

Photonic Crystals

Principle // in Nature // in Biomedicine

Agenda

- Principle of photonic crystals
- Photonic crystals in nature
- Photonic crystals in (biomedical) technologies

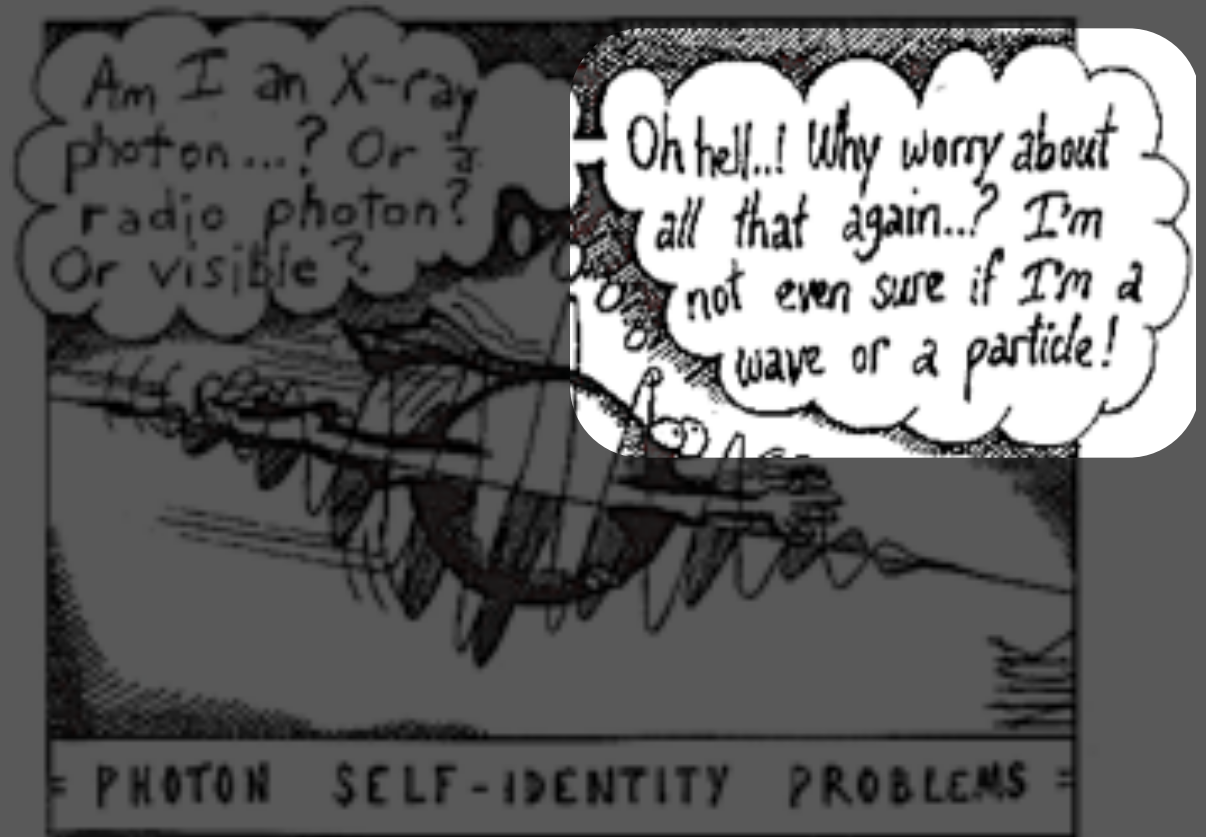
WHAT'S A PHOTONIC CRYSTAL?

WHAT
IS
LIGHT
?

WHAT IS LIGHT ?



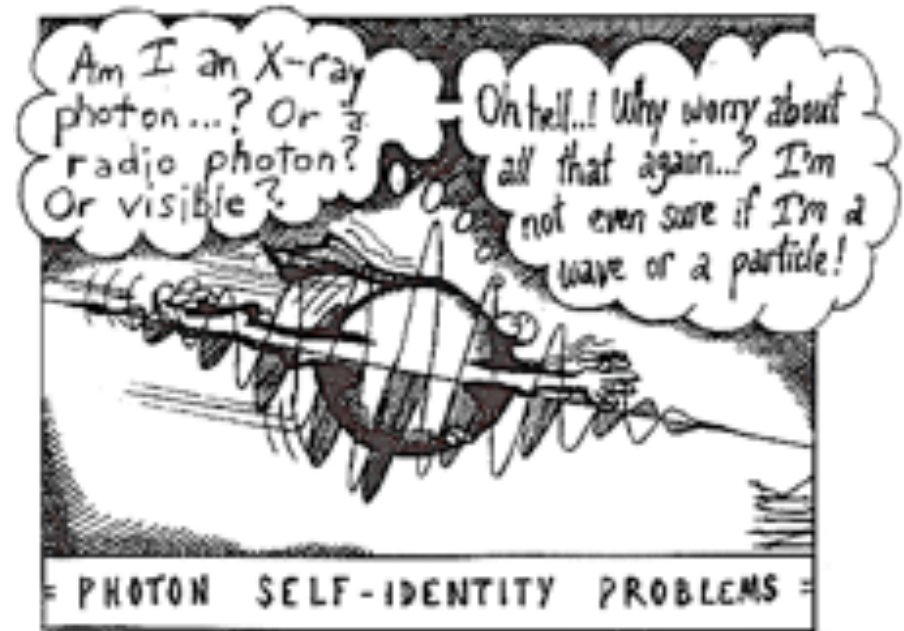
WHAT IS LIGHT ?



Principle of photonic crystals

some repetition

- (visible) light, microwaves, radio signals, X-ray, and gamma radiation are all **electro-magnetic radiation** (of different energy/frequency)!
- wave-particle duality:
 - depending on the experiment, light can be described by a wave or a particle model
- first, we will look at light as a wave.

