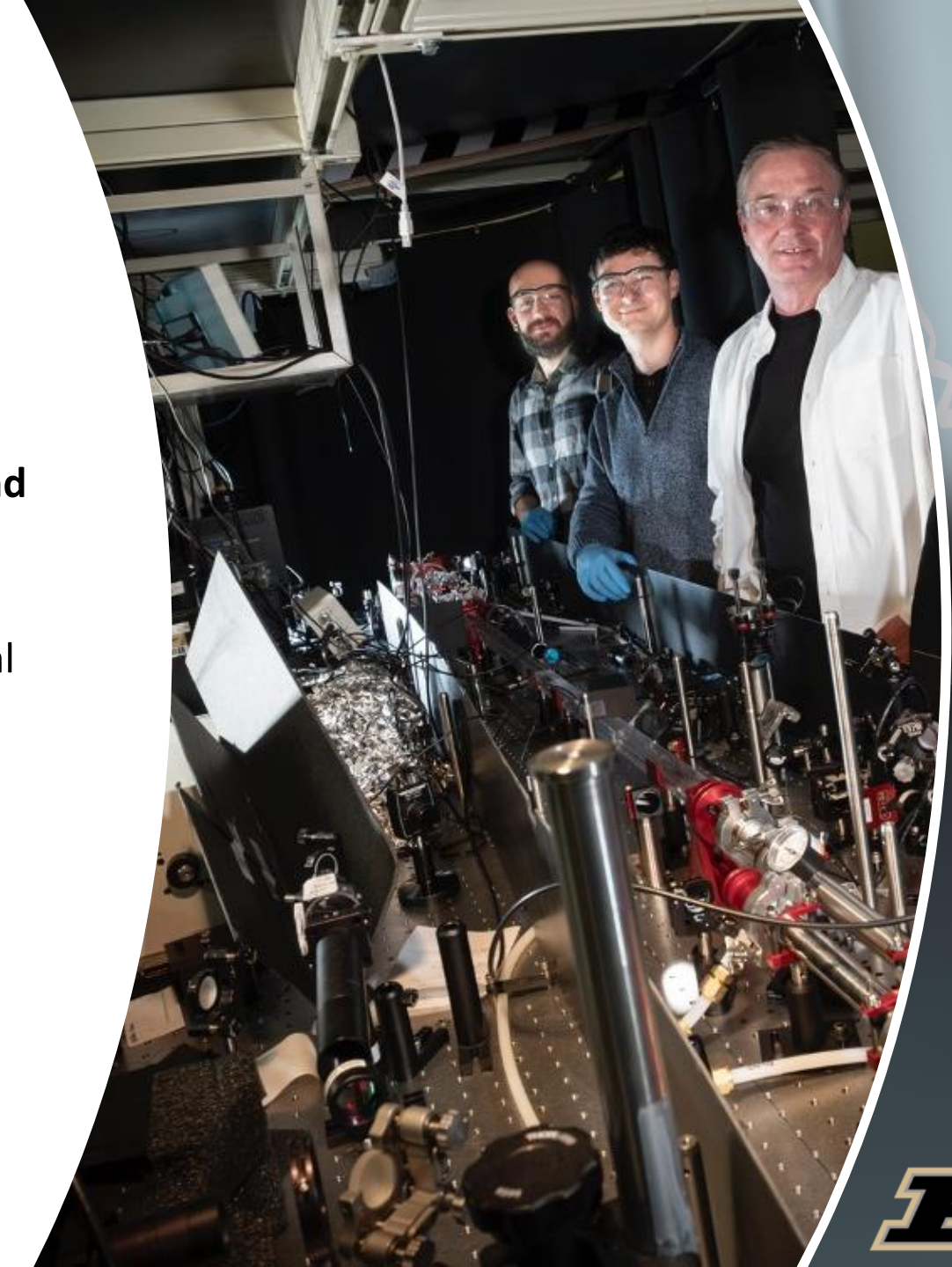
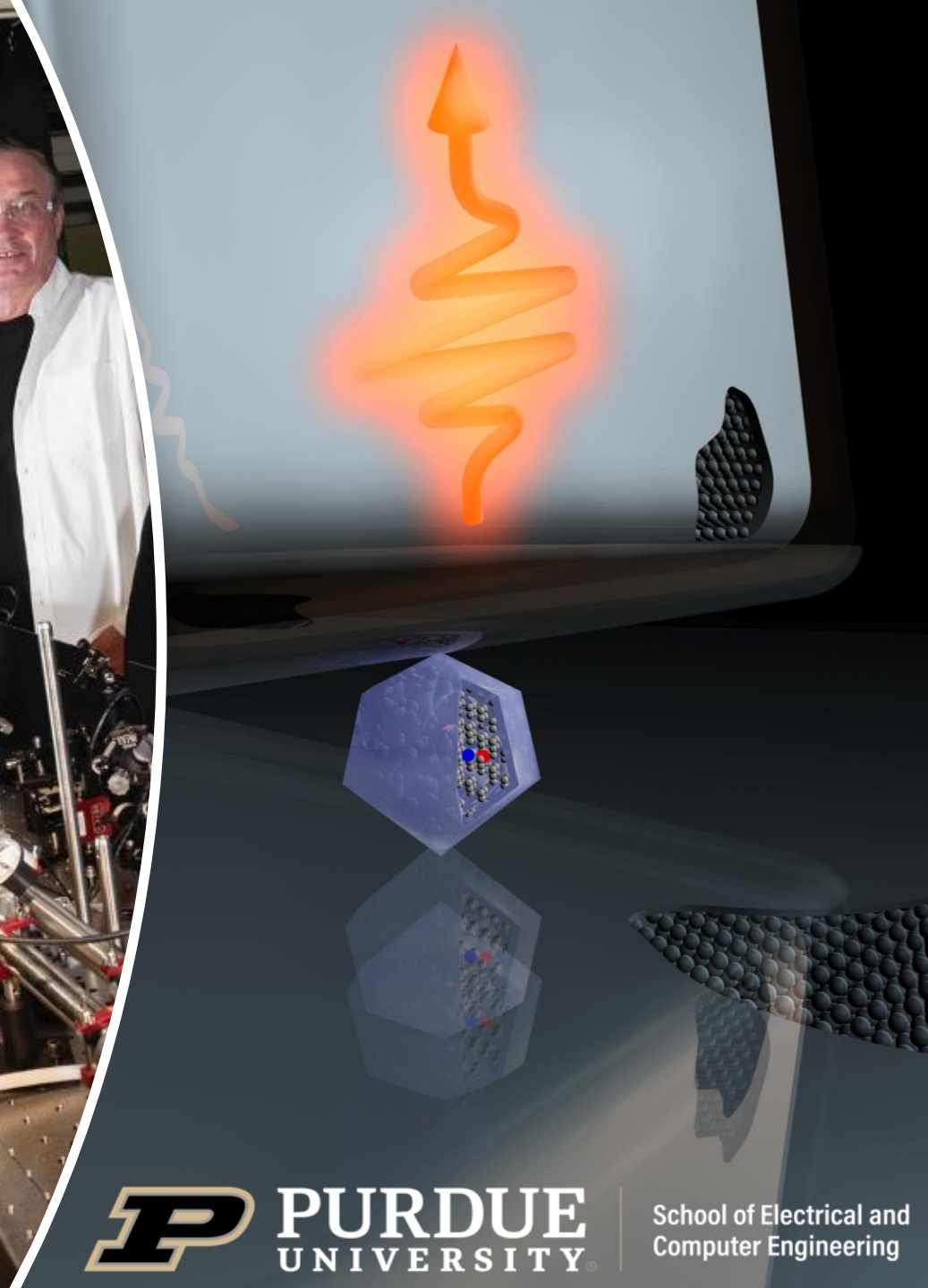
Vladimir M. Shalaev

