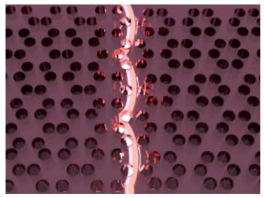


Topological Photonic Structures

SAND2020-1863C

Ganapathi (Ganesh) Subramania

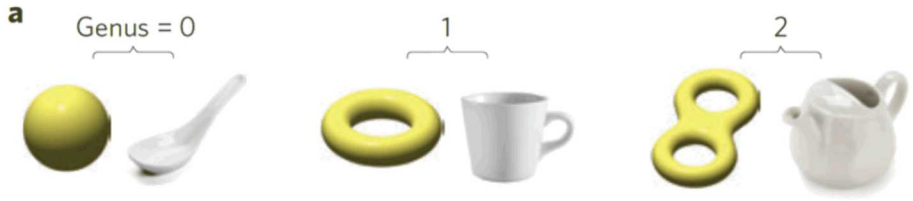
Sandia National Laboratories, Albuquerque, NM

Collaborators: P. Duke Anderson(Leonardo DRS), Jason Dominguez (SNL), and Anthony James (SNL), and Stavroula Foteinopoulou (Univ. of NM)

February 16 -19, 2020, The Workshop on Compound Semiconductor Materials and Devices
Saguaro Palm Springs, Palm Springs CA,USA

Supported by the Laboratory Directed Research and Development program at Sandia National Laboratories, a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525..

Background



Topological invariant : Genus

$$\frac{1}{2\pi}\int_{\text{surface}} \mathcal{K} dA = 2(1-g)$$

Total Gaussian curvature

Topological Protection: Approaches that exploit topological properties of the phase space of a system can offer stability and robustness to the system of interest from external disturbances. Enables scatter-free, loss-less unidirectional transport.

- Known in electronic systems (QHE)
- Predicted for photonic systems

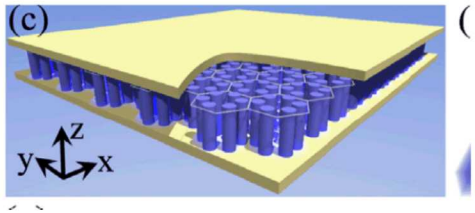
PHYSICAL REVIEW A **78,** 033834 (2008)

Analogs of quantum-Hall-effect edge states in photonic crystals

S. Raghu*
Department of Physics, Stanford University, Stanford, California 94305-4045, USA

F. D. M. Haldane
Department of Physics, Princeton University, Princeton, New Jersey 08544-0708, USA

A potential approach …

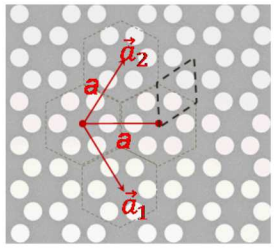


PRL **114,** 223901 (2015) PHYSICAL REVIEW LETTERS week ending 5 JUNE 2015

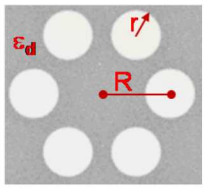
Scheme for Achieving a Topological Photonic Crystal by Using Dielectric Material

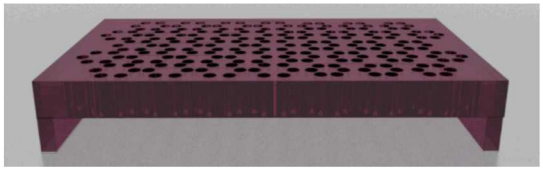
Long-Hua Wu and Xiao Hu*
International Center for Materials Nanoarchitectonics (WPI-MANA), National Institute for Materials Science, Tsukuba 305-0044, Japan
Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba 305-8571, Japan
(Received 10 February 2015; published 3 June 2015)

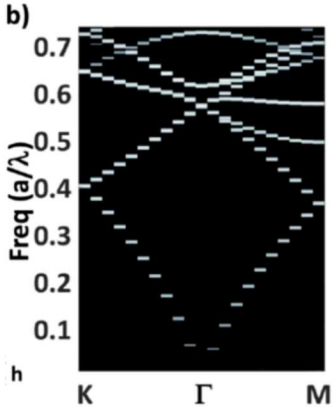
Approach



Honeycomb lattice Photonic Crystal (PhC)



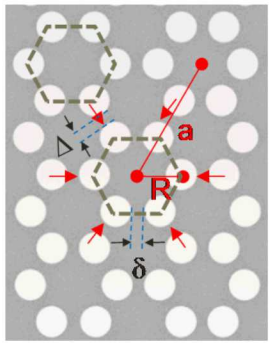


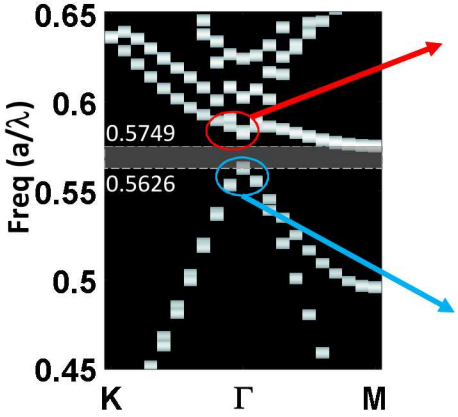


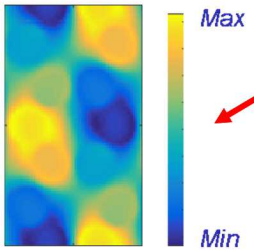
a/R = 3.0

r=0.13a

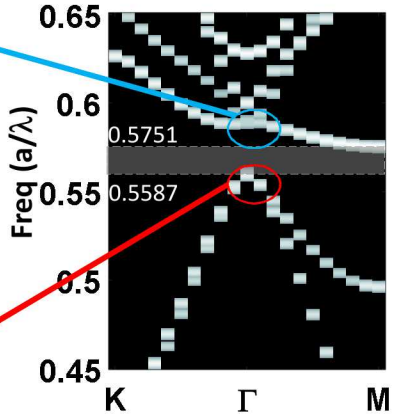
Compressed lattice a/R = 3.1
Topologically Trivial PhC