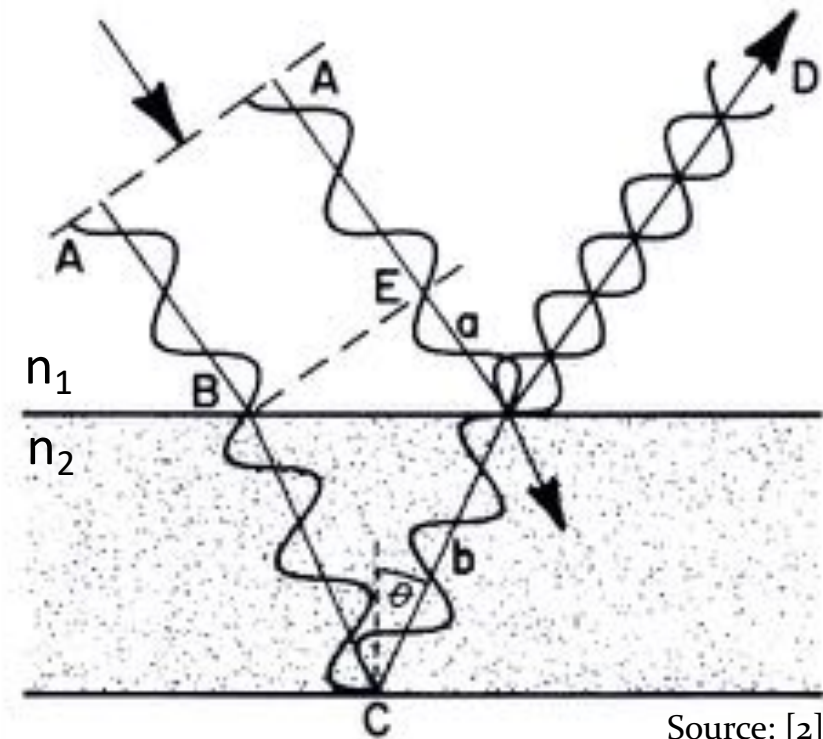


Source: [1]

Principle of photonic crystals

some repetition

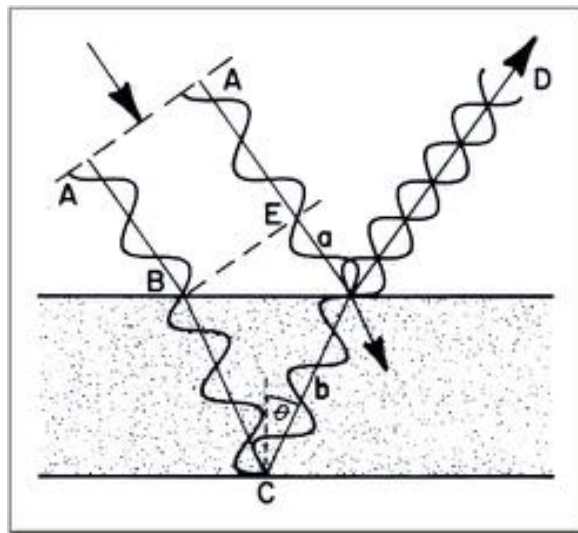
- when looking at light as a wave, two phenomena can be described well
 - diffraction
 - interference
- both can be observed on waveplates



Source: [2]

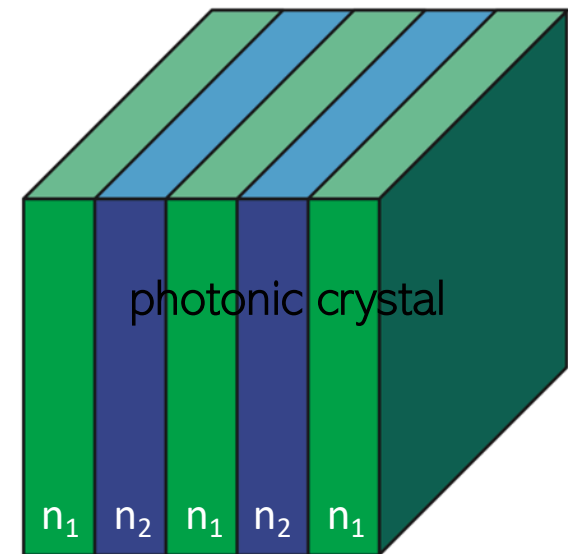
Principle of photonic crystals

from waveplates to photonic crystals



waveplate

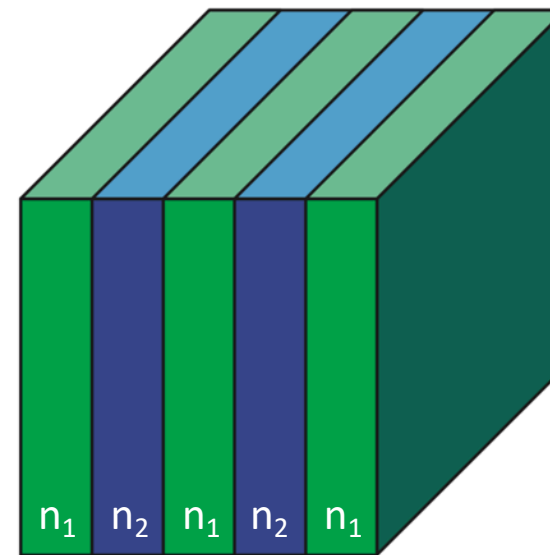
add periodicity



Principle of photonic crystals

What is a photonic crystal (PC)?