- **The Robert and Anne Burnett Distinguished Professor of Electrical and Computer Engineering**
- Professor of Physics
- Professor of Biomedical Engineering
- Director for Nanophotonics

Birck Nanotechnology Center
Purdue Quantum Science and Engineering Institute

Purdue University





PURDUE UNIVERSITY | School of Electrical and Computer Engineering

OPTICAL TECHNOLOGIES

IT/Communication

https://www.mpoptical.com

Health

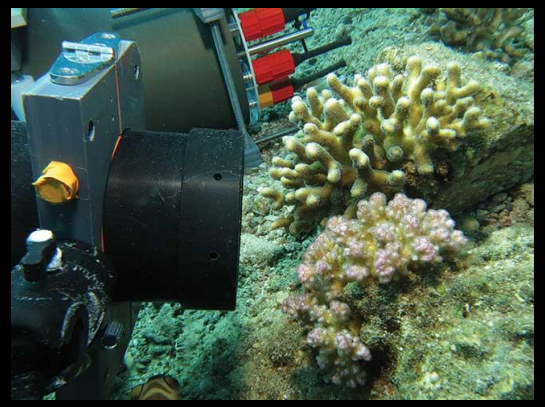
www.universalmedicalinc.com

Energy

https://www.bam.de

Economy

Environment



Scripps Inst. of Oceanography

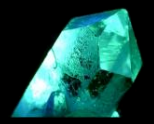
Agriculture

Consumer Physics

Social

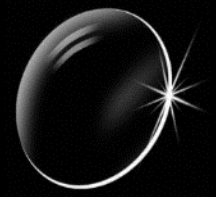
Yui Mok/Zuma Press

ALL ABOUT (META)MATERIALS



0 1 ∞

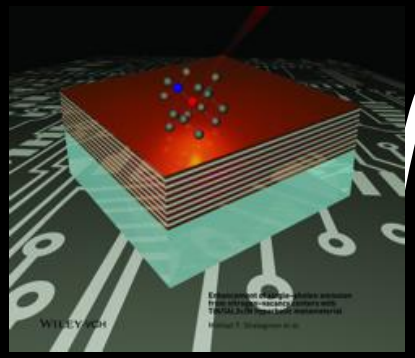
OBJECT SIZE/WAVELENGTH

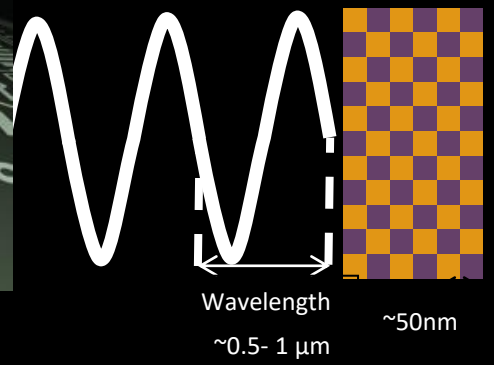


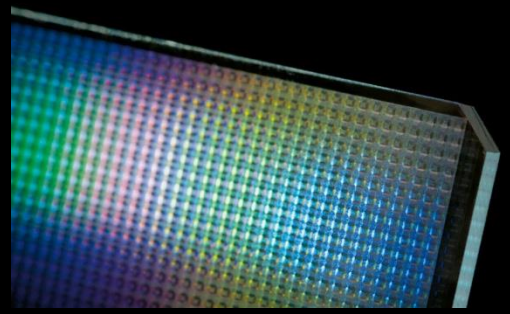
size << λ
METAMATERIALS
QUANTUM
NANOPHOTONICS

size ~ λ
Diffraction
Interference
Gratings

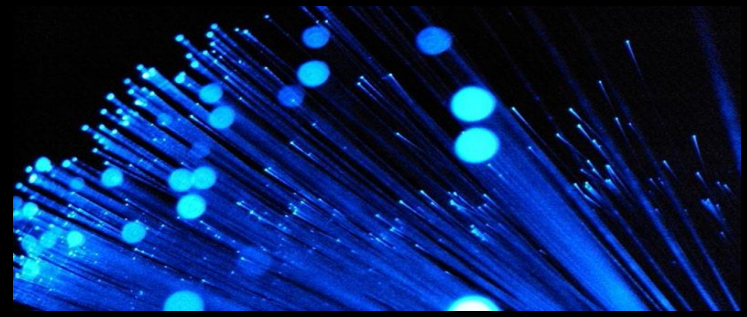
size >> λ
Geometrical Optics
Lenses, Mirrors
Fibers