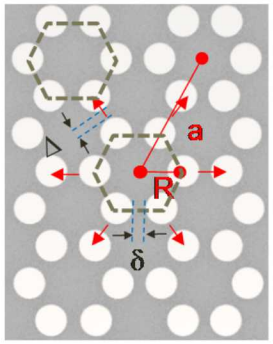






Expanded lattice a/R = 2.9
Topologically non-Trivial PhC





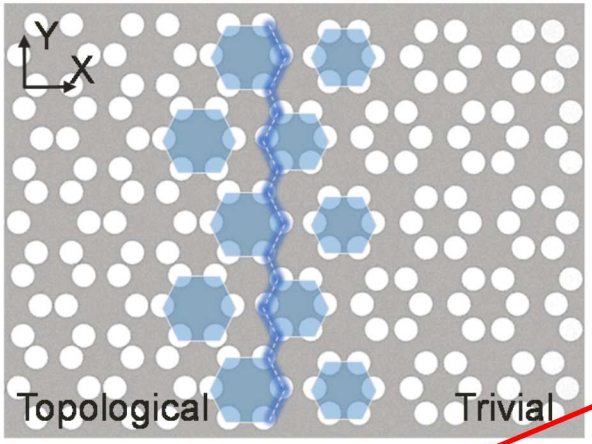
Δ=a-2 (R+r)

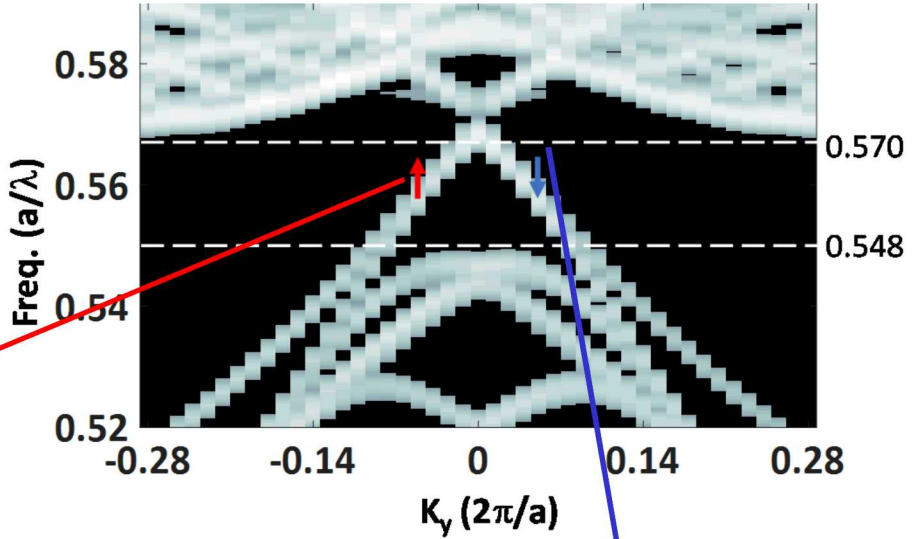
δ=R -2r

P. D. Anderson and G.Subramania, Optics Express **25** (19), 23293 (2017).

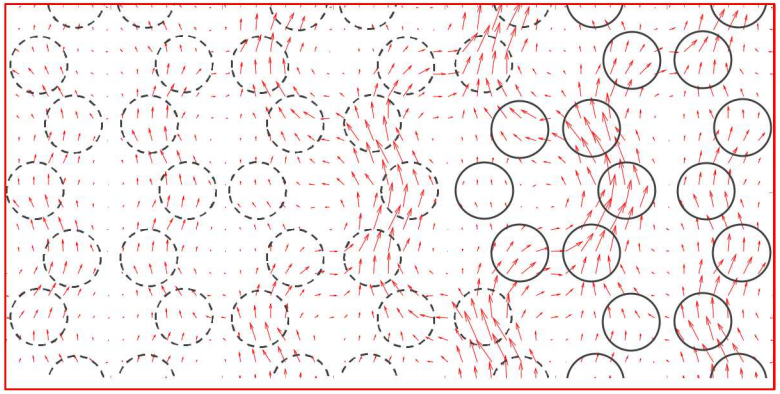
Unidirectional Edge State Propagation

Zig-zag interface

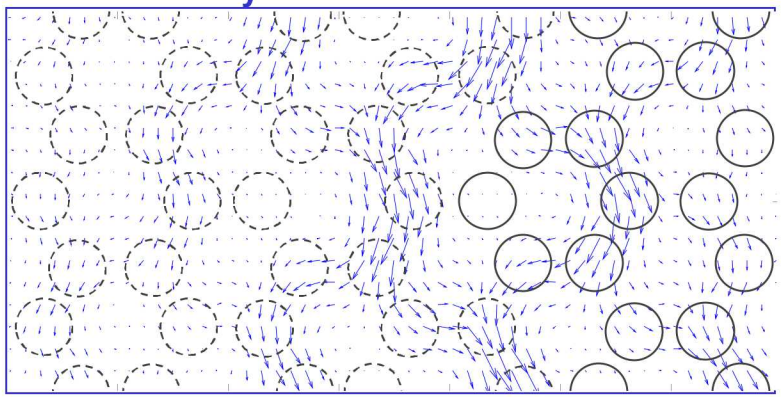




k_y= -0.05(2π/a)



