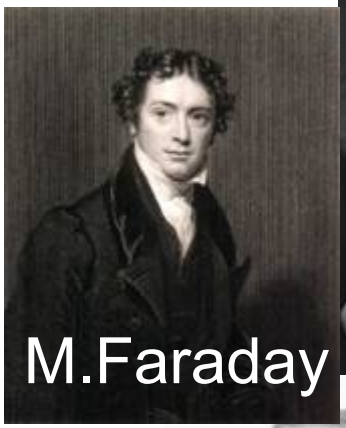
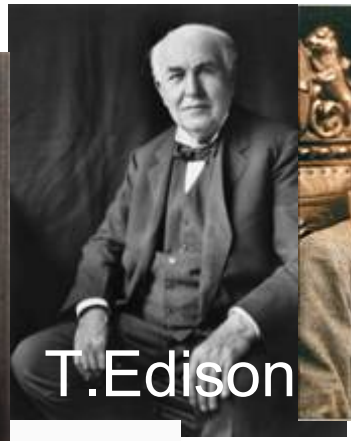
Fotonika in nanotehnologija

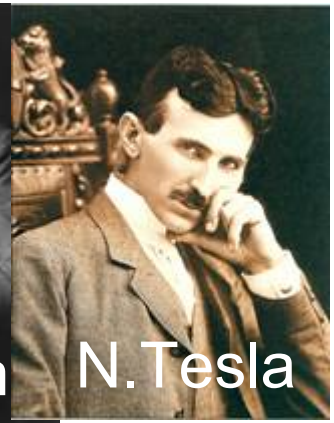
Igor Muševič

Institut J. Stefan in Fakulteta za matematiko
in fiziko, Univerza v Ljubljani

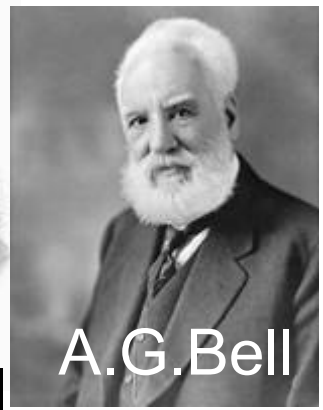
odkritja, ki so temelji sodobne tehnologije


M.Faraday


T.Edison


N.Tesla


J.C.Maxwell


A.G.Bell

leto

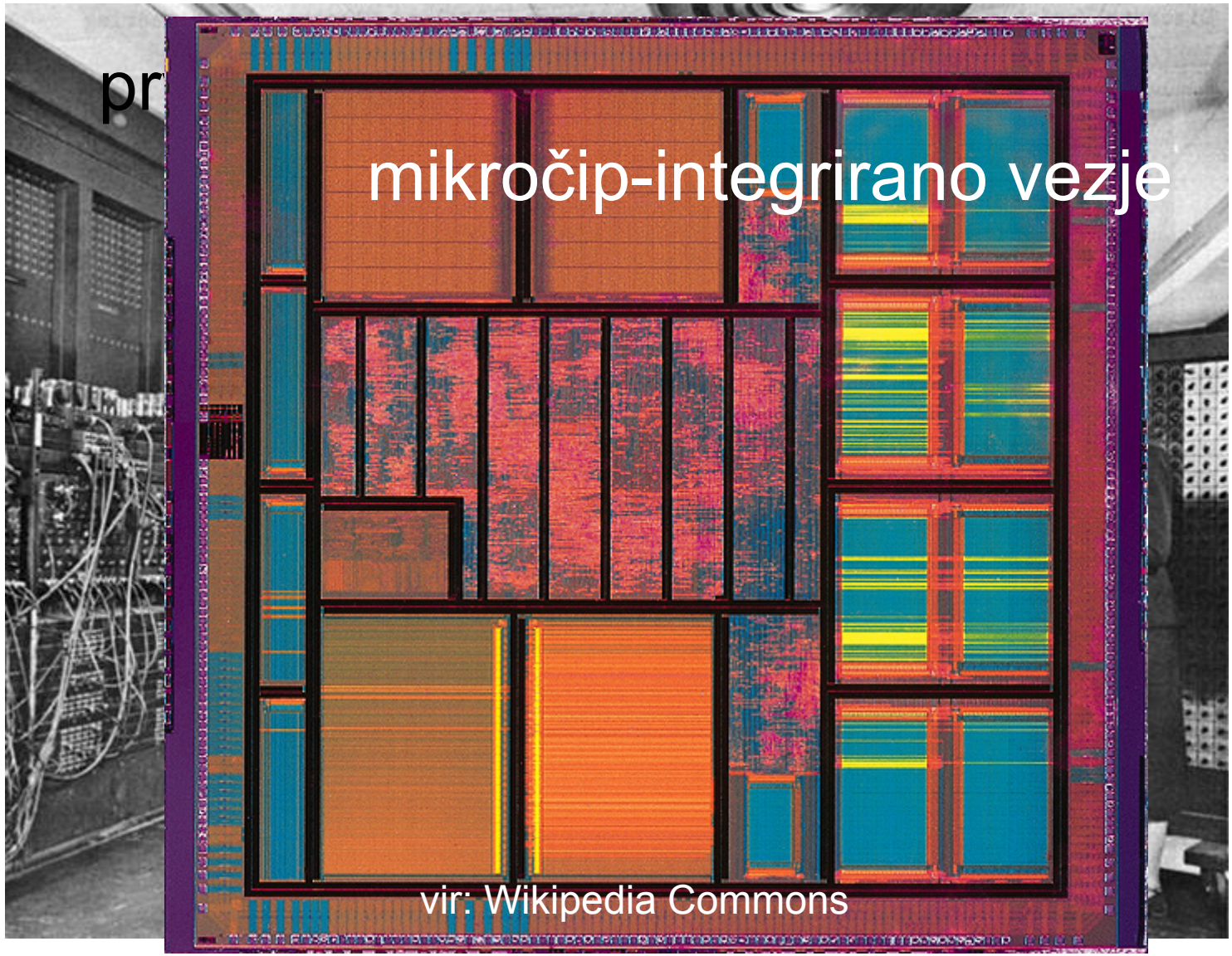
1800

1900

2000


našo civilizacijo poganja elektrika
vir: Sunita Williams, NASA, Slideshare

pr



mikročip-integrirano vezje

vir: Wikipedia Commons

FOTONIKA

Podoben razvoj lahko pričakujemo na področju svetlobe

znanost o svetlobi, njenem pridobivanju, širjenju, preoblikovanju in zaznavanju

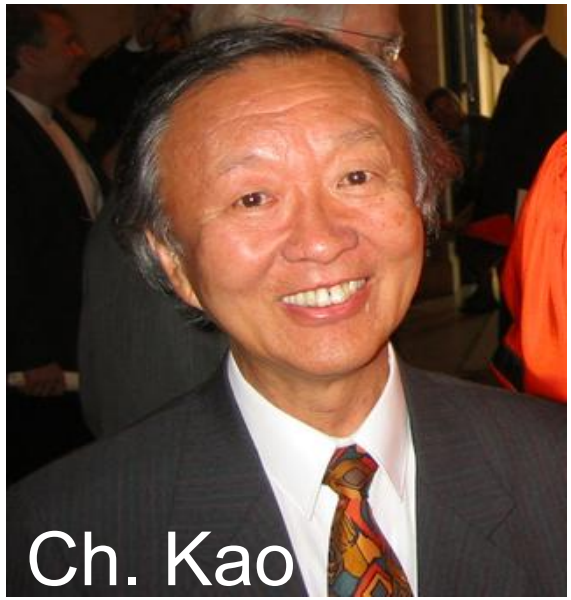
KUNGL. VETENSKAPS-AKADEMIEN

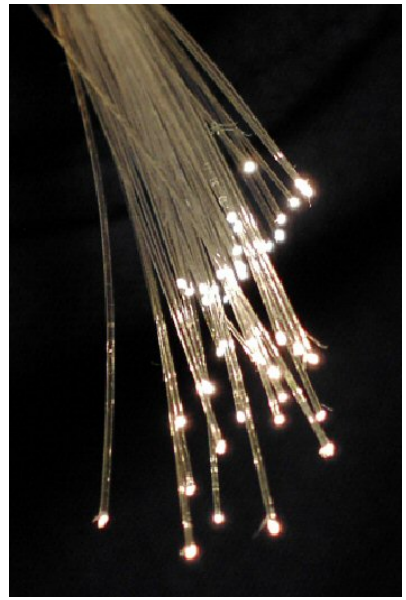
THE ROYAL SWEDISH ACADEMY OF SCIENCES

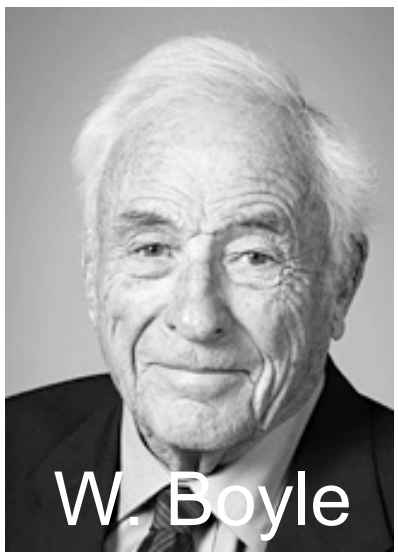
Scientific Background on the Nobel Prize in Physics 2009

TWO REVOLUTIONARY OPTICAL TECHNOLOGIES

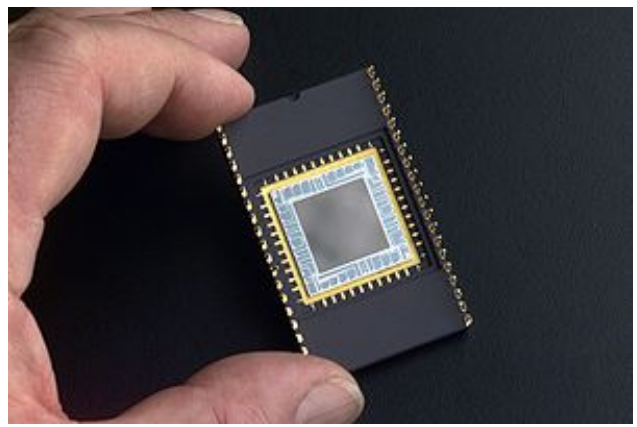
compiled by the Class for Physics of the Royal Swedish Academy of Sciences