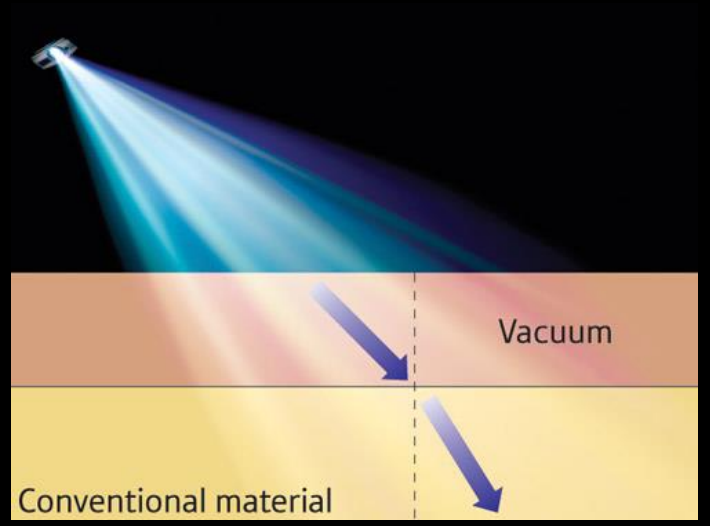
Jenoptik

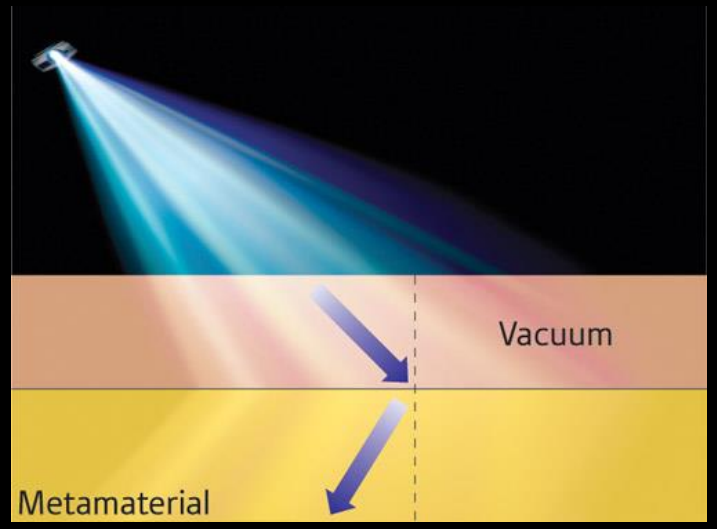


Wikipedia

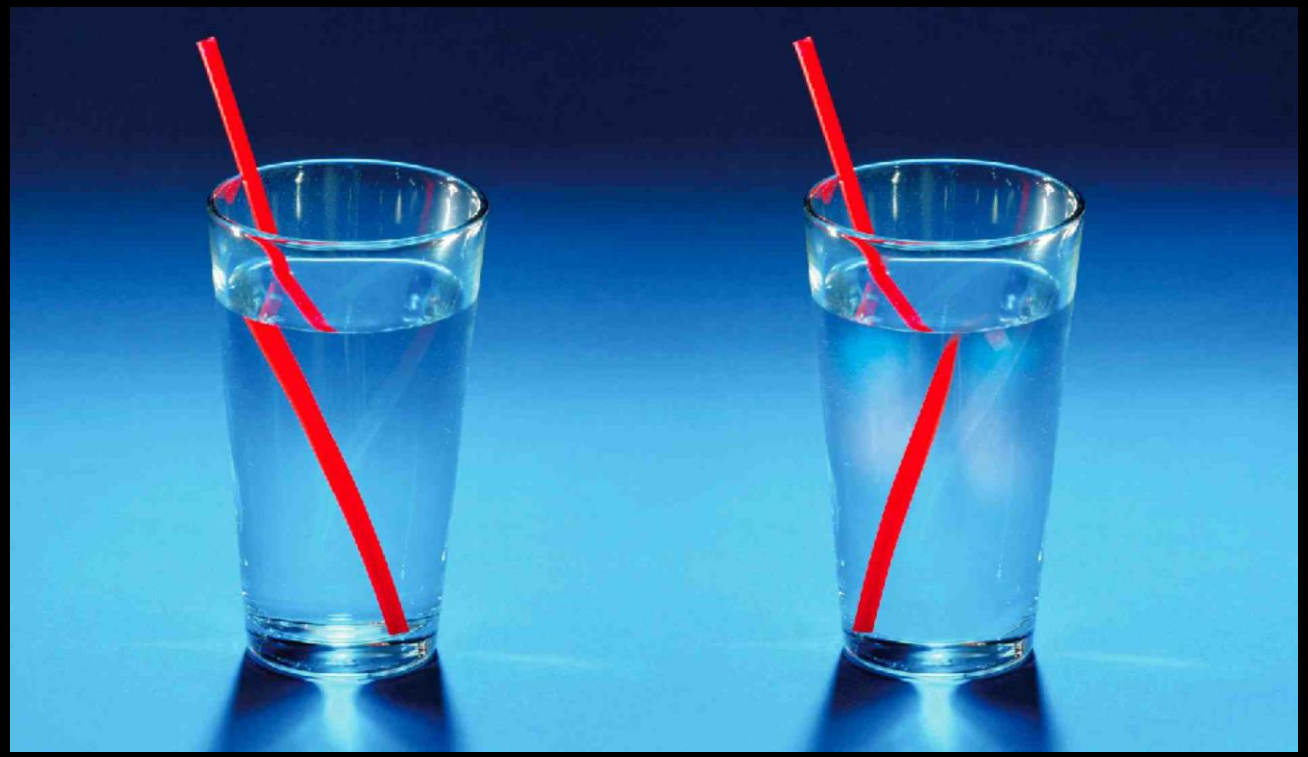
Scientists have gone from BIG LENSES and OPTICAL FIBERS (size >> λ), to diffraction gratings and photonic crystals (size ~ λ), and to
ULTRA-SMALL/THIN DEVICES with unique functionalities using METAMATERIALS (size << λ),

EXAMPLE: NEGATIVE REFRACTION





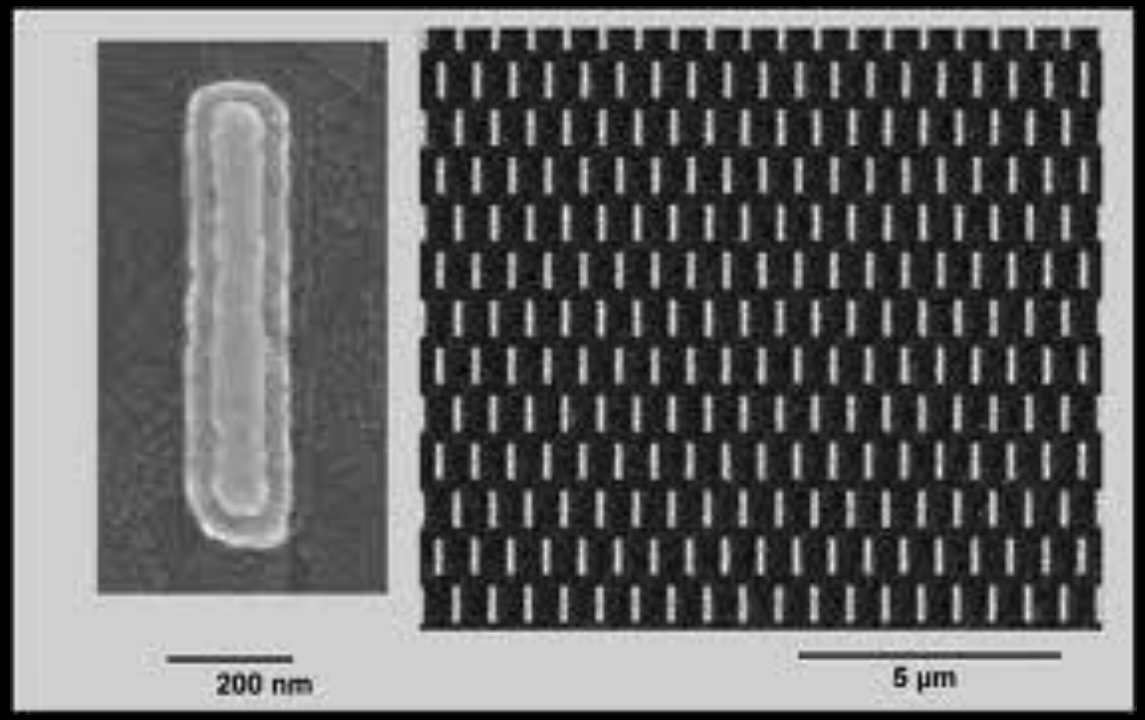
In normal materials, light cannot bend beyond the perpendicular to the interface but in MM it can!



Negatively refracting “NIM-Water”

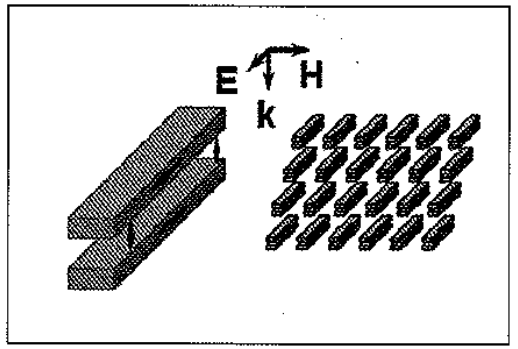
Groups of D. Smith, H. Giessen, X. Zhang, V. Shalaev

EXAMPLE: NEGATIVE REFRACTION



Engineers at Purdue University have created a material that has "negative index of refraction" in the wavelength of light used for telecommunications, a step that could lead to better communications and imaging technologies. The material consists of tiny parallel "nanorods" of gold that conduct clouds of electrons called "plasmons," with a frequency of light referred to as the near infrared.

The nanorods are an example of



A schematic for the array of parallel nanorods; the H-field-induced current in the rods (black arrows) is closed by displacement current (blue arrows).

