SAND2017-8156C

Topological photonic structures for nanophotonics

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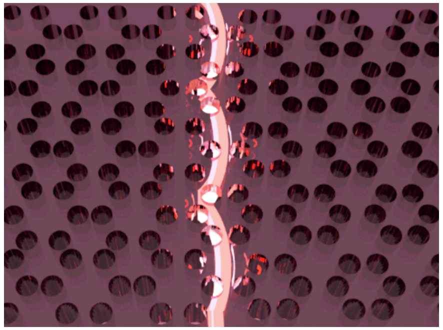
***Sandia National Laboratories, Albuquerque, NM**
+ University of Southen California, Los Angeles, CA

August 6-10, 2017
Active Photonic Platforms IX
SPIE Optics and Photonics , San Diego, CA



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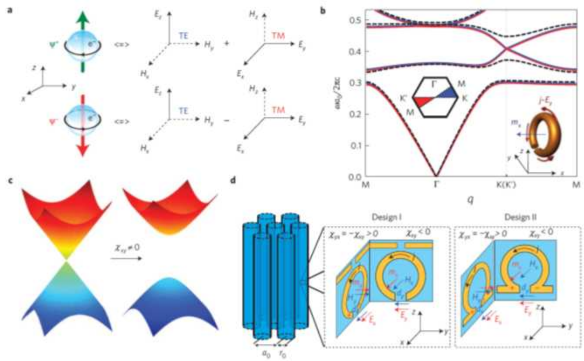
U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

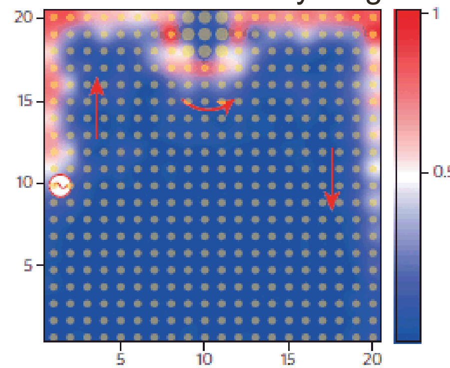
Topological Photonics Research Activities

Metamaterial Photonic Topological Insulator



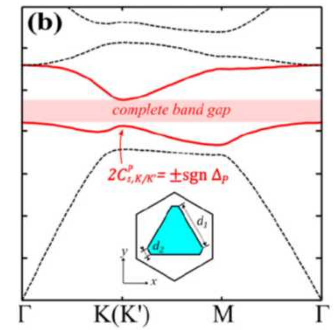
A. B. Khanikaev et.al. Nat Mater **12** (3), 233-239 (2013).

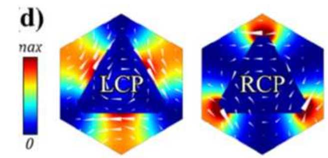
Simulation of Oneway edge transport



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

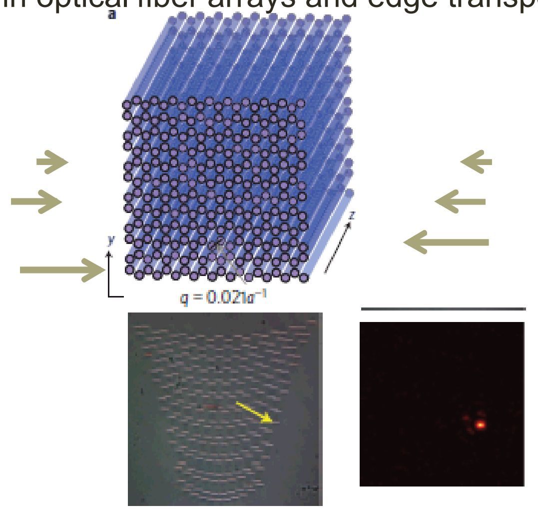
Valley hall Photonic Topological Insulator





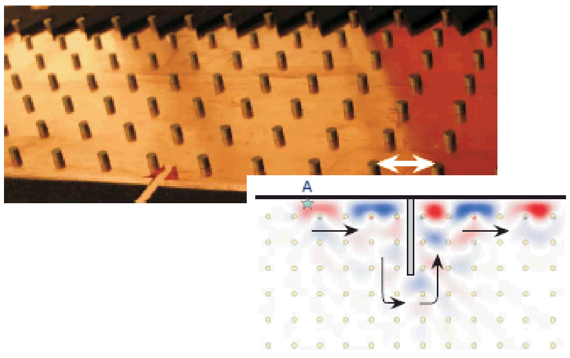
M. Tzuhsuan and S. Gennady, New Journal of Physics **18** (2), 025012 (2016).

Strain induced pseud mag. field
in optical fiber arrays and edge transport

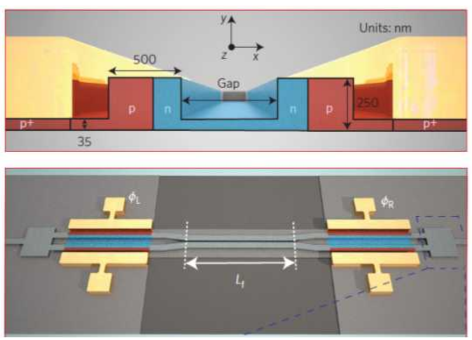


M.Rechtsman et.al. **Nat. Phot. 7** (2013)

One- way scatter transport at microwave frequency ~ 4GHz in 2DPCs



Z. Wang et. al. **Nat. 461** (2009)



L. D. Tzuang, et. al. Nat Photon **8** (9), 701-705 (2014).

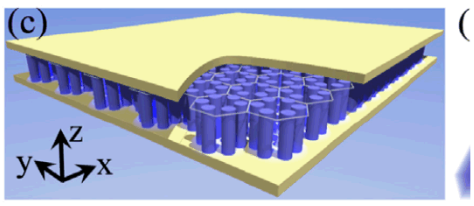
Topological Photonics Spin Hall in Dielectric PC

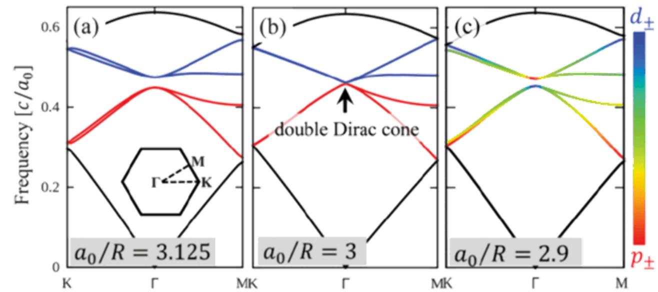
Modified honeycomb lattice of hexagonal cylindrical dielectric rods

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)



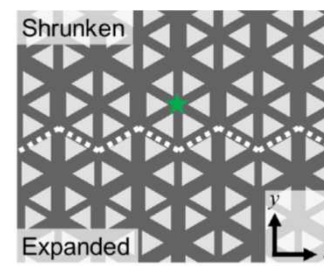


Inverse structure : holes in high dielectric matrix

- ✓ More suitable for optical frequency implementation (e.g. in SOI, III-V)

New J. Phys. 18 (2016) 113013

New Journal of Physics
The open access journal at the forefront of physics



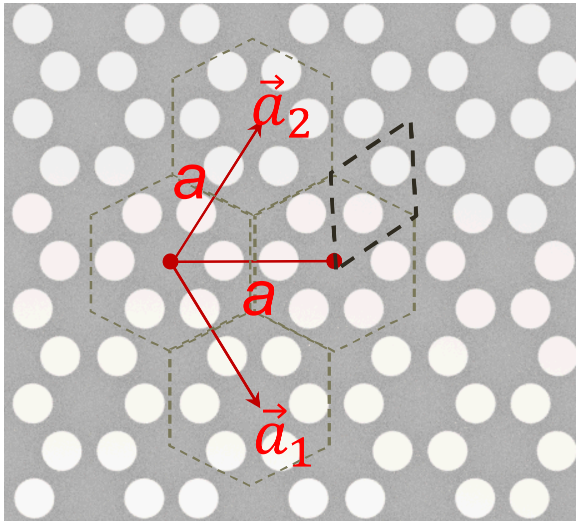
Two-dimensionally confined topological edge states in photonic crystals

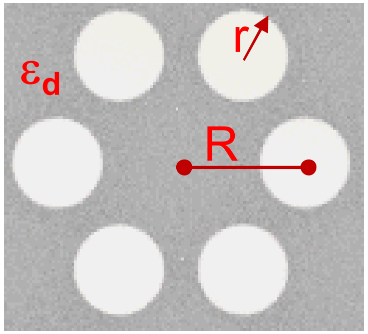
Sabyasachi Barik[1,2,5], Hirokazu Miyake[2,5], Wade DeGottardi[2], Edo Waks[2] and Mohammad Hafezi[2,3,4]

Difficult to fabricate ….

