Optoelektronika

Kryształy fotoniczne

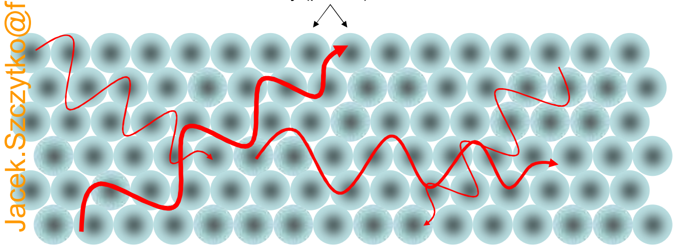
Jacek Szczytko, Wydział Fizyki UW

Źródło: www.gazeta.pl 17-11-2005

Czy dwa półprzewodniki dadzą cały przewodnik?

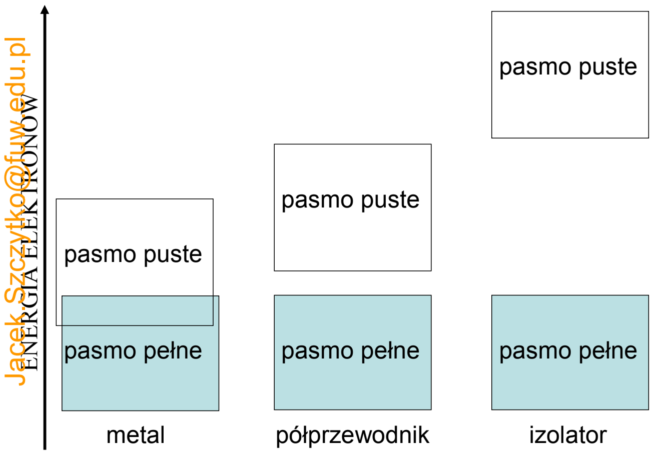
- Co to jest izolator, półprzewodnik, przewodnik?

Elektrony (prawie) swobodne



Atomy zawiązane (elektrony są fermionami i obowiązuje zakaz Pauliego)

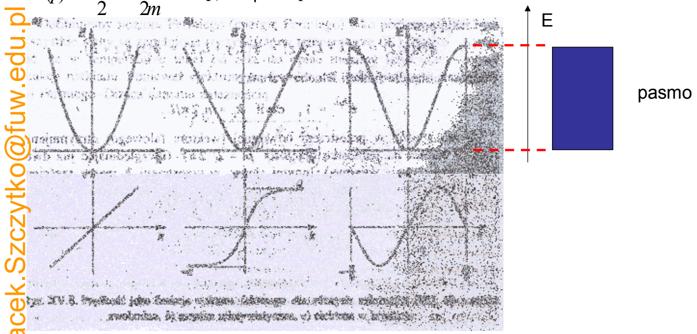
Teoria pasmowa ciał stałych.



Jak zobaczyć przerwę?

Półprzewodniki

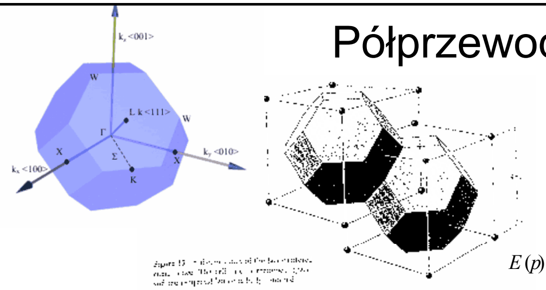
$E(p) = \frac{mv^2}{2} = \frac{p^2}{2m}$ $\quad E(p) = c\sqrt{m^2c^2 + p^2}$ $\quad E(p)$



T. Stacewicz & A. Witowski

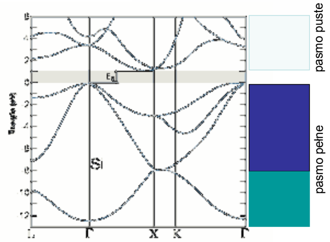
Półprzewodniki

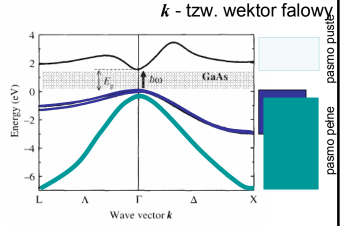
Jacek.Szczytko@fuw.edu.pl



$$E(p) = \frac{p^2}{2m^*} = \frac{\hbar^2 k^2}{2m^*}$$

k - tzw. wektor falowy





Kryształy fotoniczne

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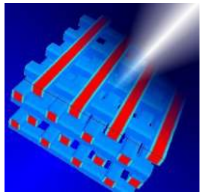
Co to są kryształy fotoniczne?
W jaki sposób je wytwarzamy?
Porównanie kryształów fotonicznych i półprzewodników.
Po co wytwarzamy kryształy fotoniczne?



Materiały dzięki uprzejmości dr hab. Dariusza Wasika

Jacek.Szczytko@fuw.edu.pl

Kryształy

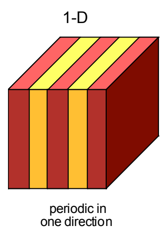
- Pole elektryczne periodyczne
- Przerwa wzbroniona
- R-nie Schroedingera
- Silne oddz. e-e

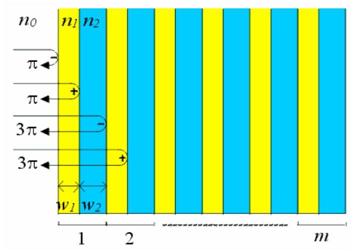
Kryształy fotoniczne

- Przenikalność elekt. periodyczna
- Przerwa wzbroniona
- R-nia Maxwella

Jeden wymiar (lustro Bragga)

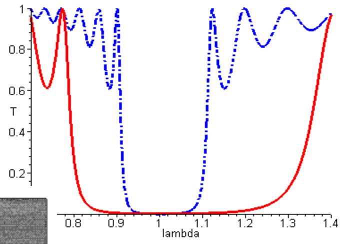
Jacek.Szczytko@fuw.edu.pl

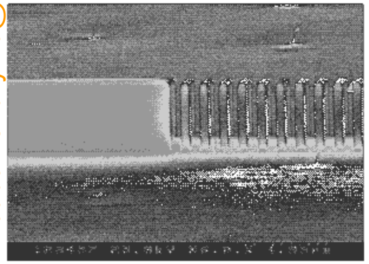


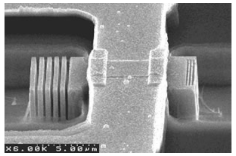


$$w_1 = \frac{\lambda_0}{4n_1}$$

$$w_2 = \frac{\lambda_0}{4n_2}$$







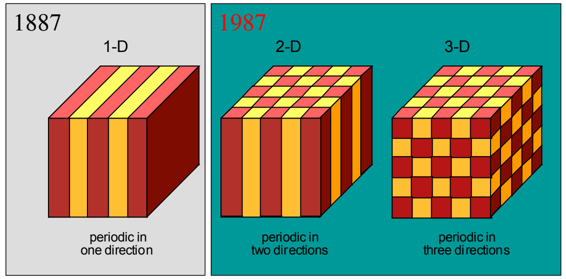
http://opto.physik.uni-wuerzburg.de/forschung/microlaser/sem.htm

http://www.physik.uni-wuerzburg.de/TEP/Website/groups/nanodevices/tunable/tunable.html

Kryształy fotoniczne

Steven G. Johnson MIT http://ab-initio.mit.edu/photons/tutorial/

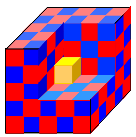
Okresowe ośrodki dielektryczne

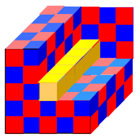


Fotoniczna przerwa energetyczna: “izolatory optyczne”

Kryształy fotoniczne

Okresowe ośrodki dielektryczne

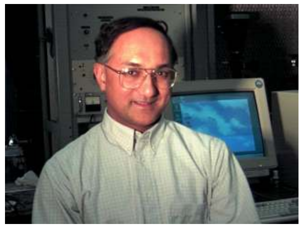




Złapanie światła we wnęki oraz przewody (falowody)

Kryształy fotoniczne

Eli Yablonovitch



Sajeev John

Obydwaj w 1987 r. wpadli na pomysł „trójwymiarowych struktur Bragga”

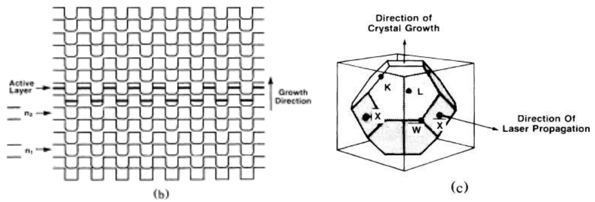
Kryształy fotoniczne

VOLUME 58, NUMBER 20 PHYSICAL REVIEW LETTERS 18 MAY 1987

Inhibited Spontaneous Emission in Solid-State Physics and Electronics

Eli Yablonovitch
Bell Communications Research, Navesink Research Center, Red Bank, New Jersey 07701
(Received 23 December 1986)

It has been recognized for some time that the spontaneous emission by atoms is not necessarily a fixed and immutable property of the coupling between matter and space, but that it can be controlled by modification of the properties of the radiation field. This is equally true in the solid state, where spontaneous emission plays a fundamental role in limiting the performance of semiconductor lasers, heterojunction bipolar transistors, and solar cells. If a three-dimensionally periodic dielectric structure has an electromagnetic *band gap* which overlaps the electronic *band edge*, then spontaneous emission can be rigorously forbidden.



Kryształy fotoniczne

VOLUME 58, NUMBER 23 PHYSICAL REVIEW LETTERS 8 JUNE 1987

Strong Localization of Photons in Certain Disordered Dielectric Superlattices

Sajeev John
Department of Physics, Princeton University, Princeton, New Jersey 08544
(Received 5 March 1987)

A new mechanism for strong Anderson localization of photons in carefully prepared disordered dielectric superlattices with an everywhere real positive dielectric constant is described. In three dimensions, two photon mobility edges separate high- and low-frequency extended states from an intermediate-frequency pseudogap of localized states arising from remnant geometric Bragg resonances. Experimentally observable consequences are discussed.

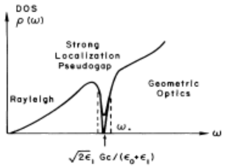
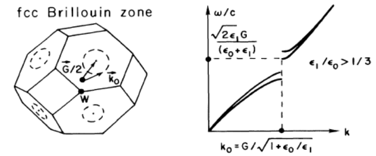
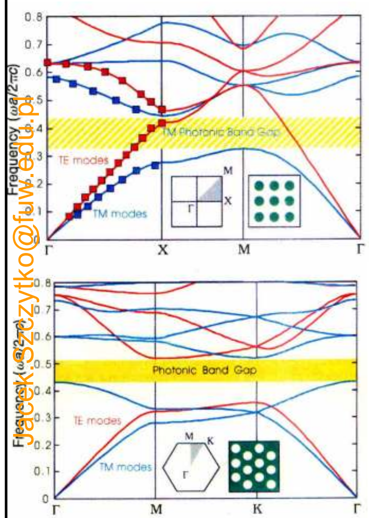


FIG. 2. Photon density of states in a disordered superlattice exhibiting low-frequency Rayleigh scattering and high-frequency geometric-optics extended states separated by a pseudogap of strongly localized photons.