Ch. Kao



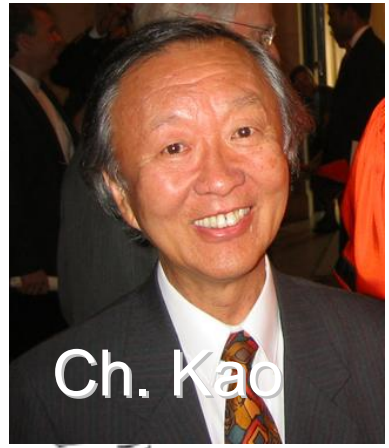

W. Boyle


G.E.Smith



KUNGL. VETENSKAPS-AKADEMIEN

THE ROYAL SWEDISH ACADEMY OF SCIENCES



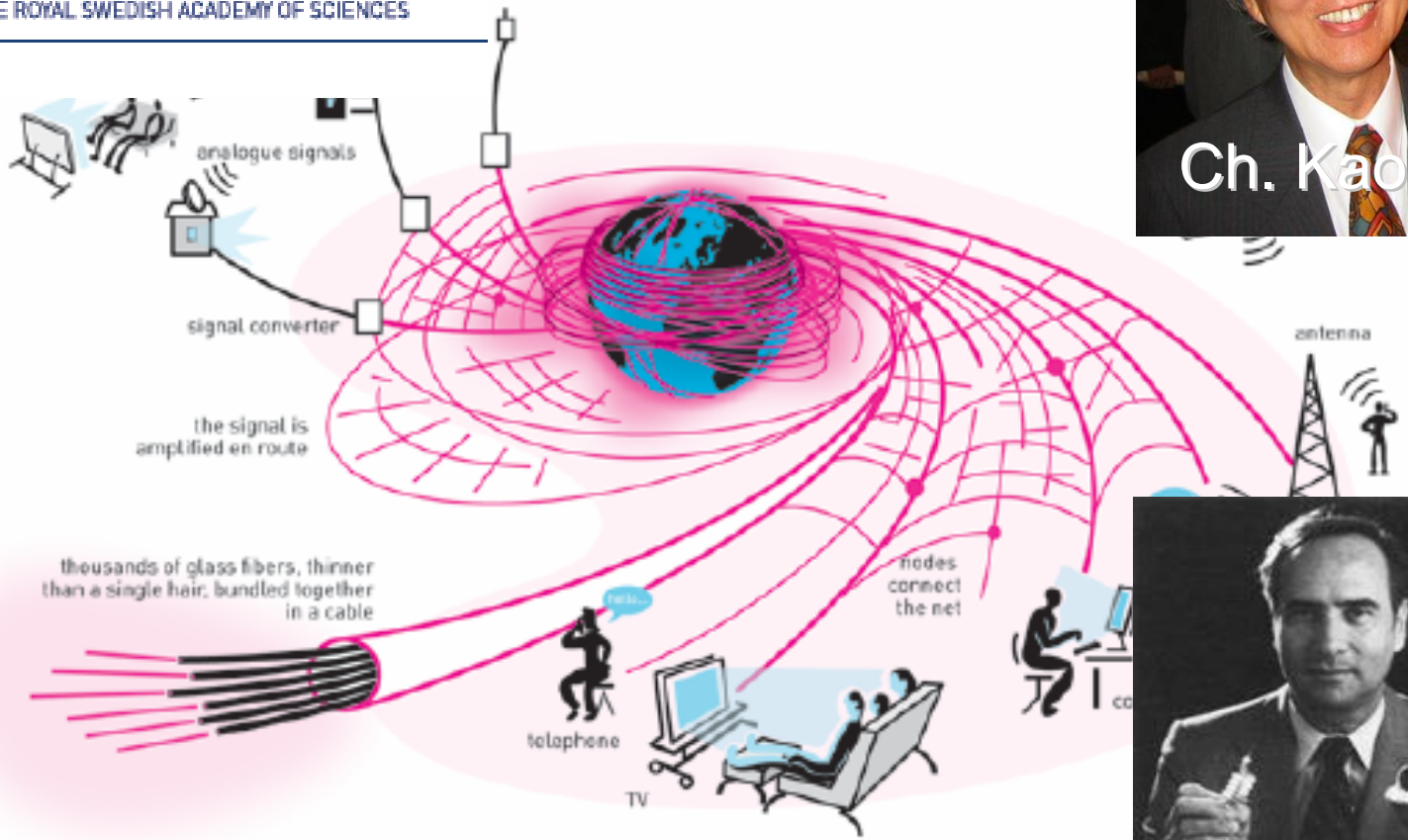
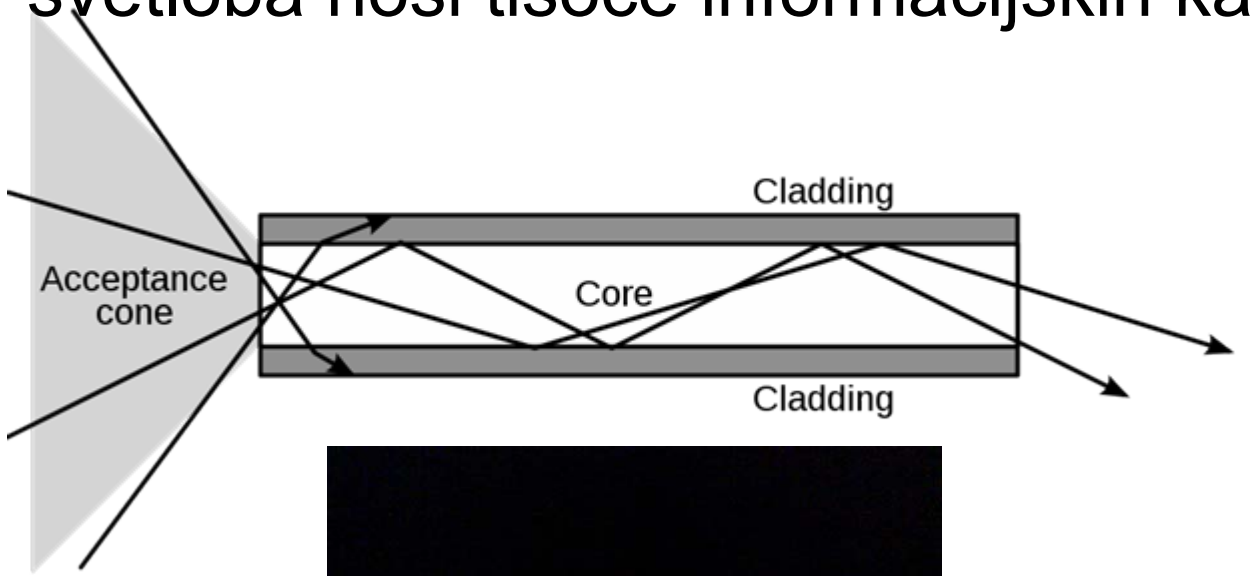
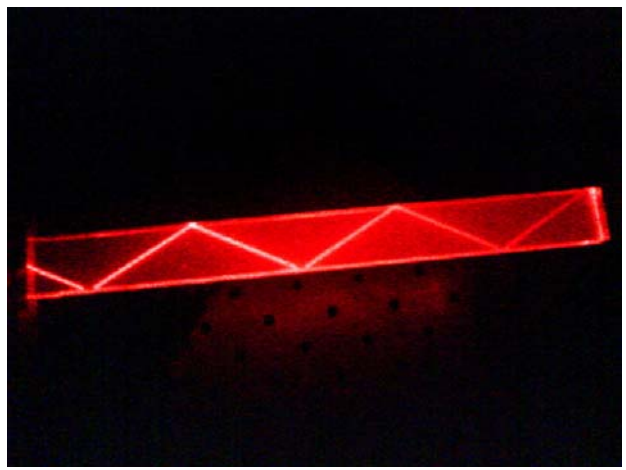


Figure 5: Artistic view of global communication

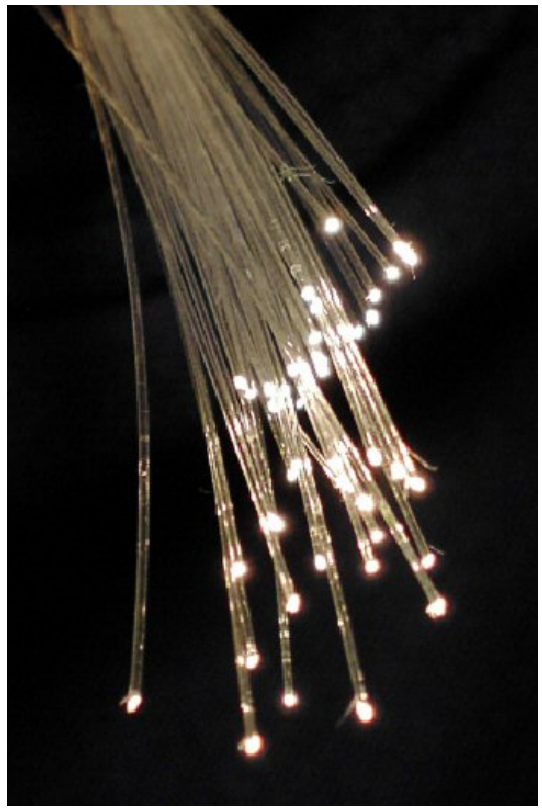
Širjenje svetlobe po optičnih vlaknih: svetloba nosi tisoče informacijskih kanalov





obstoječe naprave za uravnavanje toka svetlobe med vlakni:

vir: Nortel

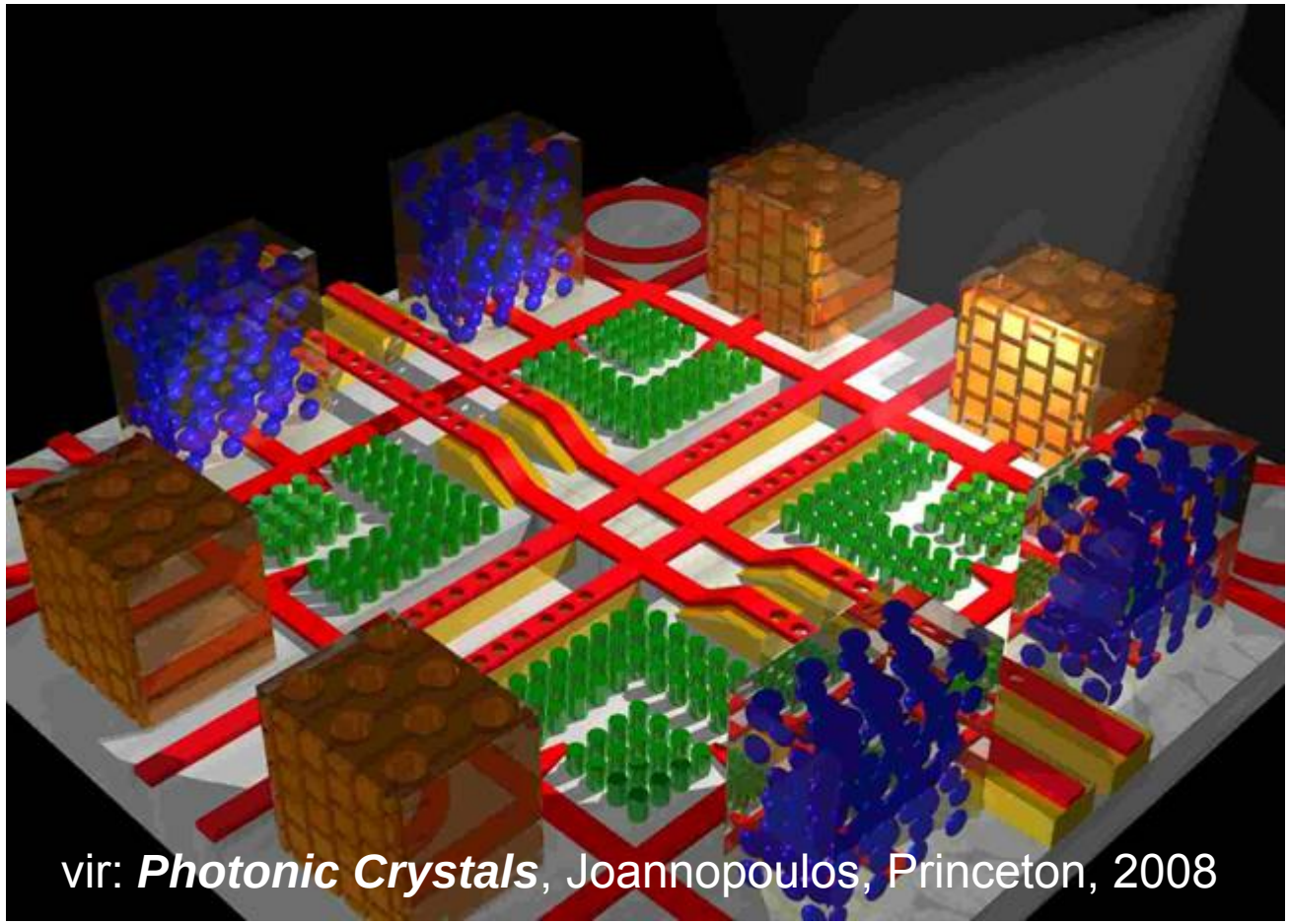


Podobnost med svetlobo in elektriko pri prenosu informacij:

ali je mogoče izdelati miniaturne naprave,

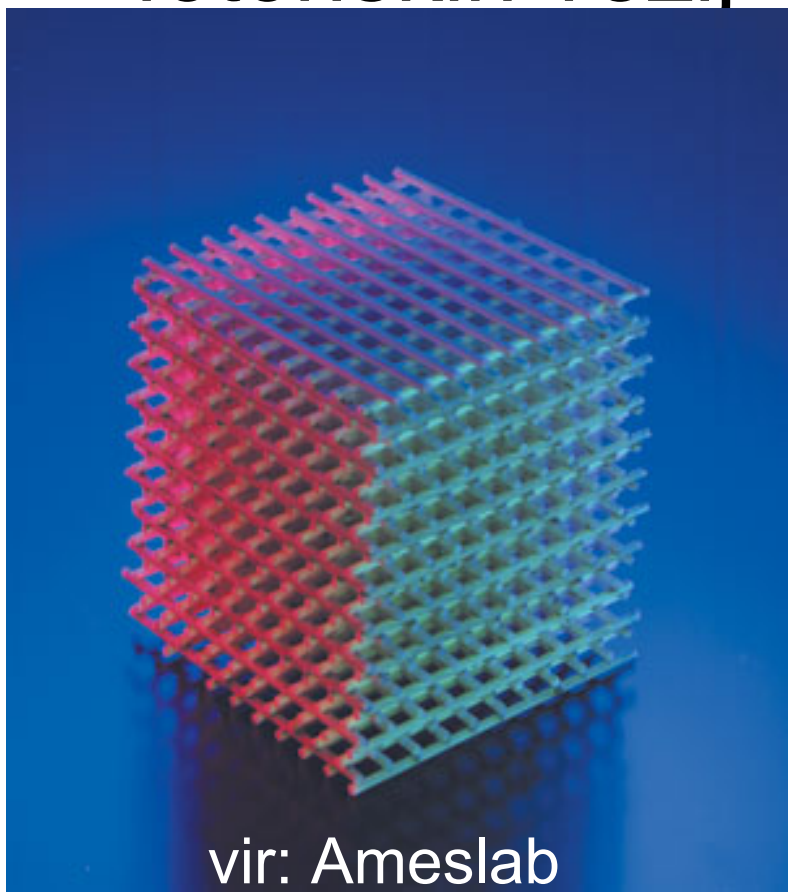
torej "**integrirano optično vezje**"?

cilj: optično mikrovezje, "optični metropolis"

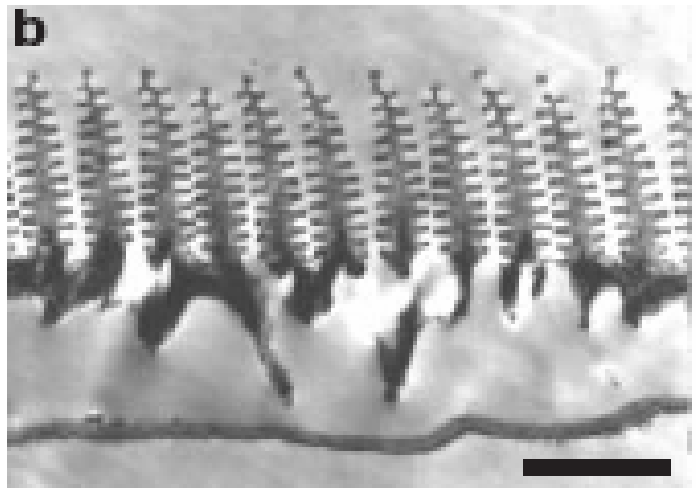


vir: ***Photonic Crystals***, Joannopoulos, Princeton, 2008

"Fotonski kristal": temeljni element fotonskih vezij



fotonski kristali so v naravi pogosti:



insight review articles

Photonic structures in biology

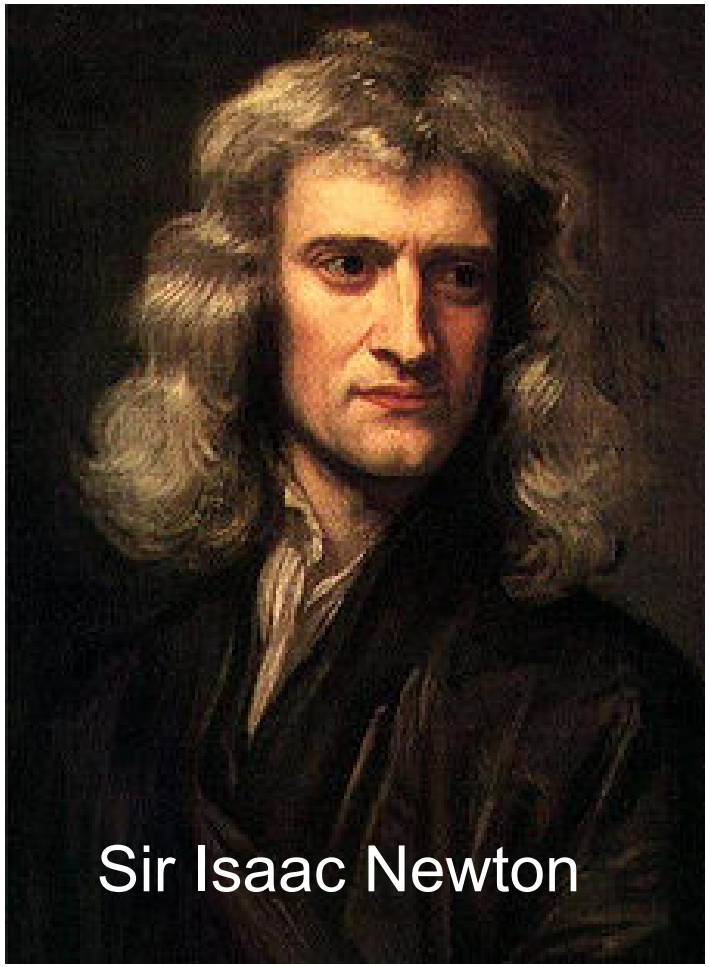
Pete Vukusic and J. Roy Sambles

Thin Film Photonics, School of Physics, Exeter University, Exeter EX4 4QL, UK (e-mail: P.Vukusic@ex.ac.uk)