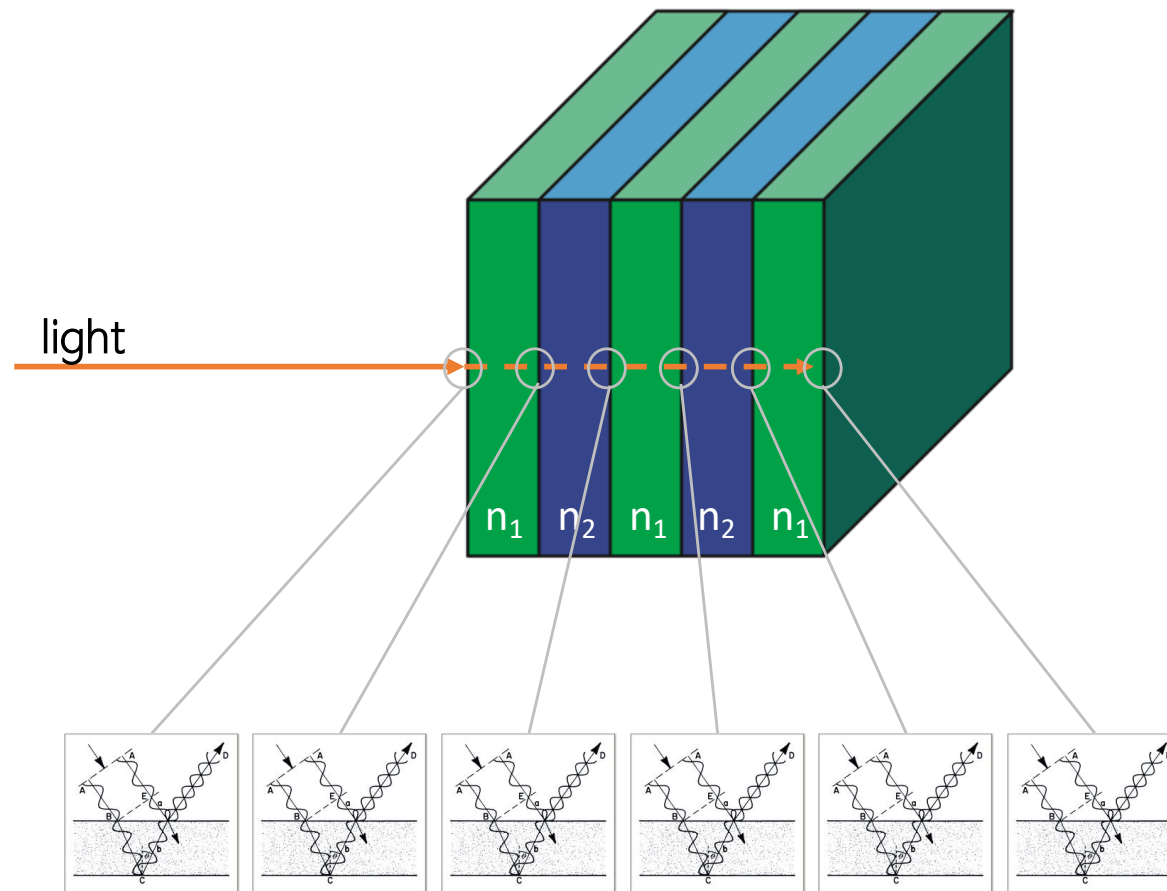
- a structured solid material with a periodically changing refractive index
- period length in range of one quarter of the wavelength of light to be manipulated
- does not have to be crystalline



photonic crystal

Source: [3]

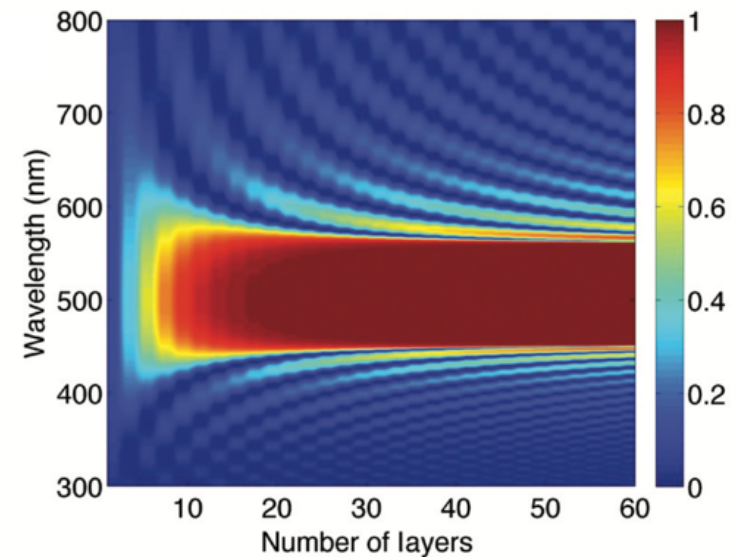
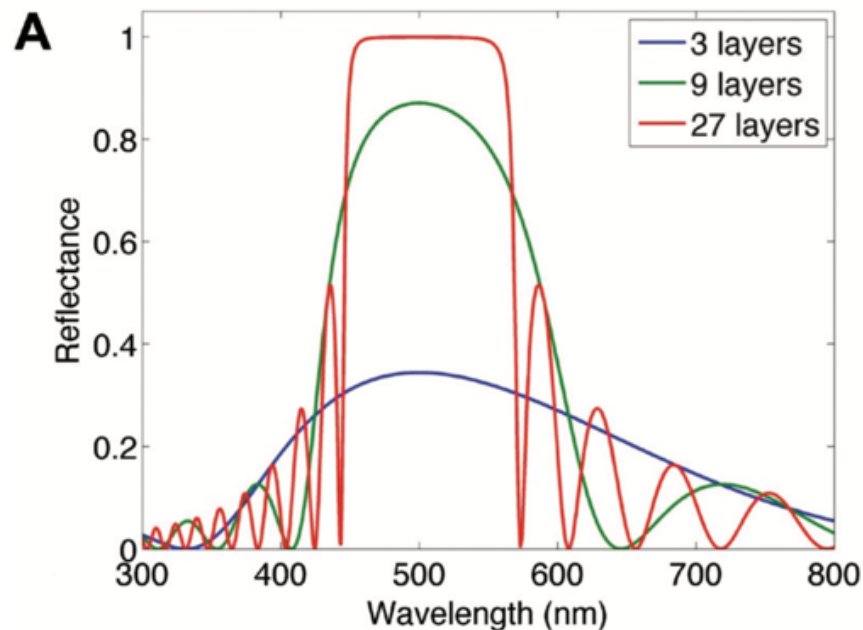
Principle of photonic crystals



Principle of photonic crystals

from waveplates to photonic crystals

- due to diffraction and interference, a **photonic band gap** (PBG) appears with increasing number of layers / size of the crystal

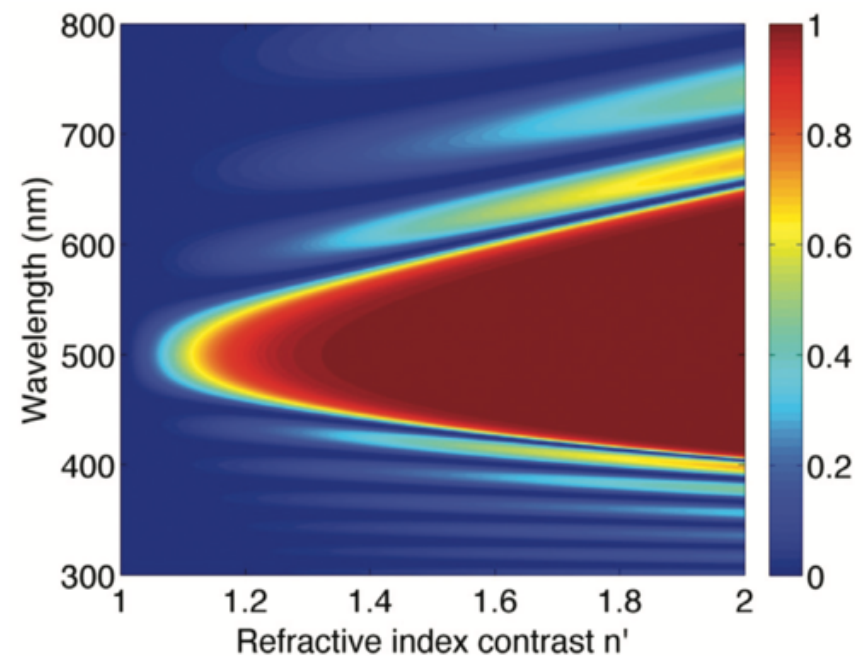


Source: [4]