Dwa wymiary

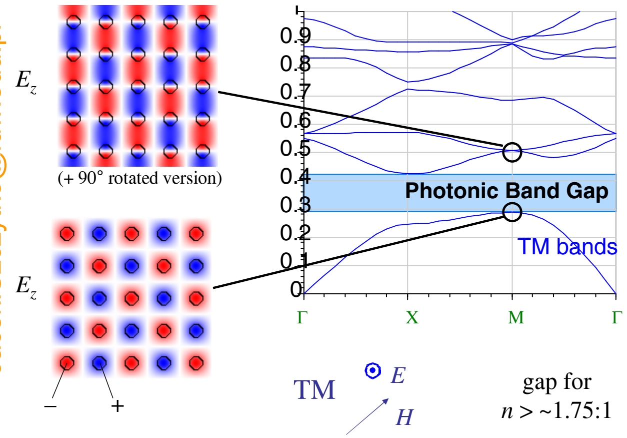
r = 0.2 a
ε = 8.9

J.D. Joannopoulos *et al.;* Nature **386**,143 (1997)

r = 0.48 a
ε = 13

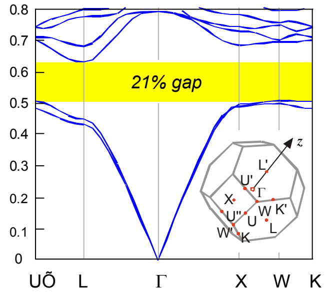
Steven G. Johnson MIT http://ab-initio.mit.edu/photons/tutorial/

2d periodicity, ε=12:1



Steven G. Johnson MIT http://ab-initio.mit.edu/photons/tutorial/

3 wymiary: pełna przerwa , ε=12:1

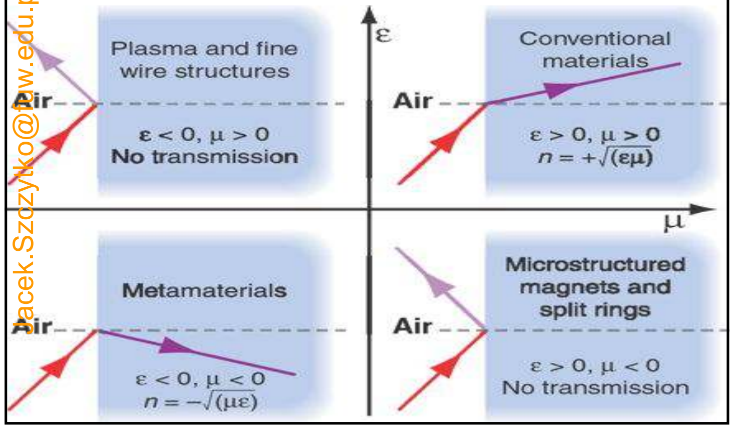


gap for $n > \sim 4:1$

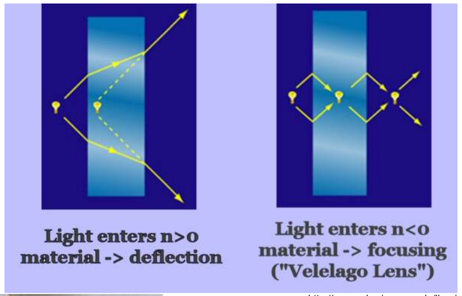
Steven G. Johnson MIT http://ab-initio.mit.edu/photons/tutorial/

[S. G. Johnson *et al.*, *Appl. Phys. Lett.* **77**, 3490 (2000)]

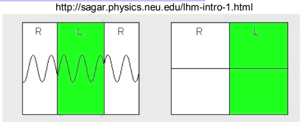
Przenikalność ε i μ, odbicie, i załamanie



Ujemny współczynnik załamania

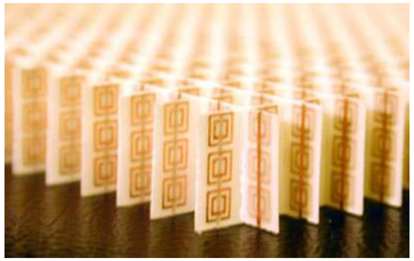


http://sagar.physics.neu.edu/lhm-intro-1.html



1967 Victor Veselago (ZSRR)

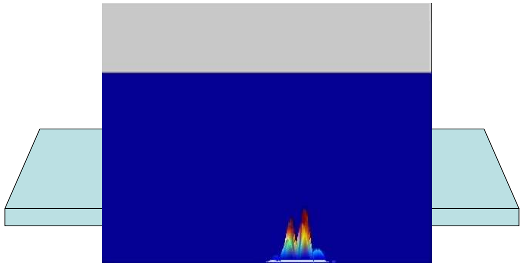
Ujemny współczynnik załamania



Researchers fashioned a prism out of this meta material that made microwaves bend backwards. The key to the material is the group of tiny copper lines on one side of the circuit boards' sections, and the circular shapes on the otherside.

"Experimental Verification of a Negative Index of Refraction," Science, April 6, 2001.

Ujemny współczynnik załamania

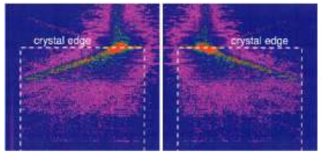


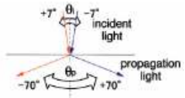
Applications of Bulk Crystals

using near-band-edge effects

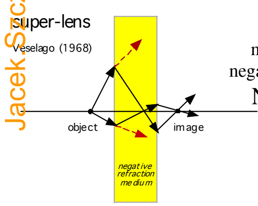
Zero group-velocity dω/dk: distributed feedback (DFB) lasers

divergent dispersion
(*i.e.* curvature):
Superprisms
[Kosaka, *PRB* **58**, R10096 (1998).]

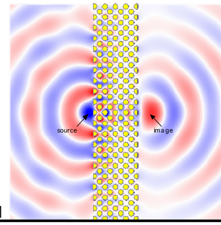




super-lens
Veselago (1968)



negative group-velocity **or**
negative curvature ("eff. mass"):
Negative refraction,
Super-lensing



[C. Luo *et al.*,
Appl. Phys. Lett. **81**, 2352 (2002)]

Ujemny współczynnik załamania ?

VOLUME 88, NUMBER 18 PHYSICAL REVIEW LETTERS 6 MAY 2002

Wave Refraction in Negative-Index Media: Always Positive and Very Inhomogeneous

P. M. Valanju,[1,2] R. M. Walser,[2] and A. P. Valanju[2]
[1]*Fusion Research Center, University of Texas at Austin, Austin, Texas 78712*
[2]*Center for Electromagnetic Materials and Devices, University of Texas at Austin, Austin, Texas 78758*
(Received 12 September 2001; published 19 April 2002)

We present the first treatment of the refraction of physical electromagnetic waves in newly developed negative index media (NIM), also known as left-handed media (LHM). The NIM dispersion relation implies that group fronts refract positively even when phase fronts refract negatively. This difference results in rapidly dispersing, very inhomogeneous waves. In fact, causality and finite signal speed always prevent negative wave signal (not phase) refraction. Earlier interpretations of phase refraction as "negative light refraction" and "light focusing by plane slabs" are therefore incorrect, and published NIM experiments can be explained without invoking negative signal refraction.

VOLUME 88, NUMBER 20 PHYSICAL REVIEW LETTERS 20 MAY 2002

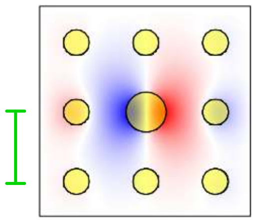
Left-Handed Materials Do Not Make a Perfect Lens

N. Garcia[1,*] and M. Nieto-Vesperinas[2,†]
[1]*Laboratorio de Fisica de sistemas Pequeños, Consejo Superior de Investigaciones Cientificas, Serrano 144, Madrid 28006, Spain*
[2]*Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Cientificas, Campus de Cantoblanco, Madrid 28049, Spain*
(Received 16 November 2001; published 3 May 2002)

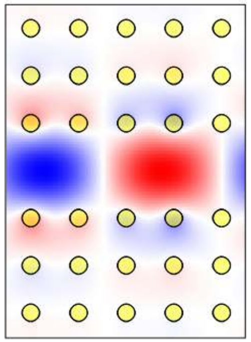
By means of an analysis on evanescent waves in left-handed materials (LHM), we show that within a slab of such a medium, sandwiched between two positive refraction media, there is amplification of evanescent waves in ideal lossless, dispersiveless media; however, contrary to previous claims, this is limited to a finite width of the slab so that it prevents their restoration and perfect focusing. We illustrate this by considering their coupling to propagating waves through a tunnel barrier containing a slab of LHM. Further, we show that the effect of absorption, necessarily present in such materials, may drastically change any evanescent amplifying wave into a decaying one.

Defekty optyczne

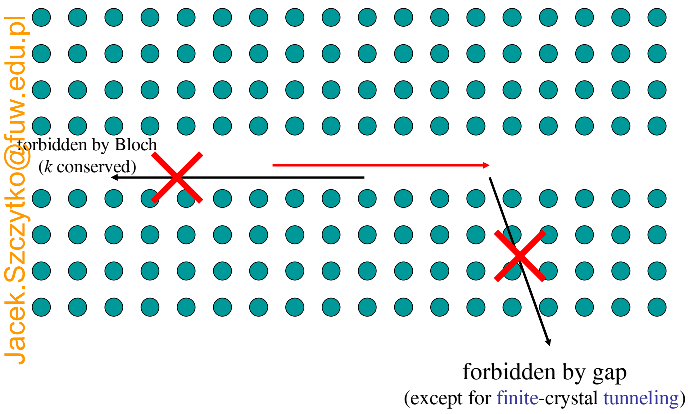
Mikrownęki



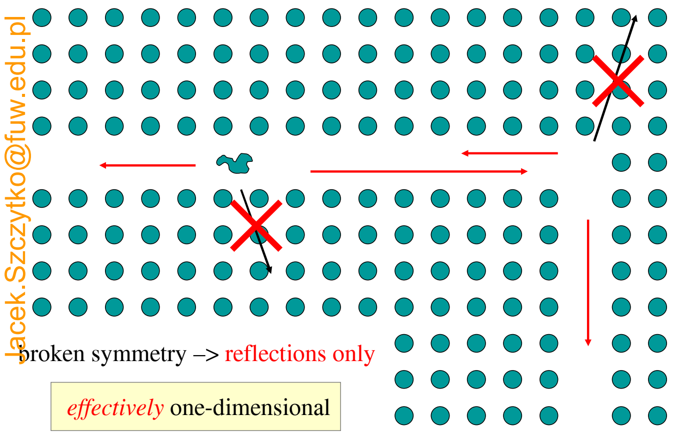
Falowody

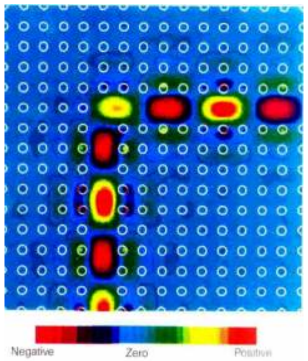


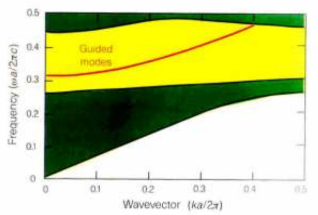
Brak rozpraszania!