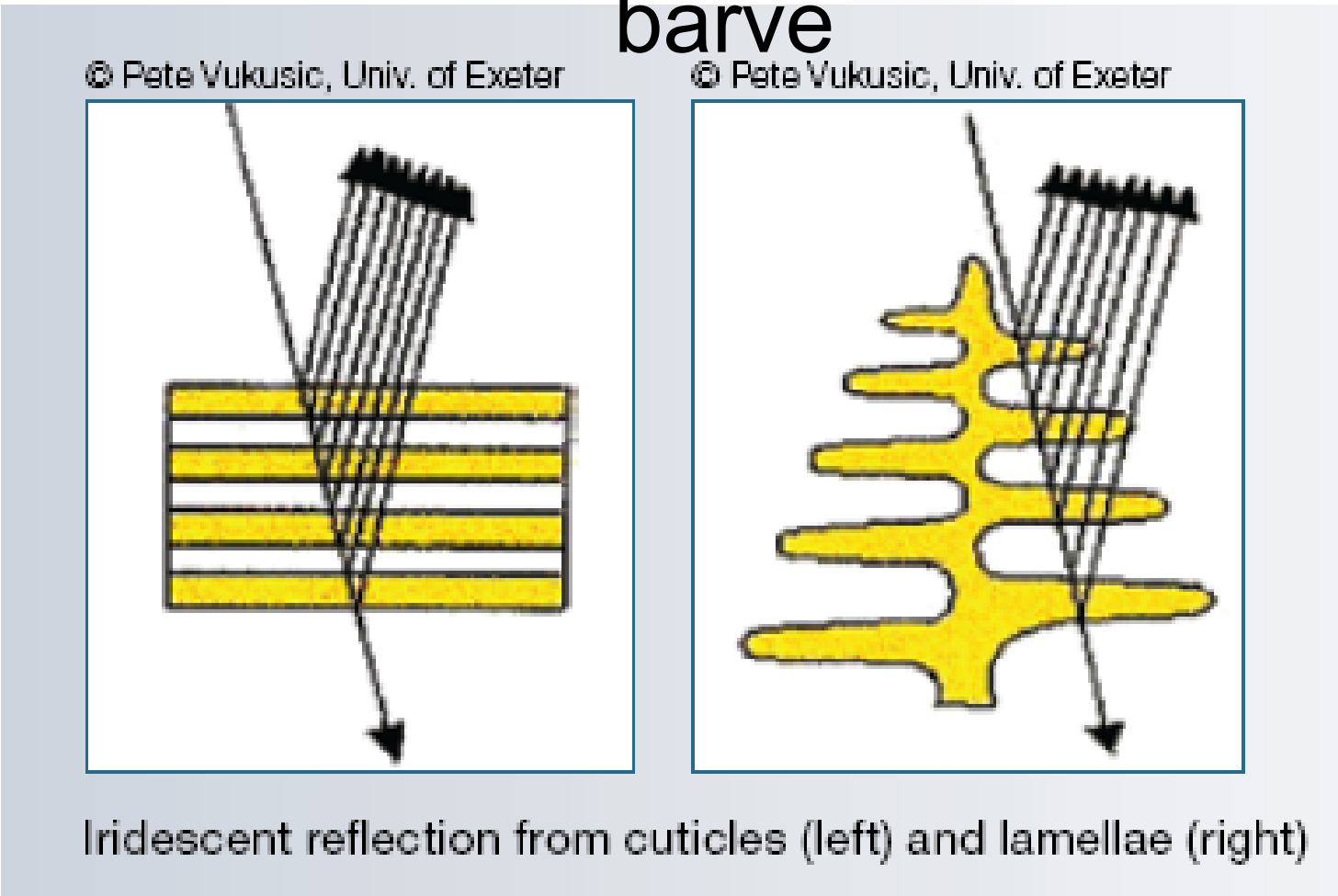
Millions of years before we began to manipulate the flow of light using synthetic structures, biological systems were using nanometre-scale architectures to produce striking optical effects. An astonishing variety of natural photonic structures exists: a species of Brittlestar uses photonic elements composed of calcite to collect light, *Morpho* butterflies use multiple layers of cuticle and air to produce their striking blue colour and some insects use arrays of elements, known as nipple arrays, to reduce reflectivity in their compound eyes. Natural photonic structures are providing inspiration for technological applications.

P.Vukusic, N.Sambles, *Nature* **424**, 852(2003)

bela svetloba je sestavljena iz svetlobe vseh mogočih barv



odbije se samo svetloba določene barve



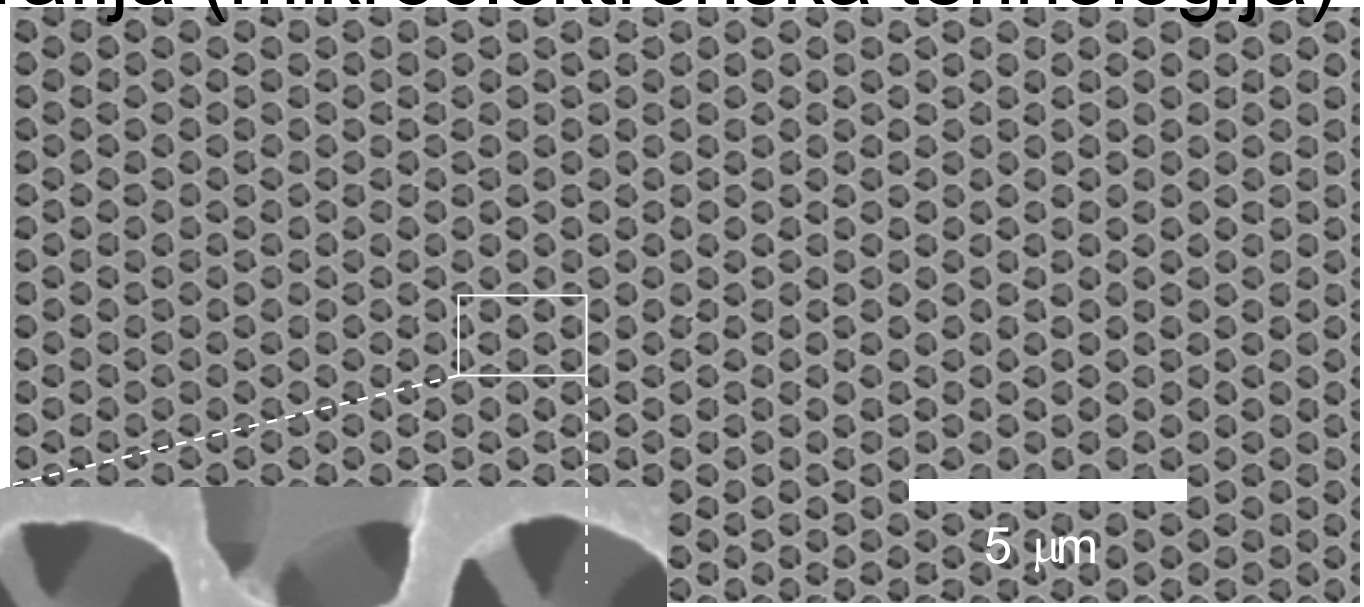
Iridescent reflection from cuticles (left) and lamellae (right)

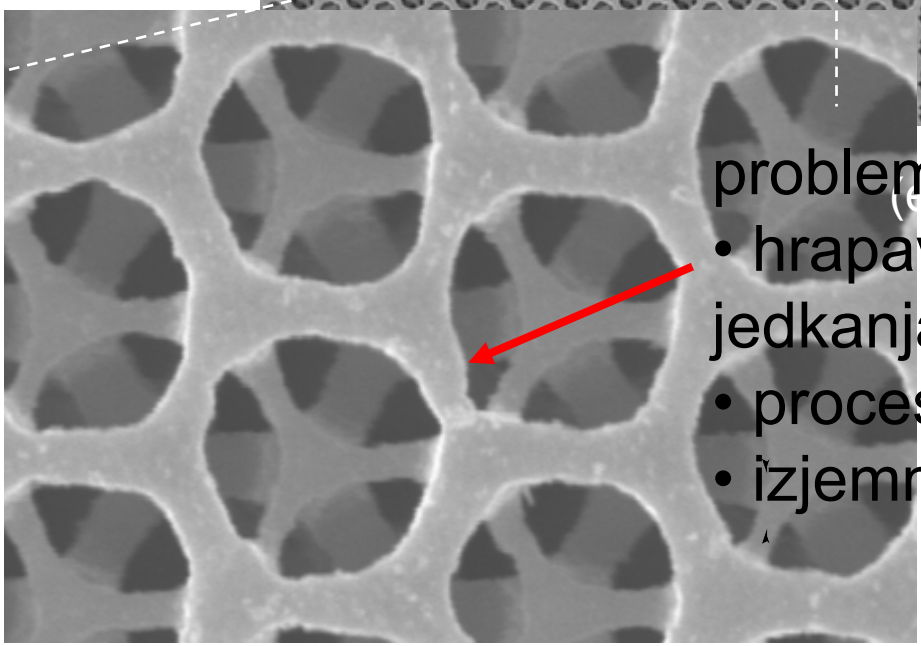
Fotonski kristali torej delujejo
kot idealna zrcala.

To pa lahko koristno uporabimo za vodenje
svetlobe

Kako izdelati takšne fotonske strukture?

fotolitografija (mikroelektronska tehnologija)

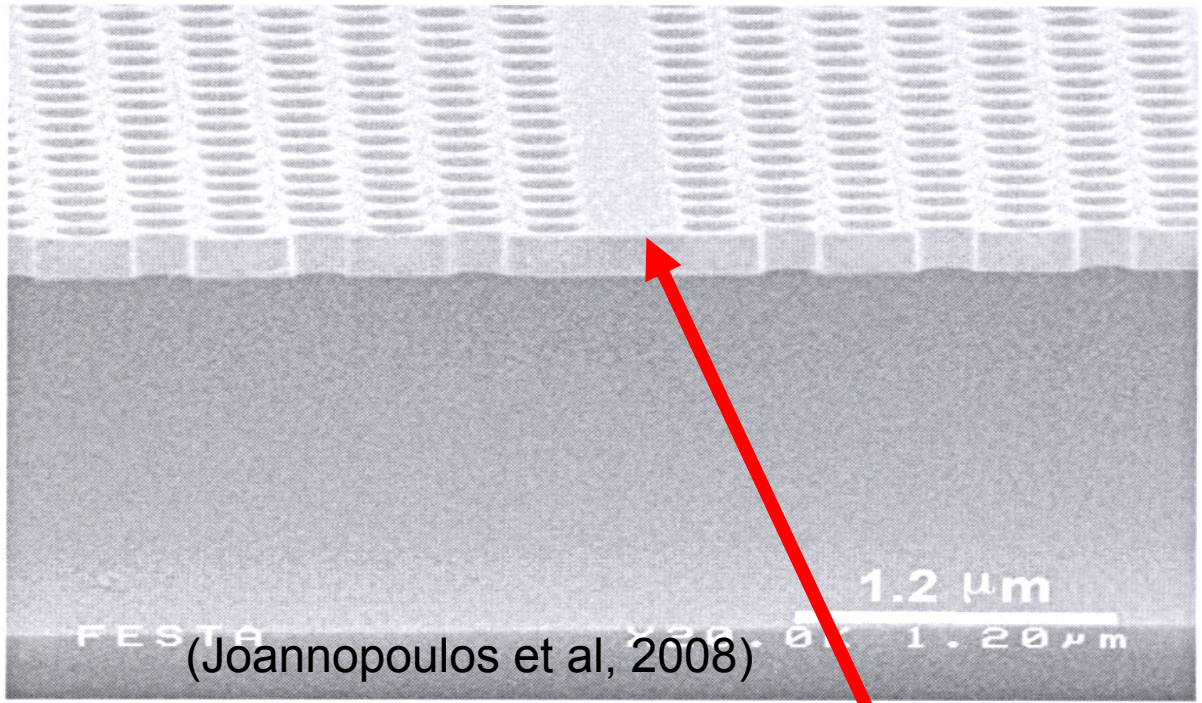




problemi:

- hrapavost površine zaradi jedkanja-sipanje svetlobe
- procesiranje različnih materialov
- izjemno zamuden proces