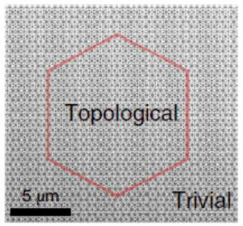
k_y= 0.05(2π/a)

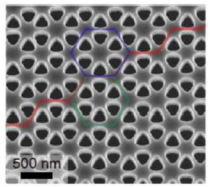


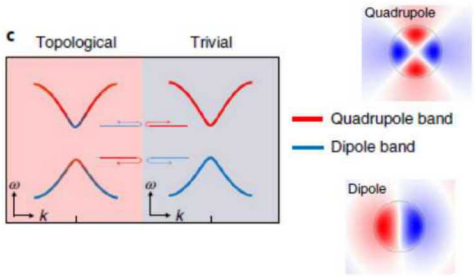
P. D. Anderson and G.Subramania, Optics Express **25** (19), 23293 (2017).

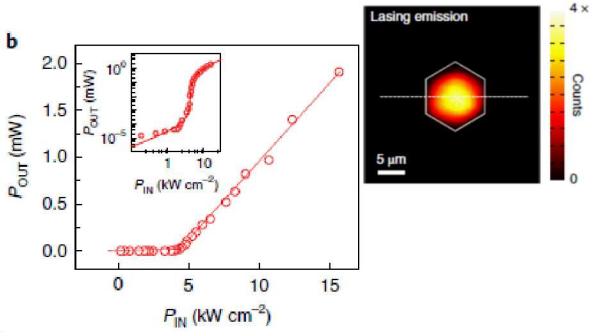
Experimental Structures

Lasing in Topological PhC structure with InGaAsP MWQ/ InP



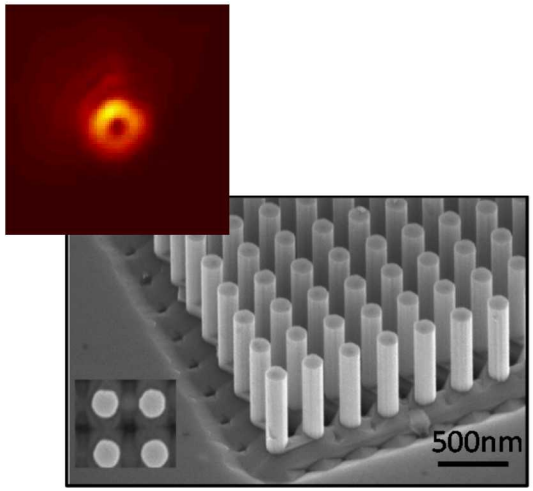


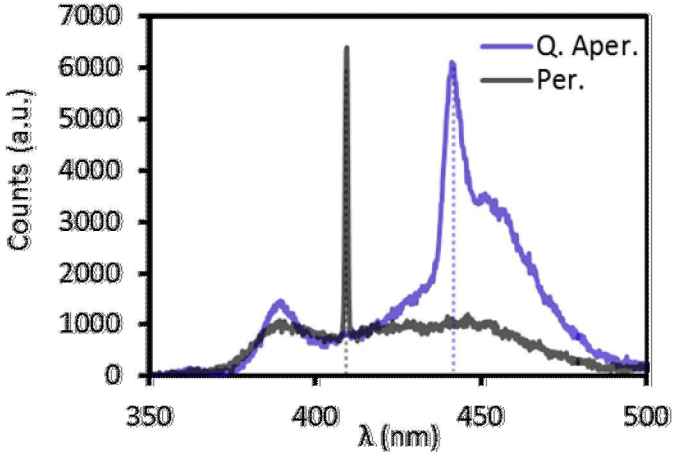


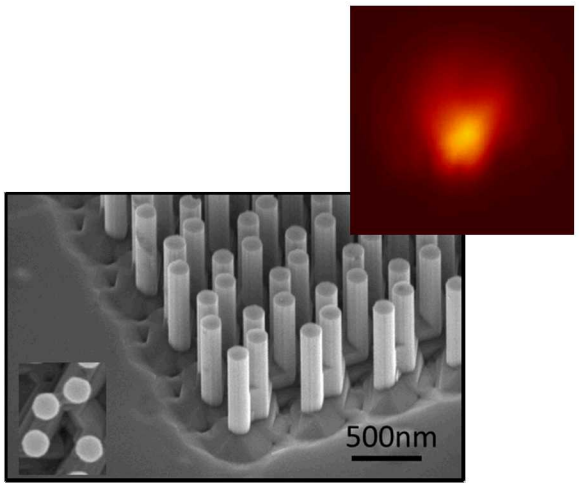


Shao, Z.-K. et.al. *Nature Nanotechnology* **2020,** *15* (1), 67-72.

Opportunities in InGaN MQW/GaN system



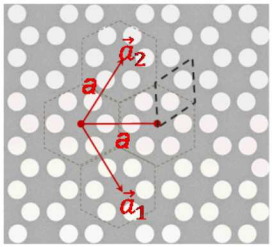




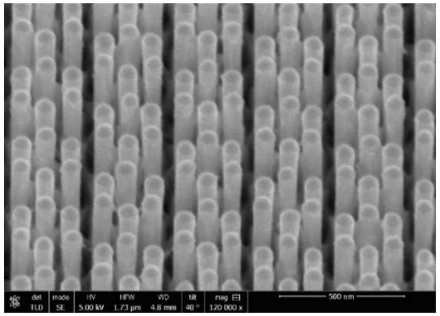
P. D Anderson, et. al.Optical Materials Express, **7** , 3634(2017).