Zyski z pełnej przerwy

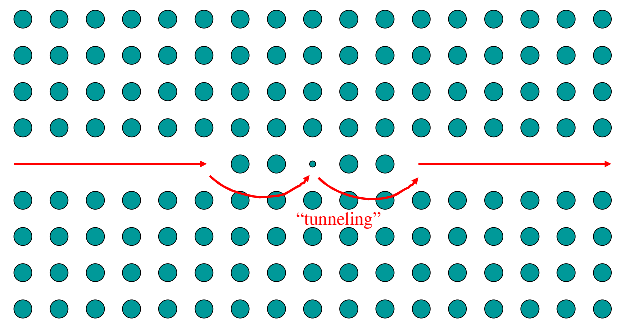




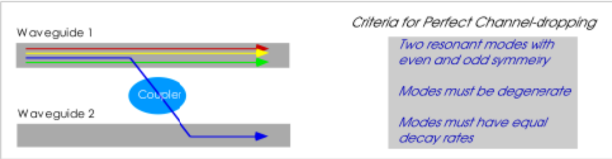


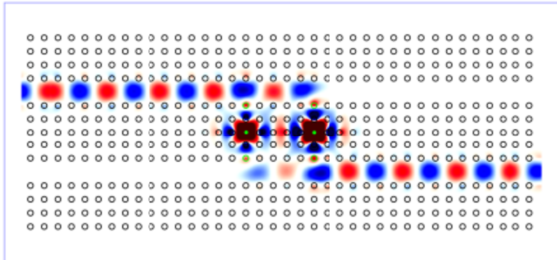
Dariusz Wasik

Falowody + wnęki = urządzenia



Channel-Drop Filters



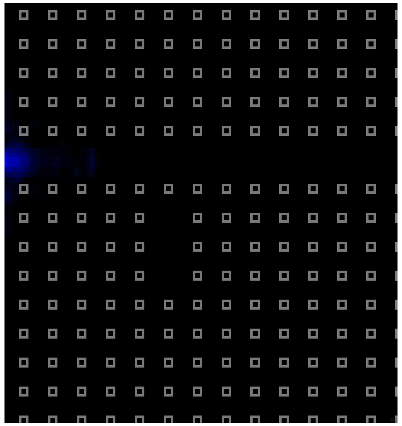


[S. Fan *et al.*, *Phys. Rev. Lett.* **80**, 960 (1998)]

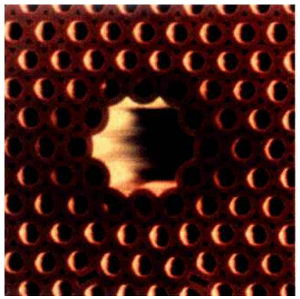
Steven G. Johnson MIT

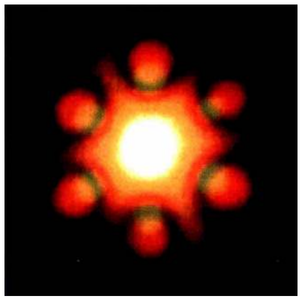
http://ab-initio.mit.edu/photons/tutorial/

Wnęka na światło



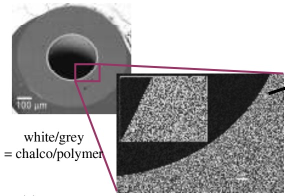
Światłowody fotoniczne





Breaking the Glass Ceiling: Hollow-core Bandgap Fibers

[figs courtesy Y. Fink *et al.*, MIT]

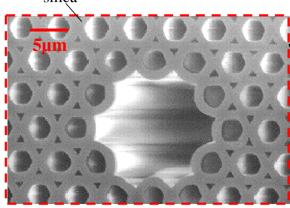


white/grey = chalco/polymer

Guiding @ 10.6µm
(high-power CO_2 lasers)
loss < 1 dB/m
(material loss ~ 10^4 dB/m)
[Temelkuran *et al.*, *Nature* **420**, 650 (2002)]

silica

[R. F. Cregan *et al.*, *Science* **285**, 1537 (1999)]

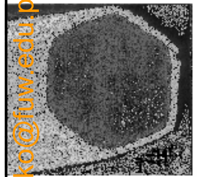


Guiding @ 1.55µm
loss ~ 13dB/km
[Smith, *et al.*, *Nature* **424**, 657 (2003)]

OFC 2004: 1.7dB/km
BlazePhotonics

Steven G. Johnson MIT / Harvard University

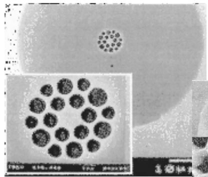
Breaking the Glass Ceiling II:
Solid-core Holey Fibers



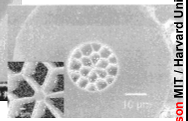
endlessly single-mode

[T. A. Birks *et al.*, *Opt. Lett.* **22**, 961 (1997)]

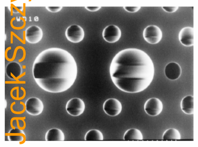
nonlinear fibers



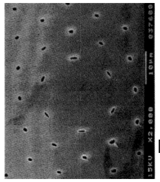
[Wadsworth *et al.*, *JOSA B* **19**, 2148 (2002)]



polarization -maintaining



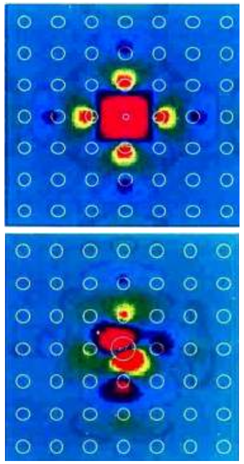
[K. Suzuki, *Opt. Express* **9**, 676 (2001)]

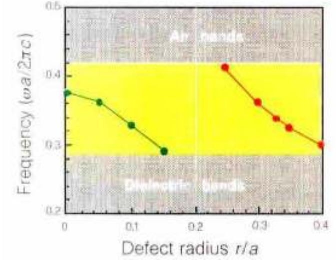


low-contrast *linear* fiber (large area)

[J. C. Knight *et al.*, *Elec. Lett.* **34**, 1347 (1998)]

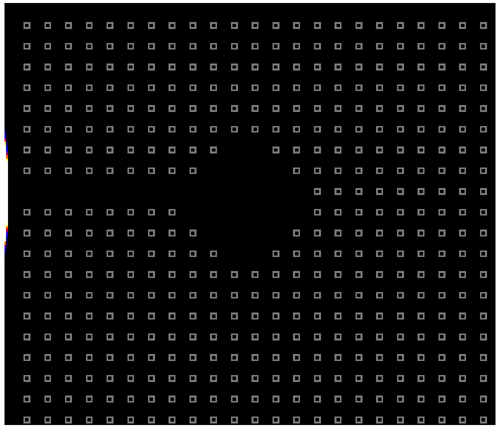
Steven G. Johnson MIT / Harvard University



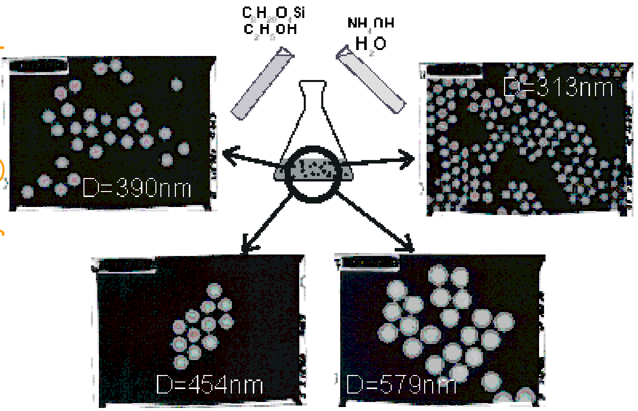


J. Joannopoulos, Nature **386**, 143 (1997)

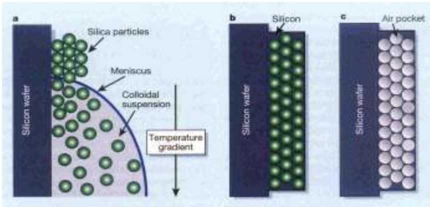
Pułapka

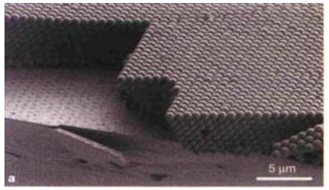


Synteza kryształów fotonicznych



http://www.icmm.csic.es/cefe/Fab/synthesis.html





V. Vlasov *et al.;* Nature **414**,291 (2001)

Steven G. Johnson MIT

Make *that*? Are you crazy? …maybe!

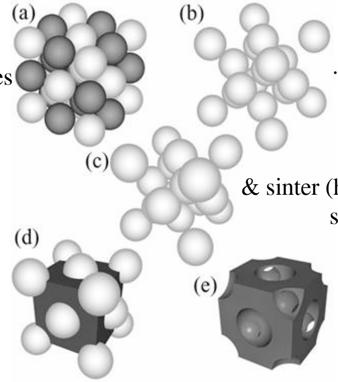
fabrication schematic

carefully stack bcc silica & latex spheres via micromanipulation

…dissolve latex

& sinter (heat and fuse) silica

make Si inverse (12% gap)

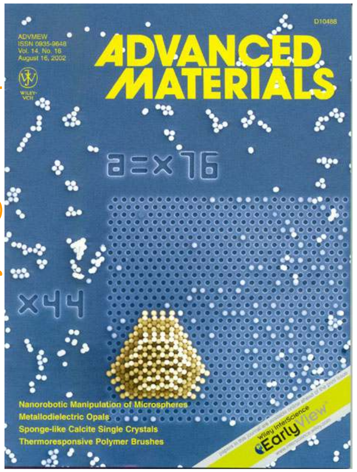


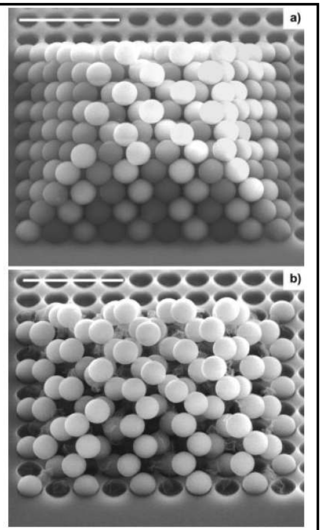
Steven G. Johnson MIT

[F. Garcia-Santamaria *et al.*, *APL* **79**, 2309 (2001)]

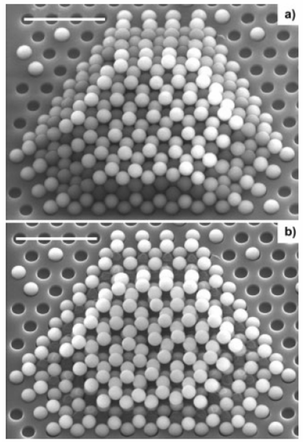
http://www.icmm.csic.es/cefe/Fab/Robot/robot_strategy.htm

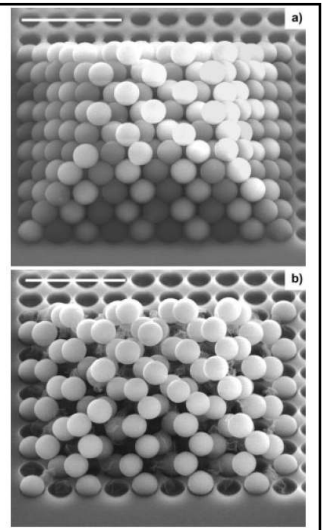
Robot manipulation





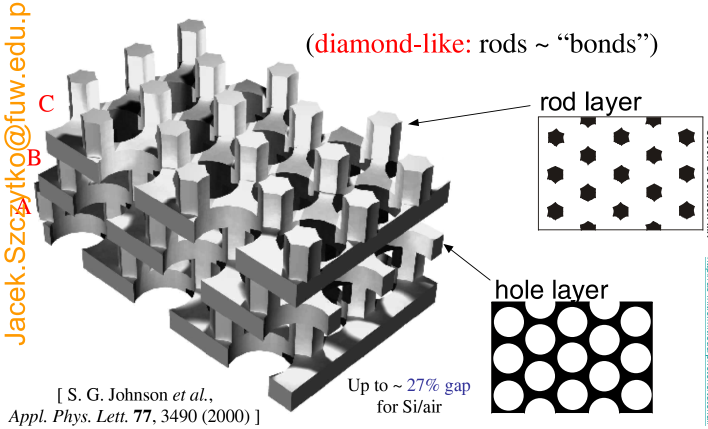
F. Garcia-Santamaria *et al.*, *Adv. Mater.* **14** (16), 1144 (2002).