Principle of photonic crystals

from waveplates to photonic crystals

- the width of the PBG increases with increasing refractive index contrast in the photonic crystal

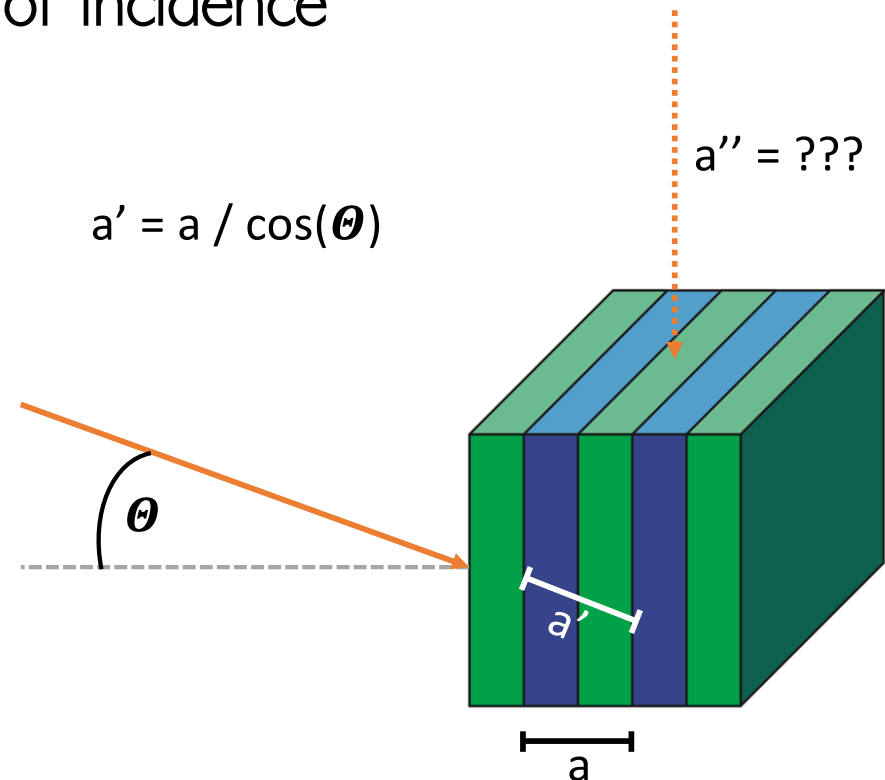


Source: [4]

Principle of photonic crystals

problem: dependence on angle of incidence

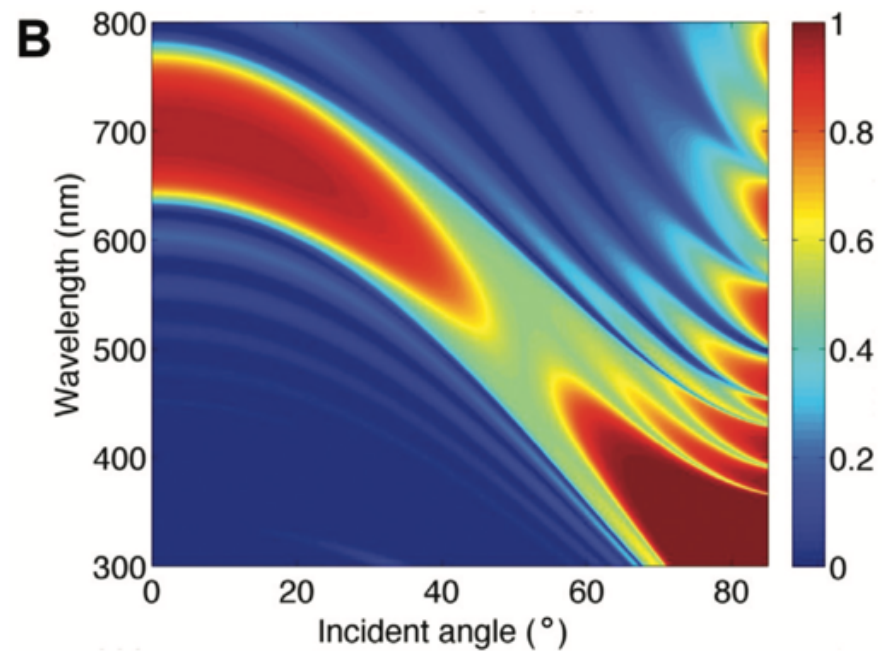
- a PC like shown on the right has periodicity only in one direction
- incident light whose direction is not perpendicular to the surface “sees” a different periodic length



Principle of photonic crystals

problem: dependence on angle of incidence

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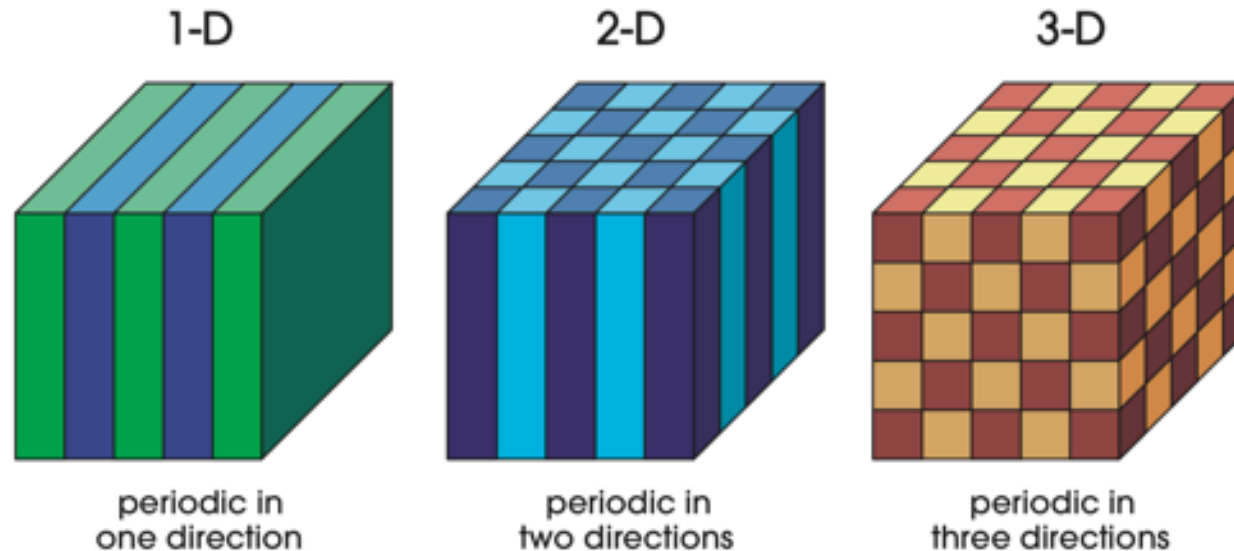