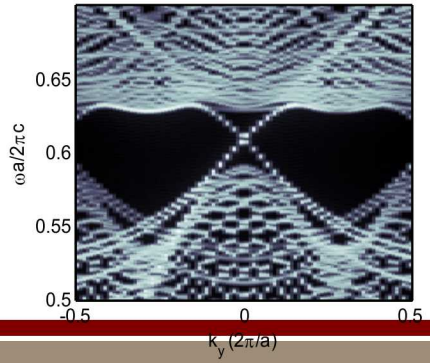
J.B. Wright, et. al. Sci. Rep., **3**, 2982 (2013).

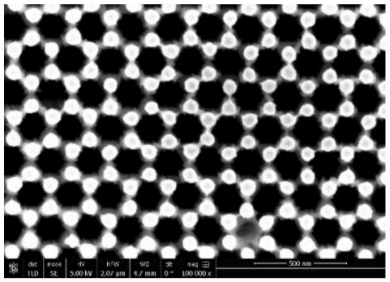
Summary and Future



- Topologically protected structures in photonics
- Interface photonics states at the topological /trivial interface
  - Unidirectional propagation of helical states
- Novel photonic cavity design for lasers
- Implementation for lasing in III-nitride rods







Sandia National Laboratories

Thank you for your attention!

Sandia National Laboratories

Extras …

Topological Photonics Research Activities

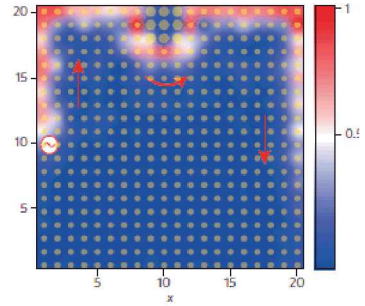
PHYSICAL REVIEW A **78**, 033834 (2008)

Analogs of quantum-Hall-effect edge states in photonic crystals

S. Raghu*
Department of Physics, Stanford University, Stanford, California 94305-4045, USA

F. D. M. Haldane
Department of Physics, Princeton University, Princeton, New Jersey 08544-0708, USA

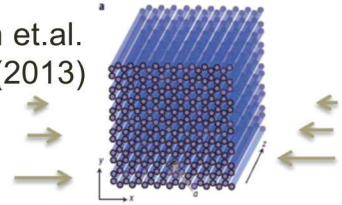
One-way edge transport



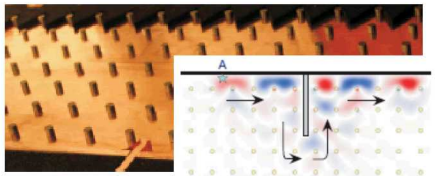
K.Fang, Z. Yu , S.H.Fan , **Nat. Phot. 6 ,** (2012)

Strain induced pseud mag. field in optical fiber arrays

M.Rechtsman et.al. **Nat. Phot. 7** (2013)

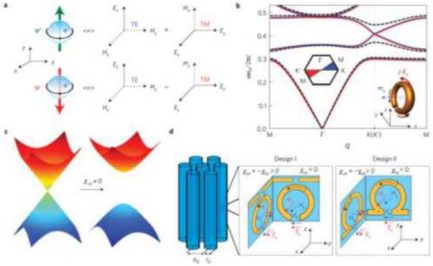


One- way transport at microwave frequency



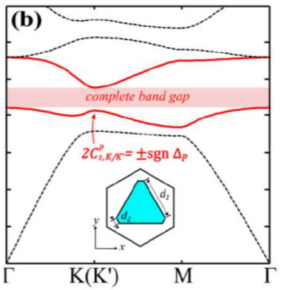
Z. Wang, Y. Chong, et.al. , Nature **461**, 772 (2009).

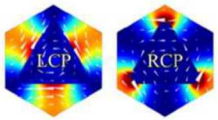
Metamaterial PTI



A. B. Khanikaev et.al. Nat Mater **12** (3), 233-239 (2013).

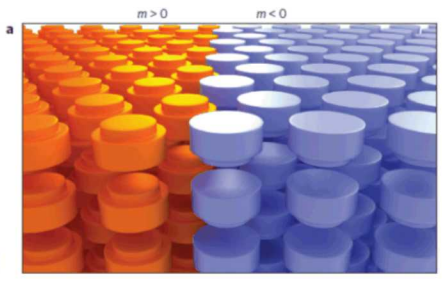
Valley hall PTI





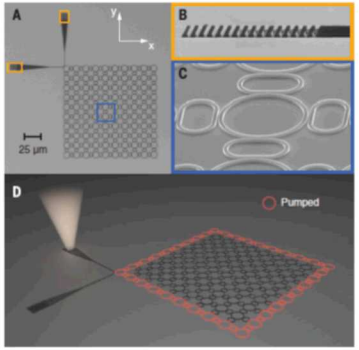
M. Tzuhsuan and S. Gennady, NJP.**18** (2) , 025012 (2016).

3D All dielectric PTI



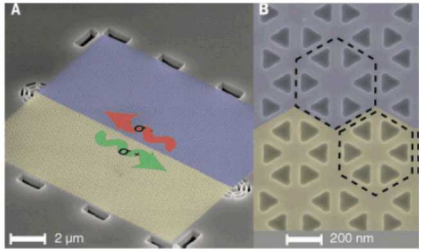
A. Slobozhanyuk, et.al. , Nat Photon **11** (2), 130-136 (2017).

PTI lasing



Bandres, M. A. *et al. Science* **359**, eaar1231 (2018).