F. Garcia-Santamaria *et al.*, *Adv. Mater.* **14** (16), 1144 (2002).

A Layered Structure

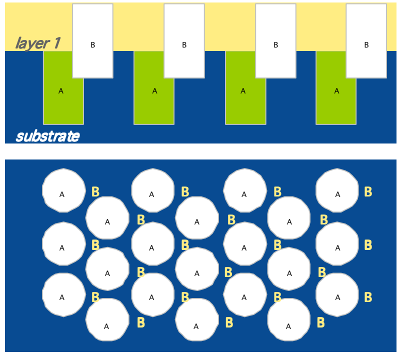


[S. G. Johnson *et al.*, *Appl. Phys. Lett.* **77**, 3490 (2000)]

Up to ~ 27% gap for Si/air

Making Rods & Holes Simultaneously

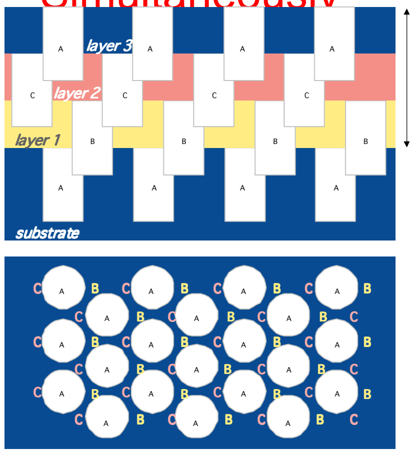
dig more holes offset & overlapping



Making Rods & Holes Simultaneously

etcetera

(dissolve silica when done)

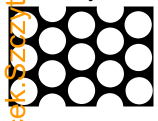


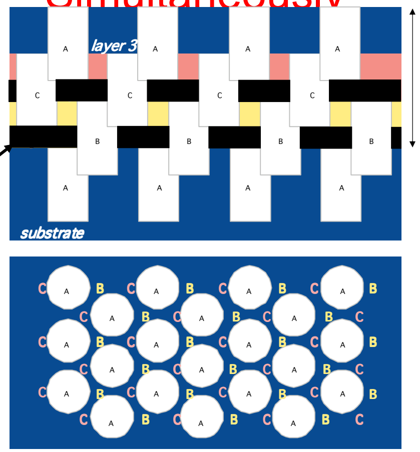
one period

Making Rods & Holes Simultaneously

etcetera

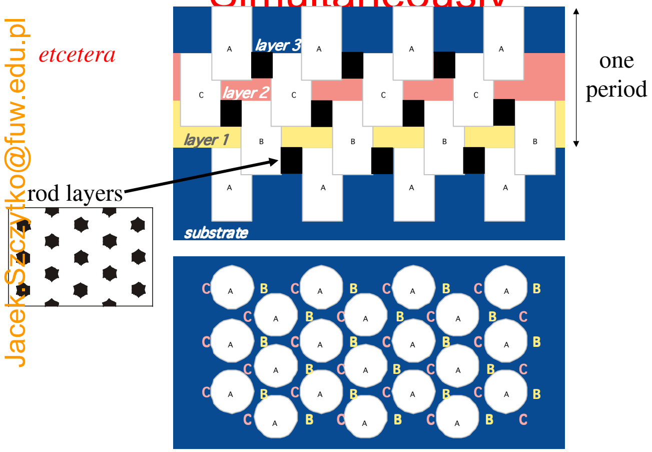
hole layers



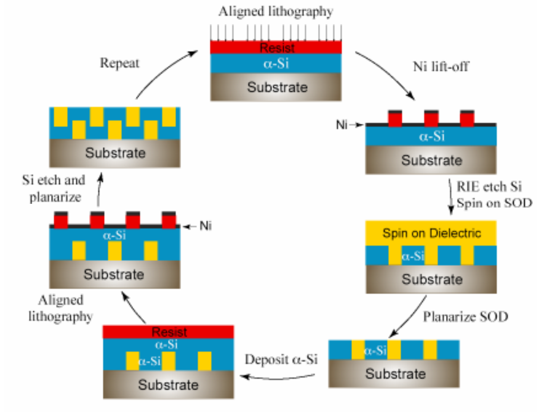


one period

Making Rods & Holes Simultaneously

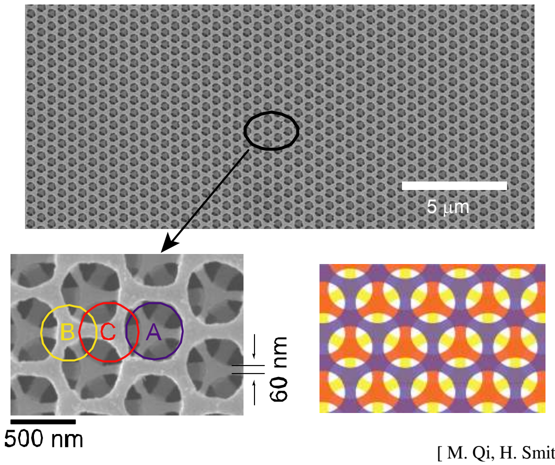


A More Realistic Schematic



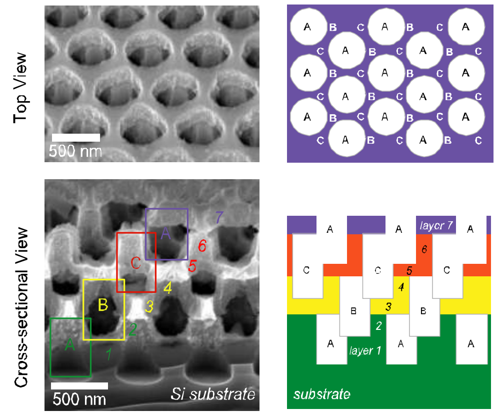
[M. Qi, H. Smith, MIT]

e-beam Fabrication: Top View



[M. Qi, H. Smith, MIT]

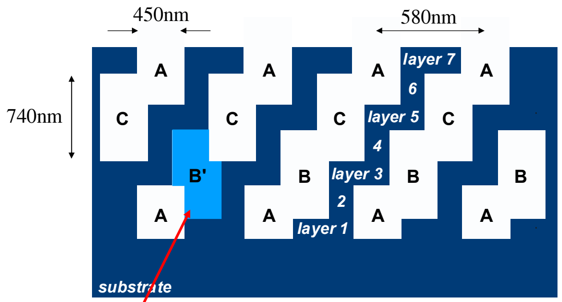
e-beam Fabrication:



(a) SEM micrograph (b) Schematic

[M. Qi, H. Smith, MIT]

Adding “Defect” Microcavities



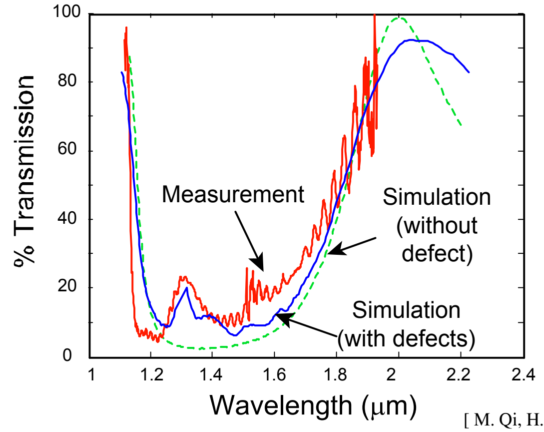
Easiest defect: don’t etch some **B** holes

— non-periodically distributed: suppresses sub-band structure

— low Q = easier to detect from planewave

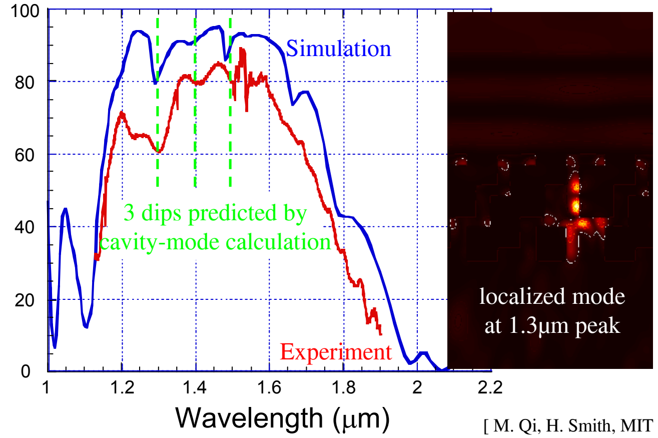
[M. Qi, H. Smith, MIT]

Supercontinuum-Source vs. Theoretical Transmission Spectra



[M. Qi, H. Smith, MIT]

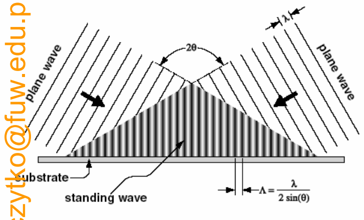
Supercontiuum vs. Theory: Reflection

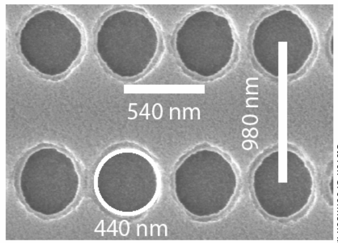


[M. Qi, H. Smith, MIT]

Future Work: X-ray Interference Lithography

[M. Qi, H. Smith, MIT]





The Good

Large area: up to 10x10cm!

Cheap ($50k vs. $500k for e-beam)

Nearly perfect periodicity

High resolution

The Ugly

Layer alignment still tricky

no defects: use e-beam locally

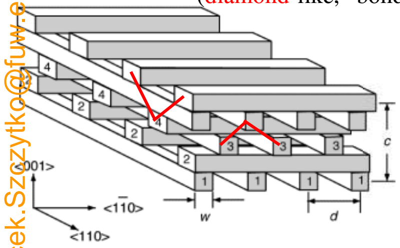
non-rectangular more tricky…

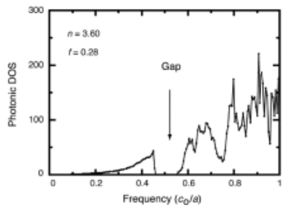
an earlier design:
(& currently more popular)

The Woodpile Crystal

[K. Ho *et al.*, *Solid State Comm.* **89**, 413 (1994)] [H. S. Sözüer *et al.*, *J. Mod. Opt.* **41**, 231 (1994)]

(diamond-like, "bonds")



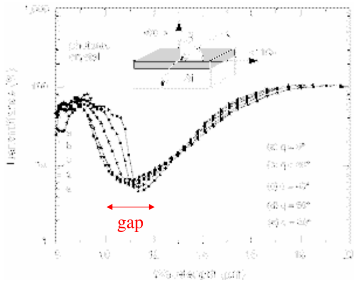


Up to ~ 17% gap for Si/air

[Figures from S. Y. Lin *et al.*, *Nature* **394**, 251 (1998)]

1.25 Periods of Woodpile

(4 "log" layers = 1 period) [S. Y. Lin *et al.*, *Nature* **394**, 251 (1998)]

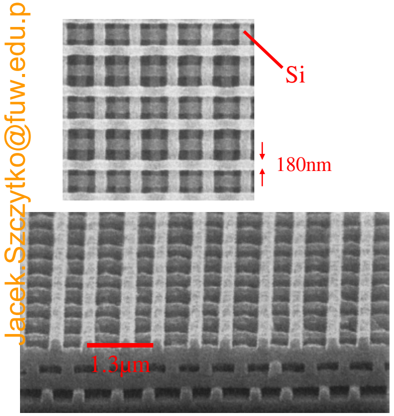


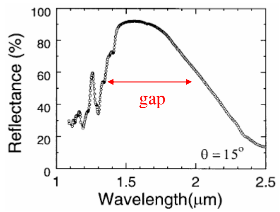
"UV Stepper:" e-beam mask at ~4x size
+ UV through mask, focused on substrate