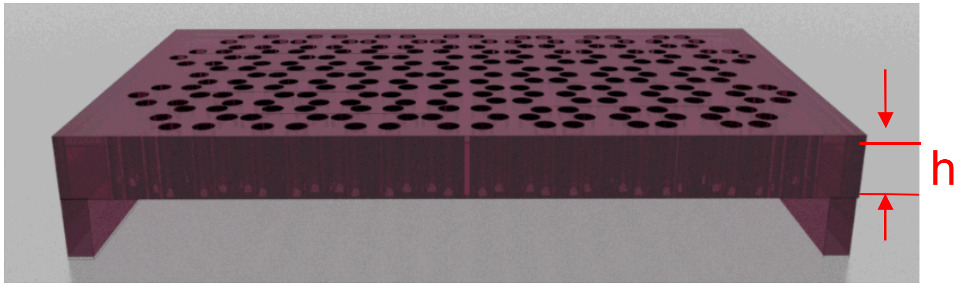
Circular Hole Array Honeycomb Lattice Photonic Crystal

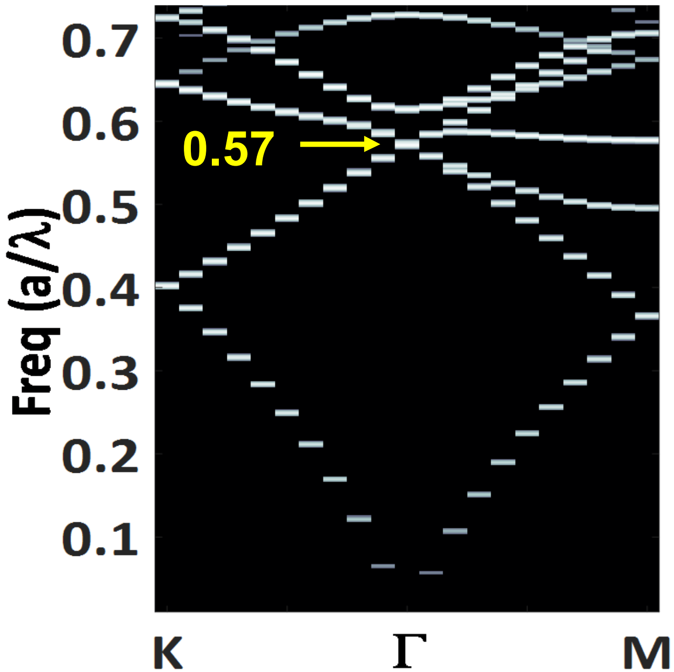
- Simplifies nanofabrication





- *a/R = 3.0*
- *r = 0.13a*
- *h = 0.25a*

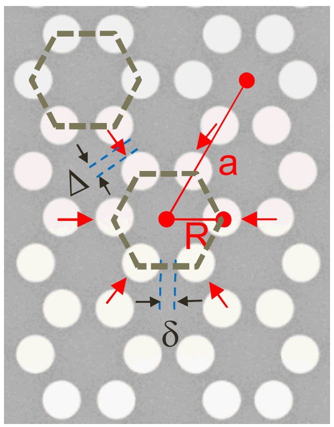




Calculated with FDTD (Lumerical ®)

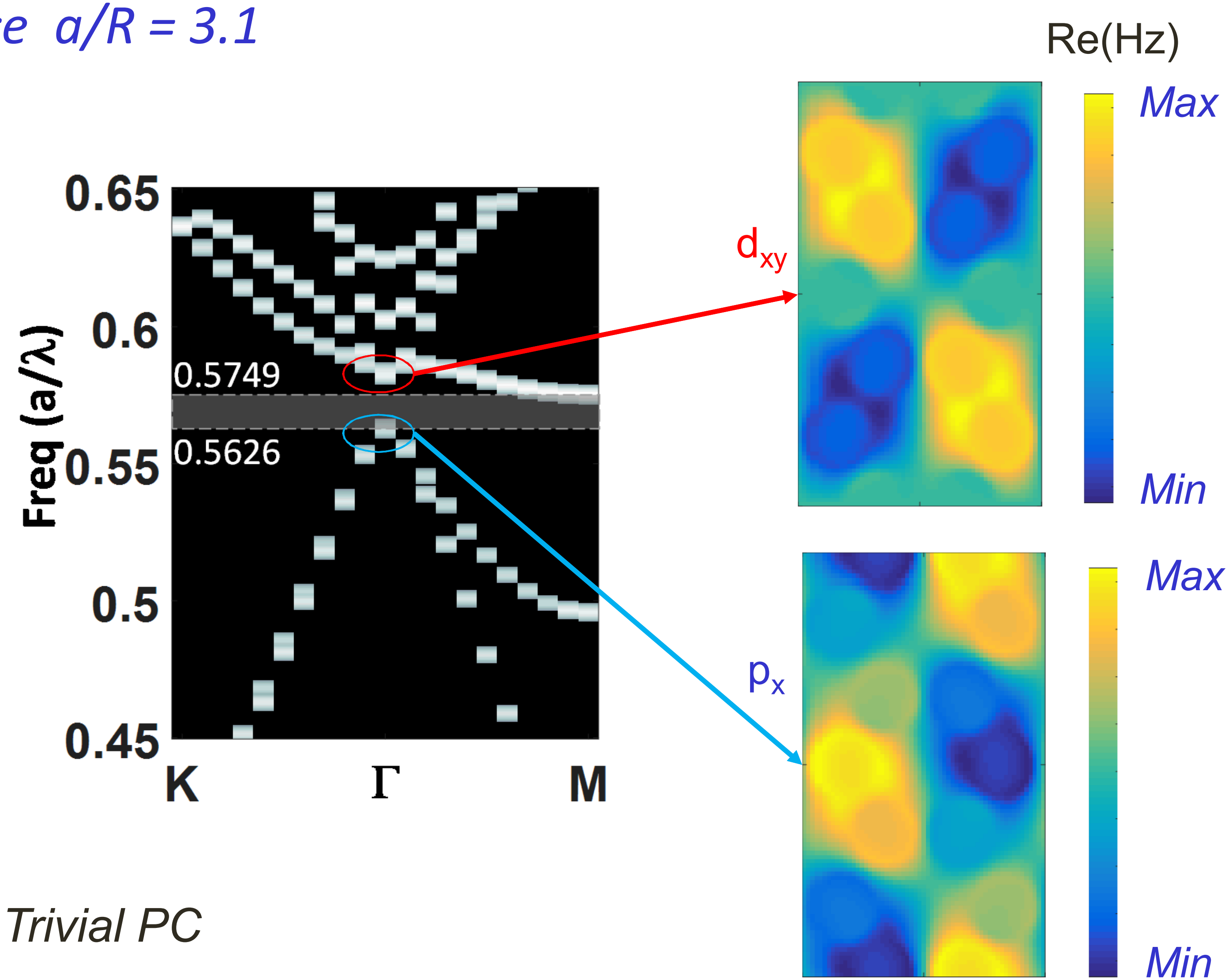
Circular Hole Array Honeycomb Lattice Photonic Crystal

Compressed lattice a/R = 3.1



Δ=a-2 (R+r)

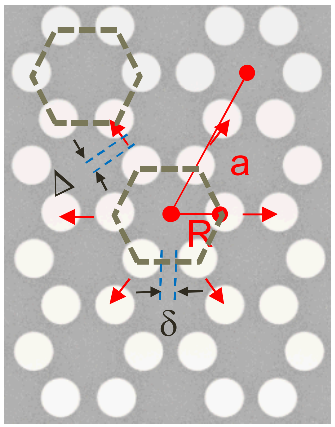
δ=R -2r



Topologically Trivial PC

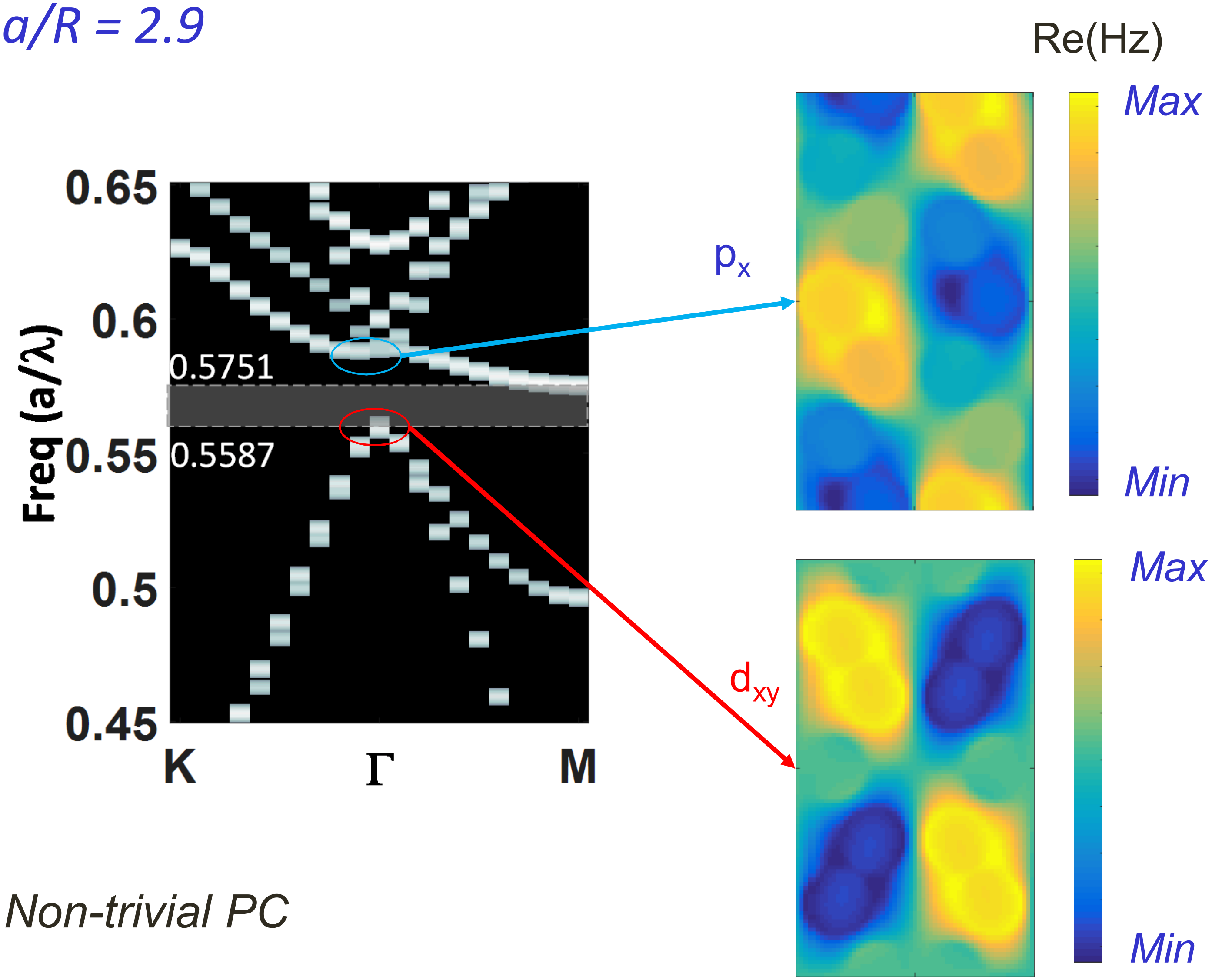
Circular Hole Array Honeycomb Lattice Photonic Crystal

Expanded lattice a/R = 2.9



Δ=a-2 (R+r)