Source: [4]

Principle of photonic crystals

problem: dependence on angle of incidence

- by adding periodicity in more dimensions, one can make the PC show a more consistent behavior for a larger range on incident angles

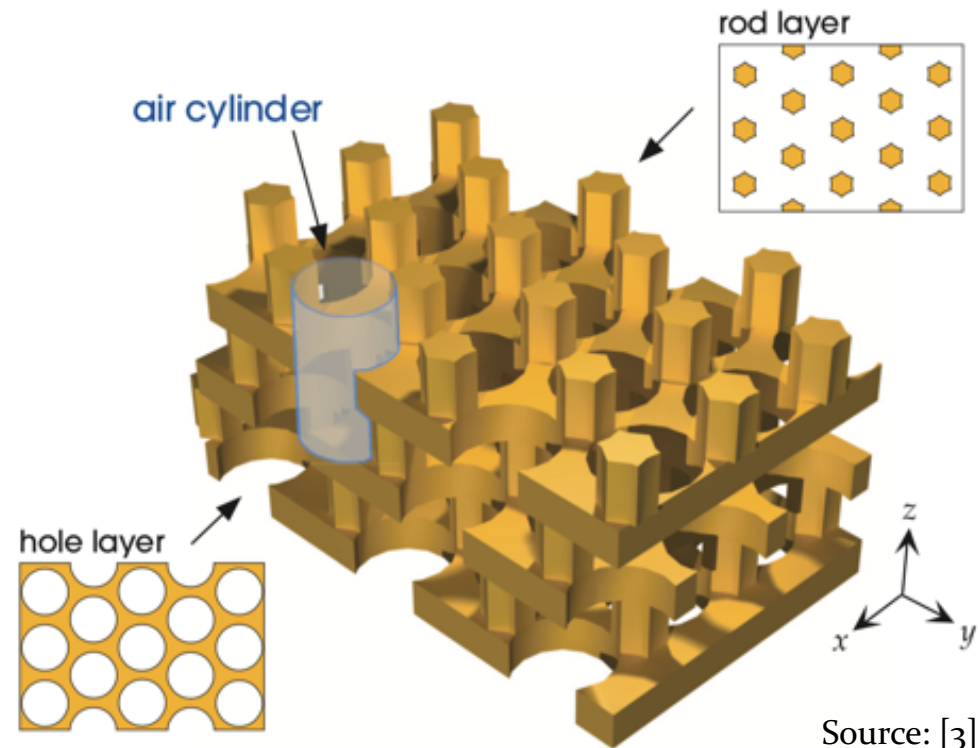


Source: [3]

Principle of photonic crystals

problem: dependence on angle of incidence

- complex three-dimensional structures are used to create 3d PCs



Source: [3]

Principle of photonic crystals

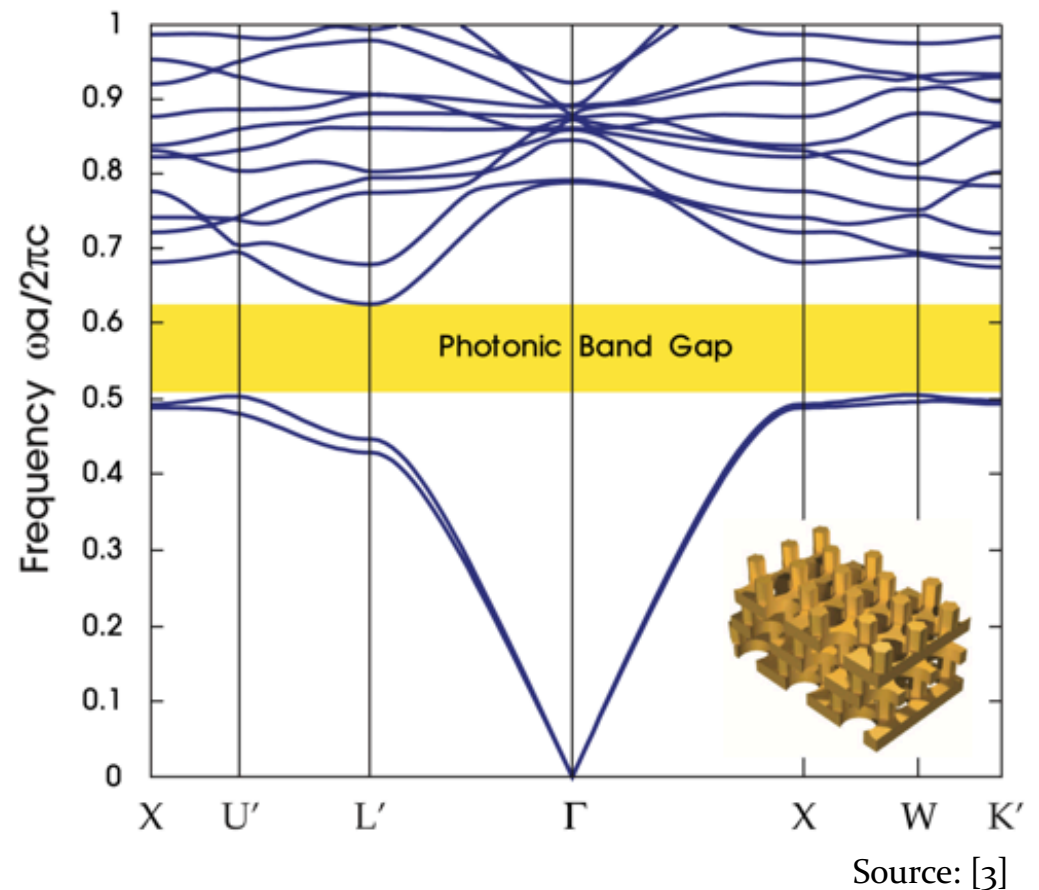
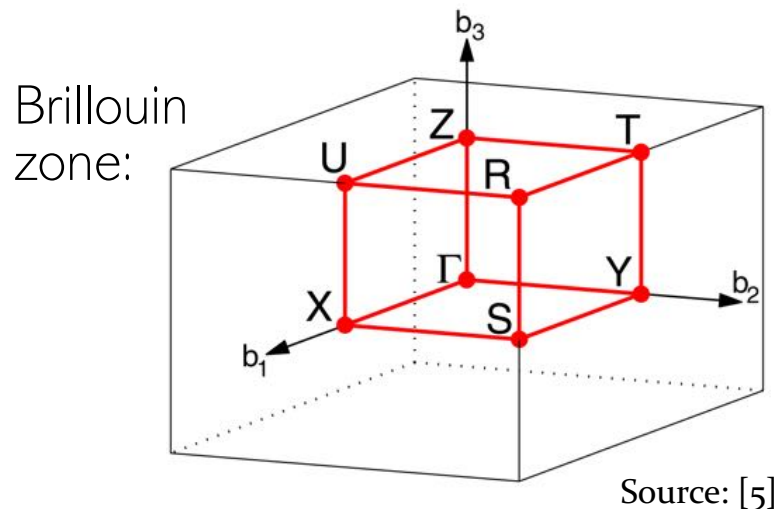
transition from wave model to particle model