Good: high resolution, mass production Bad: expensive ($20 million)

1.25 Periods of Woodpile @ 1.55μm

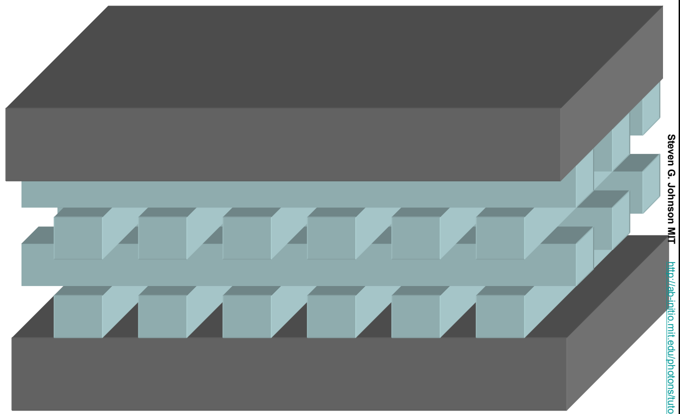
(4 "log" layers = 1 period) [S. Y. Lin *et al.*, *Nature* **394**, 251 (1998)]



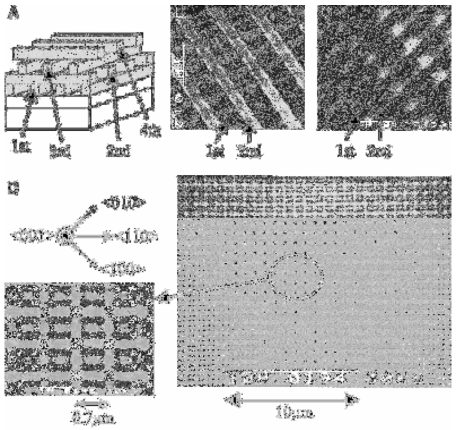


Woodpile by Wafer Fusion

double, double, toil and trouble…

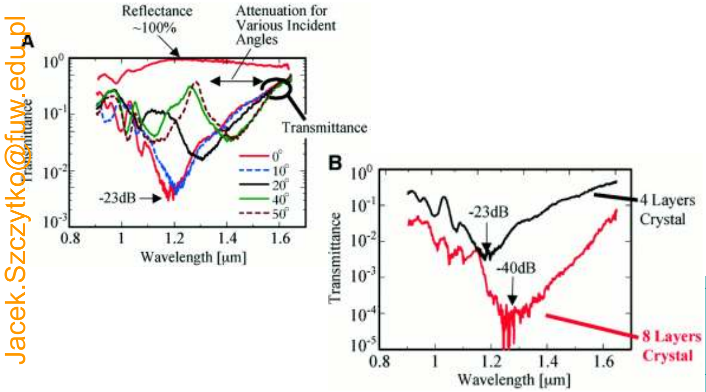


[S. Noda *et al.*, *Science* **289**, 604 (2000)]



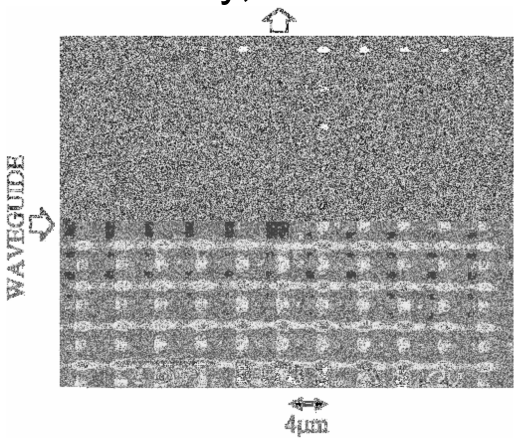
[S. Noda *et al.*, *Science* **289**, 604 (2000)]

Woodpile Gap from 1.3–1.55μm



[S. Noda *et al.*, *Science* **289**, 604 (2000)]

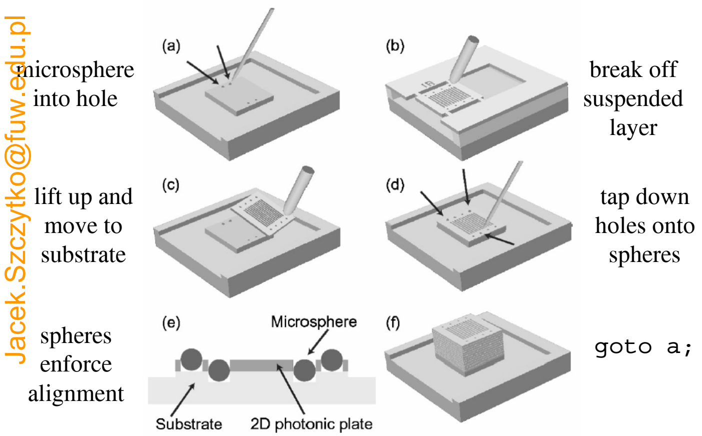
Finally, a Defect!



[S. Noda *et al.*, *Science* **289**, 604 (2000)]

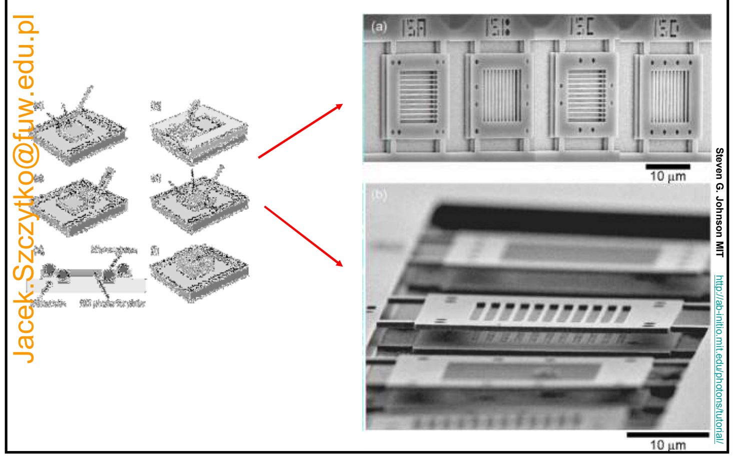
Stacking by Micromanipulation

[K. Aoki *et al.*, Appl. Phys. Lett. 81 (17), 3122 (2002)]



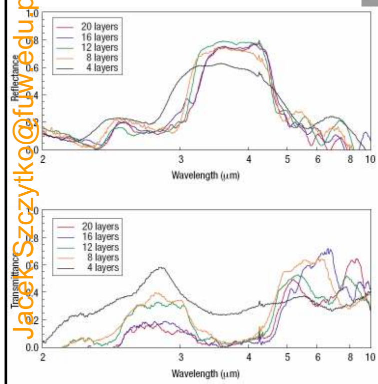
Stacking by Micromanipulation

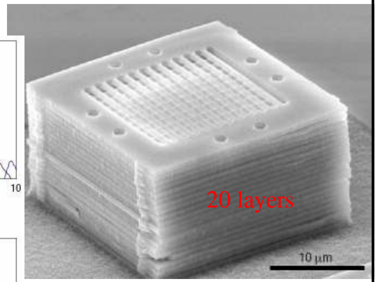
[K. Aoki *et al.*, Appl. Phys. Lett. 81 (17), 3122 (2002)]



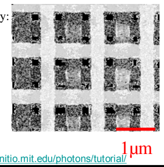
Yes, it works: Gap at ~4μm

[K. Aoki *et al.*, *Nature Materials* **2** (2), 117 (2003)]





50nm accuracy:

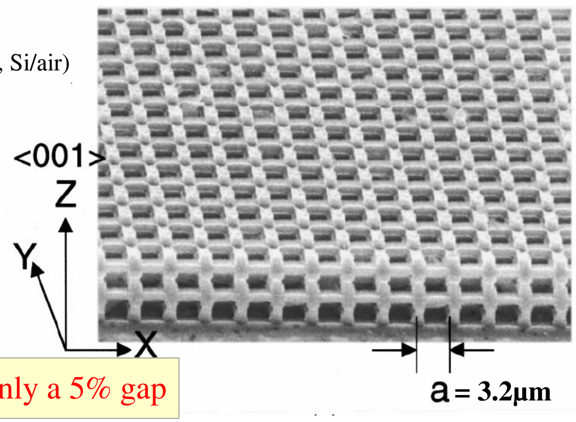


(gap effects are limited by finite lateral size)

Cubic lattice

[S.-Y. Lin *et al.*, *JOSA B* **18**, 32 (2001).]

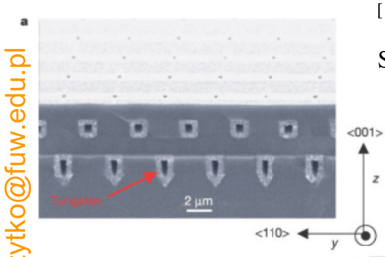
(UV stepper, Si/air)



only a 5% gap

A *Metal* Photonic Crystal

[J. G. Fleming *et al.*, *Nature* **417**, 52 (2002)]

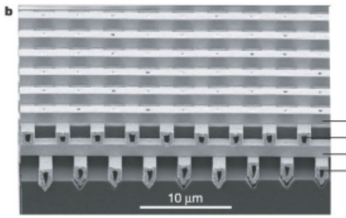


Start with Si woodpile in SiO_2…

dissolve Si with KOH…

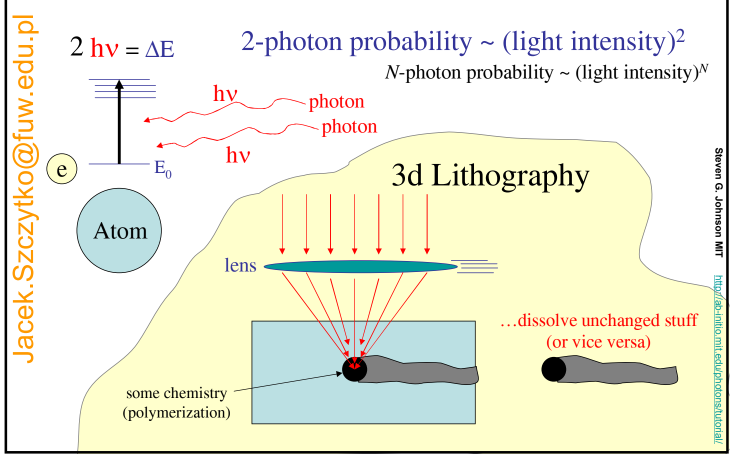
fill with Tungsten
via chemical vapor deposition (CVD)
(on thin TiN layer)

dissolve SiO_2 with HF…



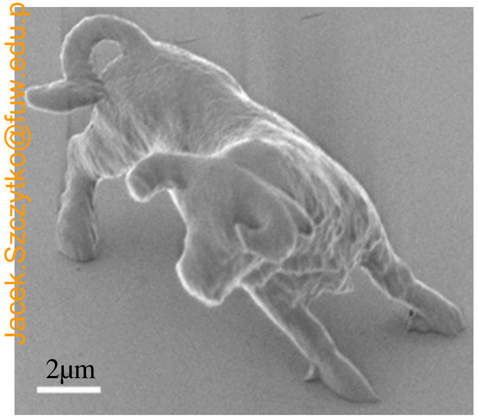
Litografia 3D

Two-Photon Lithography



Lithography is a Beast

[S. Kawata *et al.*, *Nature* **412**, 697 (2001)]