δ=R -2r



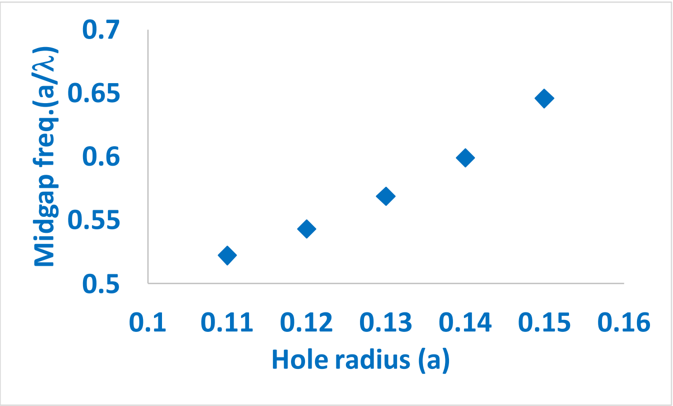
Topologically Non-trivial PC

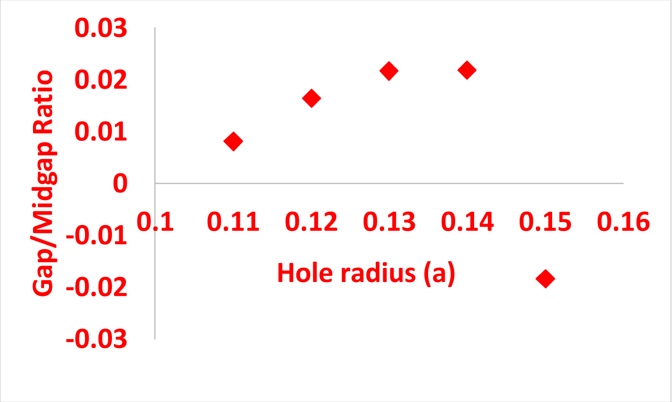
Circular Hole Array Honeycomb Lattice Photonic Crystal

Hole radius 'r' dependence

Membrane thickness 'h' = 0.25a

Compressed a/R = 3.1

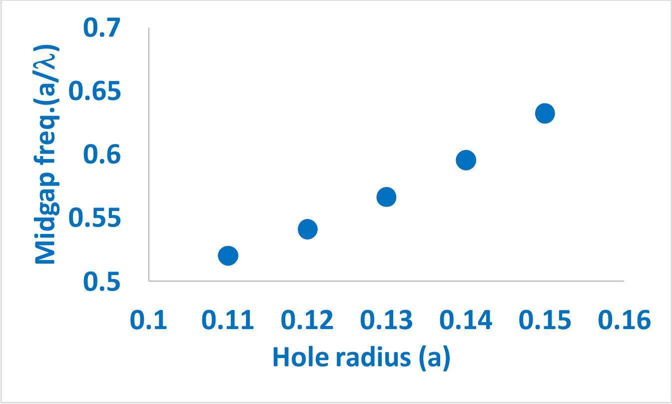


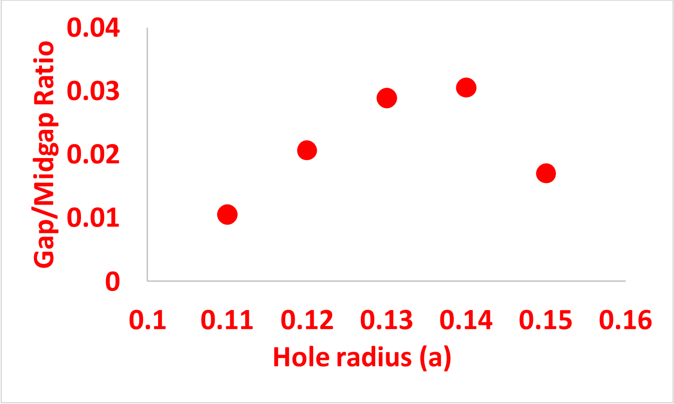


At $\lambda \sim 1500$nm

$\Delta\lambda \sim 30$nm

Expanded a/R = 2.9





At $\lambda \sim 1500$nm

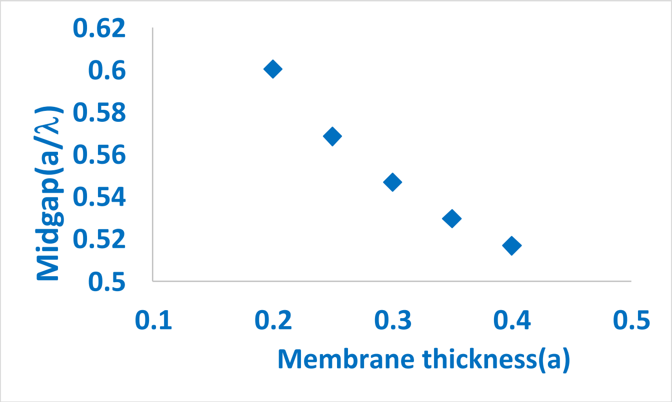
$\Delta\lambda \sim 45$nm

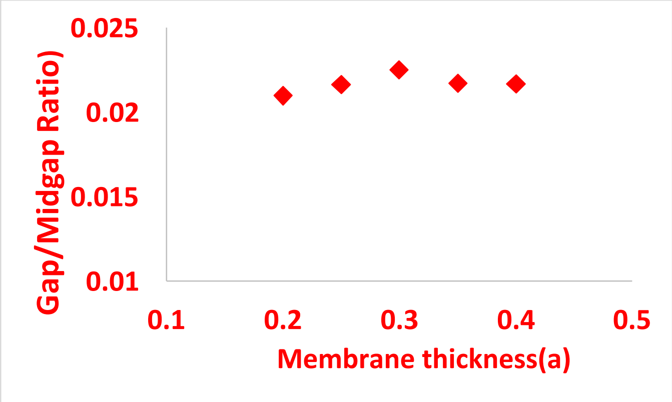
Reasonable operational bandwidth possible at the telecom frequencies