- by shaping the geometry of PC one can manipulate light or rather photons in a similar way as semiconductors can be designed to manipulate electrons
- the energy of a photon corresponds to wavelength of the light wave: $E = h * \frac{c}{\lambda}$
- therefore, a PBG can be described as a group of disallowed energy states which photons can not enter within the PC

Principle of photonic crystals

transition from wave model to particle model

- a common way in semiconductor physics as well as in photonics to visualize the allowed and disallowed energy states is a band structure plot



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Photonic crystals in nature

- photonic crystals are used by many animals to create colors
- this works because photons whose energy is forbidden inside the crystal get reflected
- consequently, the wavelengths of PBG are reflected and give the material a vibrant color

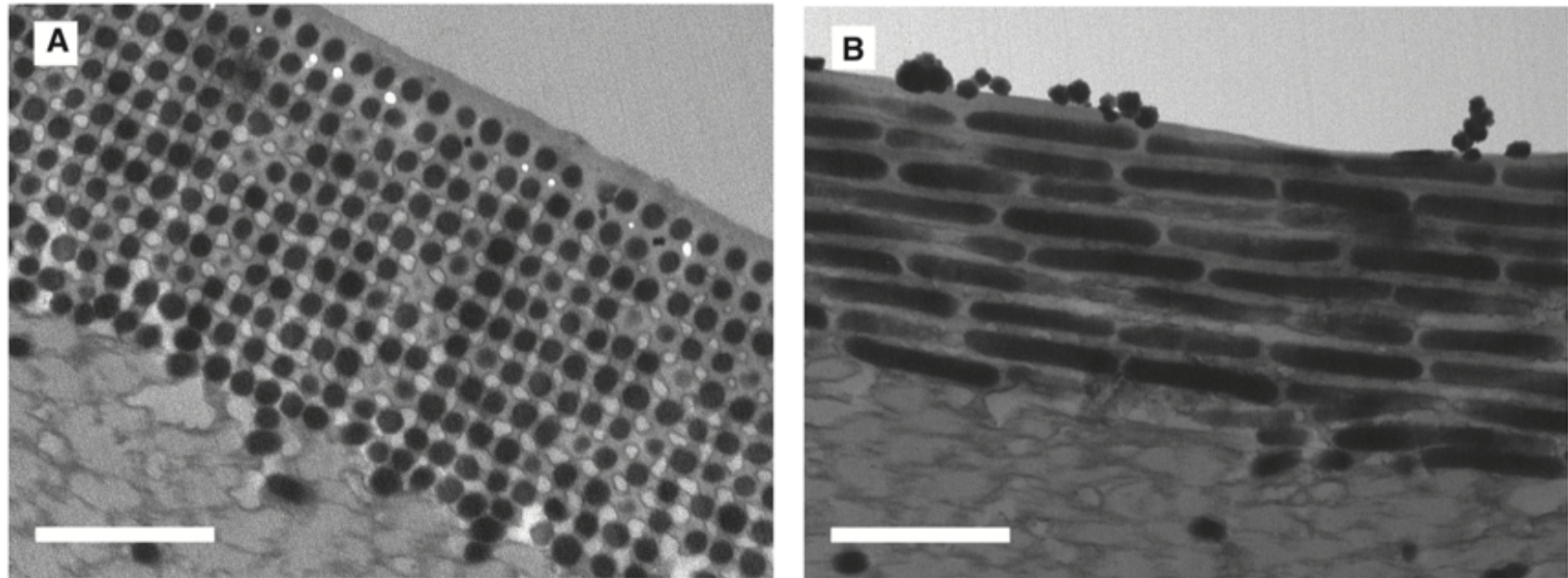
Photonic crystals in nature

- peacock feathers consist of highly ordered structures of about 100nm in diameter
- these structures build photonic crystals with different PBG which create different metallic and vibrant colors



Source: [6]

Photonic crystals in nature



Source: [4]

Photonic crystals in nature

- butterflies and other insects use very complex structured photonic crystals to create their characteristic colors