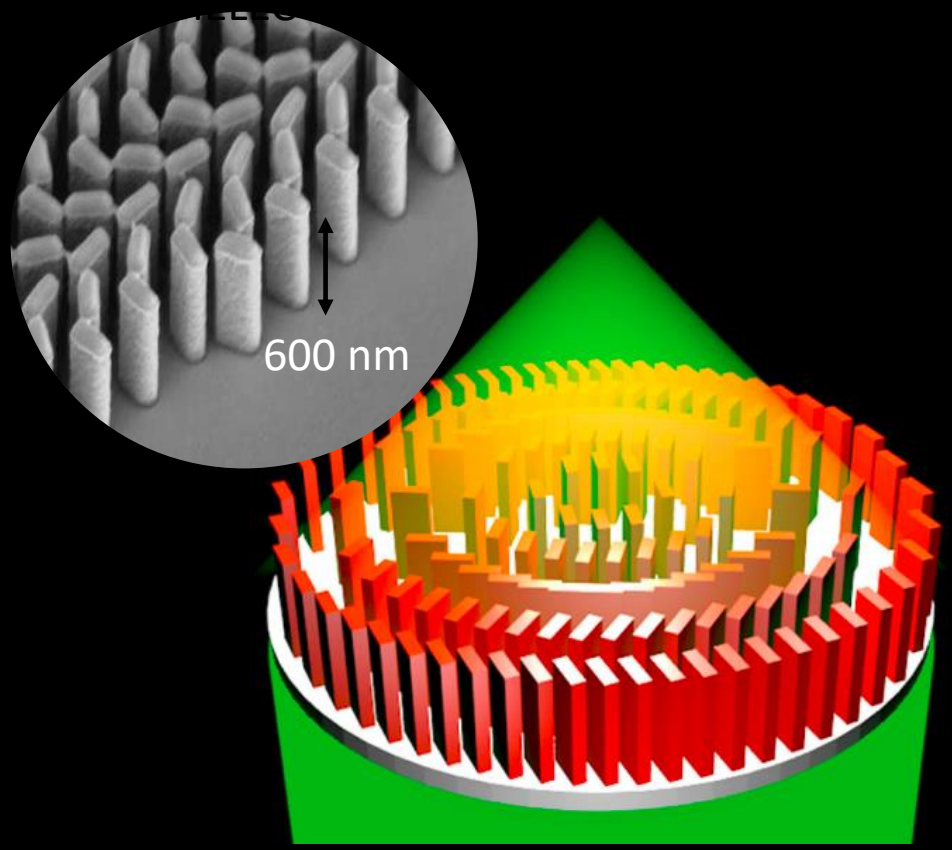
OPTICS/PHOTONICS

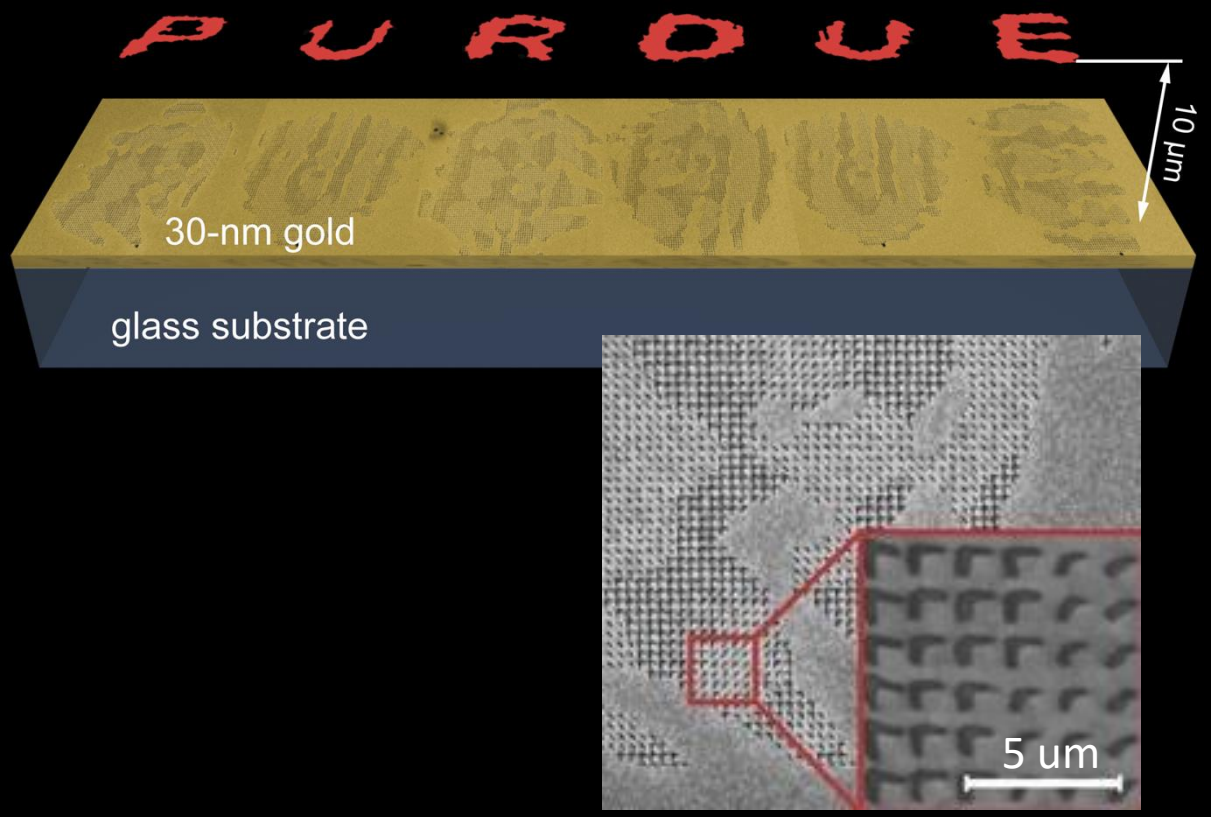
TECHNOLOGY AWARD

Purdue University
West Lafayette, IN
Nanorod Material

"Nanorods that reverse refraction": Won the 2006 Nano 50 Award

METASURFACE: Monolayer METAMATERIAL!