Circular Hole Array Honeycomb Lattice Photonic Crystal

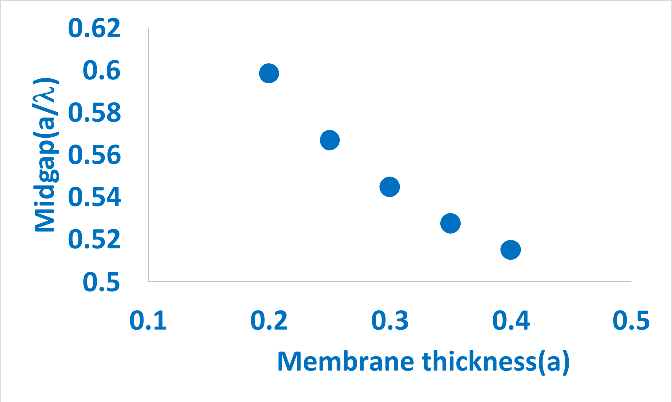
Membrane thickness 'h' dependence

Compressed a/R = 3.1





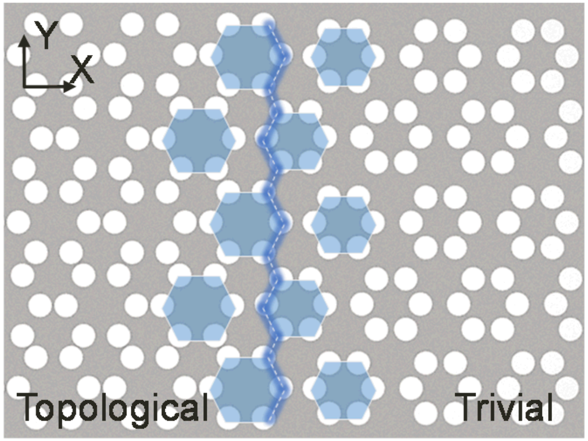
Expanded a/R = 2.9

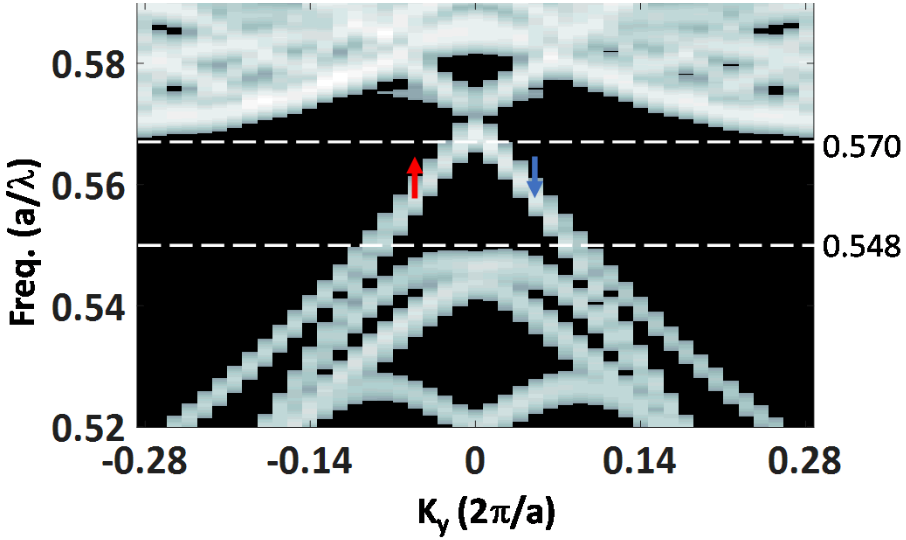


Bandgap relatively robust to nominal variation in membrane thickness

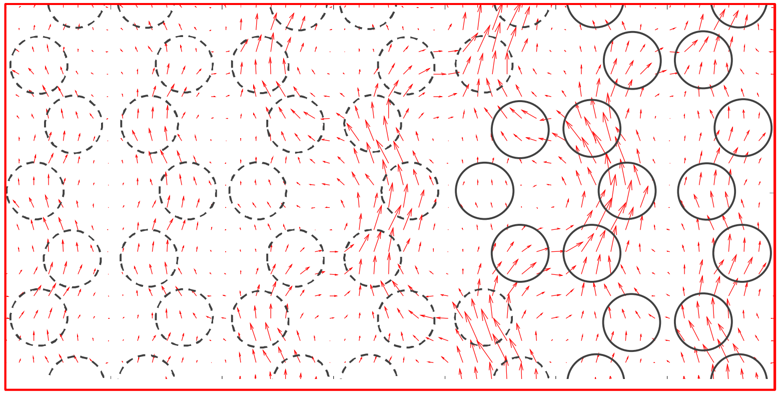
Unidirectional Edge State Propagation

Zig-zag interface

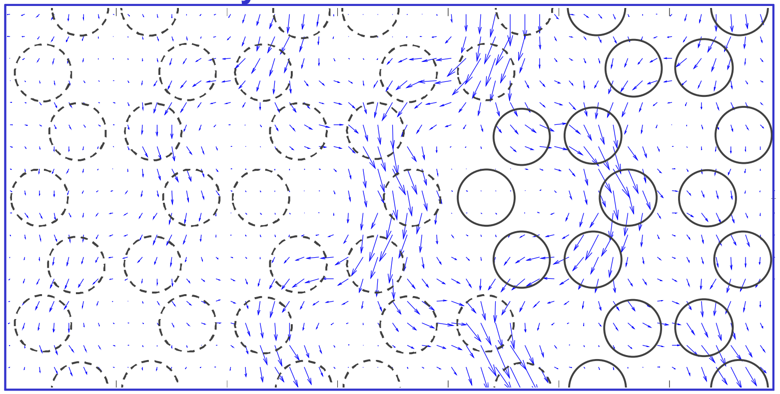




k_y= -0.05(2π/a)

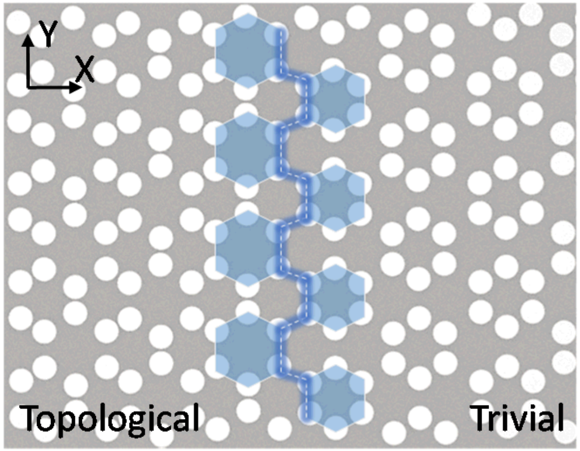


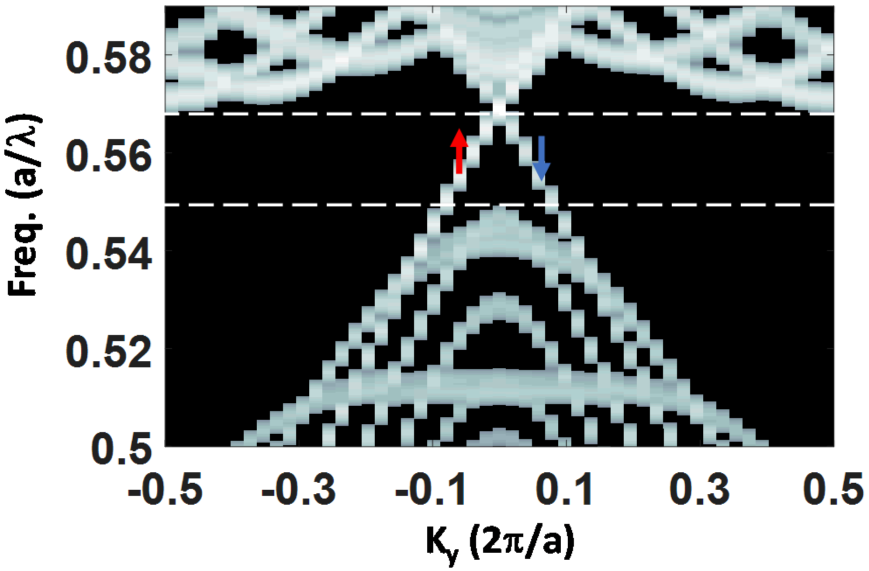
k_y= 0.05(2π/a)



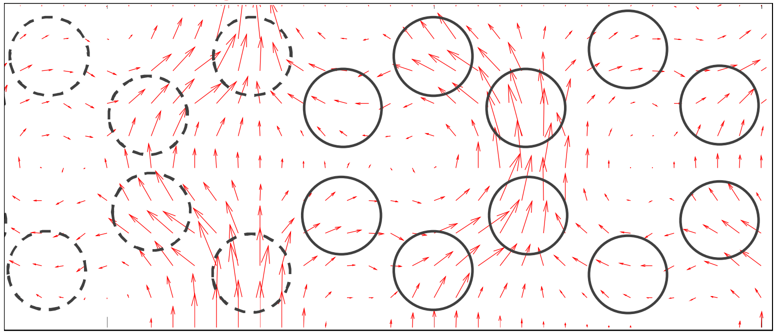
Unidirectional Edge State Propagation

Armchair interface

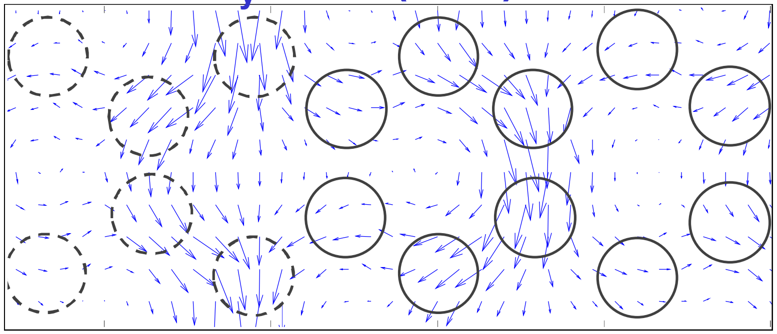




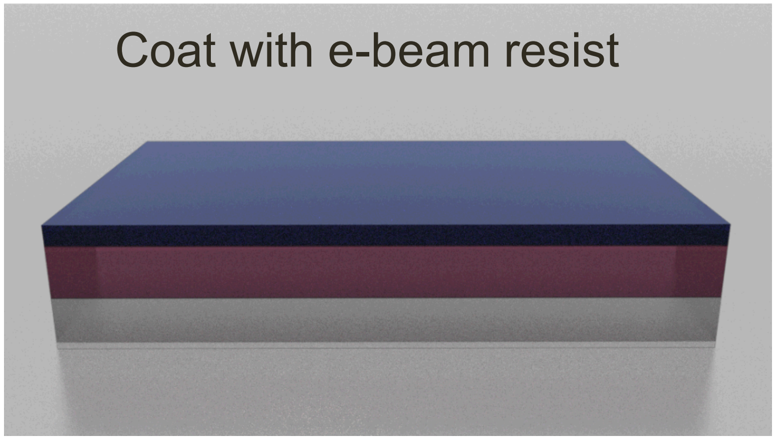
k_y= -0.06(2π/a)

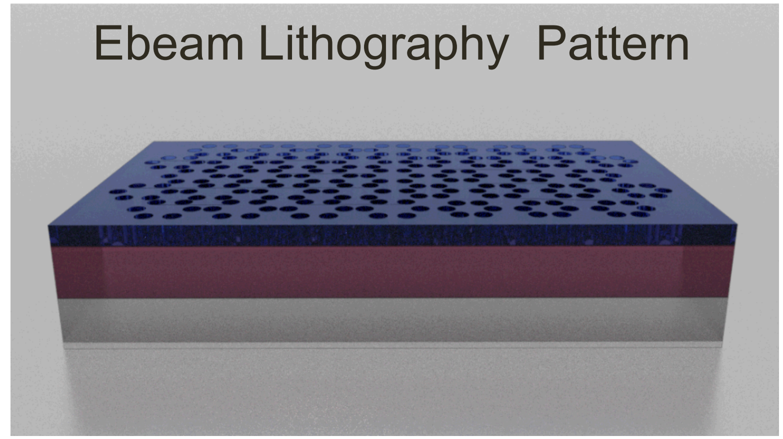


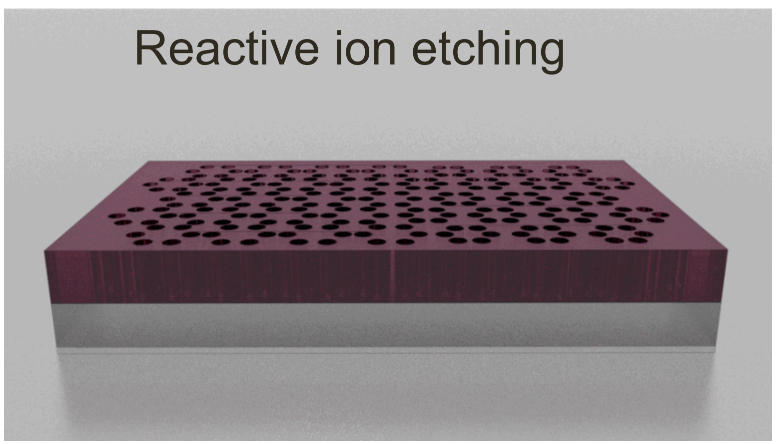
k_y= 0.06(2π/a)