Topological edge states in III-V



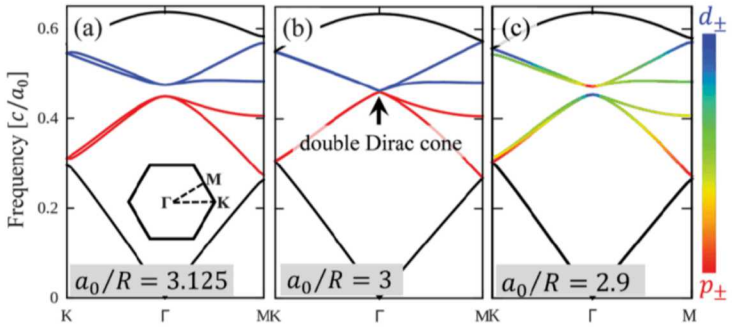
Barik, S. *et al.. Science* **359**, 666 (2018).

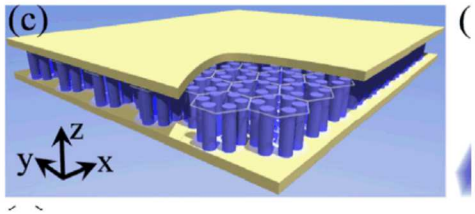
Topological Photonics Spin Hall in Dielectric PC

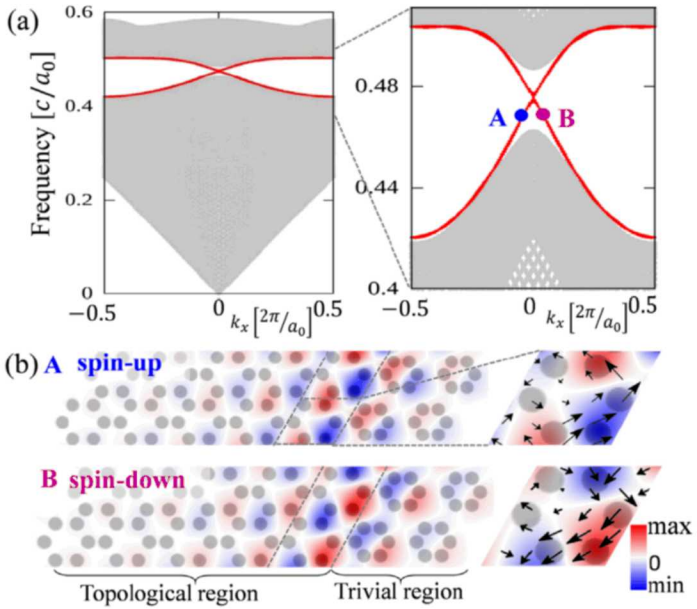
PRL 114, 223901 (2015) PHYSICAL REVIEW LETTERS week ending 5 JUNE 2015

Scheme for Achieving a Topological Photonic Crystal by Using Dielectric Material

Long-Hua Wu and Xiao Hu*
International Center for Materials Nanoarchitectonics (WPI-MANA), National Institute for Materials Science, Tsukuba 305-0044, Japan
Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba 305-8571, Japan
(Received 10 February 2015; published 3 June 2015)







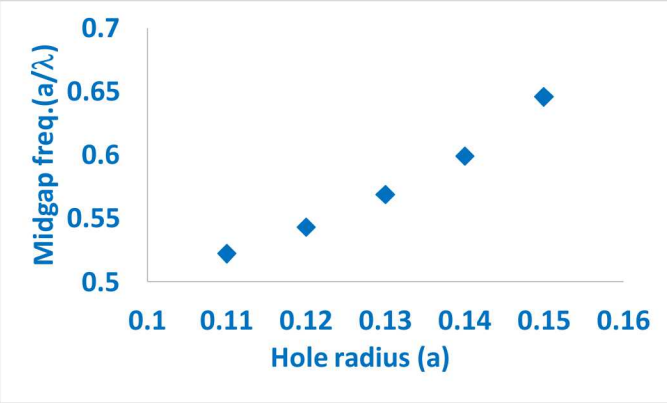
Modified honeycomb lattice of hexagonal cylindrical dielectric rods

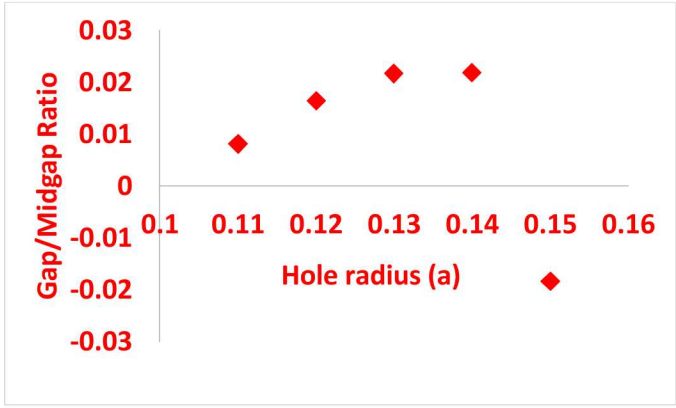
Circular Hole Array Honeycomb Lattice Photonic Crystal