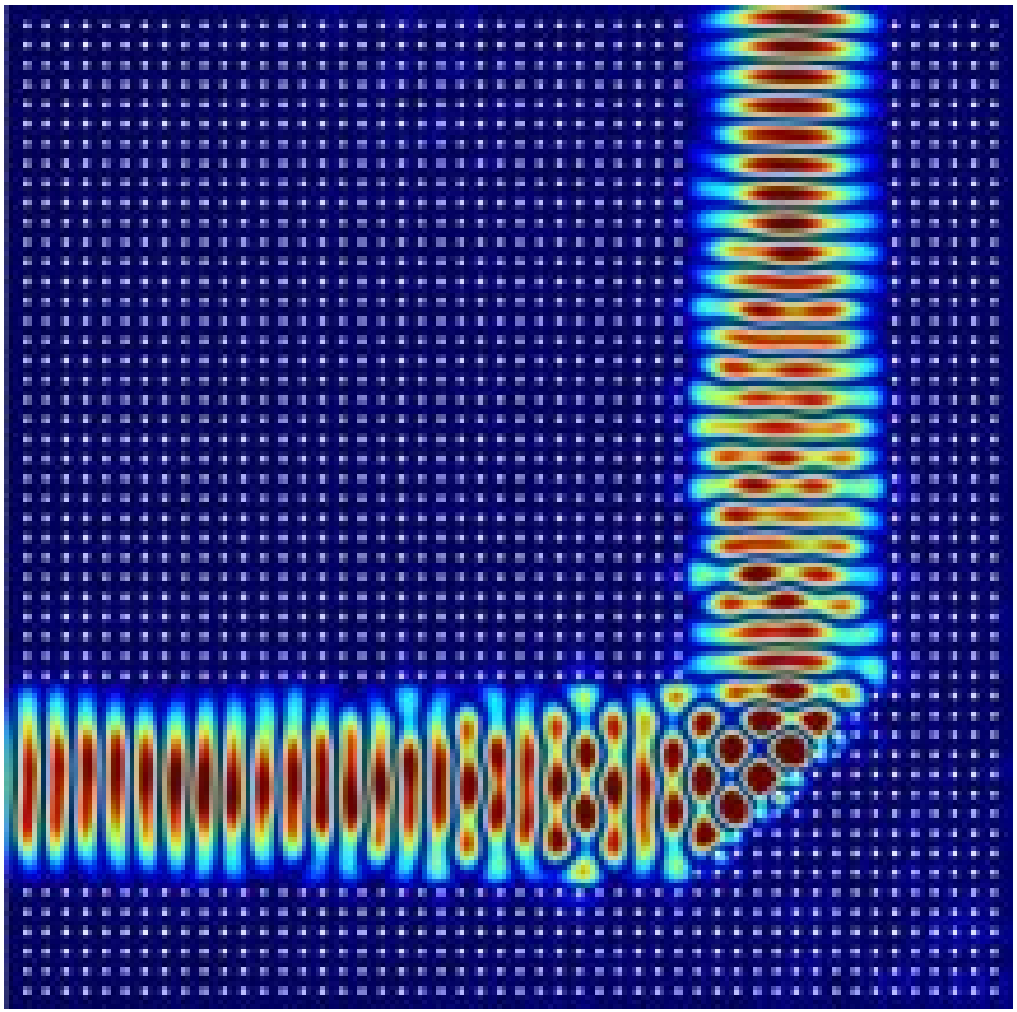
"stanje tehnike":
planarne, 2D fotonske mikrostrukture



(Joannopoulos et al, 2008)

svetloba je "ujeta" v plasti

svetlobo vodimo po fotonskih kristalih



Tiskovno sporočilo družbe Intel, 23. julij 2010

INTERVIEW | FOCUS

Integrating silicon photonics

Mario Paniccia, Intel fellow and director of Intel's Photonics Technology Lab, talks to *Nature Photonics* about the company's progress in commercializing high-speed silicon photonics.

Tell us about Intel's latest developments.
We have been working on the individual building blocks of silicon photonics for some time now, and have always stated that the ultimate goal of silicon photonics is the integration of individual photonic devices. We have now fabricated and demonstrated the first end-to-end silicon photonics integrated link, with integrated hybrid silicon lasers operating at 50 Gbit s^{-1} over a single fibre.

This achievement represents a major advancement towards the development of low-cost highly integrated optical interconnects operating at terabit-per-second speeds. This is a very exciting time for photonics, and specifically for silicon photonics, which is still in its infancy. The integrated circuit celebrated its fiftieth

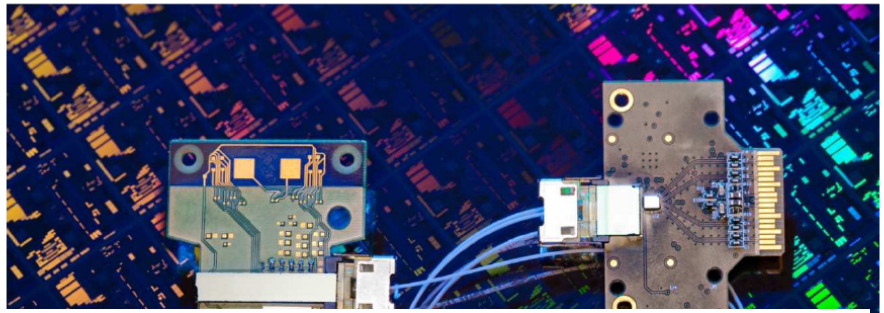
Mario Paniccia unveils the latest silicon photonics news from Intel Corporation that will soon bring optical technology to a computer near you.

How fast can the silicon link operate?
Although the link was designed for an aggregate bandwidth of 40 Gbit s^{-1}, with data being transmitted down a single fibre at four distinct wavelengths (each at 10 Gbit s^{-1}), we were able to push the bandwidth to 50 Gbit s^{-1} — 12.5 Gbit s^{-1} per channel. The system operates at room temperature without active cooling, and our tests have demonstrated a bit error rate of $<10^{-12}$. Although the link is obviously not yet a commercial product, the bit-error-rate performance gives us cause to be optimistic for good levels of link and system stability.

Why do you not integrate the electronics with the photonics?
Although the integration of electronics and

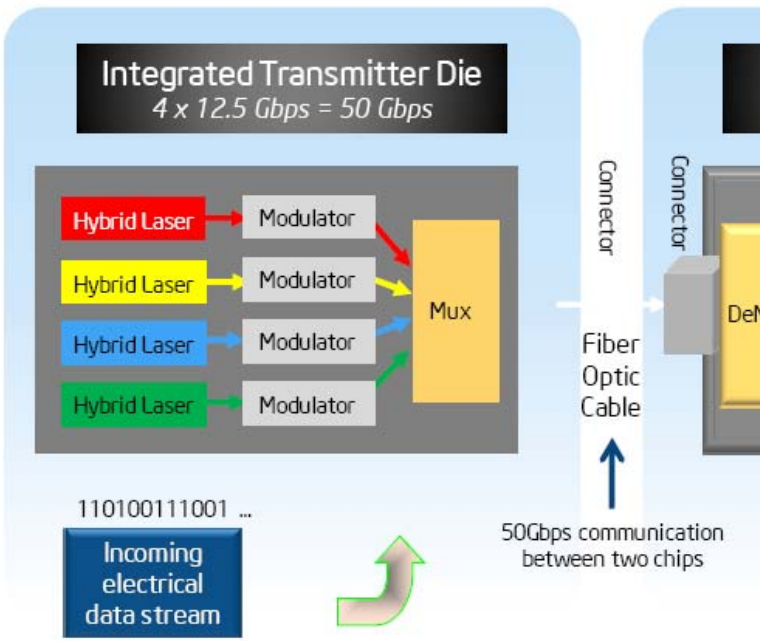
The 50G Silicon Photonics Link

The world's first silicon-based optical d
connection with integrated lasers



Notable Intel breakthroughs include:

- February 2004: world's first 1 GHz silicon modulator
- February 2005: world's first continuous wave silicon Raman laser
- April 2005: world's first 10 Gbps silicon modulator
- September 2006: world's first hybrid silicon laser
- July 2007: world's first 40 Gbps silicon modulator
- August 2007: world's first 40 Gbps PIN photodetector
- December 2008: world's first 340 GHz Gain*BW avalanche photodetector (APD)



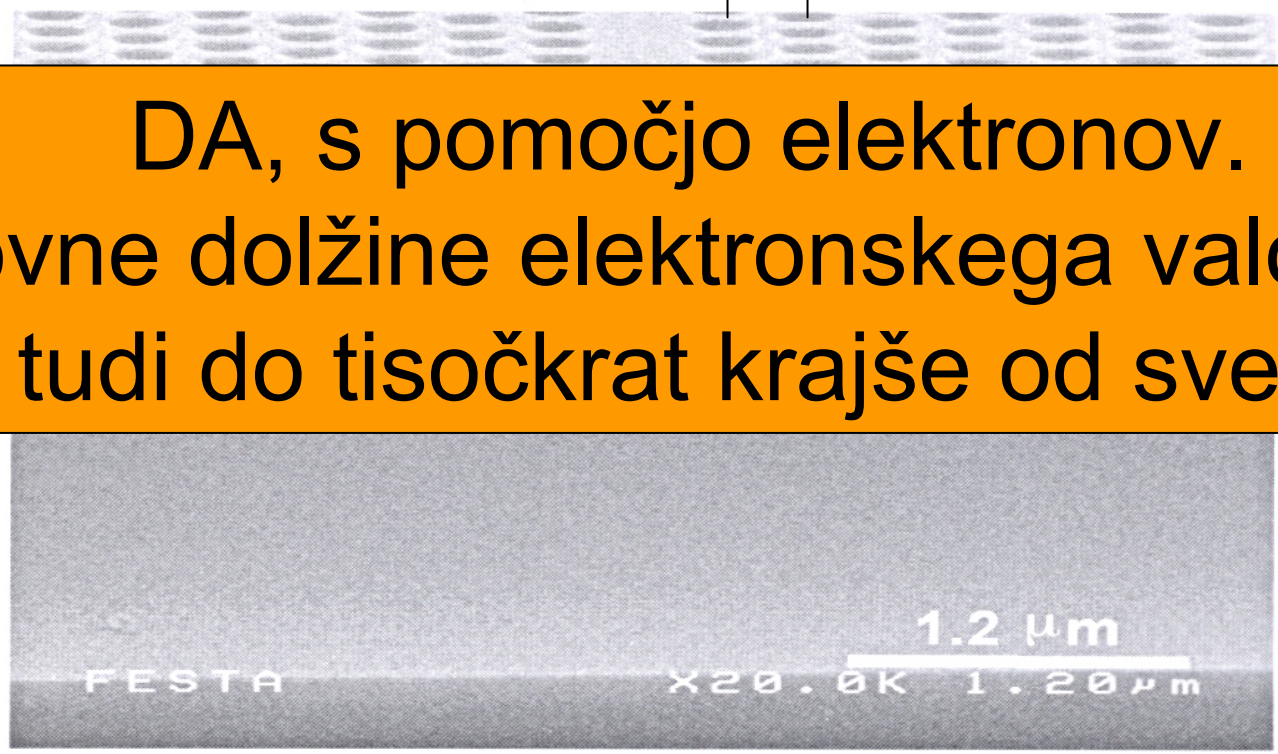
http://techresearch.intel.com.

Ali je mogoče tok svetlobe uravnavati na nanometerskih razdaljah?

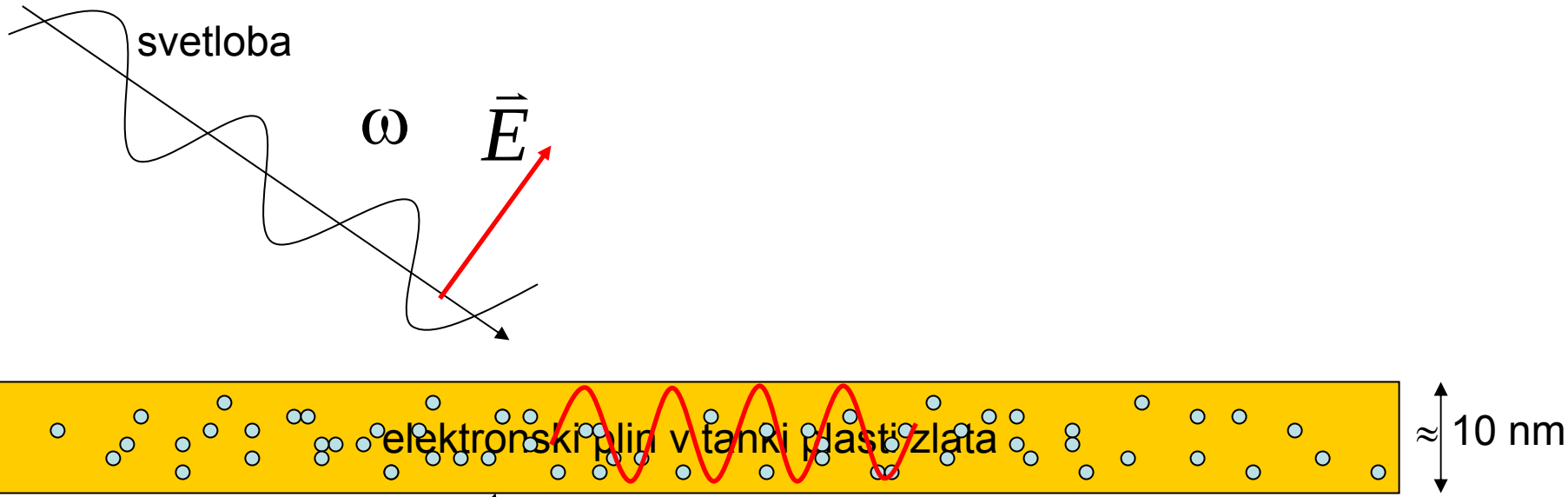
približno enako valovni dolžini svetlobe

≈500 nm

DA, s pomočjo elektronov.
valovne dolžine elektronskega valovanja so tudi do tisočkrat krajše od svetlobe



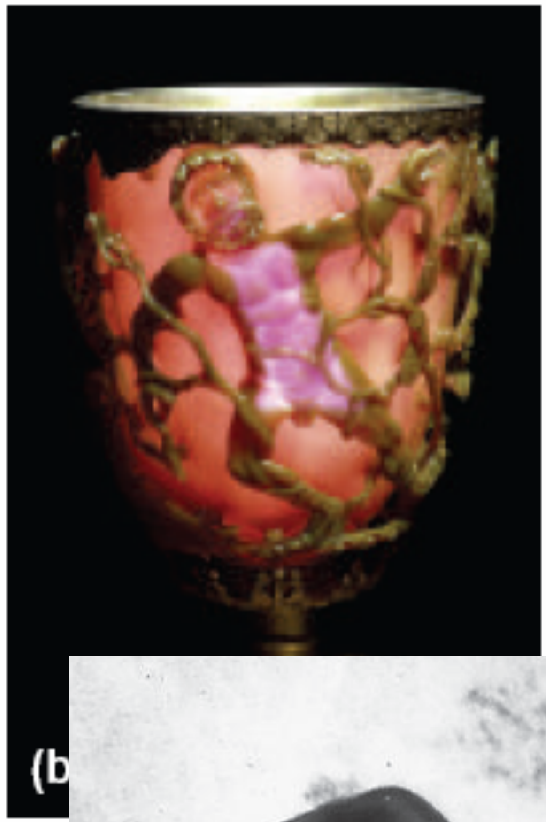
osnovna ideja: svetloba poganja v gibanje proste elektrone v kovini