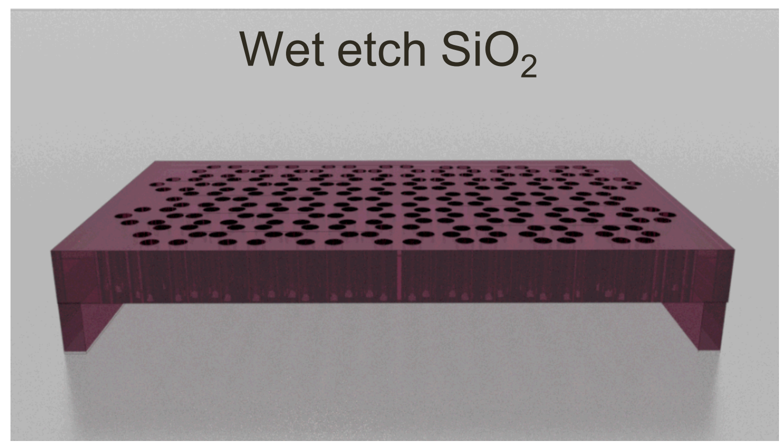


Fabrication on Silicon on Insulator (SOI) - Membrane



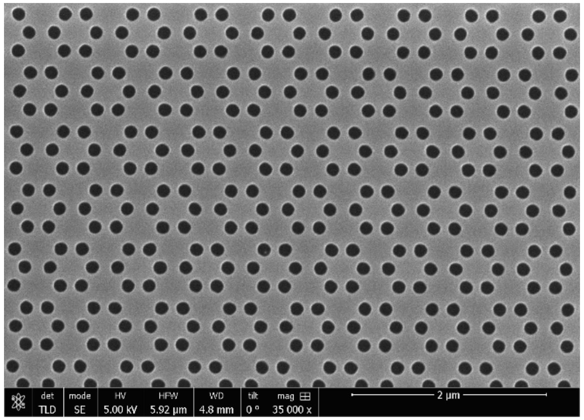


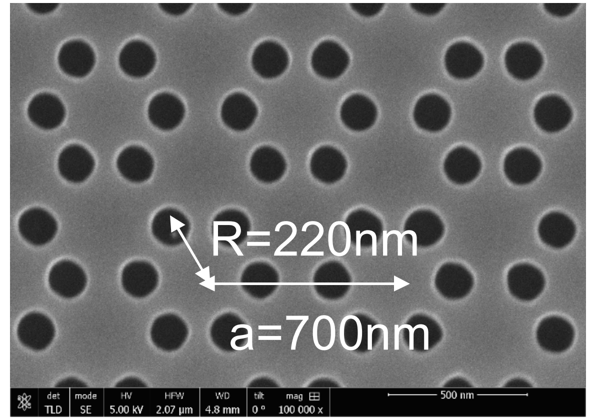




Fabrication on Silicon on Insulator (SOI) - Membrane

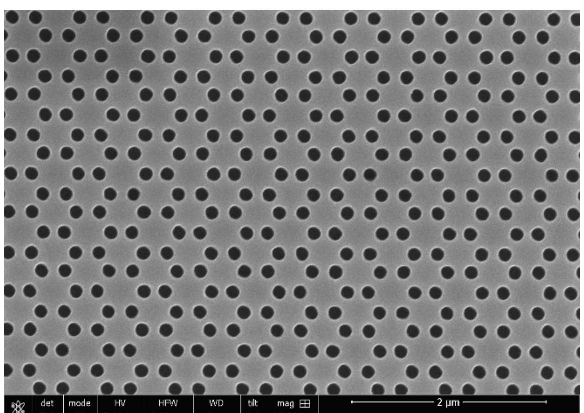
Trivial/Compressed Structure

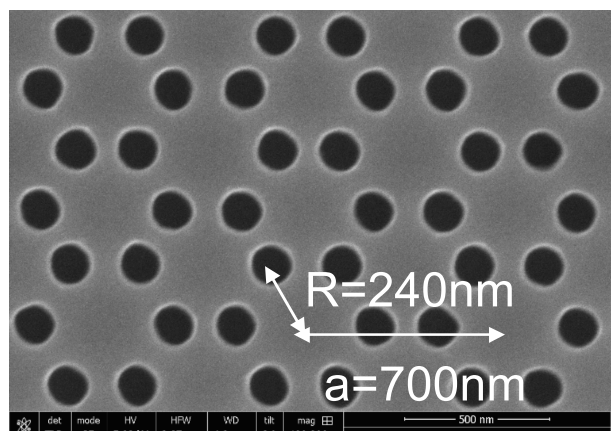




a/R = 3.18

Topological/Expanded Structure





a/R = 2.9

Fabrication on Silicon on Insulator (SOI) - Membrane

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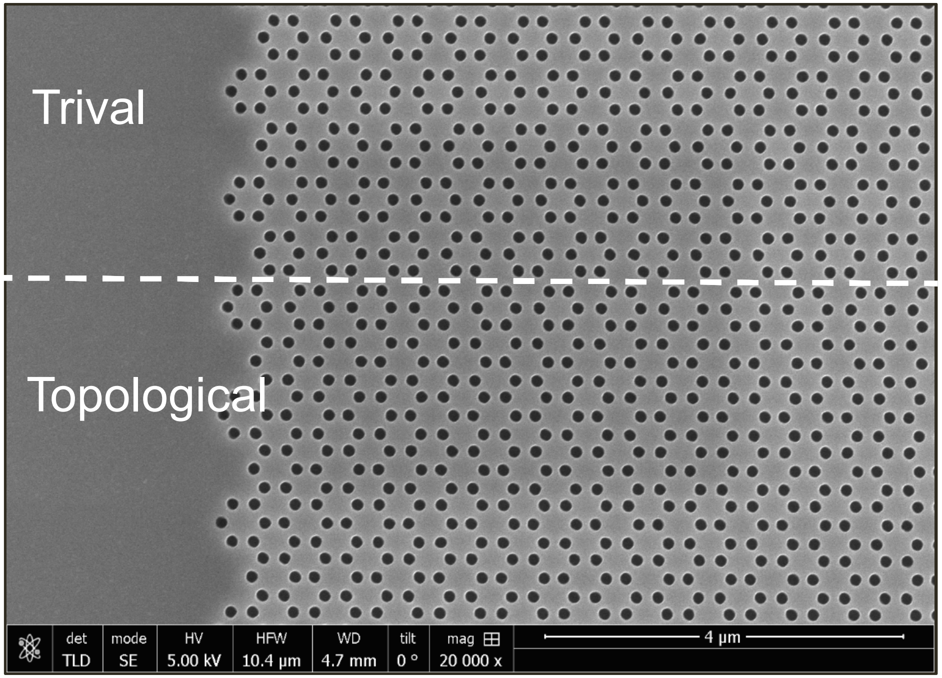
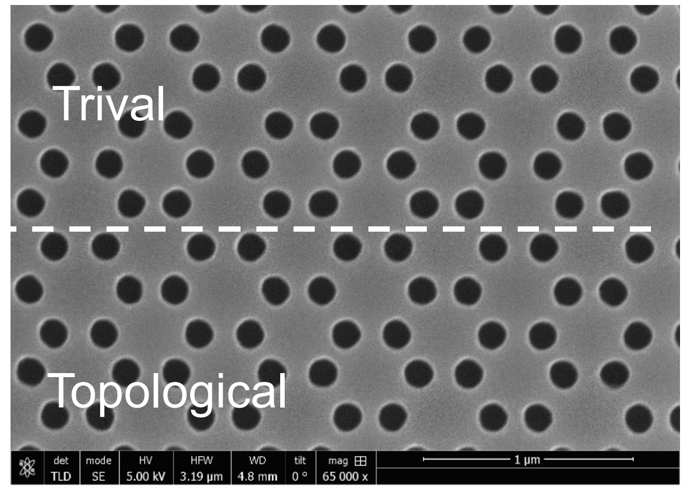
Topological/Trivial Interface structure



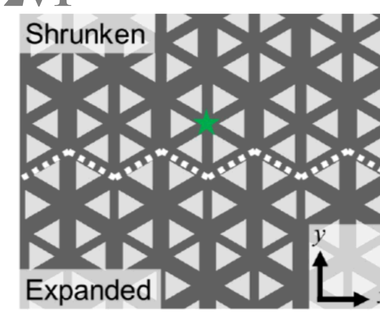


Alternate design …

arXiv:1605.08822v1

Two-Dimensionally Confined Topological Edge States in Photonic Crystals

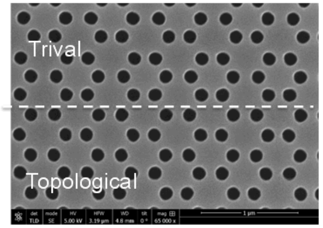
Sabyasachi Barik[1,2], Hirokazu Miyake[2], Wade DeGottardi[2], Edo Waks[2,3], Mohammad Hafezi[2,3,4]

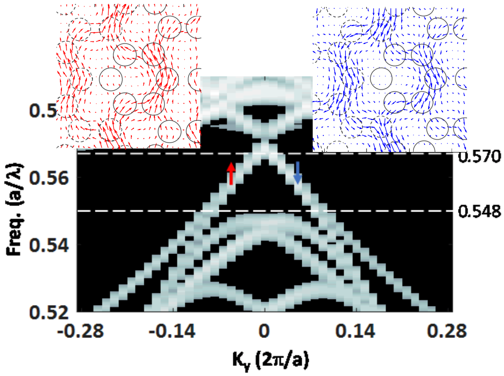


Fabrication could be challenging …

Summary and Future directions

- Design of hole array honeycomb Topological PC in high dielectric membrane
- Robust bandgap with hole radii and membrane height
- Appreciable bandgap and operational bandwidth around 1550nm → 30-45nm
- Unidirectional modes at topological/trivial PC interface
- Fabrication process development in SOI





Next…

- Optimize design and fab – SOI
- Optical measurement to demonstrate Topological behavior

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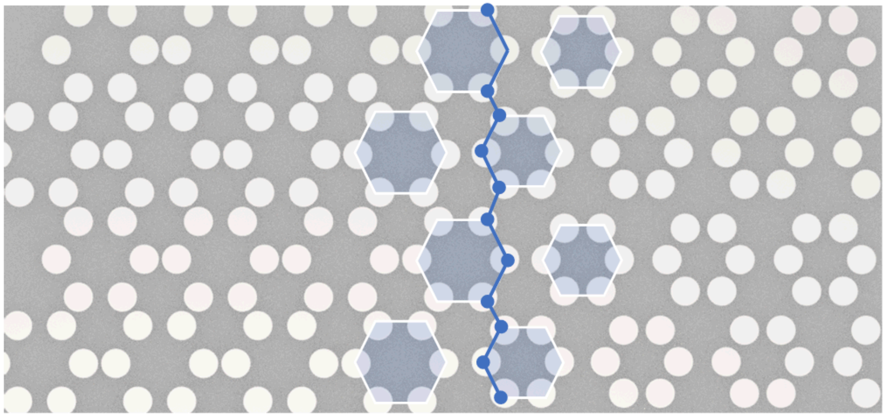
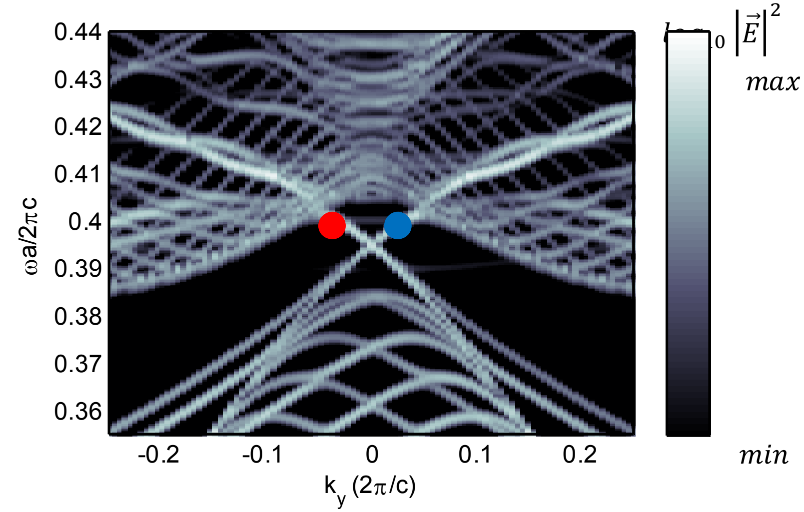
Thank you for your attention!