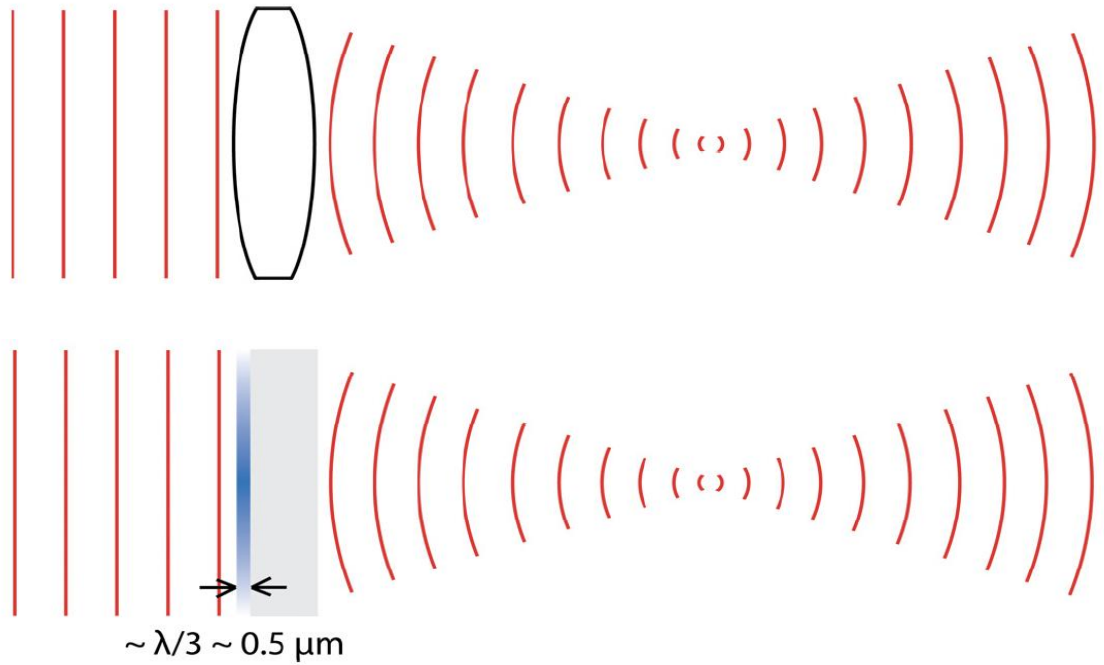


V. Shalaev, Purdue

M. Khorasaninejad, et al., Jour. Quantum. Electron., 23, 4700216 (2016)
X. Ni, et al., Nat. Comm., 4, 2807 (2013)

Seminal works on metasurfaces: Capasso, Hasman, Lalanne, Shalaev, Zheludev, Bozhevolnyi, Levy, Tsai, Zhang, Smith, Kivshar, Atwater, Brongersma, Luk'yanchuk, Kuznestov, Faraon, Neshev…

Ultra Thin Planar METALENS



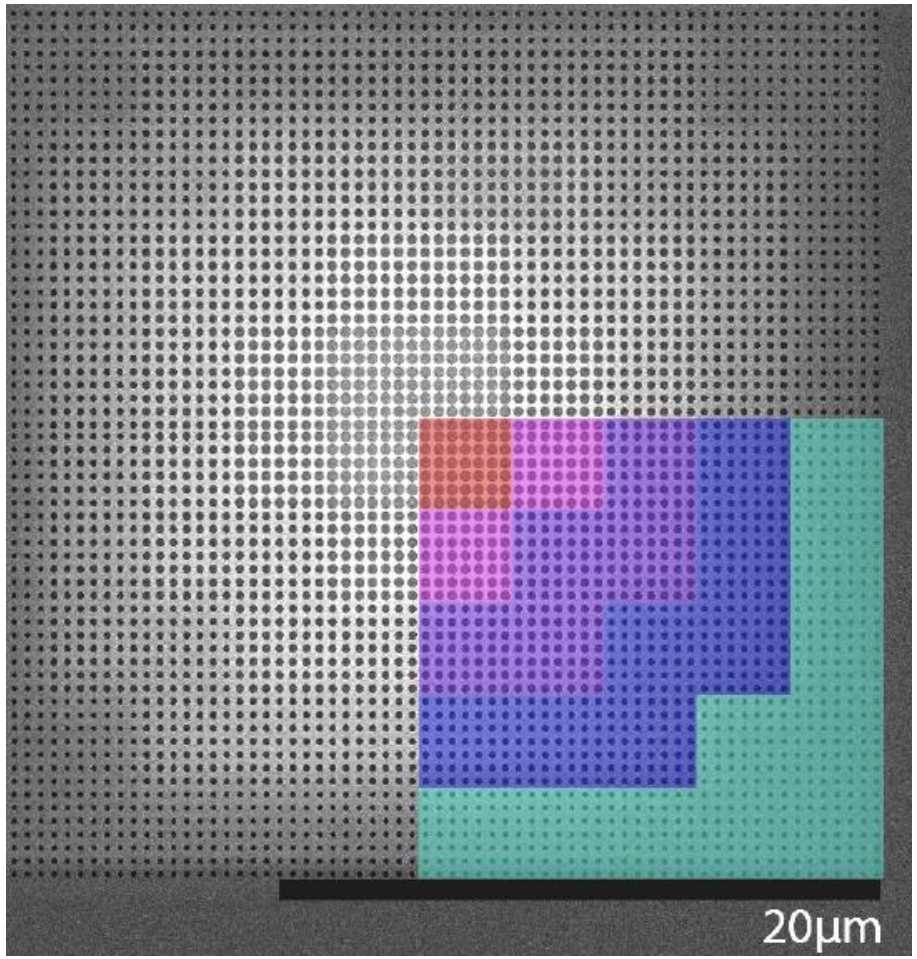
All-dielectric subwavelength metasurface focusing lens

Paul R. West,[1] James L. Stewart,[1] Alexander V. Kildishev,[1,*] Vladimir M. Shalaev,[1] Vladimir V. Shkunov,[2] Friedrich Strohkendl,[2] Yuri A. Zakharenkov,[2] Robert K. Dodds,[2] and Robert Byren[2]

[1]School of Electrical and Computer Engineering and Birck Nanotechnology Center, Purdue University, West Lafayette, IN 47907, USA

[2]Raytheon Space and Airborne Systems, 2000 East El Segundo Blvd, PO Box 902, El Segundo, CA 90245, USA

[*]kildishev@purdue.edu



Raytheon

Real-life Application for National Security

Raytheon

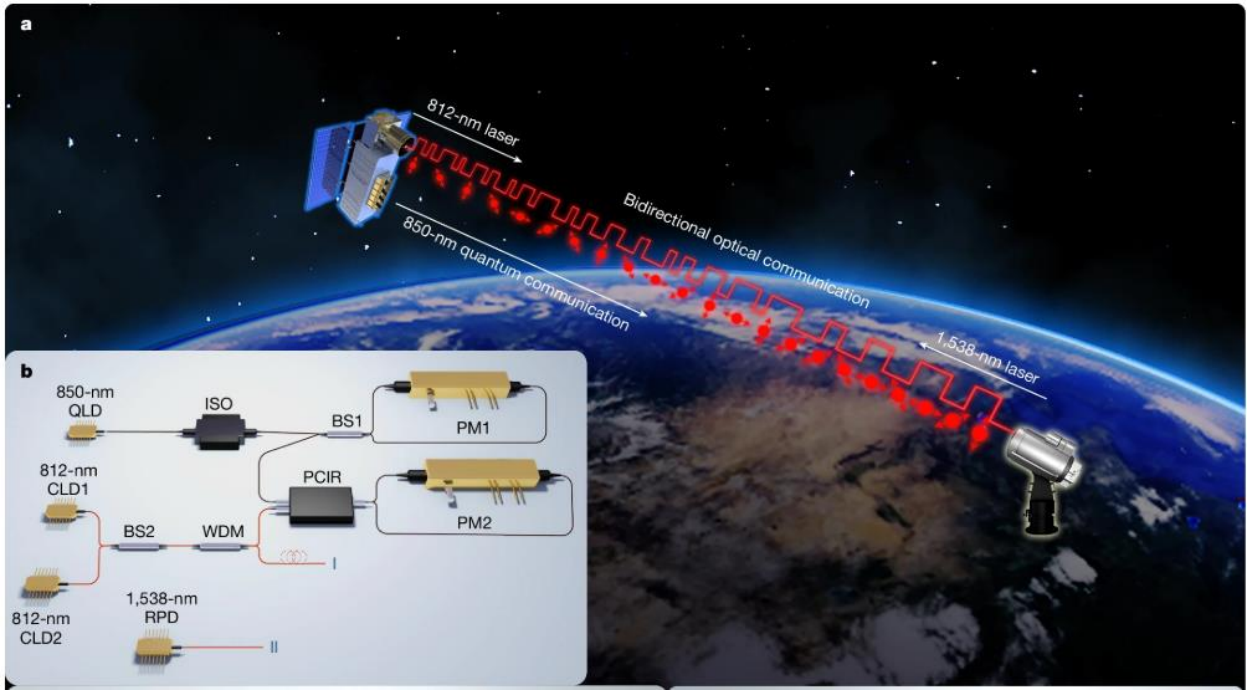
Raytheon gets order for 180 AIM-9X infrared-guided air-to-air missiles for U.S. and allied air forces

PATUXENT RIVER NAS, Md. – U.S. Navy aerial warfare experts are asking the Raytheon Co. to build 180 AIM-9X precision short-range infrared-guided air-to-air missiles for jet fighters and other combat aircraft under terms of a $82.8 million order announced last week.

