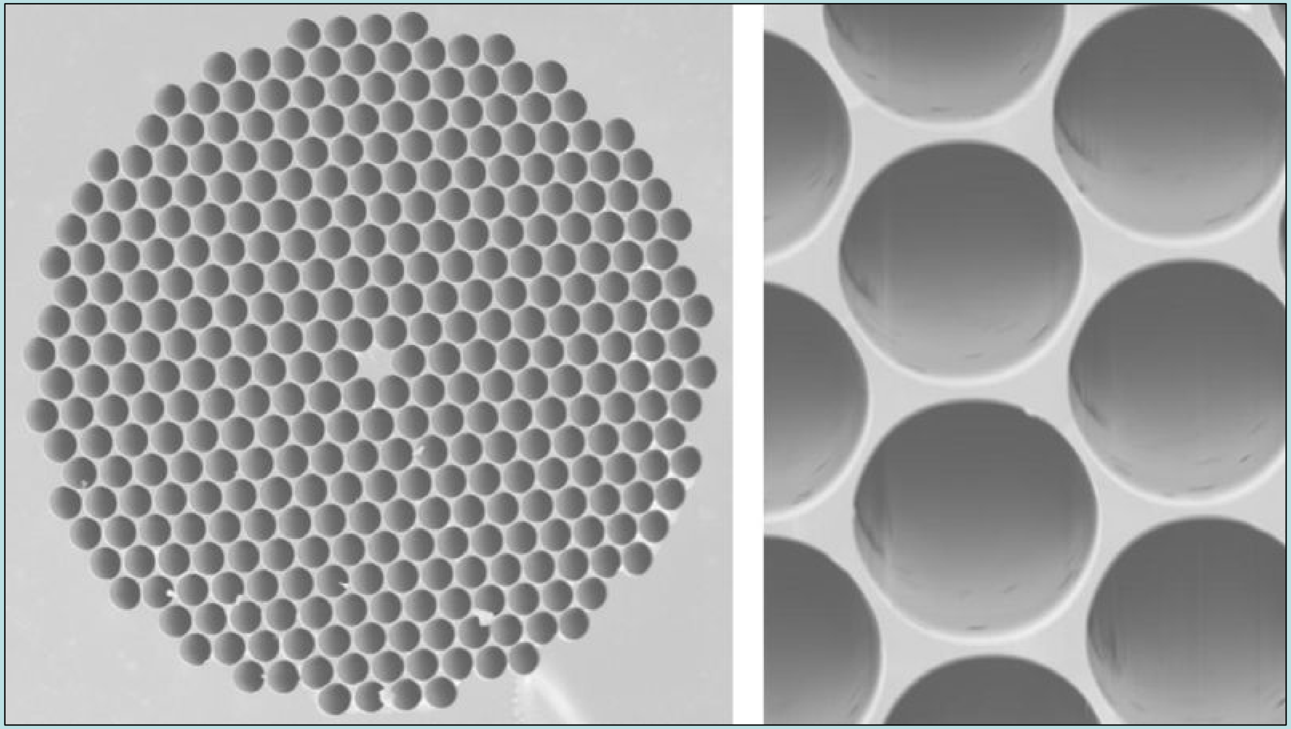
Practical applications

- 1-D: Thin-film optics

  Mirrors multilayer coating – Bragg mirrors.

Practical applications

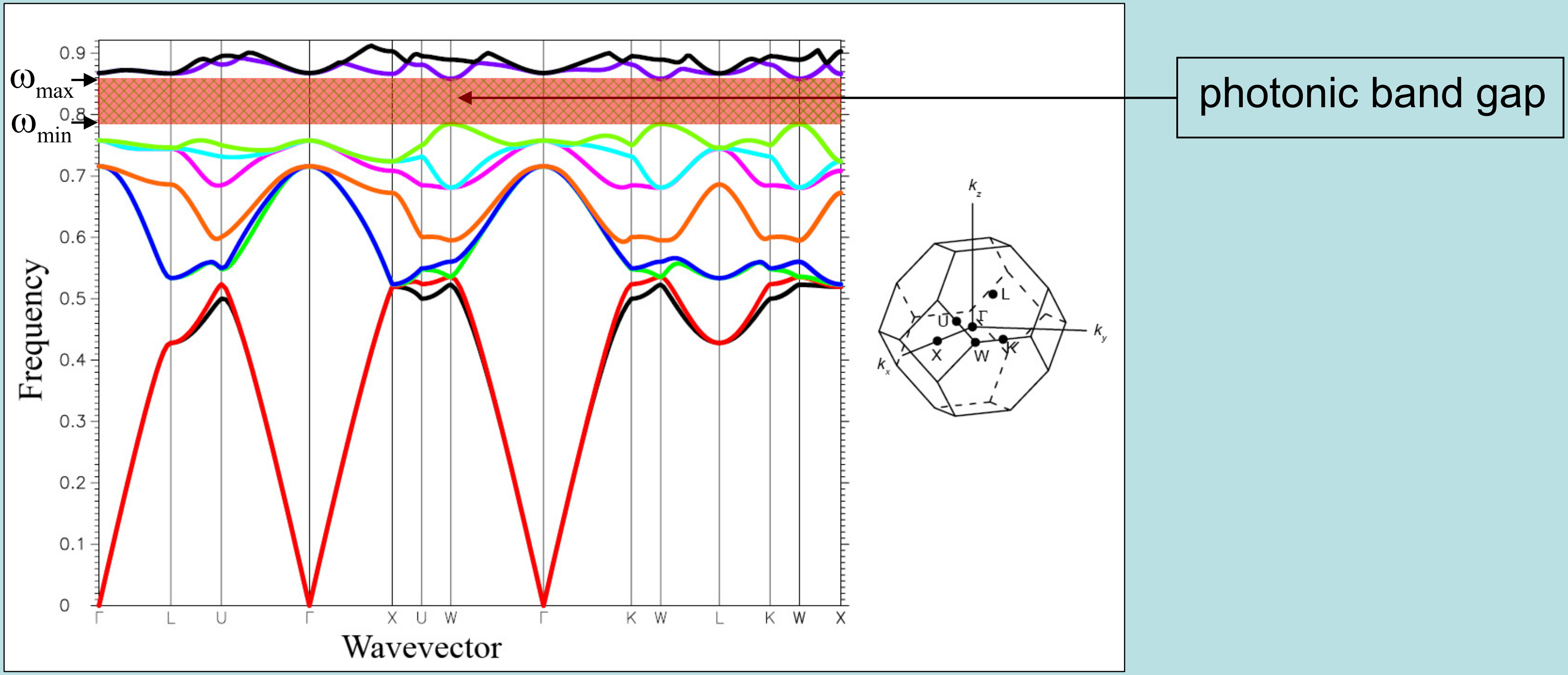
- 2-D: Photonic-crystal fibers



SEM micrographs of US Naval Research Laboratory-produced photonic-crystal fiber.
The diameter of the solid core at the center of the fiber is 5 μm, while the diameter of the holes is 4 μm.

Practical applications

- 3-D: Spontaneous emission inhibition



Photonic band structure of inverted opal

Atoms with $\omega_{min} < \omega_0 < \omega_{max}$ can't emit radiation.

Literature

- *C. Lopez*. **Material aspects of photonic crystals**. Adv. Mater., Vol. 15(20), 1679–1704 (2003).
- *K. Sakoda*. **Optical properties of photonic crystals**. Springer series in optical sciences. Vol. 80, Berlin–Heidelberg–New York, Springer (2001).

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Thank You for Your Attention!