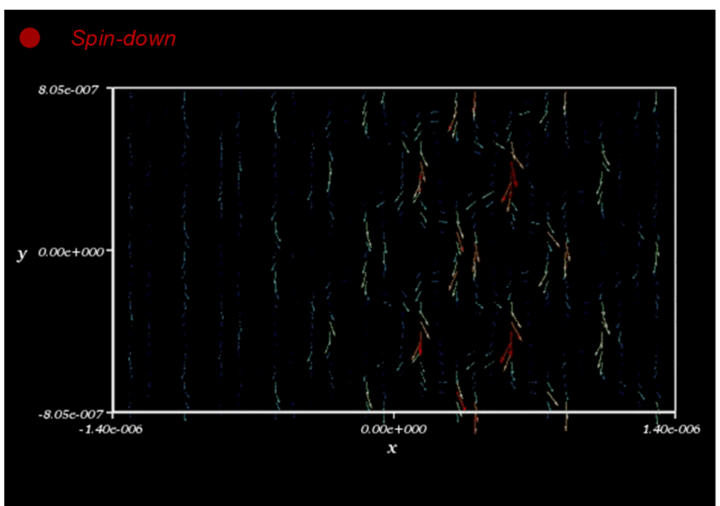
Band structure for Topological/Trivial Zig-zag Interface

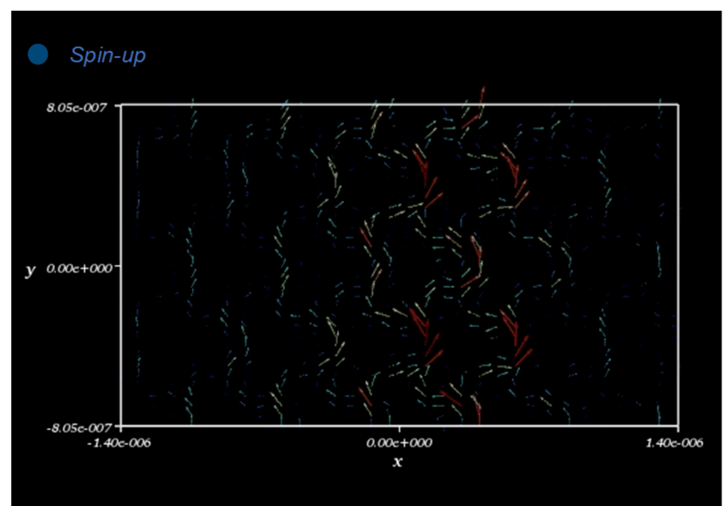




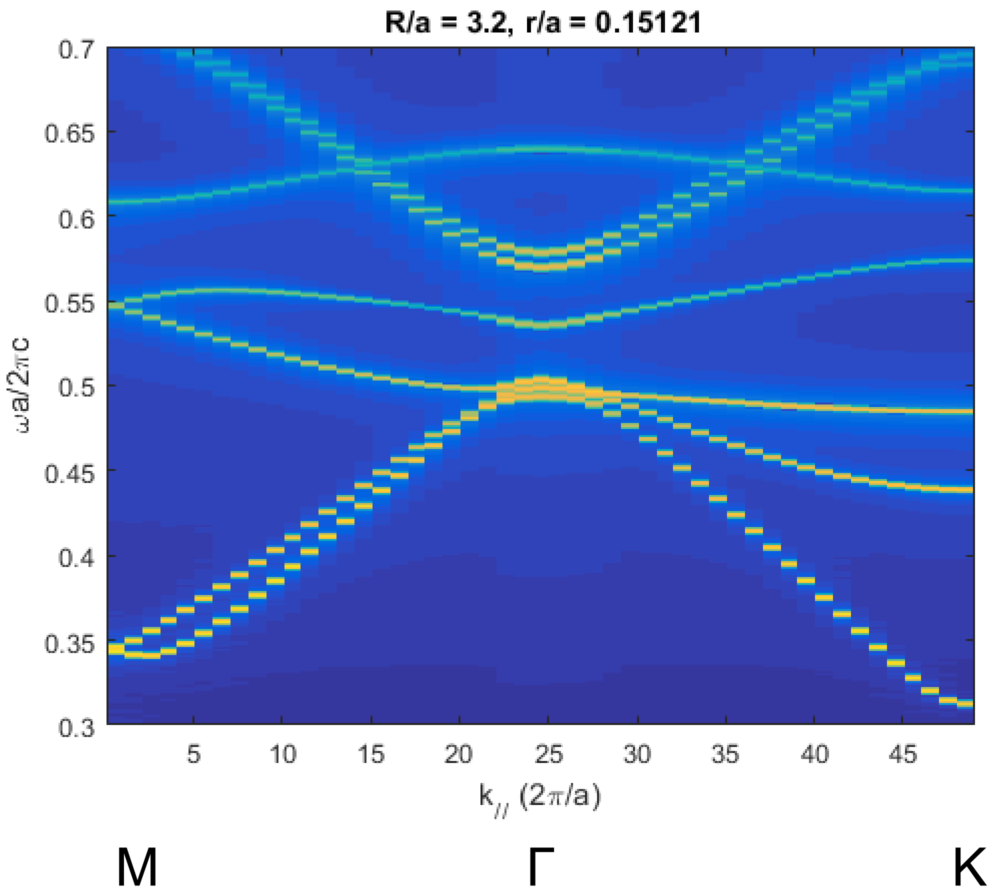
(r/a ~ *0.12*)

- Crossing unidirectional edge states are observed

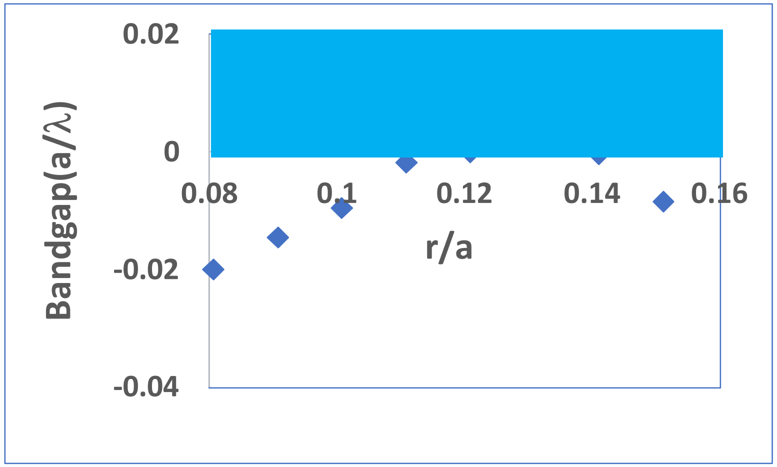




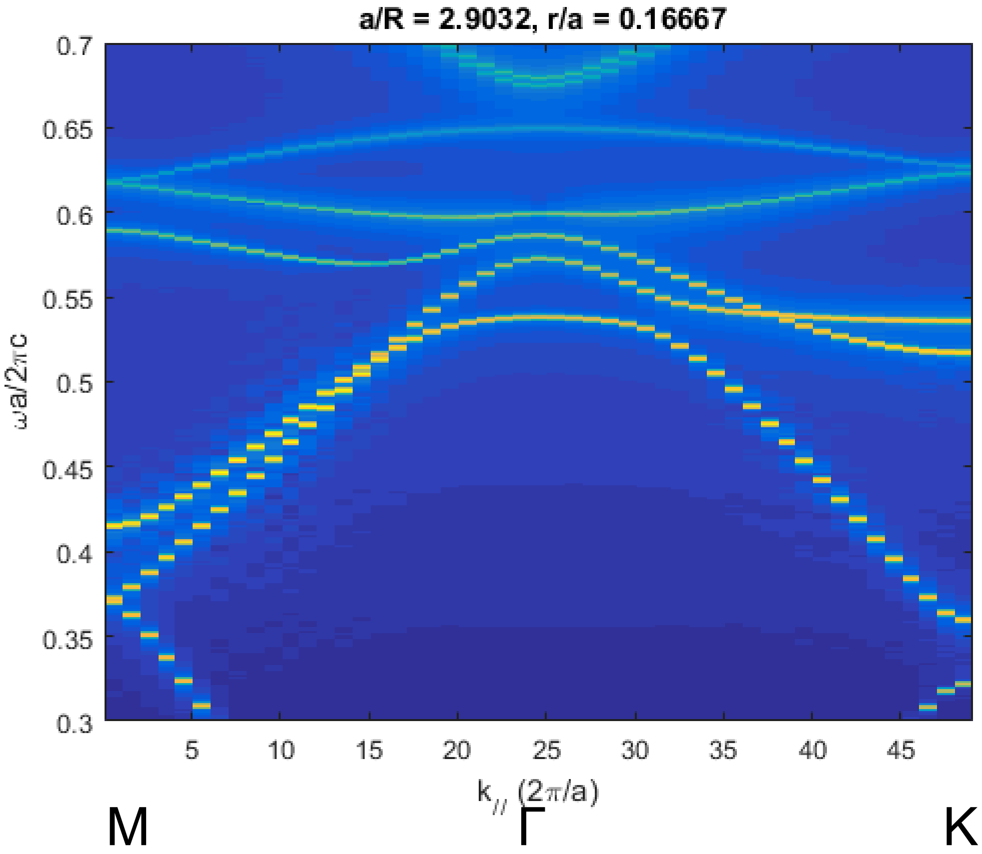
Band structure for Trivial Lattice (a/R =3.2) varying r/a)