λ = 780nm

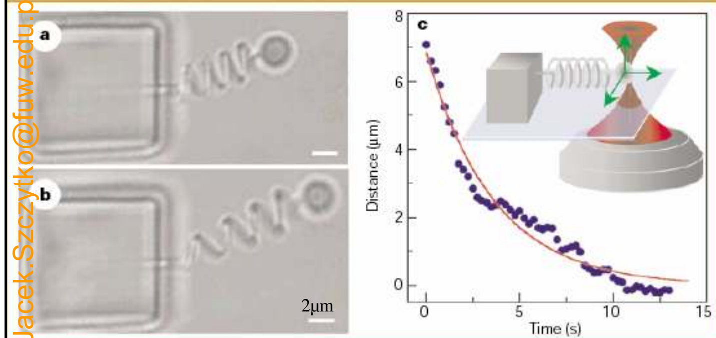
resolution = 150nm

7μm

(3 hours to make)

For a physicist, this is cooler…

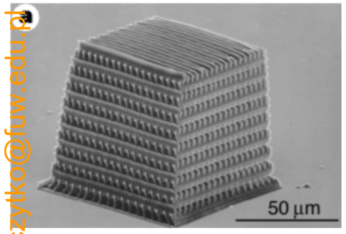
[S. Kawata *et al.*, *Nature* **412**, 697 (2001)]



(300nm diameter coils, suspended in ethanol, viscosity-damped)

A Two-Photon Woodpile Crystal

[B. H. Cumpston *et al.*, *Nature* **398**, 51 (1999)]

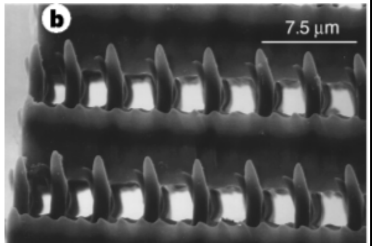


(much work on materials
with lower power 2-photon process)

• Arbitrary lattice
• No "mask"
• Fast/cheap prototyping

Difficult topologies

[fig. courtesy J. W. Perry, U. Arizona]



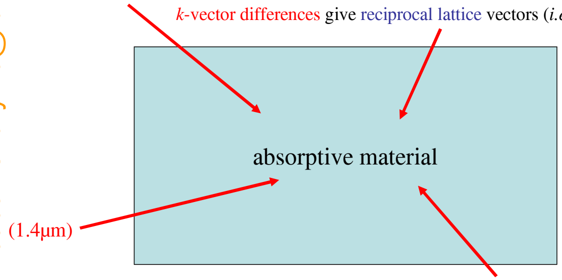
Produkcja masowa?

One-Photon
Holographic Lithography

[D. N. Sharp *et al.*, *Opt. Quant. Elec.* **34**, 3 (2002)]

Four beams make 3d-periodic interference pattern

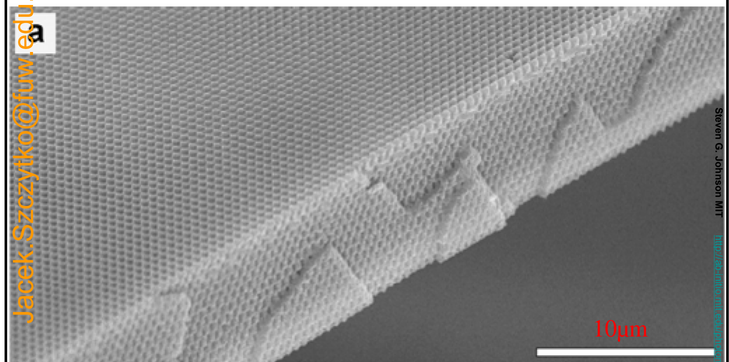
k-vector differences give reciprocal lattice vectors (*i.e.* periodicity)



beam polarizations + amplitudes (8 parameters) give unit cell

One-Photon
Holographic Lithography

[D. N. Sharp *et al.*, *Opt. Quant. Elec.* **34**, 3 (2002)]

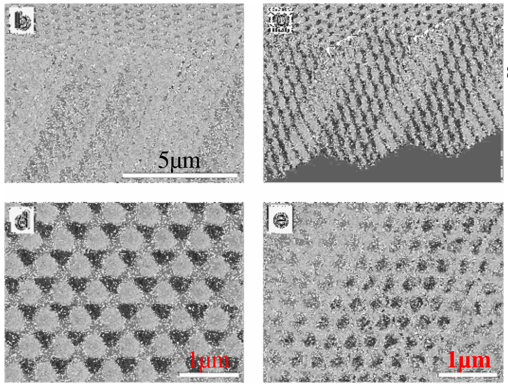


huge volumes, long-range periodic, fcc lattice…backfill for high contrast

One-Photon Holographic Lithography

[D. N. Sharp *et al.*, *Opt. Quant. Elec.* **34**, 3 (2002)]

[111] cleavages

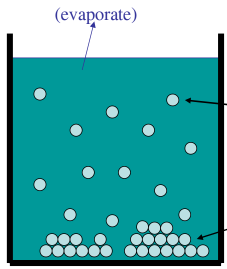


simulated structure

[111] closeup

titania inverse structure

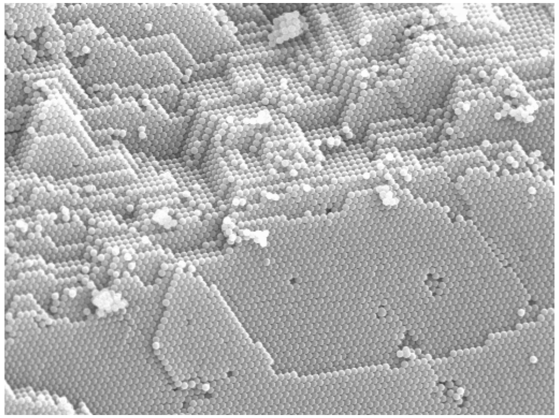
Mass-production II: Colloids



silica (SiO_2) microspheres (diameter < 1μm)

sediment by gravity into close-packed fcc lattice!

Mass-production II: Colloids



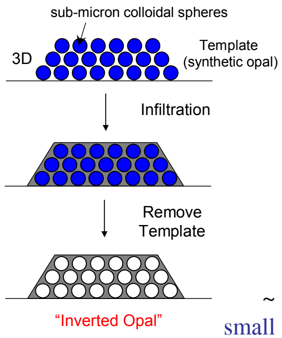
http://www.icmm.csic.es/cefe/

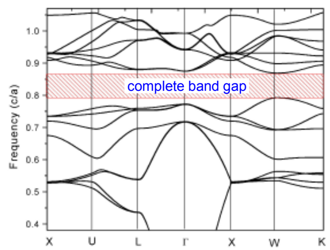
Inverse Opals

[figs courtesy D. Norris, UMN]

fcc solid spheres do not have a gap…

…but fcc spherical holes in Si *do* have a gap



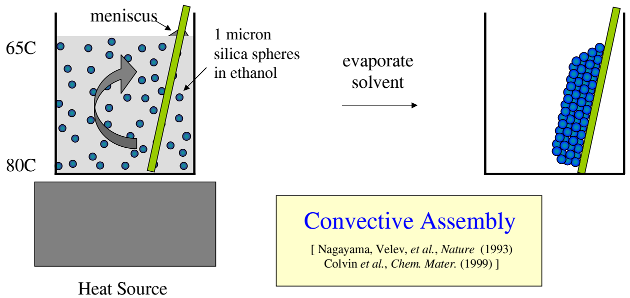


~ 10% gap between 8th & 9th bands

small gap, upper bands: sensitive to disorder

In Order To Form a More Perfect Crystal…

[figs courtesy D. Norris, UMN]



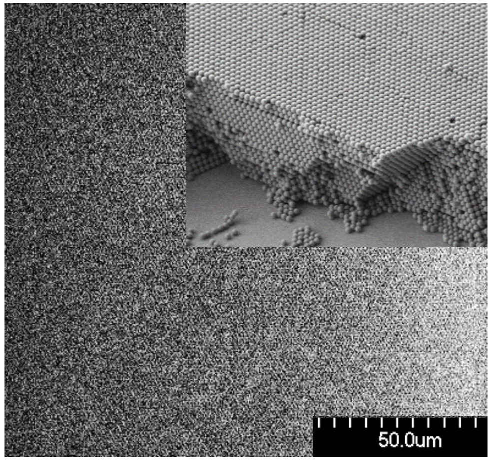
Convective Assembly

[Nagayama, Velev, *et al.*, *Nature* (1993)
Colvin *et al.*, *Chem. Mater.* (1999)]

- Capillary forces during drying cause assembly in the meniscus
- Extremely flat, large-area opals of controllable thickness

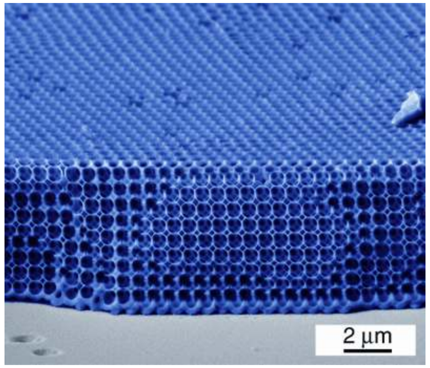
A Better Opal

[fig courtesy D. Norris, UMN]



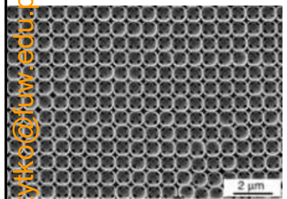
Inverse-Opal Photonic Crystal

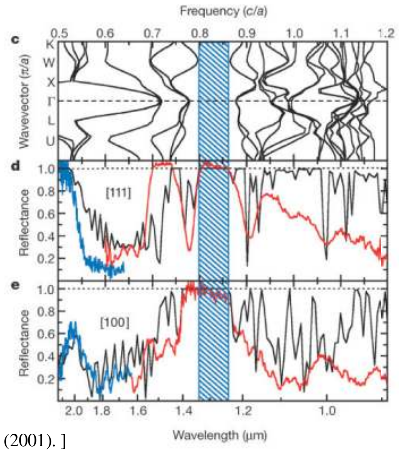
[fig courtesy D. Norris, UMN]



[Y. A. Vlasov *et al.*, *Nature* **414**, 289 (2001).]

Inverse-Opal Band Gap





good agreement between **theory** (black) & experiment (red/blue)

[Y. A. Vlasov *et al.*, *Nature* **414**, 289 (2001).]

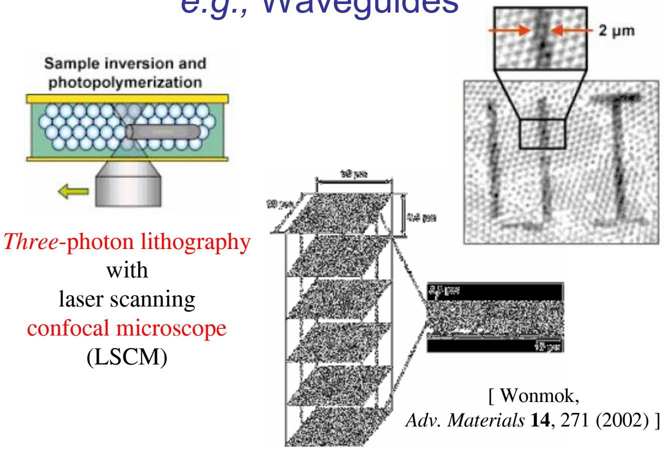
Produkcja masowa?

A co z defektami?
(Pamiętacie wnęki, falowody…?)