PLAZMONI in Nano-Optika

vsiljeno gibanje elektronov in EM polja lahko uravnavamo na zelo majhih razdaljah

Plazmone v nanodelcih Au in Ag in so poznali že Rimljani



The Lycurgus Cup – A Roman Nanotechnology

Ian Freestone[1], Nigel Meeks[2], Margaret Sax[2] and Catherine Higgitt[2]

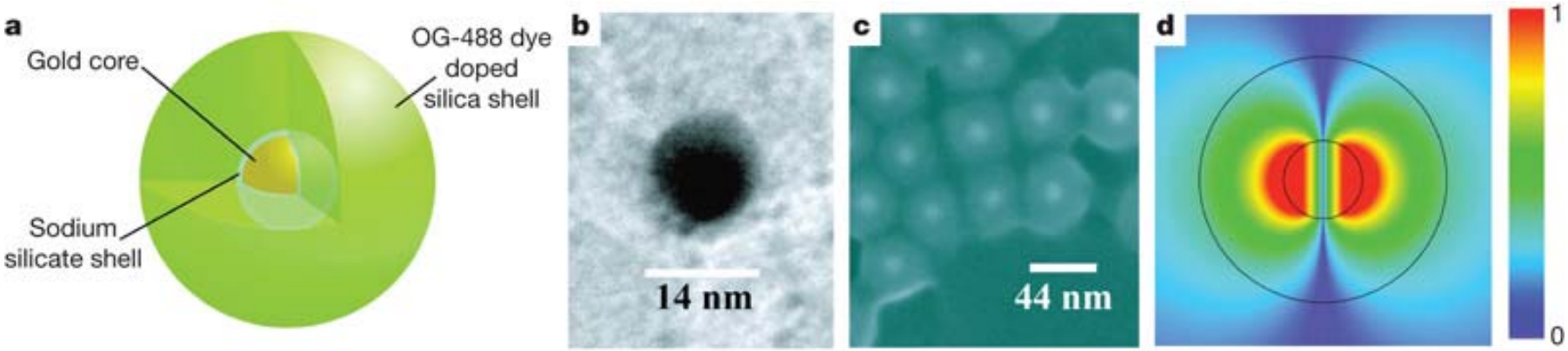
[1] Cardiff School of History and Archaeology, Cardiff University, Cardiff CF10 3EU, Wales UK
[2] Department of Conservation, Documentation and Science, The British Museum, London WC1B 3DG, UI

The British Museum
Late Roman, 4th century AD
Probably made in Rome

Ag in Au nanodelci, plazmonska resonanca

primeri iz plazmonske nano-optike: SPASER- nanolaser

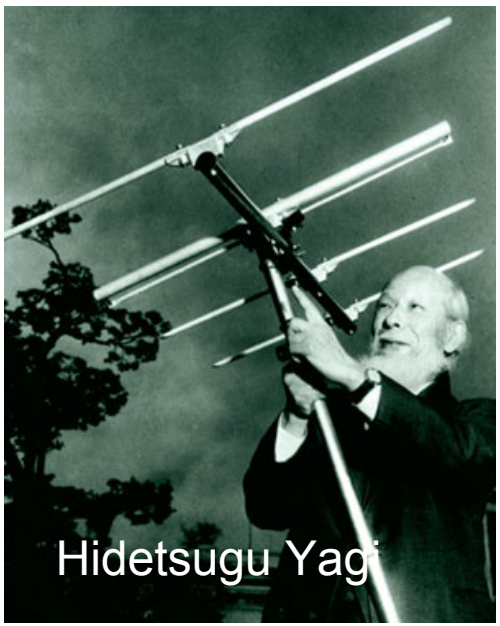
najmanjši laser: zlata kroglica s premerom 14 nm

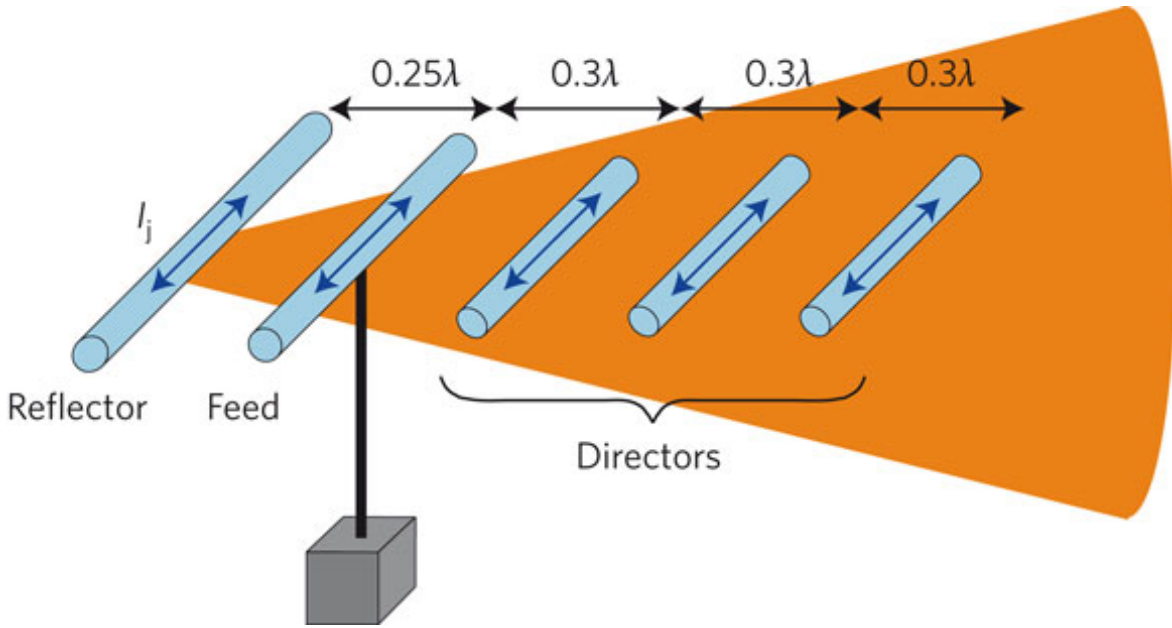


MA Noginov *et al. Nature* **000**, 1-3 (2009) doi:10.1038/nature08318

nature

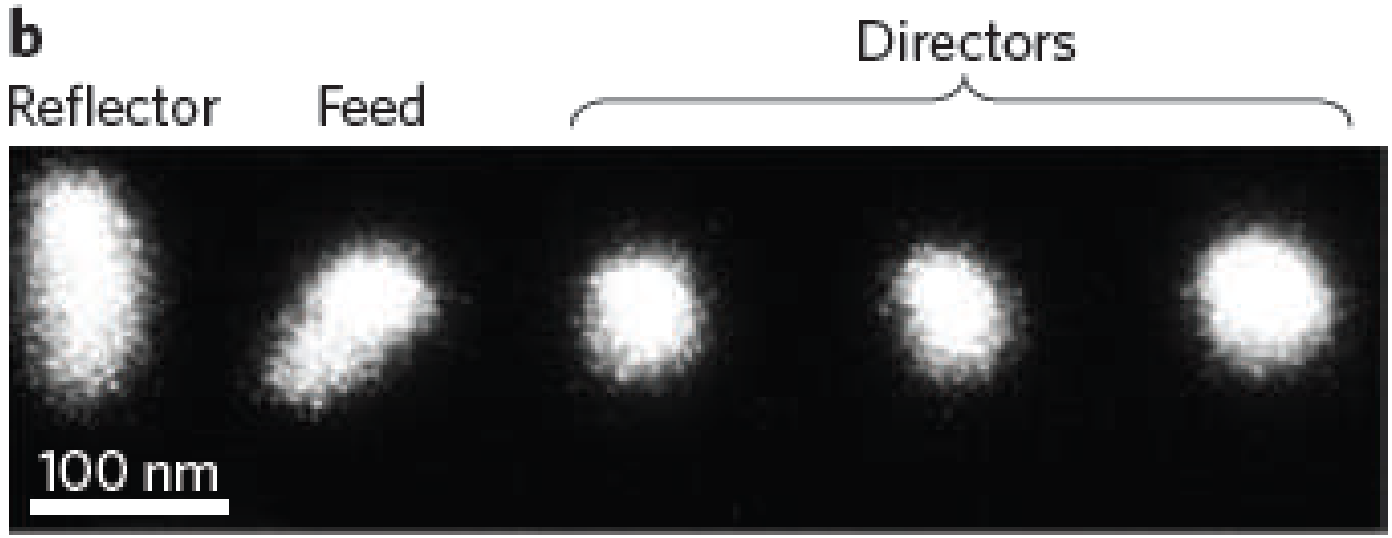
Drugi primer: Yagi-Uda nanoantena





H.Yagi in Shintaro Uda, 1926

Yagi-Uda nano-antena za vidno svetlobo



LETTERS
PUBLISHED ONLINE: 14 MARCH 2010 | DOI: 10.1038/NPHOTON.2010.34
nature photonics

Directional control of light by a nano-optical Yagi–Uda antenna

Terukazu Kosako, Yutaka Kadoya* and Holger F. Hofmann

Tretji primer: plazmonska zbiralna leča iz Au nanodelcev na Au

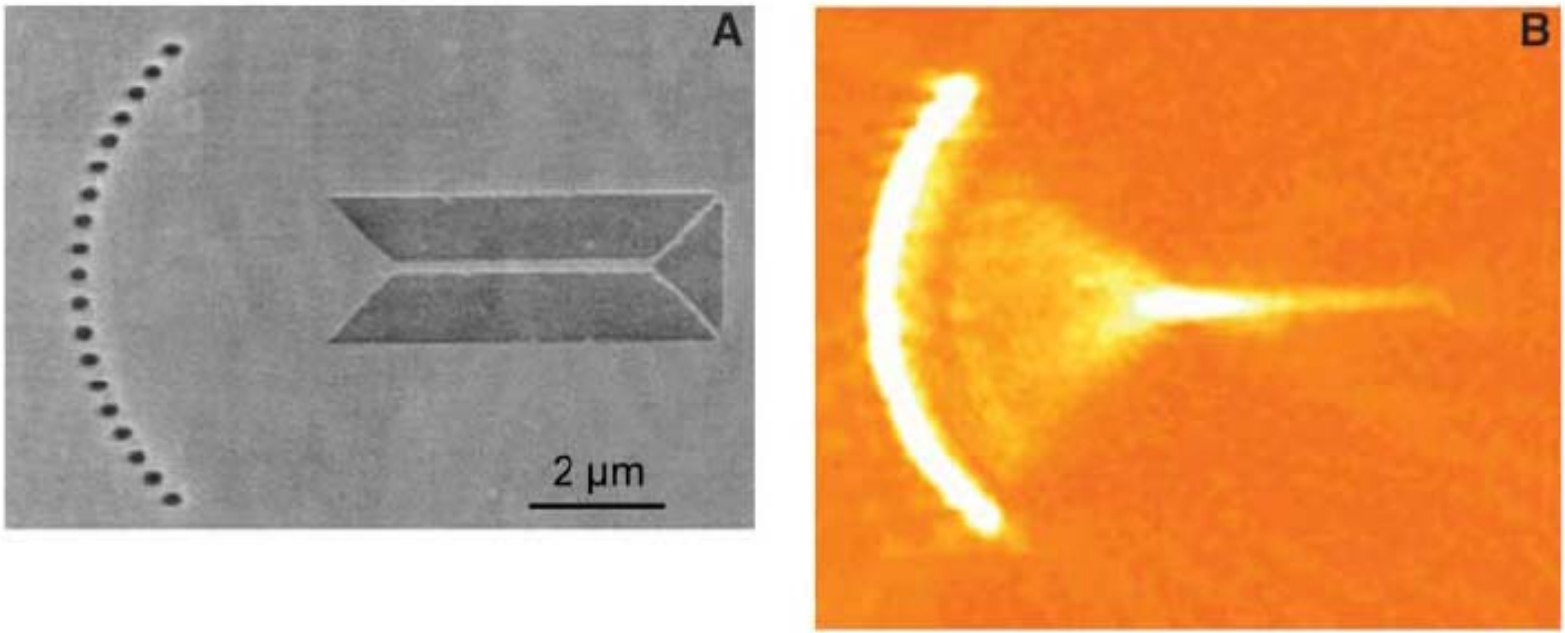


Fig. 2. (**A**) SEM image of a nanodot focusing array coupled to a 250-nm-wide Ag strip guide. (**B**) NSOM image of the SP intensity showing subwavelength focusing. [Adapted from (*15*)]

APPLIED PHYSICS LETTERS **86**, 181108 (2005)

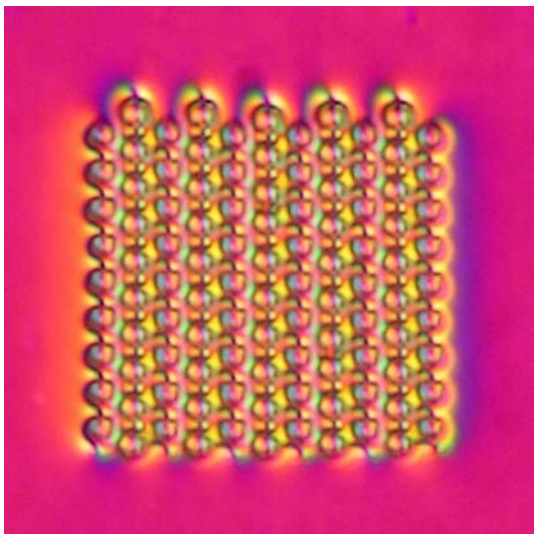
Nanodot coupler with a surface plasmon polariton condenser for optical far/near-field conversion

Wataru Nomura[a)] and Motoichi Ohtsu[b)]
School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan 113-8656

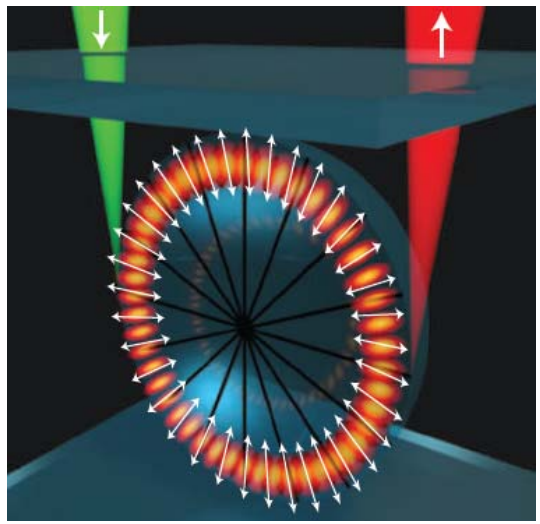
Takashi Yatsui
Solution-Oriented Research for Science and Technology (SORST), Japan Science and Technology Agency, 687-1 Tsuruma, Machida, Tokyo, Japan 194-0004