~ 0.0025 gap

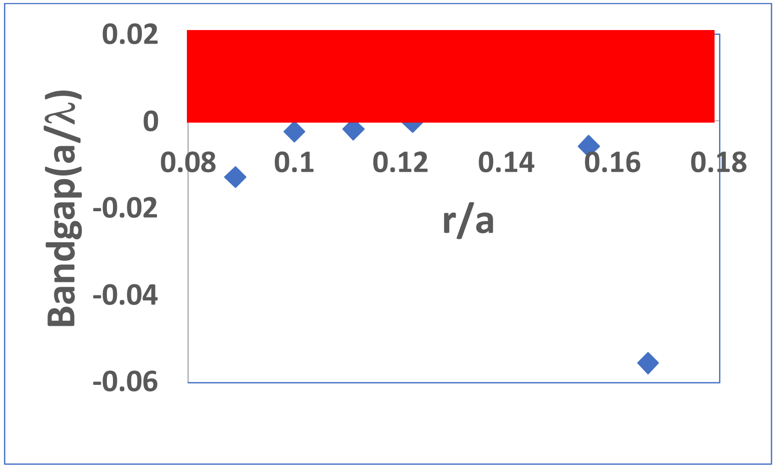


Band structure for Topological Lattice (a/R < 2.9) varying r/a

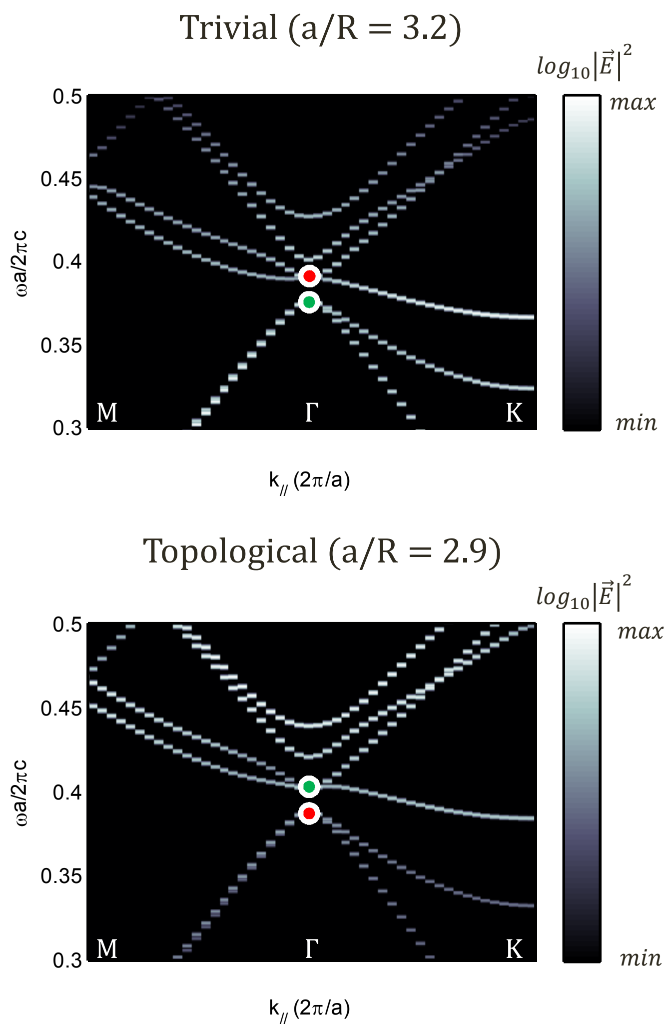


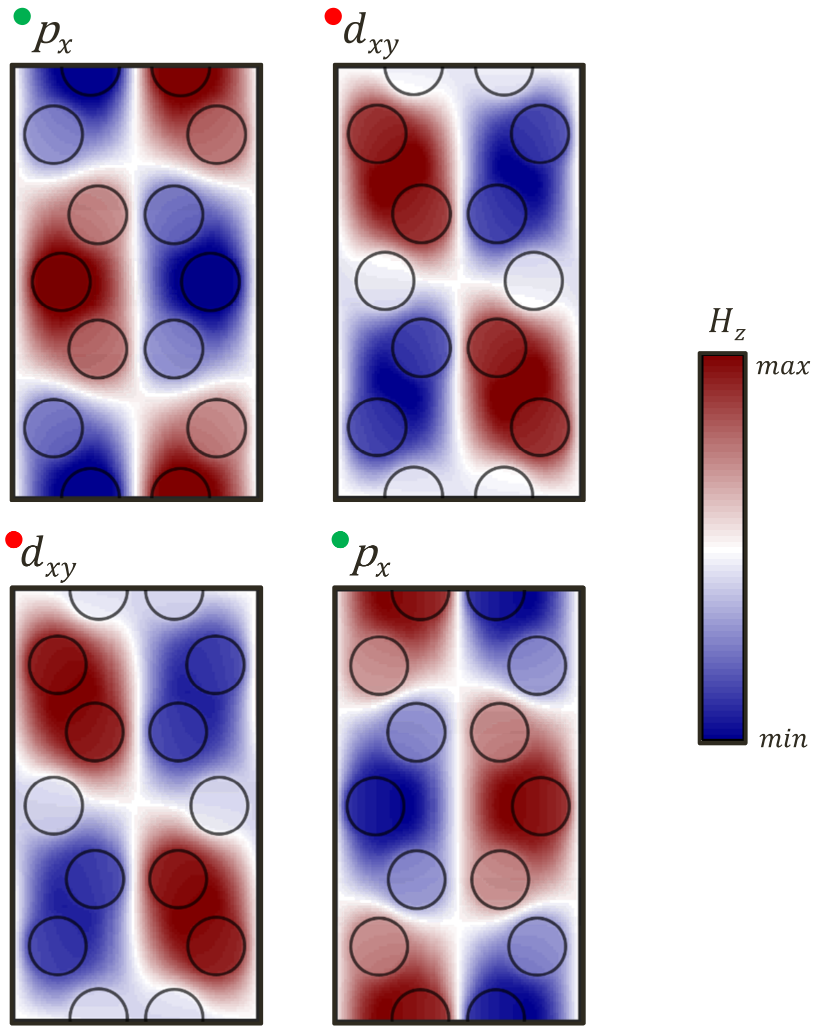
~ 0.007 gap at ~ 0.46

~ 23 nm @ λ = 1550nm



Field Distribution

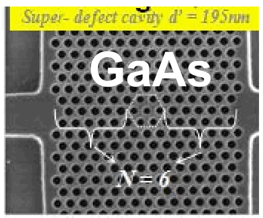


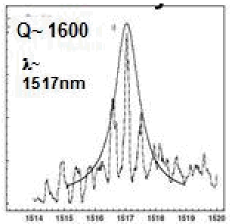


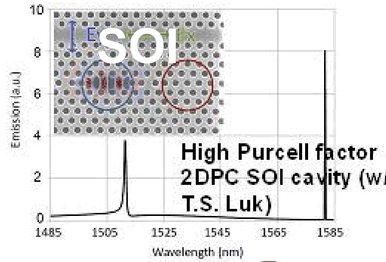
Nanophotonics Activity

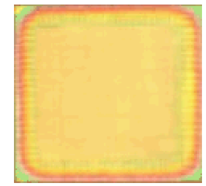
Sandia National Laboratories

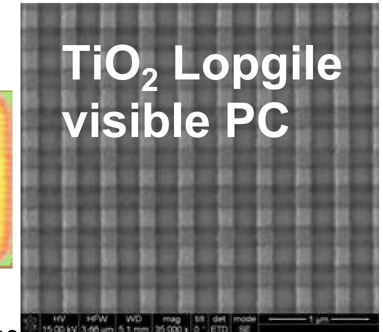
Integrated Photonics, Nanoscale lasing, Strong coupling, Full 3D emission control, Thermal control, Solid State lighting, Energy conversion

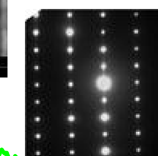


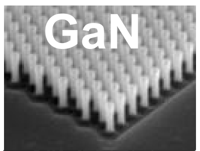










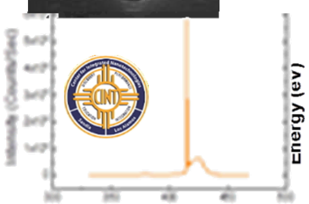


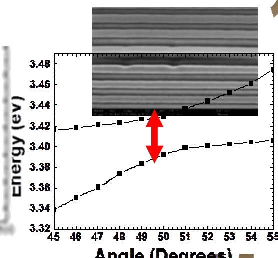
Strong coupling
(w/A. Fischer)