Promise of Quantum Photonic Technologies

Photons are unparalleled units of information: SPEED + NO DECOHERENCE
Light wavelength vs qubit size mismatch -> Weak light-matter coupling -> FAST YET SLOW!
NEED: METAMATERIALS for strong light-matter coupling on demand

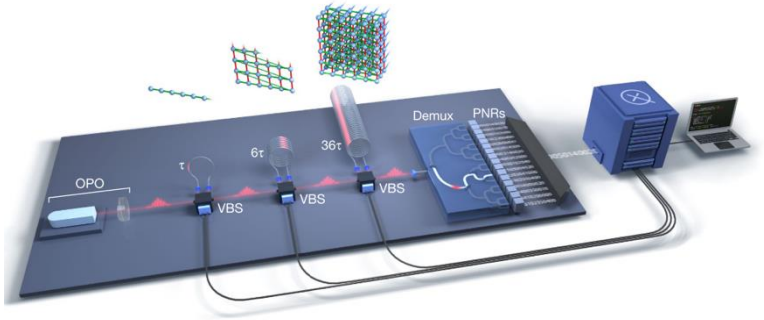
Quantum Communication



Li, Y., Cai, WQ., Ren, JG. et al. **Microsatellite-based real-time quantum key distribution**. Nature 640, 47–54 (2025)

Quantum simulation and computation

Zhong, Han-Sen, *Science* 370.6523 (2020): 1460-1463 (Pan group)

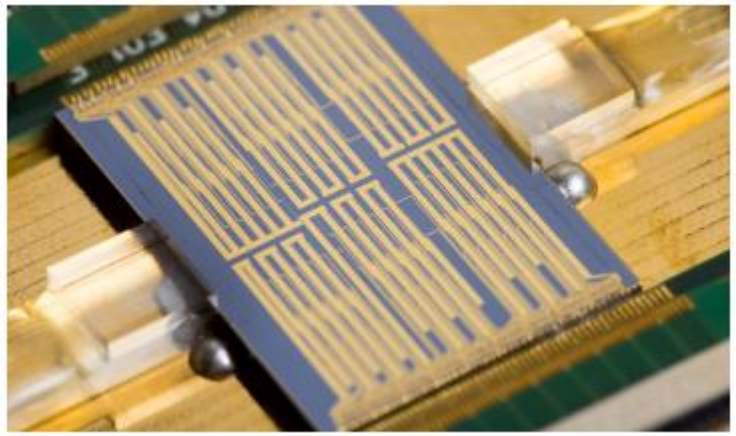


Bosonic sampling

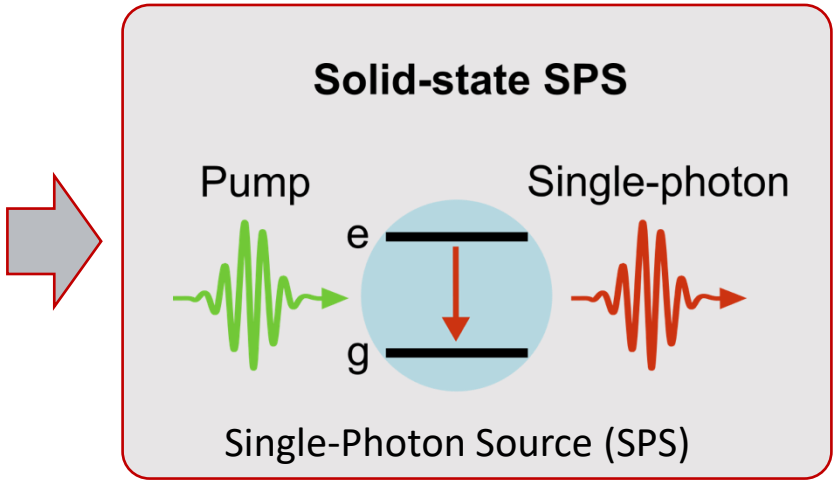
Madsen, L.S., Laudenbach, F., Askarani, M.F. *et al. Nature* 606, 75–81 (2022)

Promise of SiN for Quantum Photonic Integrated Circuits

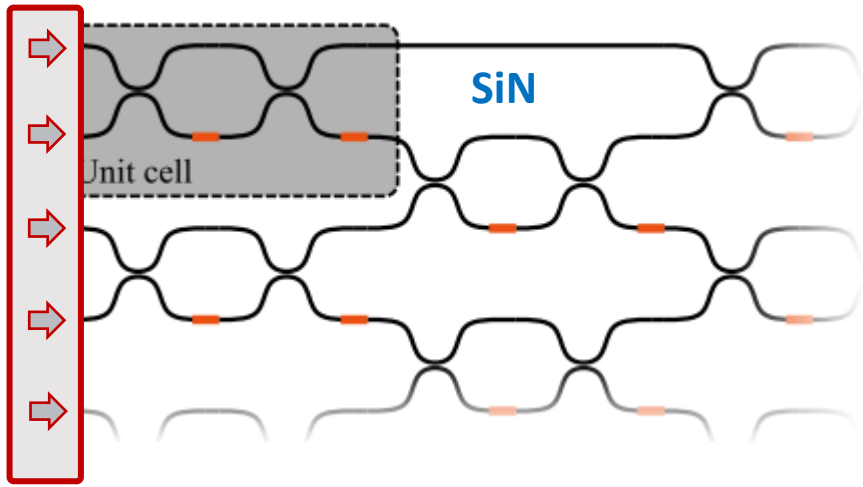
Integrated **Silicon Nitride** photonic chip



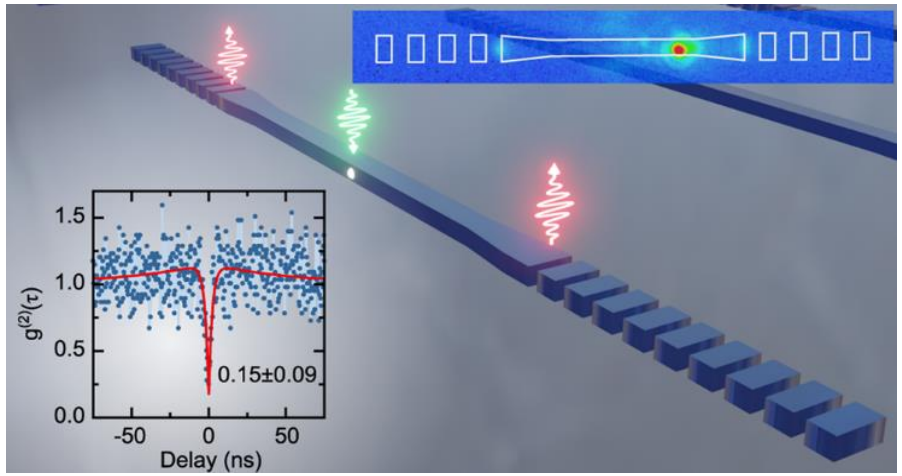
C. Taballione et al., ArXiv Prepr. 1 (2022) [**QuiX Quantum**]
see also J. M. Arrazola et al., Nature **591**, 54 (2021) [**Xanadu**]