Najpierw kryształ fotoniczny produkcji masowej

+ *N*-photon lithography do defektów

Inserting Defects in Inverse Opals
e.g., Waveguides



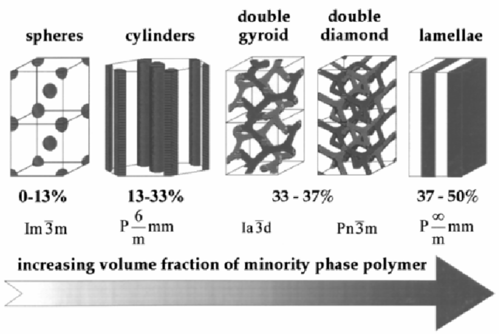
Three-photon lithography
with
laser scanning
confocal microscope
(LSCM)

[Wonmok, *Adv. Materials* **14**, 271 (2002)]

Mass-Production III:
Block (not Bloch) Copolymers

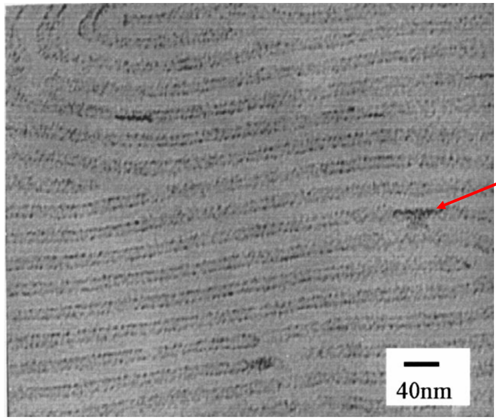
two polymers
can segregate,
ordering into
periodic arrays

periodicity ~
polymer block size
~ 50nm
(possibly bigger)



[Y. Fink, A. M. Urbas, M. G. Bawendi, J. D. Joannopoulos, E. L. Thomas, *J. Lightwave Tech.* **17**, 1963 (1999)]

Block-Copolymer 1d Crystal



CdSe nanocrystals
for higher index

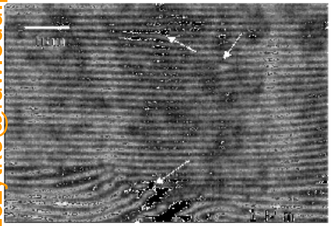
(with surfactant
to attract particles
to one phase)

(UV bandgap)

[Y. Fink, A. M. Urbas, M. G. Bawendi, J. D. Joannopoulos, E. L. Thomas, *J. Lightwave Tech.* **17**, 1963 (1999)]

Block-Copolymer 1d Visible Bandgap

/ homopolymer

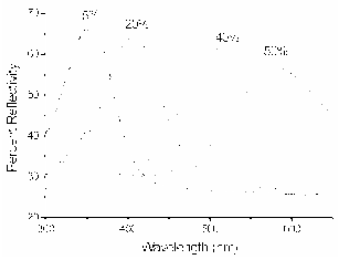


dark/light:
polystyrene/polyisoprene

n = 1.59/1.51

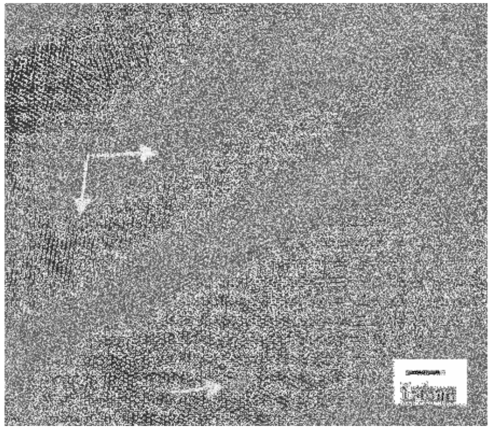
Flexible material:
bandgap can be
shifted by stretching it!

reflection for differing homopolymer %



[A. Urbas *et al.*, *Advanced Materials* **12**, 812 (2000)]

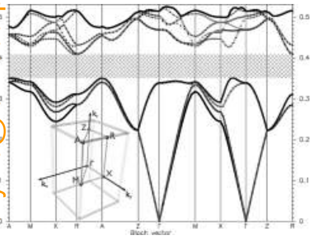
Block-Copolymer 2d Crystal



[Y. Fink, A. M. Urbas, M. G. Bawendi, J. D. Joannopoulos, E. L. Thomas, *J. Lightwave Tech.* **17**, 1963 (1999)]

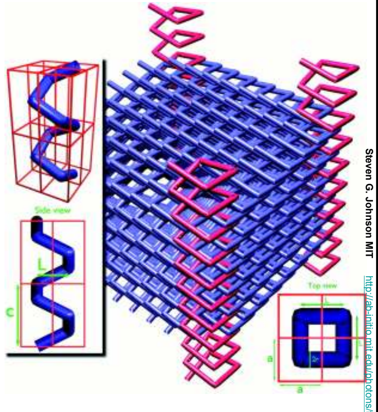
Be GLAD: Even more crystals!

"GLAD" = "GLancing Angle Deposition"



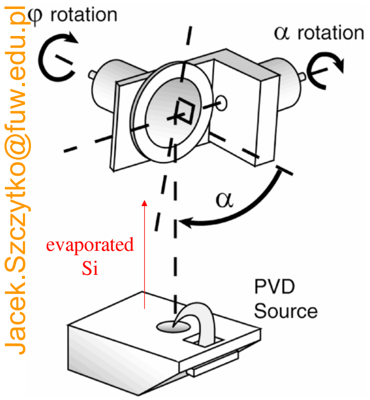
15% gap for Si/air

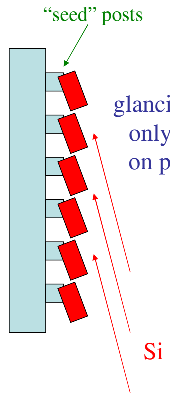
diamond-like
with "broken bonds"
doubled unit cell, so gap between 4th & 5th bands



[O. Toader and S. John, *Science* **292**, 1133 (2001)]

GLAD it works?



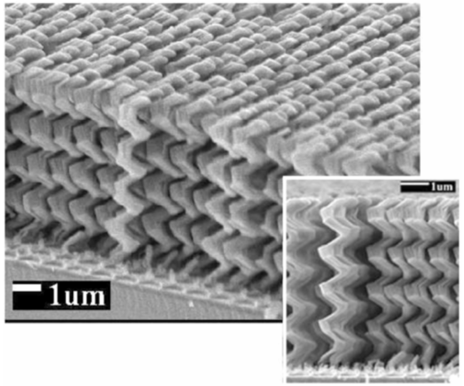


glancing-angle Si
only builds up
on protrusions

…rotate to
spiral

[S. R. Kennedy *et al.*, *Nano Letters* **2**, 59 (2002)]

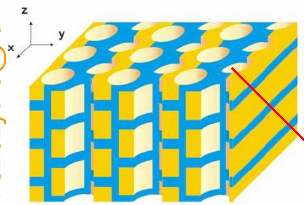
GLAD it works!



[S. R. Kennedy *et al.*, *Nano Letters* **2**, 59 (2002)]

A new twist on layer-by-layer…

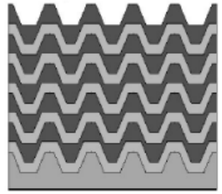
start with an old layer-by-layer



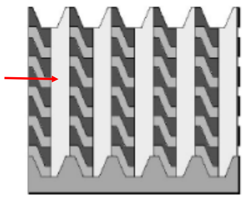
(don't forget the holes)

(14% gap for Si/SiO_2/air)

[S. Fan *et al.*, *Appl. Phys. Lett.* **65**, 1466 (1994)]



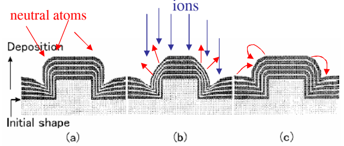
modify layering slightly…



[S. Kawakami *et al.*, *Appl. Phys. Lett.* **74**, 463 (1999)]

Auto-cloning

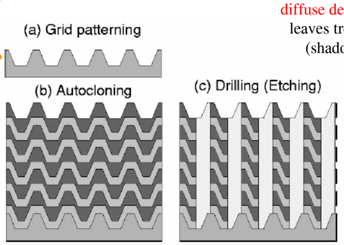
Competition between 3 processes "clones" shape of substrate



diffuse deposition leaves trenches (shadows)

bias sputtering cuts corners (prefers 60°)

re-deposition fills trenches



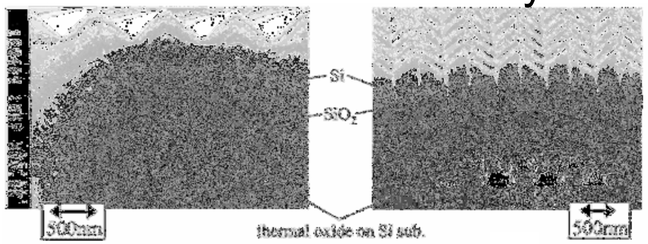
… so, only planar patterning is in substrate

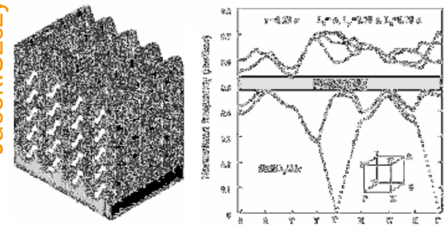
…only drilling needs alignment

…minimize etch roughness

[S. Kawakami *et al.*, *Appl. Phys. Lett.* **74**, 463 (1999)]

Auto-cloned Photonic Crystal





[E. Kuramochi *et al.*, *Opt. Quantum. Elec.* **34**, 53 (2002)]

“Yablonovite”

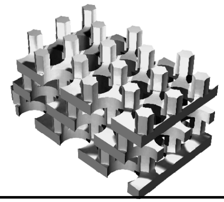
[E. Yablonovitch, T. M. Gmitter, and K. M. Leung, *Phys. Rev. Lett.* **67**, 2295 (1991)]

[image: `http://www.ee.ucla.edu/labs/photon/`]

diamond-like fcc crystal

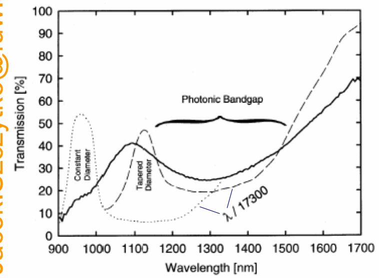
earliest “fabrication-amenable” alternative to diamond spheres

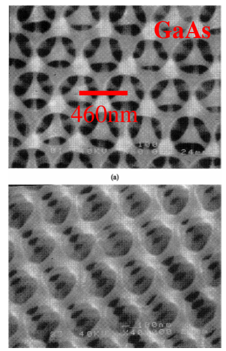
(Topology is very similar to 2000 layer-by-layer crystal)



Making Yablonovite

e-beam mask + chemically-assisted ion-beam etching



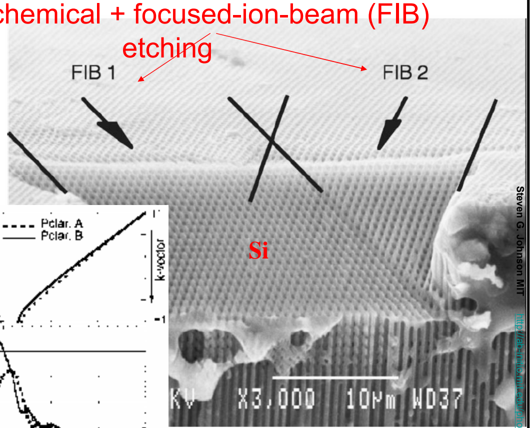


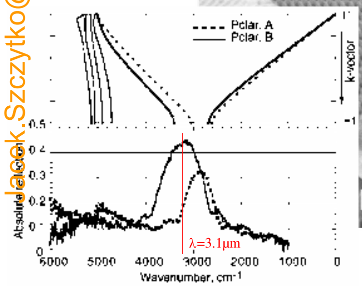
[C. C. Cheng *et al.*, *Physica Scripta.* **T68**, 17 (1996)]

Making ~Yablonovite (II)