Hole radius 'r' dependence

Membrane thickness 'h' = 0.25a

Compressed a/R = 3.1

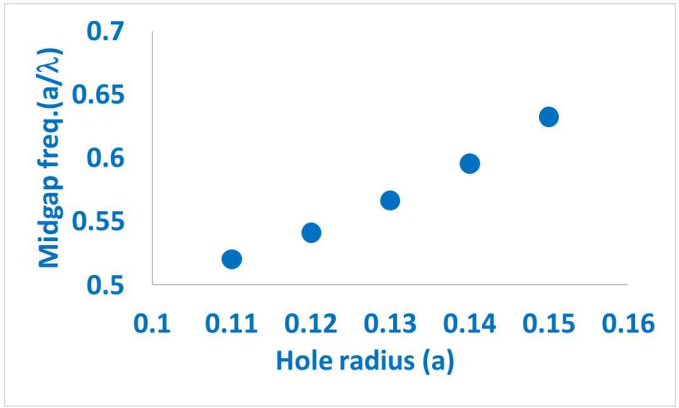


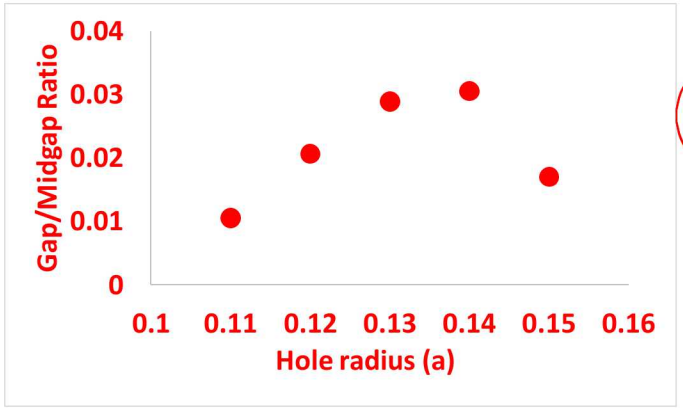


At λ ~ 1500nm

Δλ ~ 30nm

Expanded a/R = 2.9





At λ ~ 1500nm

Δλ ~ 45nm

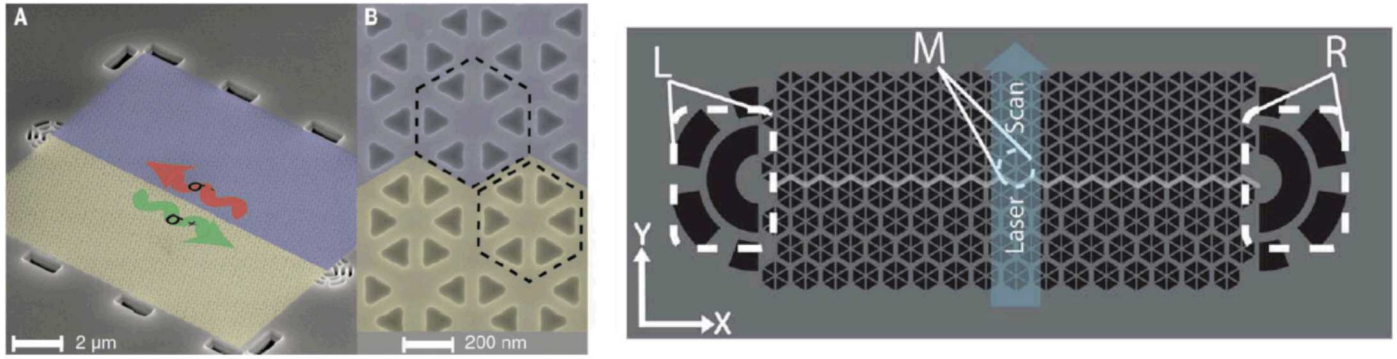
Reasonable operational bandwidth possible at the telecom frequencies

P. D. Anderson and G.Subramania, Optics Express **25** (19), 23293 (2017).

How to launch a helical source?

Quantum Dot based Helical Sources

Barik, S., et al. (2018). "A topological quantum optics interface." Science **359**(6376): 666.



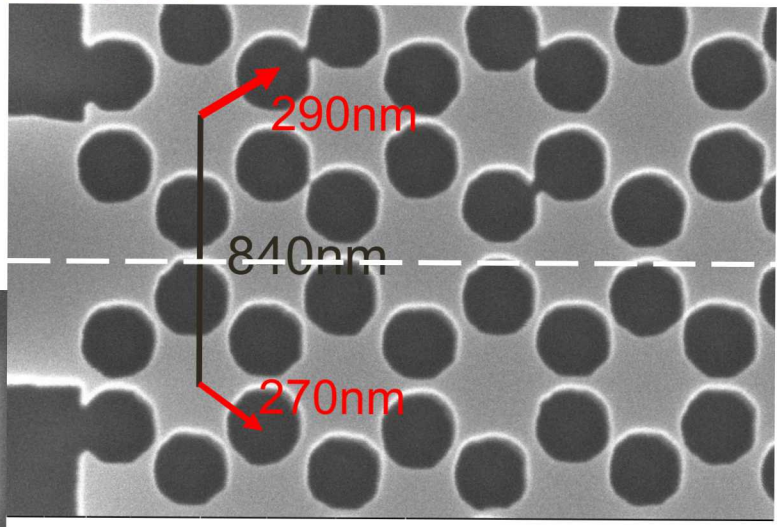
- Create a quantum dot inside the structure
- Apply high B field to split energy level as well as helicity
- Unidirectional propagation of single photon source
- Bandwidth difficult to demonstrate