Waveguides and thermo-optic phase actuators



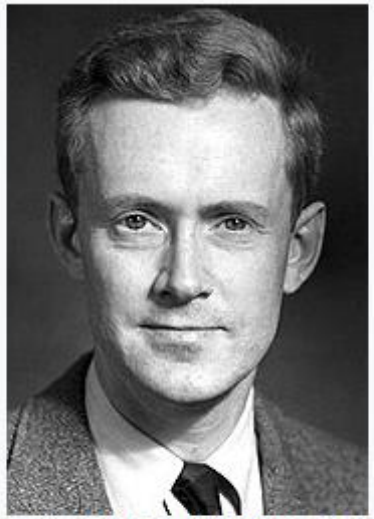
Purdue-discovered single-photon sources in SiN



A. Senichev et al., Sci. Adv. 7, 50 (2021)
A. Senichev et al., ACS Photonics **9**, 3357 (2022)

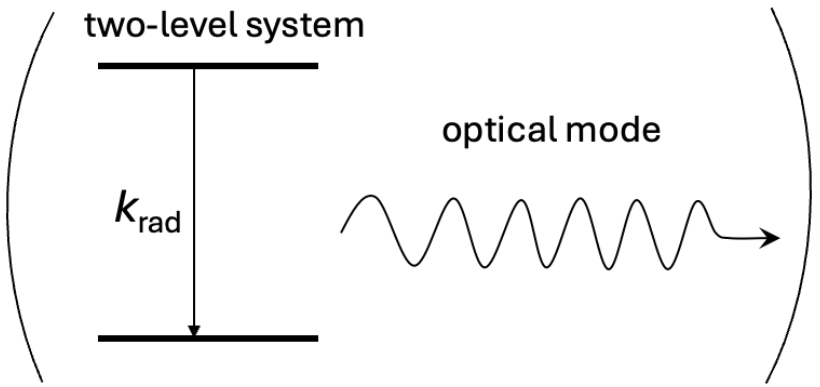
Light-Matter Coupling in Photonics & Plasmonics

Edward Mills Purcell



Edward Mills Purcell (1912–1997)

Born	August 30, 1912 Taylorville, Illinois, United States
Died	March 7, 1997 (aged 84) Cambridge, Massachusetts, United States
Nationality	United States
Alma mater	Purdue University (BSEE) Harvard University (M.A.) Harvard University (Ph.D)
Known for	Nuclear magnetic resonance (NMR) Smith-Purcell effect 21 cm line Scallop theorem
Awards	Nobel Prize for Physics (1952)



$$\text{Purcell Factor} \propto \left(\frac{\lambda_0}{n}\right)^3 \frac{Q}{V}$$

λ_0 = wavelength in vacuum

n = refractive index

Q = optical mode quality factor

V = optical mode volume

$$k_{rad} = k_{rad}^{vac} \times \text{Purcell Factor}$$

B10. **Spontaneous Emission Probabilities at Radio Frequencies.** E. M. PURCELL, *Harvard University*.—For nuclear magnetic moment transitions at radio frequencies the probability of spontaneous emission, computed from

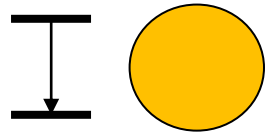
$$A_\nu = (8\pi\nu^2/c^3)h\nu(8\pi^3\mu^2/3h^2) \text{ sec.}^{-1},$$

if small metallic particles of diameter 10^{-3} cm are mixed with a nuclear-magnetic medium at room temperature, spontaneous emission should establish thermal equilibrium in a time of the order of minutes, for $\nu = 10^7$ sec.$^{-1}$.

Plasmonic resonator

Low Q (FAST!)

small, nm-scale V



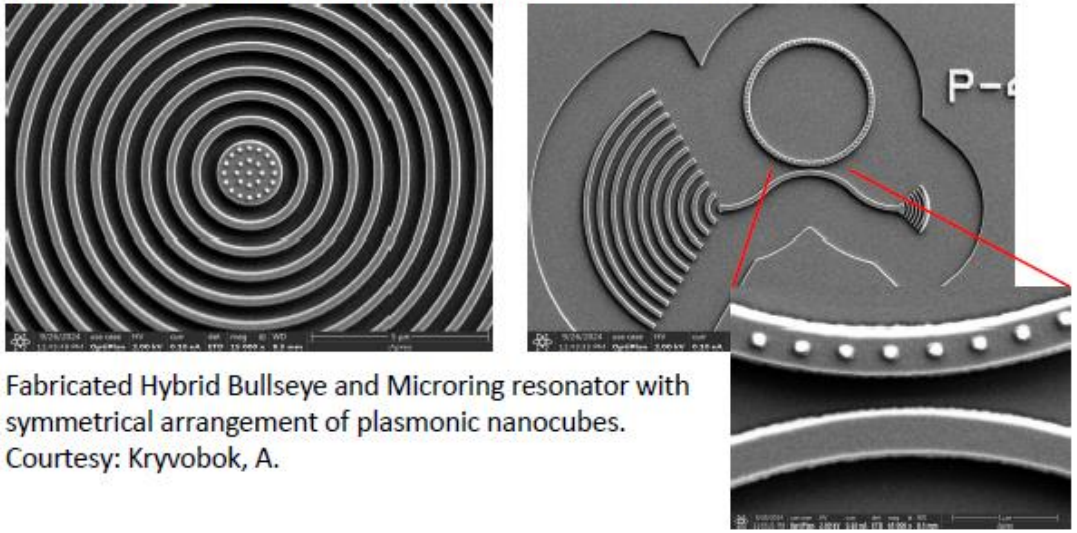
metal nanoparticle

Bogdanov, et al Optica 7, 463 (2020)