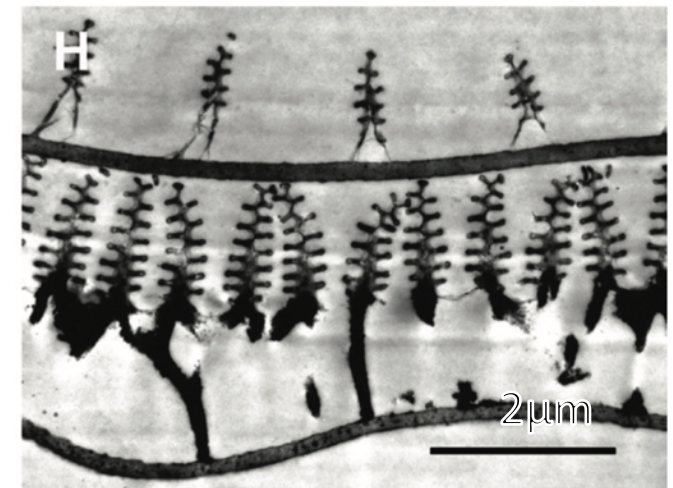
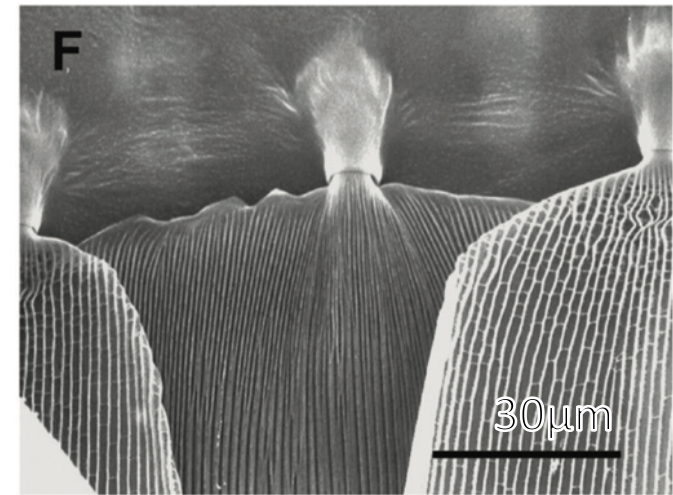
Source: [7]

Photonic crystals in nature

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Source: [8]



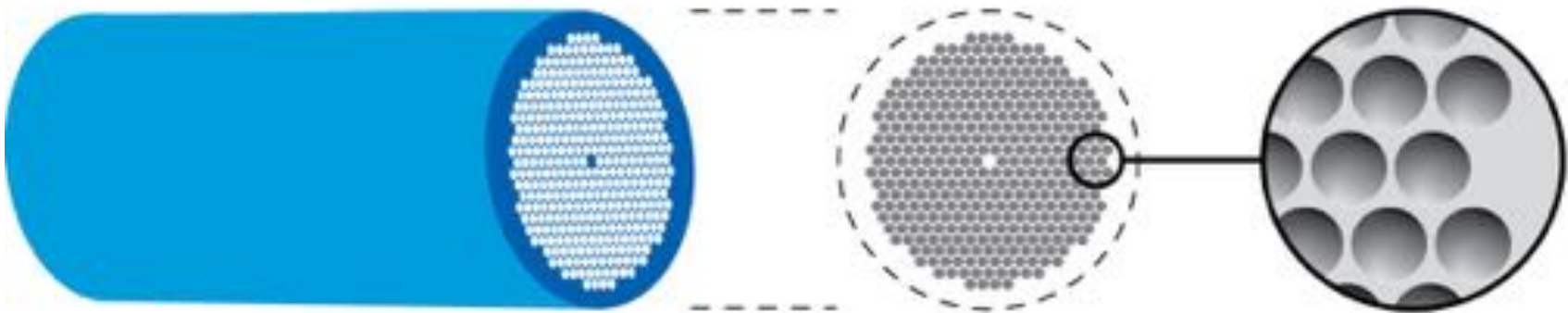
Source: [4]

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Photonic crystals in biomedical technologies

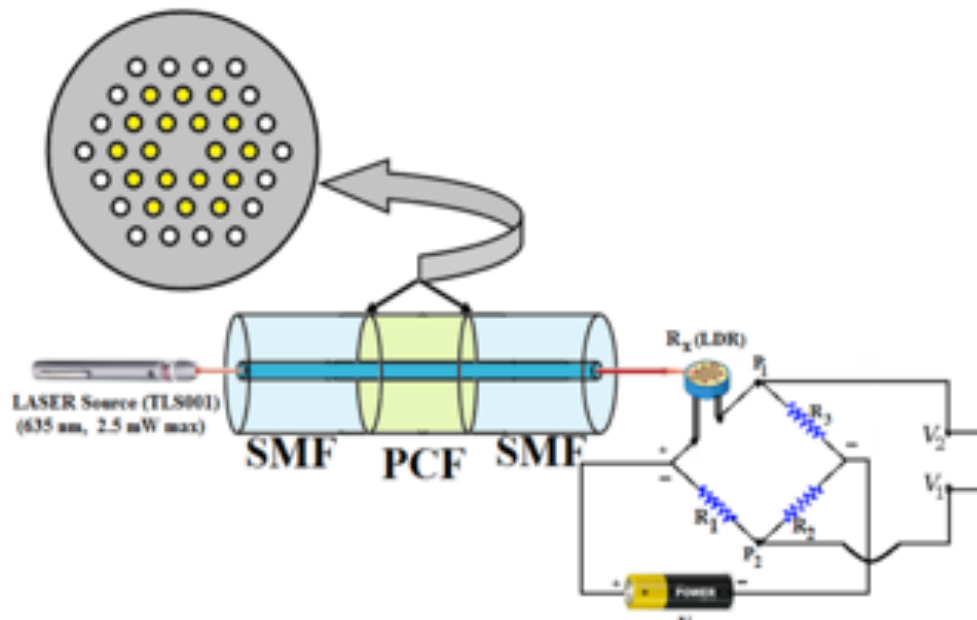
- photonic crystal fibers are light guiding fibers with much lower losses than conventional fiber which guide by total reflection
- using these fibers, a much smaller bending radius can be achieved:
 - cm range vs. down to a few μm
- can be used in many optical devices, for example high-resolution OCT



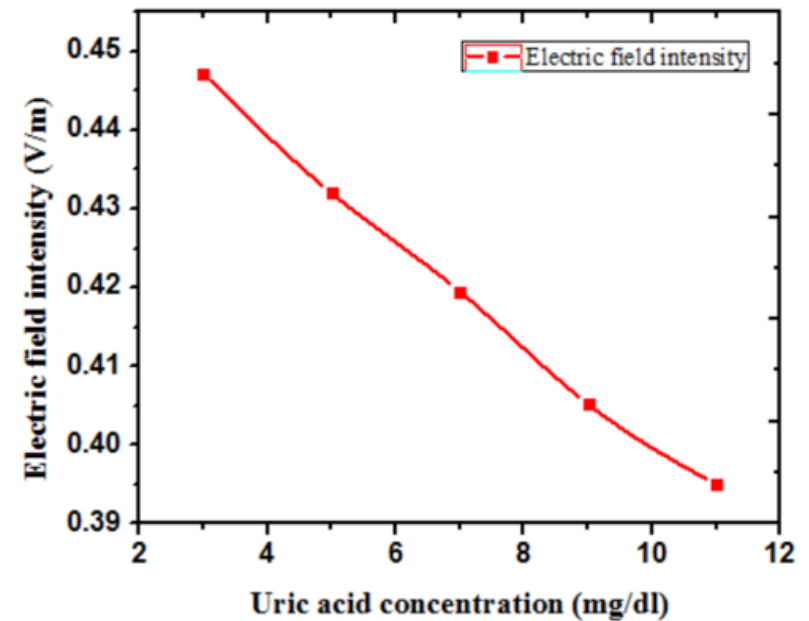
Source: [9]