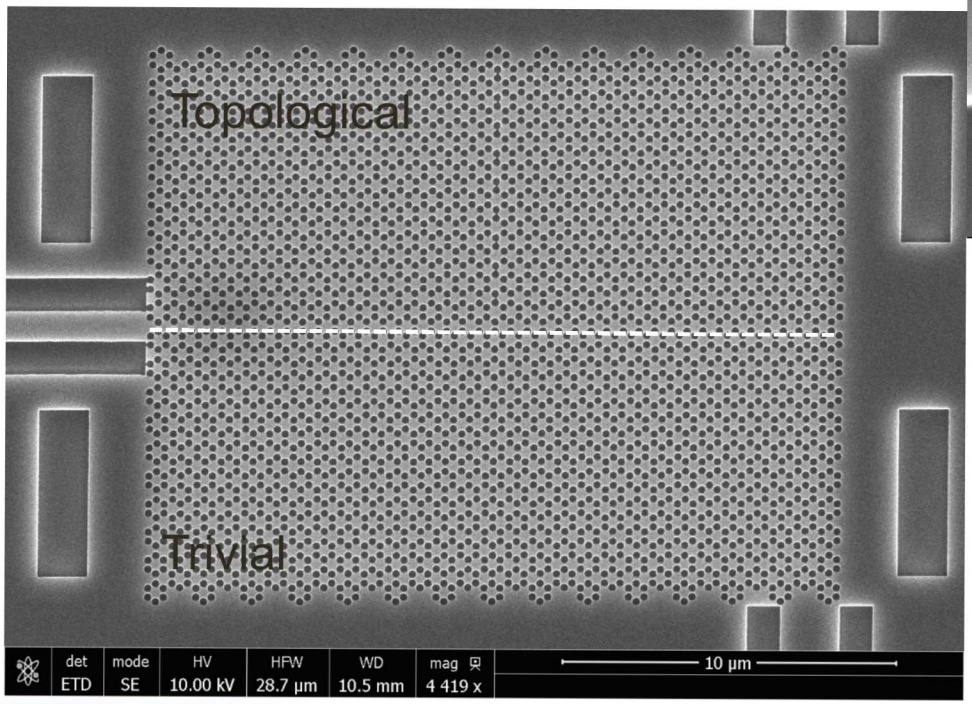
What about a passive structure to manipulate light incident from elsewhere?

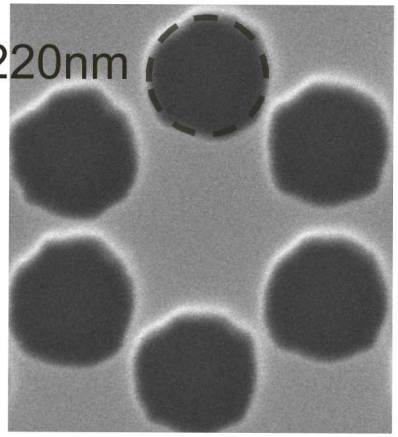
Fabrication on Silicon on Insulator (SOI) - Membrane

Pattern transfer to Si

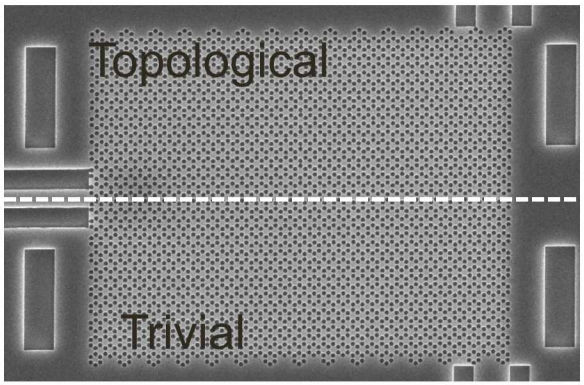
- ~ 50 nm SiO2 is used as hardmask for pattern transfer
- Highly selective HBr based RIE for Si etch