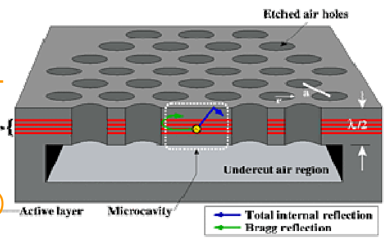
electrochemical + focused-ion-beam (FIB) etching

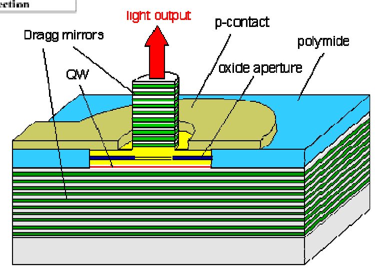
(deep vertical holes)

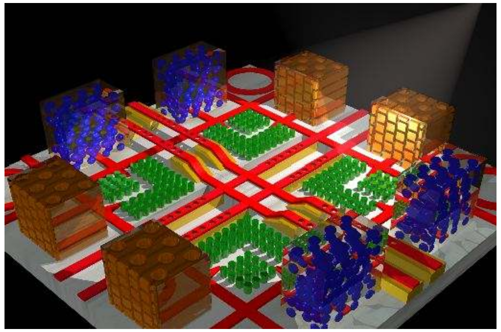




[A. Chelnokov *et al.*, *Appl. Phys. Lett.* **77**, 2943 (2000)]



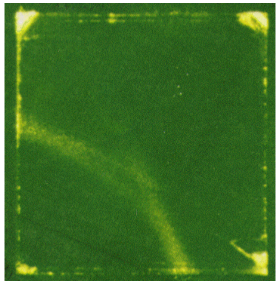




http://www.acr.atr.co.jp/~wendin/FigureLegends/SelfAdaptOptFig.html

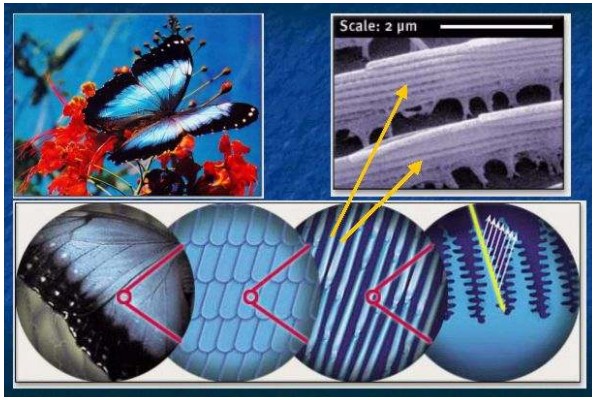
Self-adaptive optical link

- Introduction
- There are crystals, known as photorefractive crystals, in which laser beams can spontaneously link. This phenomenon involves the self-re-organization of electronic charge distributions in the crystal.
- An algorithmic model of this phenemenon may serve asa general mechanism for self-organizing networks.

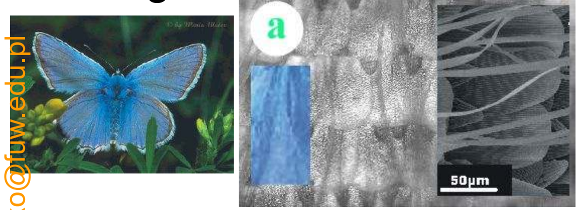


Biologiczne kryształy fotoniczne

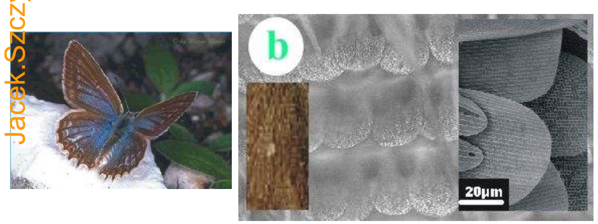
Biologiczne kryształy fotoniczne



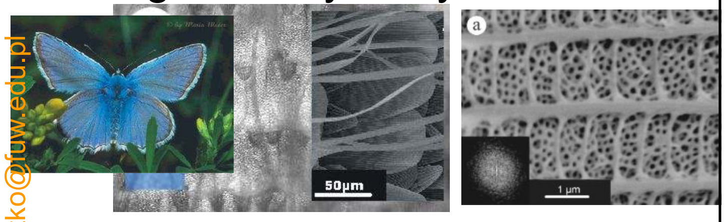
Biologiczne kryształy fotoniczne



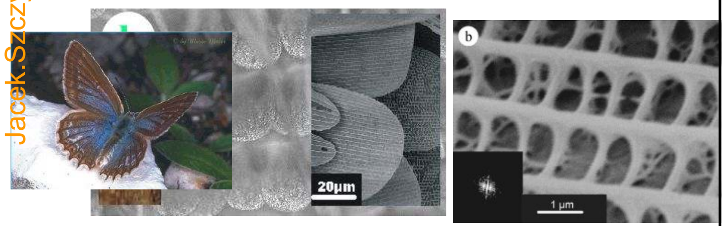
http://www.mfa.kfki.hu/int/nano/online/2002_butterfly/

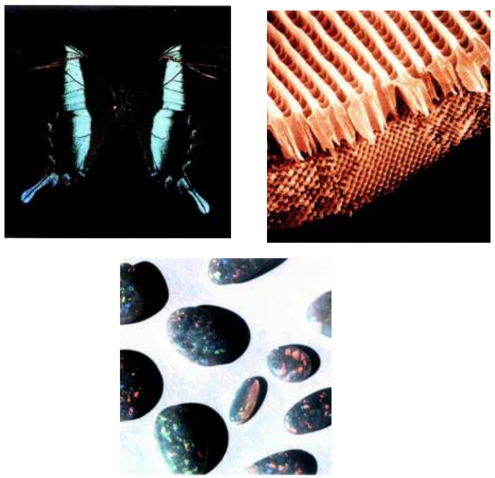


Biologiczne kryształy fotoniczne



http://www.mfa.kfki.hu/int/nano/online/2002_butterfly/





ZAKŁAD OPTYKI INFORMACYJNEJ, IGF, Wydział Fizyki UW

ul. Pasteura 7, V piętro, http://zoi.igf.fuw.edu.pl/

Profesorowie: K. Chałasińska-Macukow, **T. Szoplik,** M. Kowalczyk

Doktorzy: **R. Kotyński, R. Buczyński, J. Pniewski, R.Kasztelanic**

Doktoranci: **W. Saj, T. Antosiewicz,** M. Mrozowicz, A. Sagan

Programy Europejskie:

European Cooperation in the Field of Scientific and Technical Research COST P11 - **Physics of linear, non-linear and active photonic crystals**

http://www.cost.esf.org/

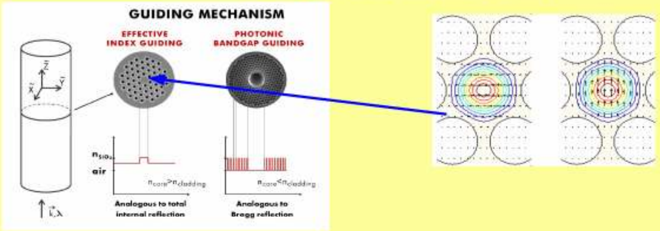
FP6 Network of excellence - **Metamaterials Organised for radio, millimeter wave and Photonic Superlattice Engineering**

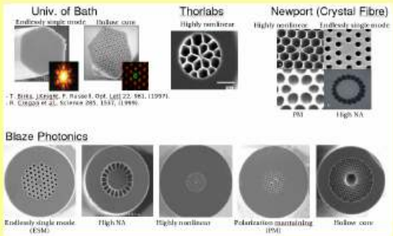
http://www.metamaterials-eu.org/

FP6 Network of excellence on **Micro-optics**

http://www.micro-optics.org/

ŚWIATŁOWODY FOTONICZNE (PCF)



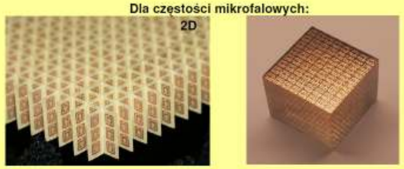


Prace w ZOI:

- Fotoniczna struktura pasmowa
- Własności dyspersyjne modów
- Struktury dwójłomne
- Struktury wielordzeniowe
- Struktury z siatkami Bragga

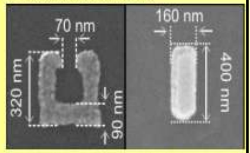
(Meta)materiały o ujemnym efektywnym współczynniku

Dla częstości mikrofalowych:

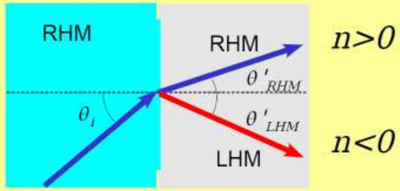


Shelby et al. *Experimental Verification of a Negative Index of Refraction*, Science 292, 77 (2001)

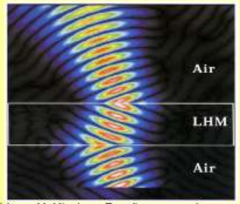
Dla częstości optycznych:



S. Linden et al., *Magnetic Response of Metamaterials at 100 Terahertz*, Science 306, 1351 (2004)

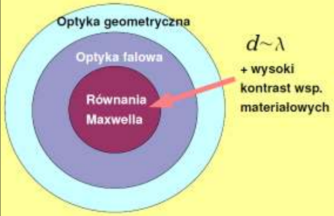


Opis



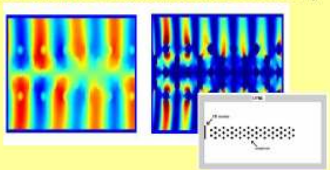
I. Shadrivov, Y. Kivshar, *Bending waves in a wrong way*, The Physicist, 41, (2004).

Modelowanie – struktury podfalowe

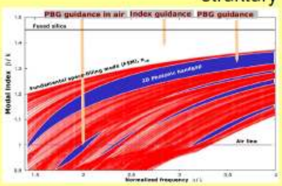


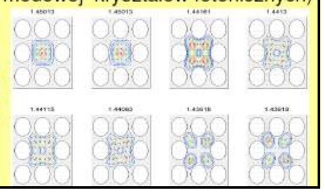
$d \sim \lambda$
+ wysoki kontrast wsp. materiałowych

FDTD (Metoda różnic skończonych zatosowana do r. Maxwella z czasem)



PWM (Met. fal płaskich- do wyznaczania struktury modowej kryształów fotonicznych)





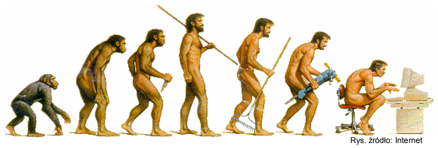
Podziękowania

Dr hab. Dariusz Wasik
Dr Rafał Kotyński
Wydział Fizyki Uniwersytetu Warszawskiego

W przyszłym tygodniu

Czy komputer może myśleć?

1. Tw. Gödla kontra Matrix
2. Moim zdaniem



Rys. źródło: Internet

W przyszłym tygodniu

Prezentacja prac studentów

1. Krzysztof Łopacki *Nowy gatunek* 10 min
2. Konrad Bojar *Disruptive Technologies* 10 min
3. Rafał Opiela, Rafał Hałasa *Internet, telefon, radio i TV, łączność i lokalizacja* 15 min
4. Aleksandra Kulczyk, Jakub Teska *Samochód przyszłości* 15 min
5. Paweł Paluch, Piotr Kakietek *Dom przyszłości* 15 min.

Krzysztof Czarnecki „Kanapka z szynką”
Maciej Bindas „Dom za kilka lat”
Katarzyna Pawlikowska „Jeszcze nie wiesz, że chcesz to mieć!”

Rys. źródło: Internet