Photonic crystals in biomedical technologies

photonic crystals offer different ways to be used as biosensors, for example by filling the hollow channels of a photonic crystal fiber with body fluids which causes different wavelengths to be confined in the central light guiding channel of the fiber



Source: [10]

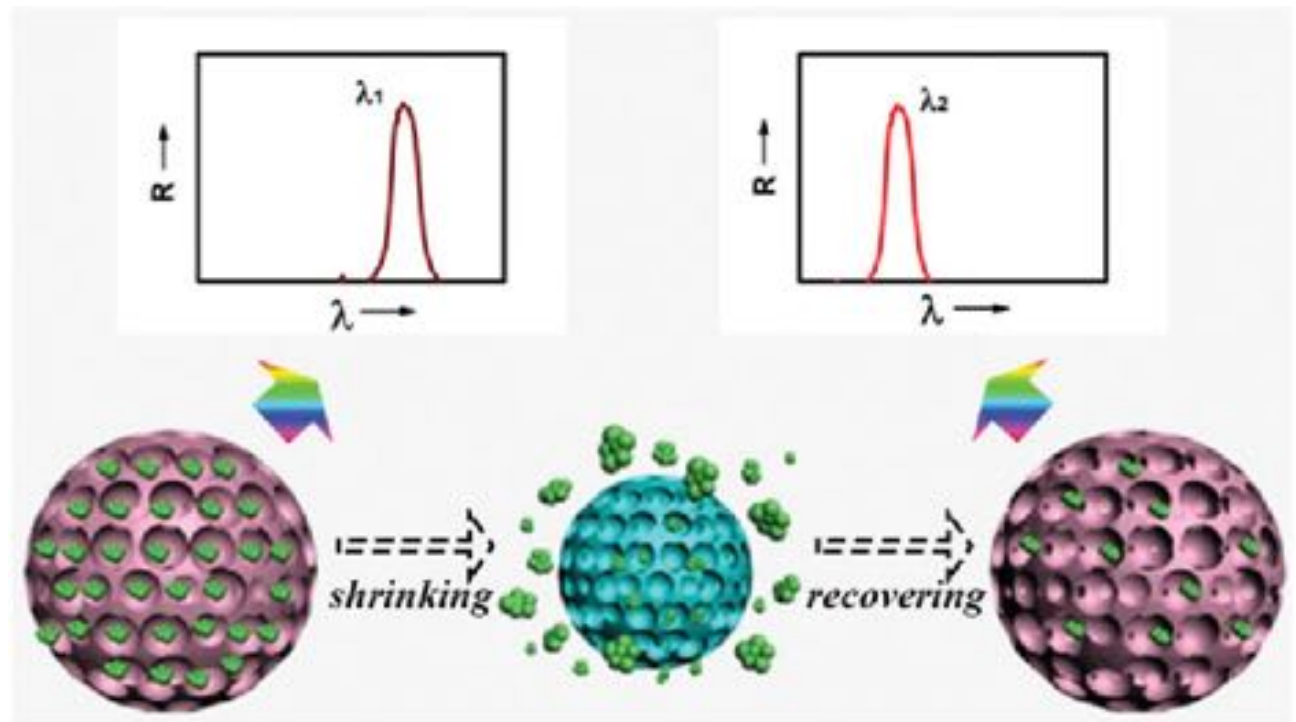


Source: [10]

Photonic crystals in biomedical technologies

photonic crystal based drug delivery systems:

1. drug is integrated into a photonic crystal
2. drug gets released by activating the transporter
3. frequency shift of reflected spectrum is used to determine the amount of released drug

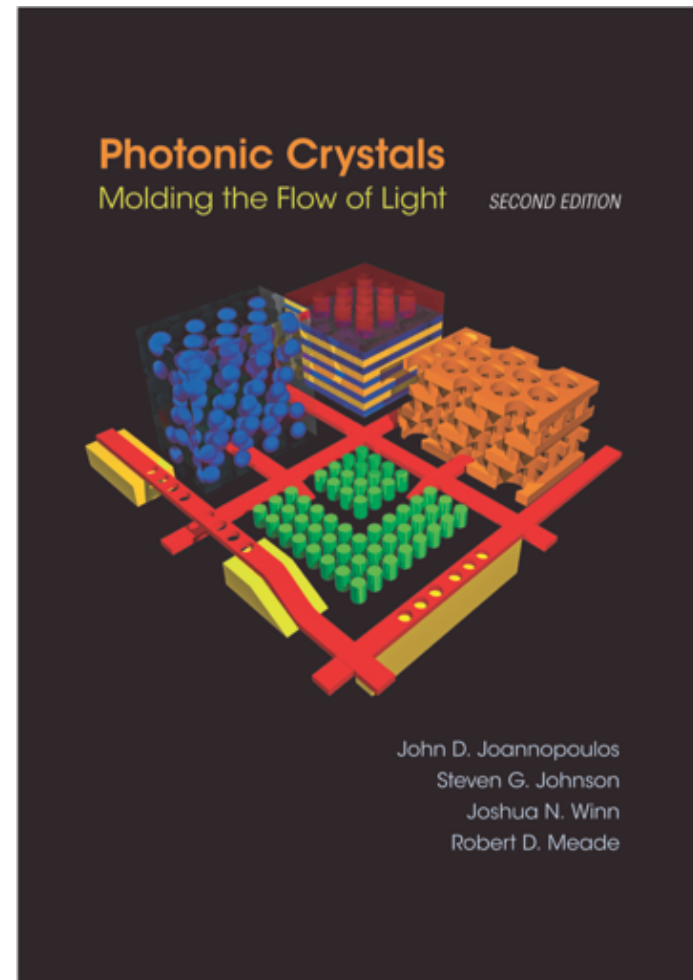


Literature recommendation

Photonic Crystals

Molding the Flow of Light

by Joannopoulos, Johnson, Winn, Meade



Available at <http://ab-initio.mit.edu>

References

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