(Received 8 November 2004; accepted 11 March 2005; published online 28 April 2005)

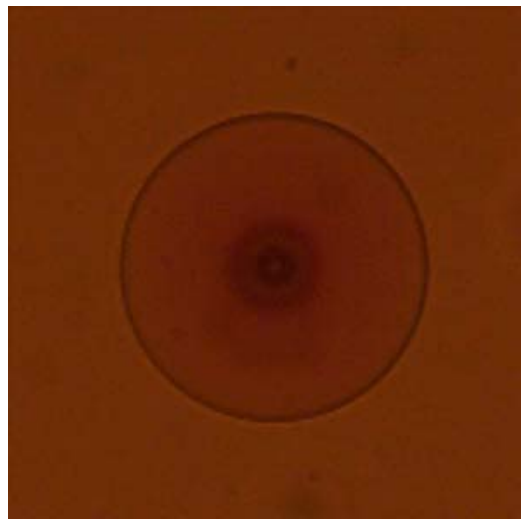
Dosežki raziskovalcev IJS in Univerze v Ljubljani na področju mikro-fotonike:



2D fotonski kristal

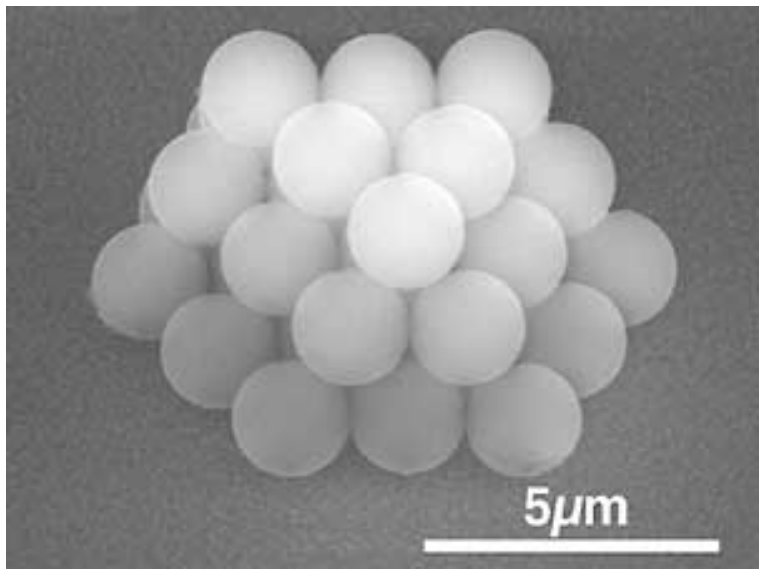


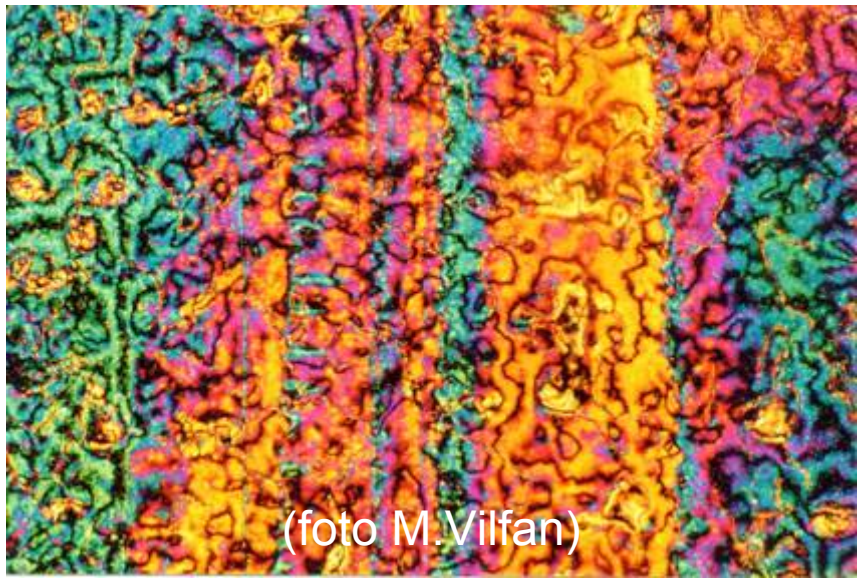
fotonski mikroresonator



3D mikrolaser

izbrali smo nenavaden pristop:

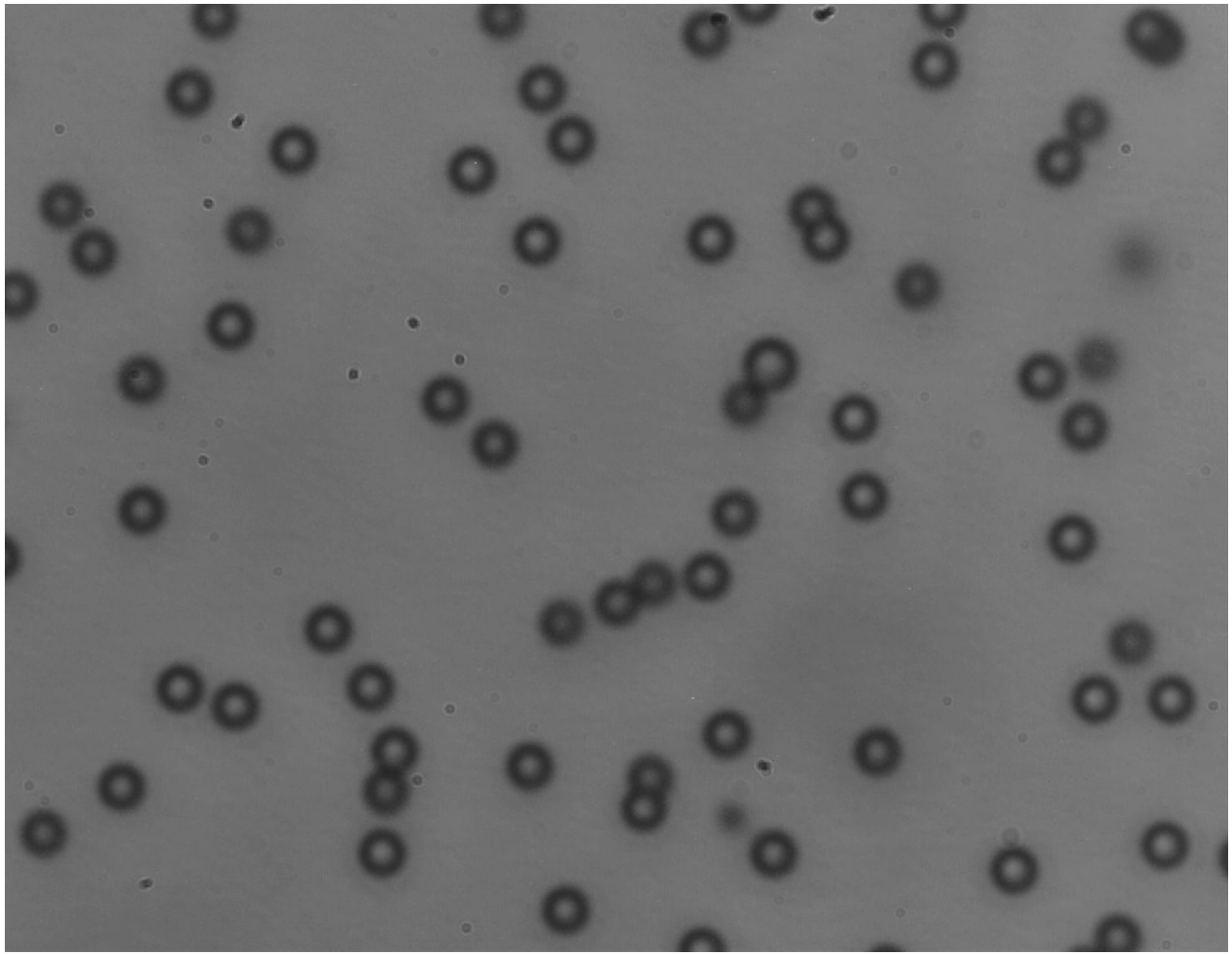




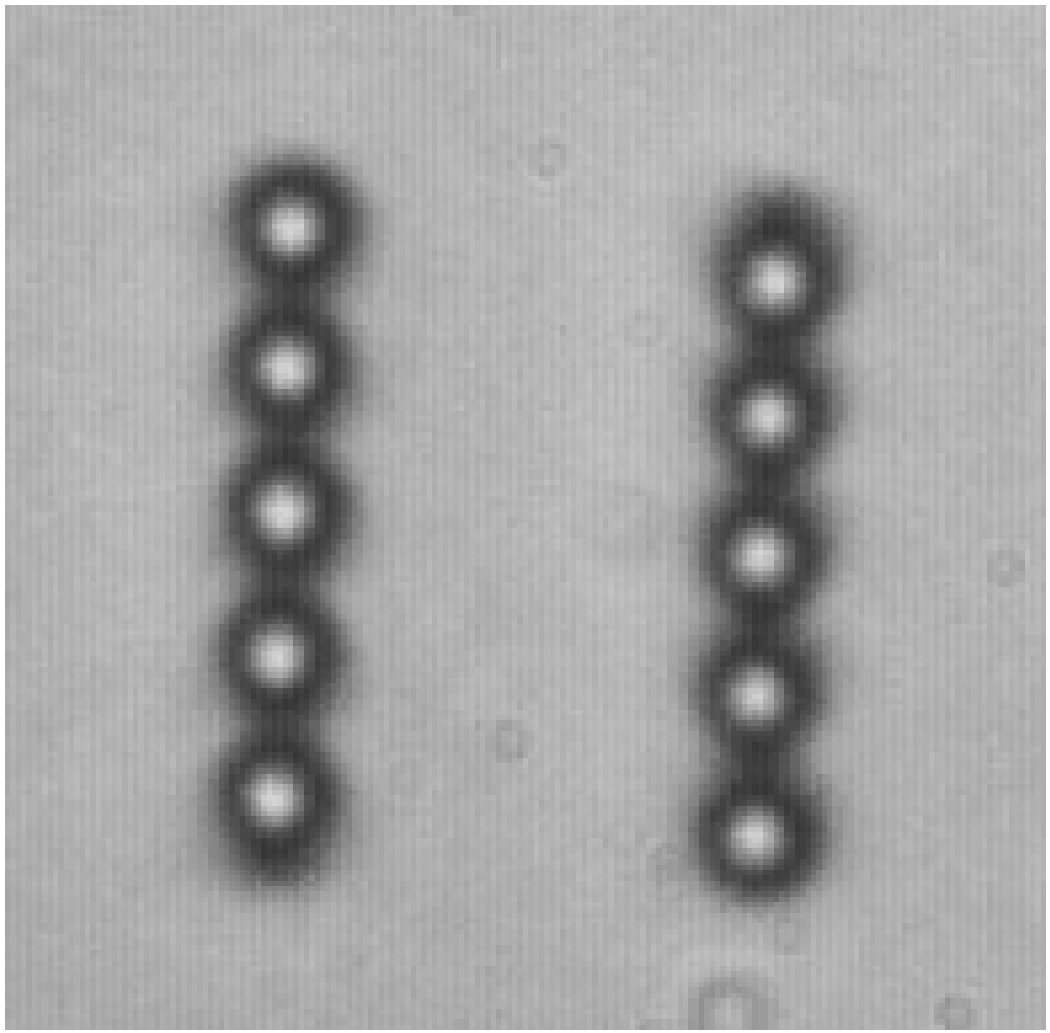
steklene mikro kroglice

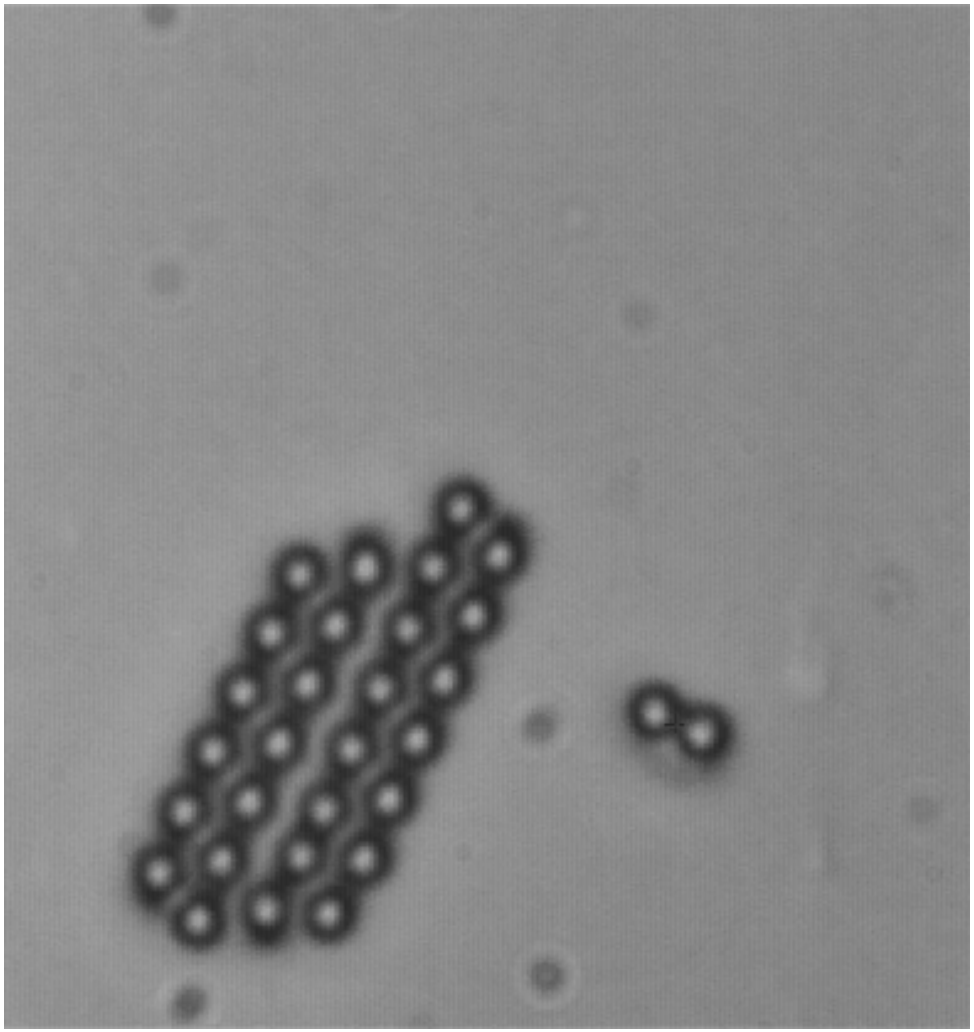
tekoči kristal

kroglice v običajni tekočini

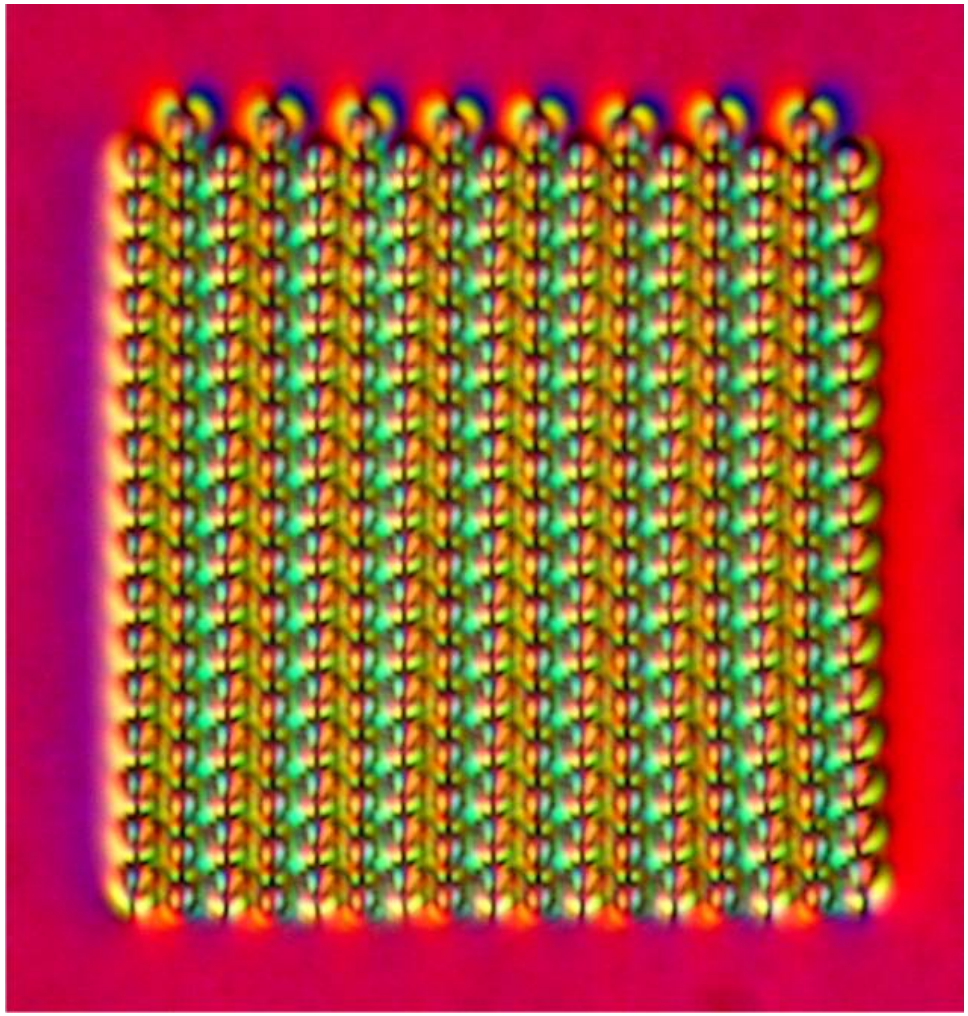


kroglice v tekočem kristalu

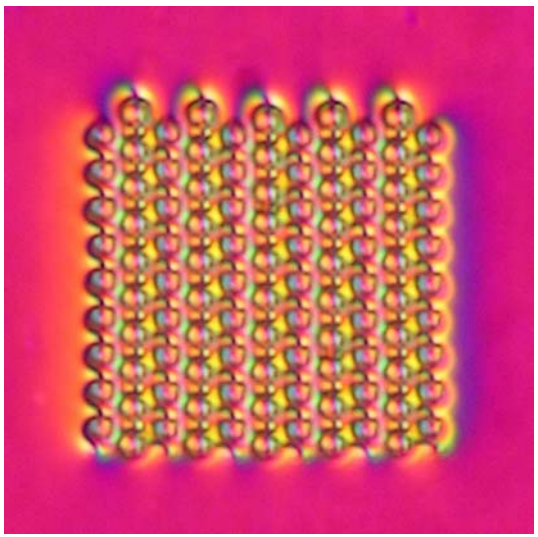




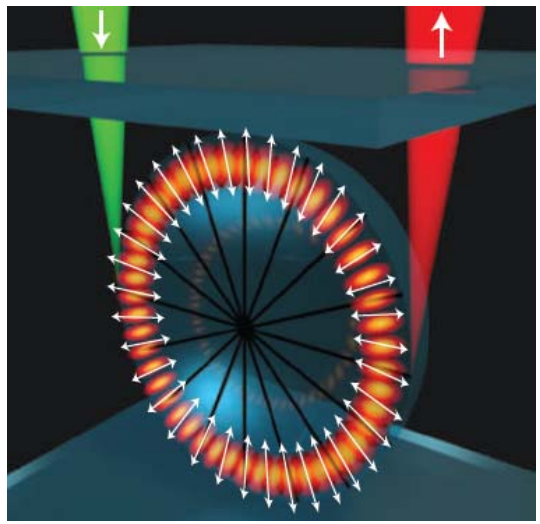
2D fotonski kristal



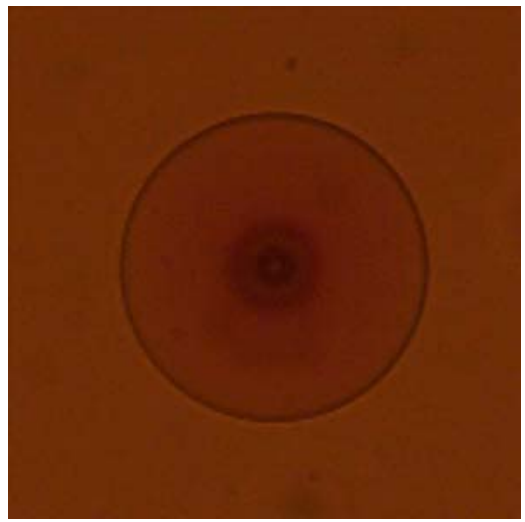
Muševič, Škarabot, Tkalec, Ravnik, Žumer, *Science* (2006)