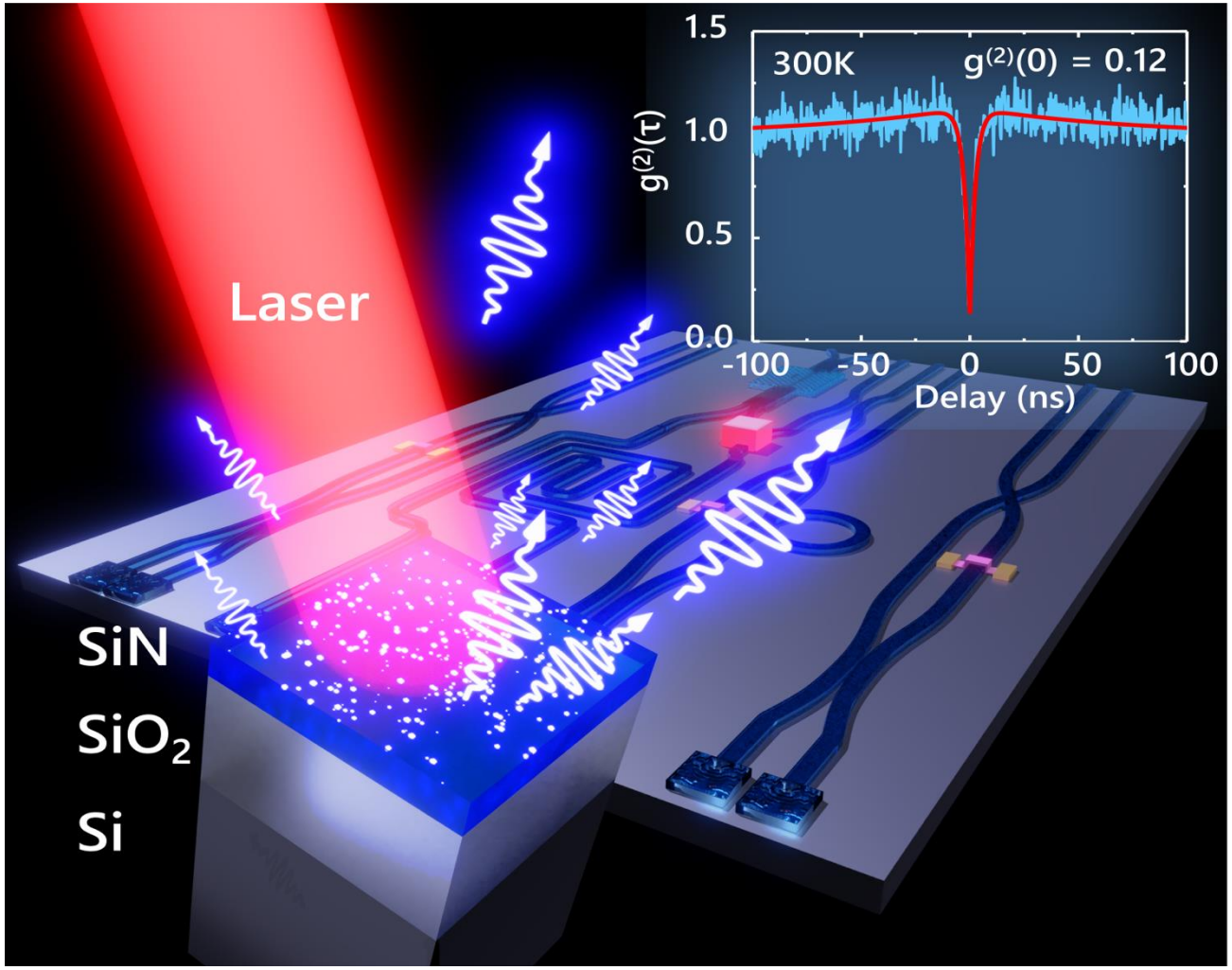
Quantum Meta-Photonics High-Speed Platform: SiN + Plasmonics

By combining photonic and plasmonic components, hybrid cavities can maintain the benefits of high-Q modes from the photonic side while utilizing the extreme field enhancement offered by plasmonic modes. The expected result is a system that can achieve Purcell enhancement, increasing the emission rate of quantum emitters, such as single-photon emitters (SPEs), through improved spontaneous emission coupling.

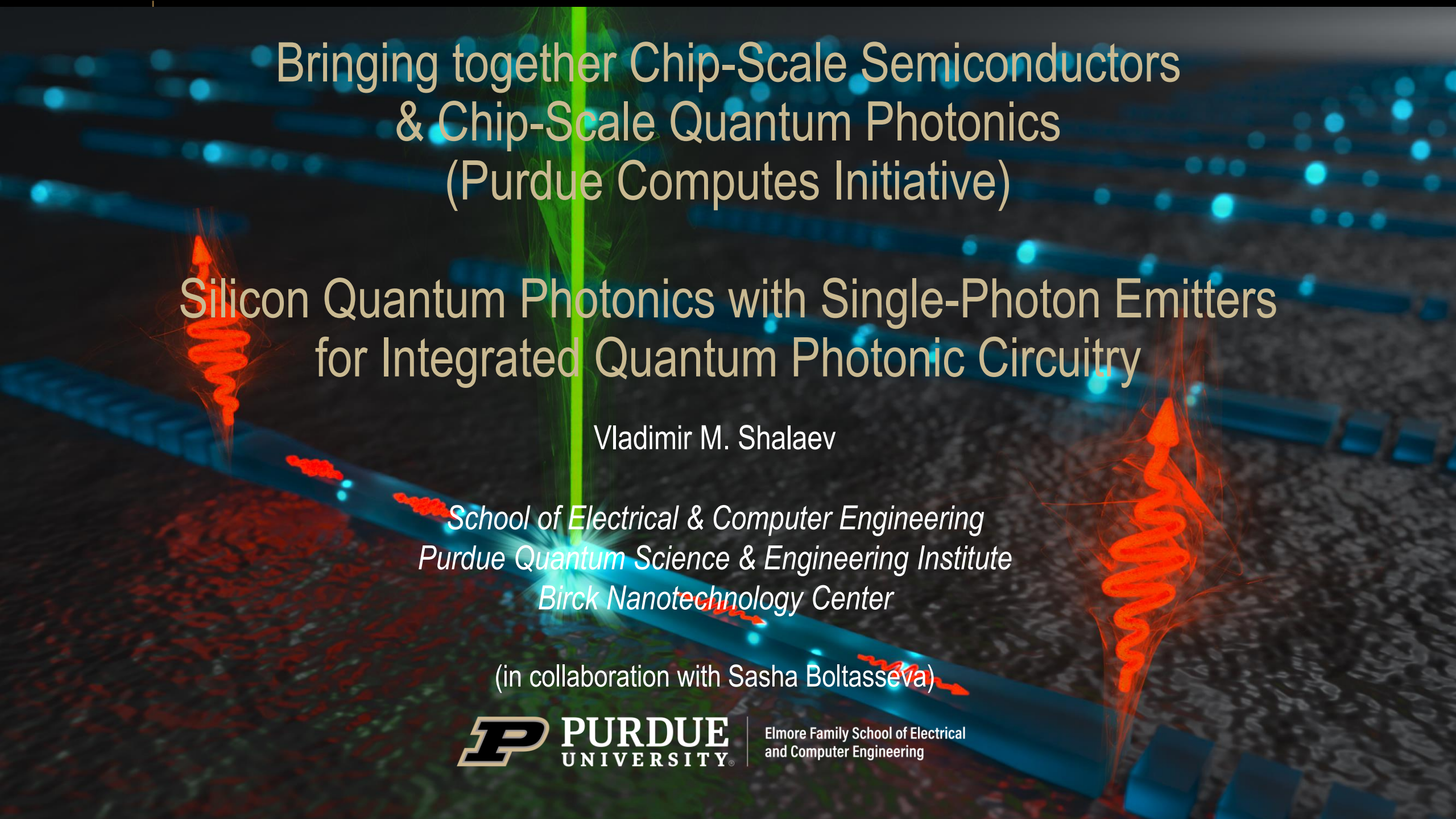
Concept of CBG and Microring resonator with distributed plasmonic nanocubes matching phase of propagating mode. Courtesy: Kryvobok, A.



Fabricated Hybrid Bullseye and Microring resonator with symmetrical arrangement of plasmonic nanocubes. Courtesy: Kryvobok, A.



Interaction between qubits strongly enhanced by plasmonics: high speed devices immune to loss and decoherence at RT



Bringing together Chip-Scale Semiconductors & Chip-Scale Quantum Photonics (Purdue Computes Initiative)

Silicon Quantum Photonics with Single-Photon Emitters for Integrated Quantum Photonic Circuitry

Vladimir M. Shalaev

School of Electrical & Computer Engineering
Purdue Quantum Science & Engineering Institute
Birck Nanotechnology Center

(in collaboration with Sasha Boltasseva)

PURDUE UNIVERSITY | Elmore Family School of Electrical and Computer Engineering