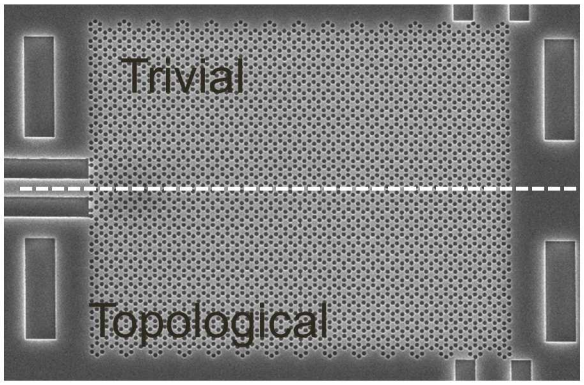


Optical Measurement

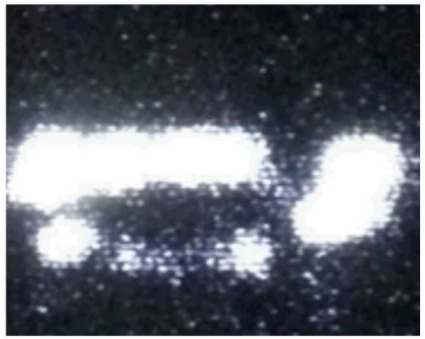


IR laser

$\lambda \sim 1536nm$

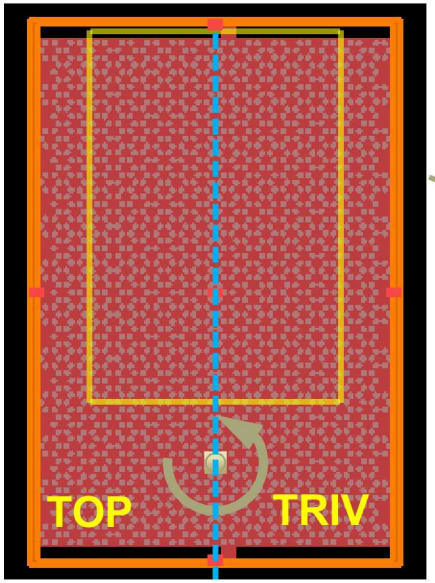


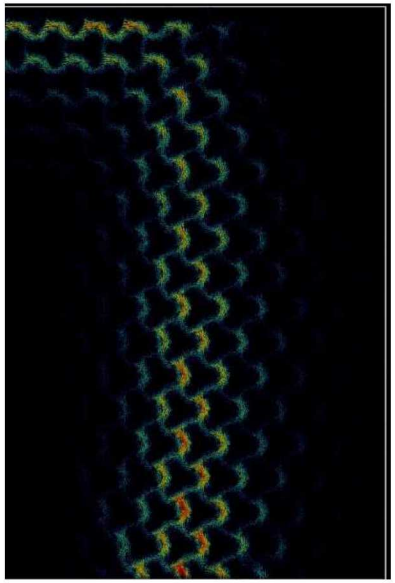
IR laser



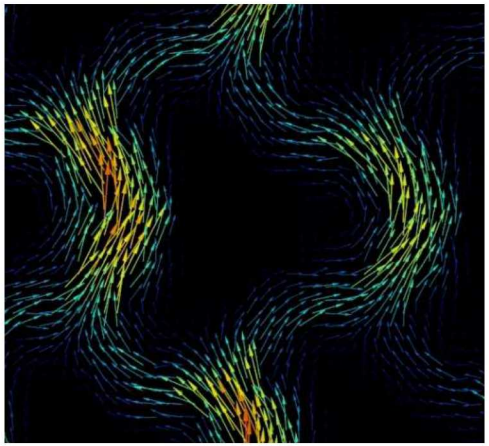
- Light propagation shows clear distinction based on orientation of the Topological PhC relative to the Trivial PhC
- In progress …

Unidirectional Propagation with Helical Sources

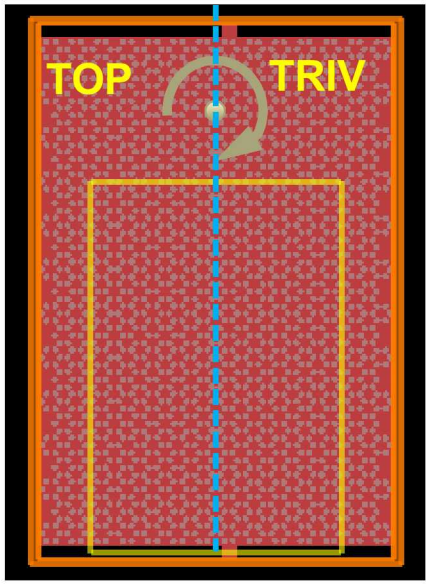


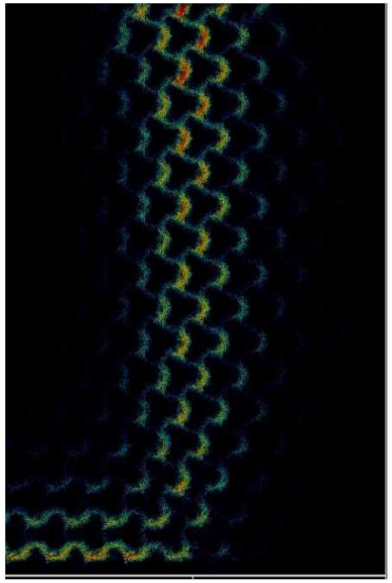


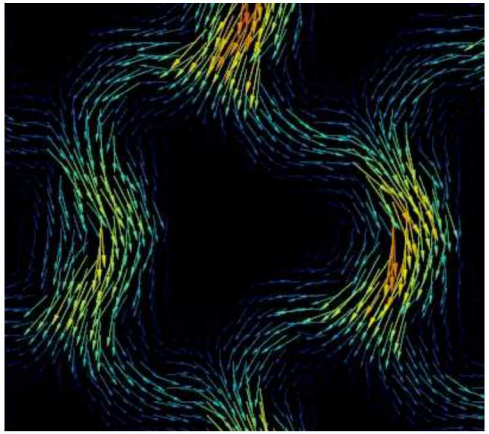
$a/\lambda \sim 0.567$



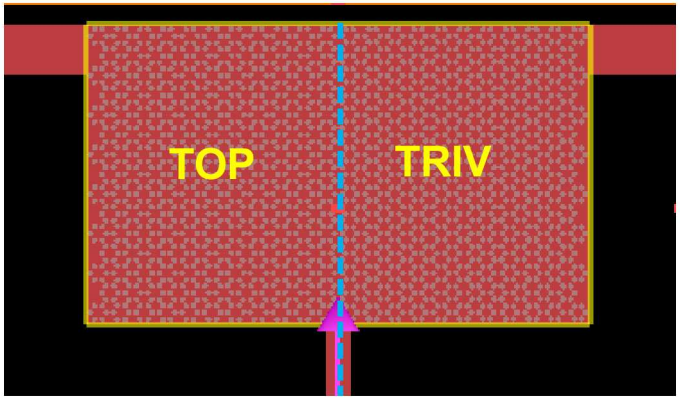
up

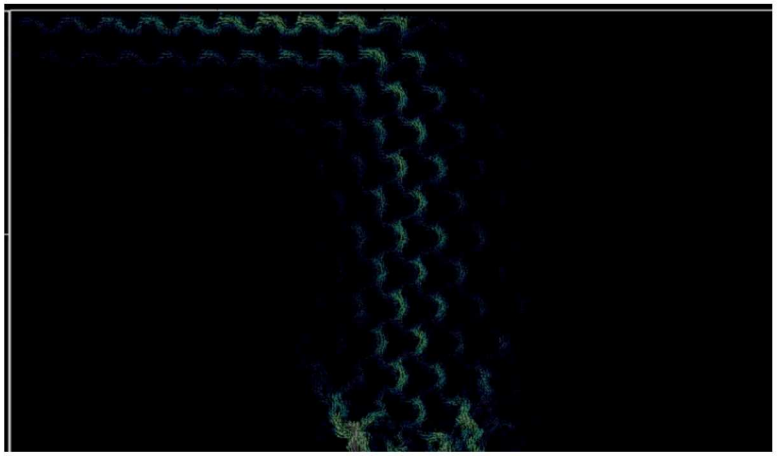






down





High index trivial medium