2D fotonski kristal

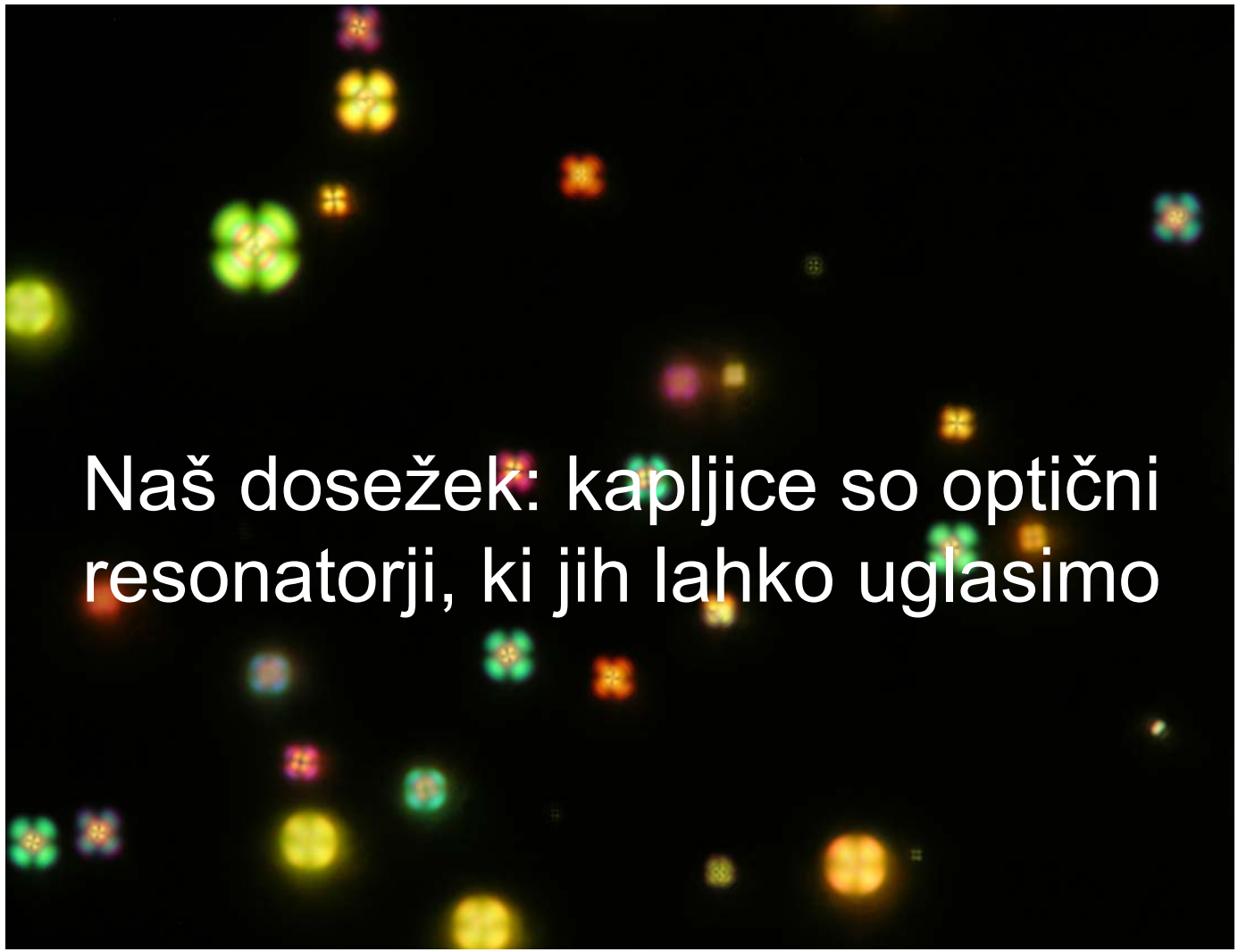


fotonski mikroresonator



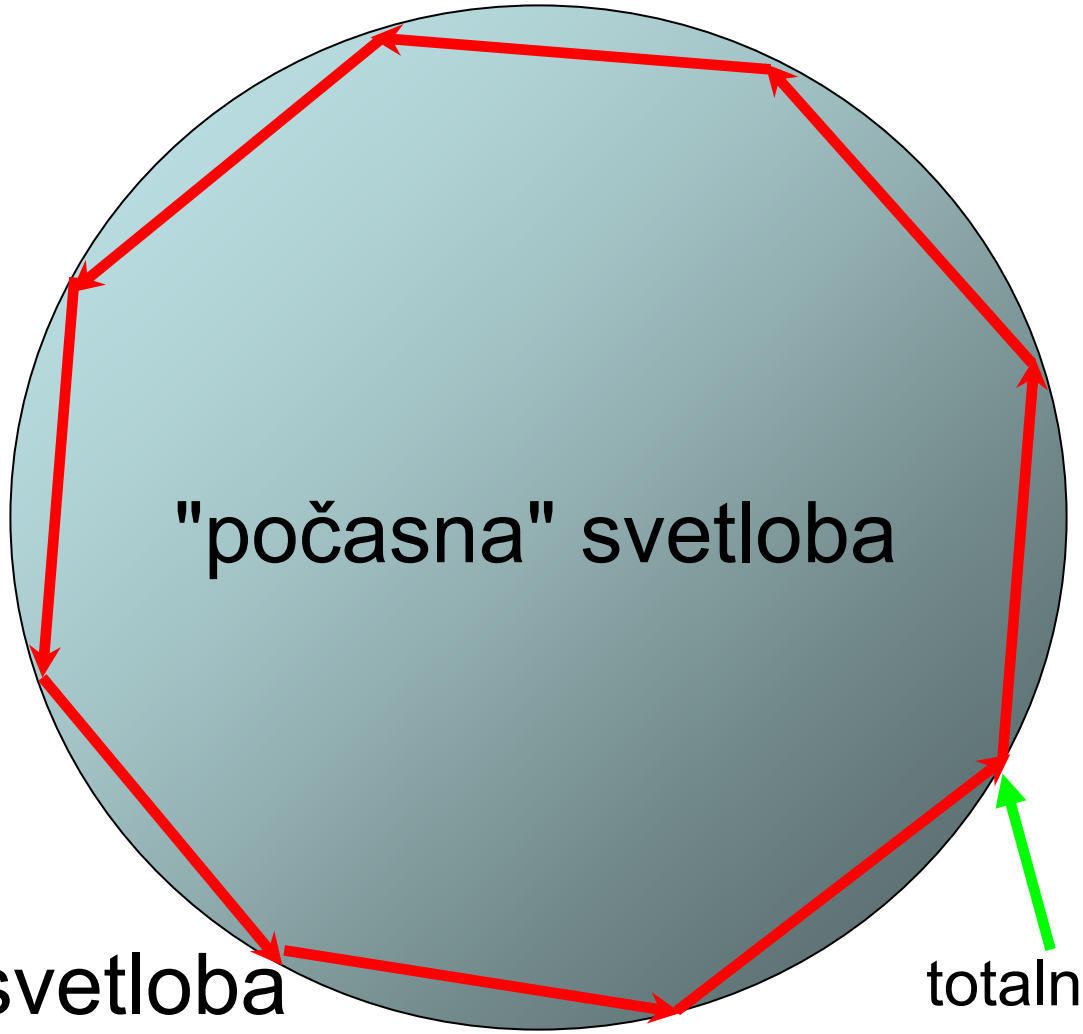
3D mikrolaser

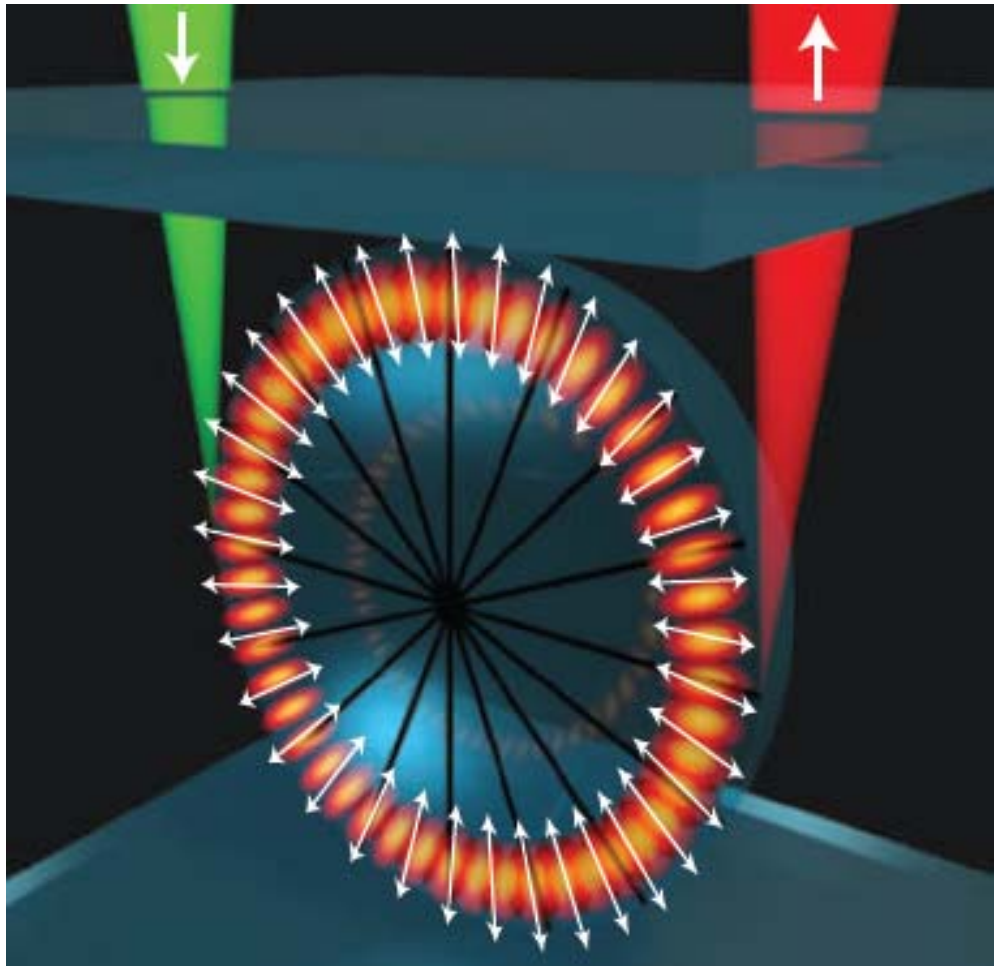
mikro-kapljice tekočega kristala v vodi ali polimeru



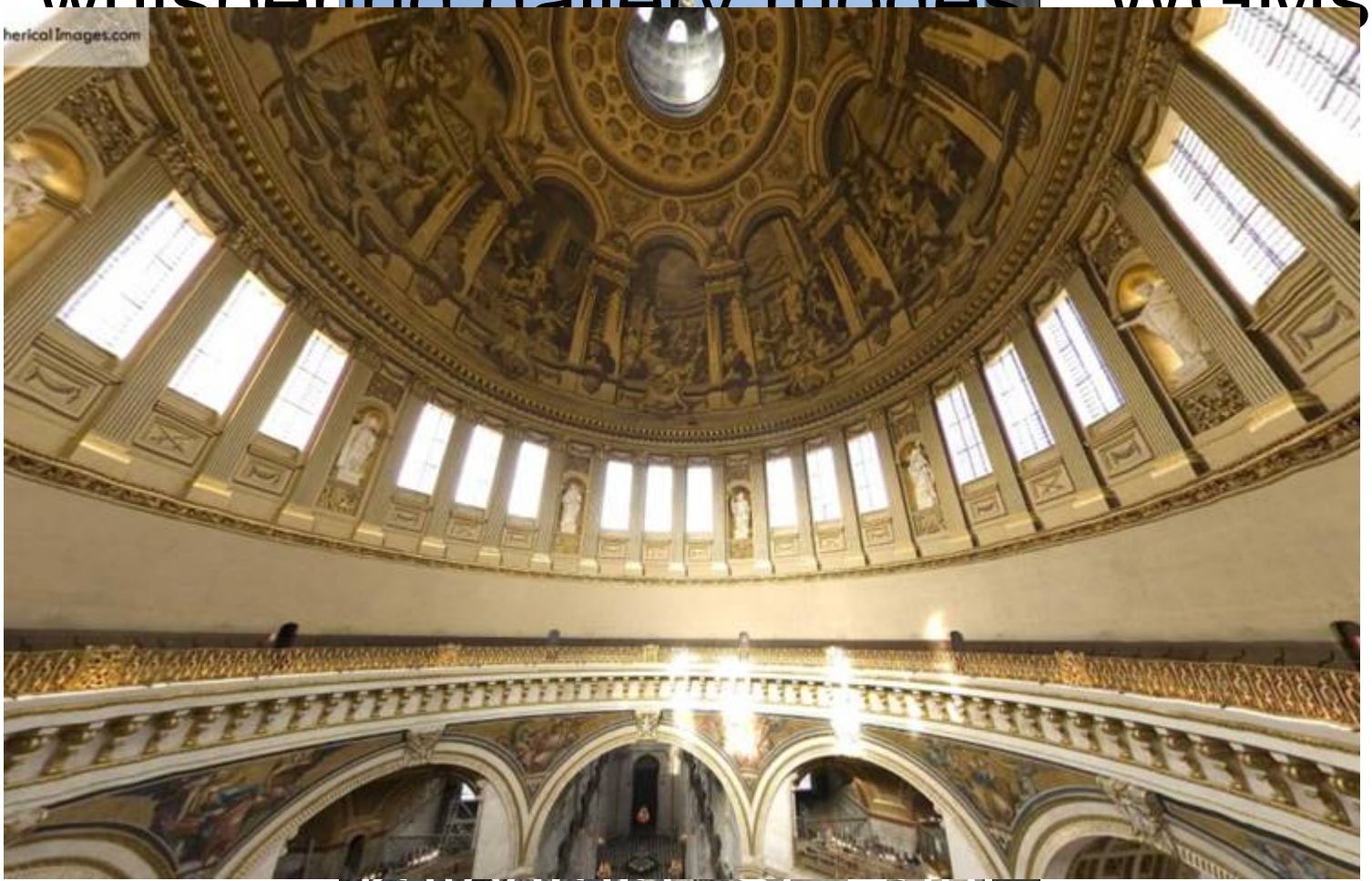
Opazujemo optične lastnosti
ene same mikro-kapljice
tekočega kristala v polimeru

kapljica z višjim lomnim količnikom od okolice je lahko optični resonator



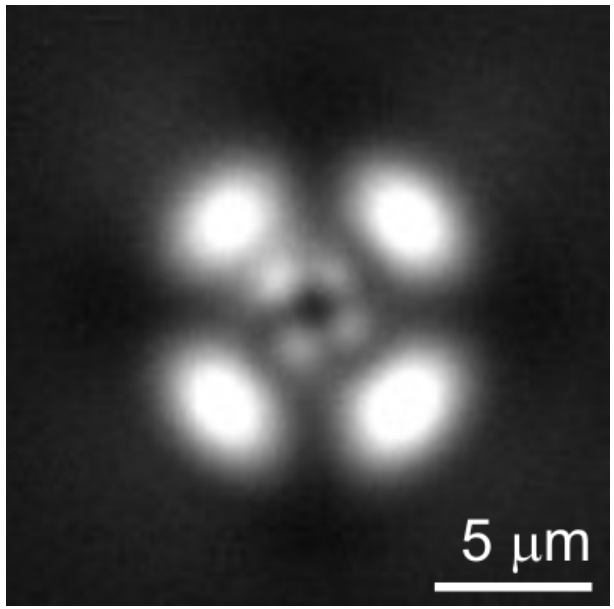


"whispering gallery modes" - WGMs

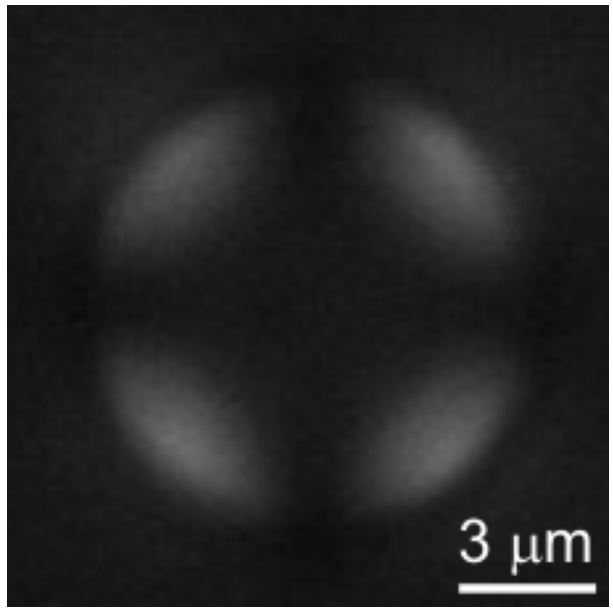


Katedra St. Paul

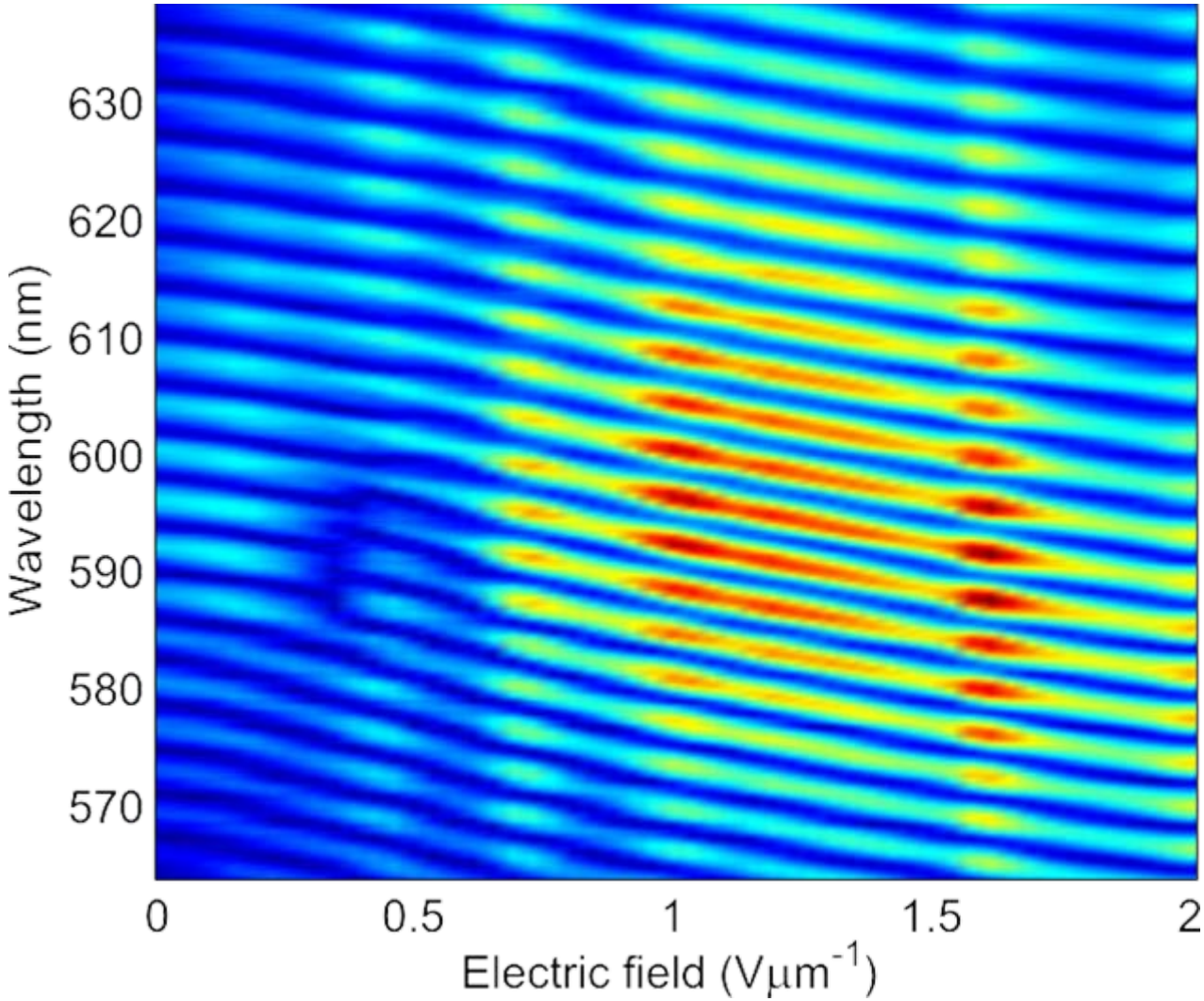
ali lahko resonančni spekter uglasimo z električnim poljem?



brez polja



s poljem



~100 krat večji obseg uglaševanja kot v trdni snovi!

Humar, Ravnik, Pajk, Muševič, *Nature Photonics* **3**, 595(2009)

Zaključek:

- napoved: **21. stoletje bo stoletje svetlobe**
- učinkovita fotovoltaika in nova svetila
- prenos informacij s svetlobo in integrirana fotonika
- združenje nanotehnologije in fotonike
- prikaz in hranjenje informacij
- svetlobni računalniki?

Zahvala

- Miha Škarabot, IJS, Ljubljana

- Uroš Tkalec, IJS, Ljubljana
- Matjaž Humar, IJS, Ljubljana
- Miha Ravnik, UNI LJ, Ljubljana
- Slobodan Žumer, UNI LJ, Ljubljana
- Igor Poberaj, UNI LJ, Ljubljana
- Natan Osterman, UNI LJ, Ljubljana
- Dušan Babič, UNI LJ, Ljubljana
- Ulyana Ognysta, IOP, Kiev
- Andriy Nych, IOP, Kiev
- Vassili Nazarenko, IOP, Kiev
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