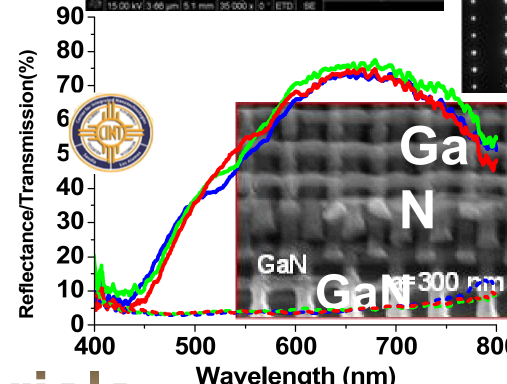
1,2D PC

3D PC

Photonic Nanostructures





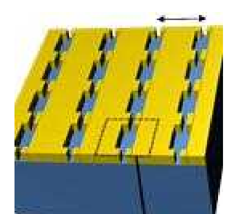


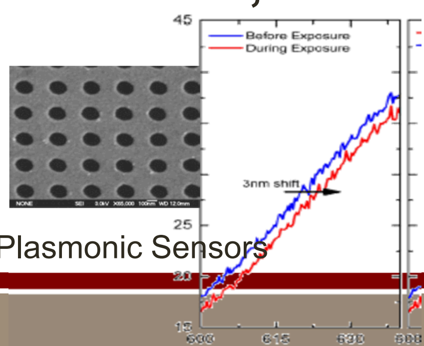
GaN 2DPC laser w/ G. Wang, I. Brener

Metal optics and Metamaterials

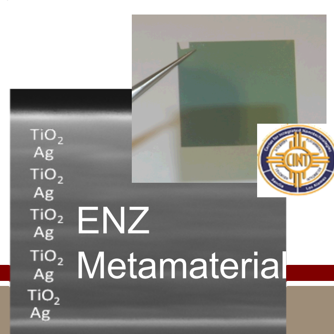
(w/ G.Wang, A. Fischer, D. Koleske)

Ultrasubwavelength light control, Detection, Sensing , Nanocircuitry



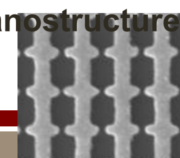


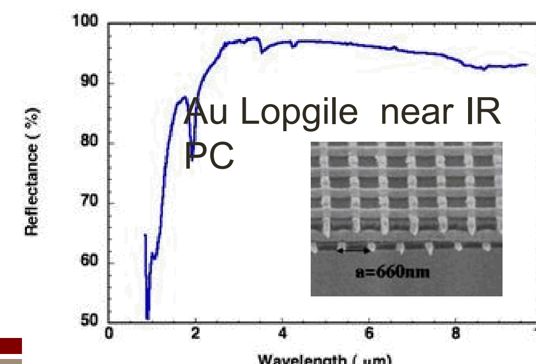
Plasmonic Sensors



ENZ Metamaterial

Double groove Metal Nanostructure





Au Lopgile near IR PC

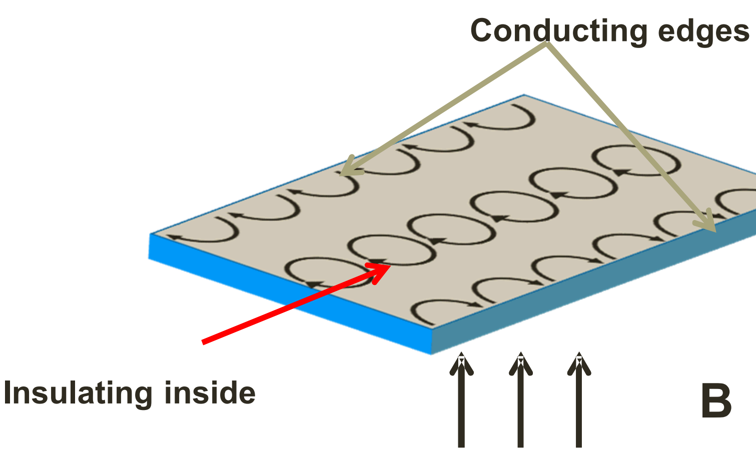
Motivation: Topological Systems in Electronics

Electronic Topological Insulators : Systems exhibiting Quantum Hall Effect → 2DEGs

Time reversal symmetry is broken by applying magnetic (B) field

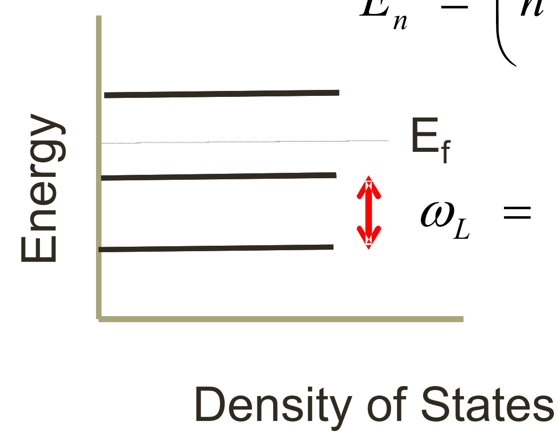
- Discrete highly degenerate Landau Levels
- Conducting edge states within insulator gap
- Topologically protected "one way" electronic transport

- *Needs high B fields*
- *Low temperatures*



Landau Levels

$$E_n = \left(n + \frac{1}{2}\right)\frac{\hbar e B}{m}$$

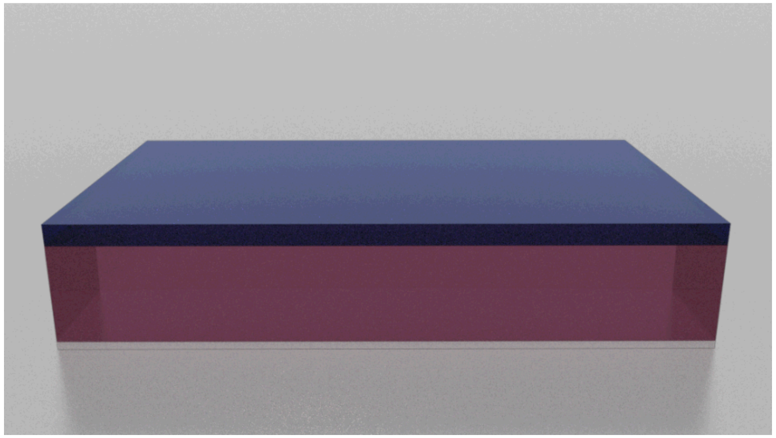


$$\omega_L = \frac{eB}{m}$$

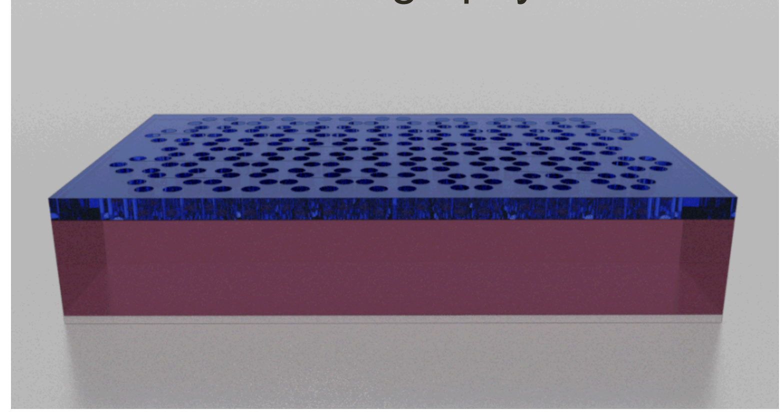
It turns out appropriately designed photonic structures can exhibit similar topological properties too!

F. D. M. Haldane and S. Raghu, Phys. Rev. Lett. **100** (1), 013904 (2008).

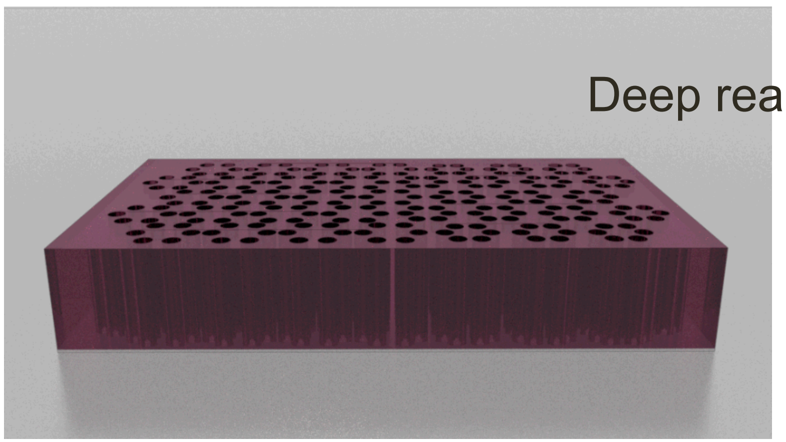
Fabrication on Thick Si using deep etch

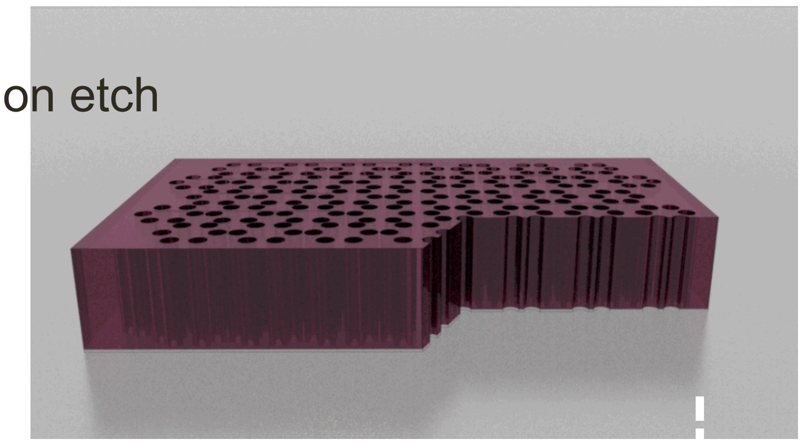


Ebeam Lithography Pattern



Deep reactive Ion etch



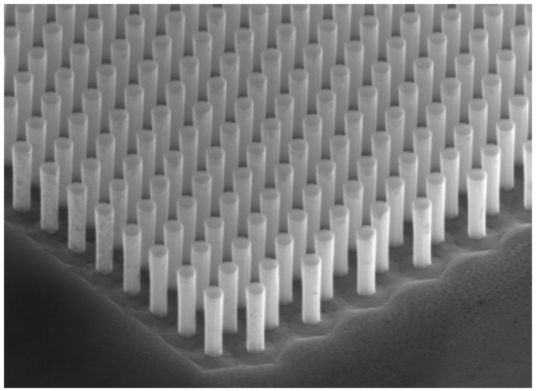


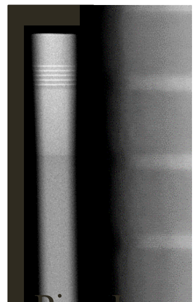
SEM image

Topological structure in active material systems

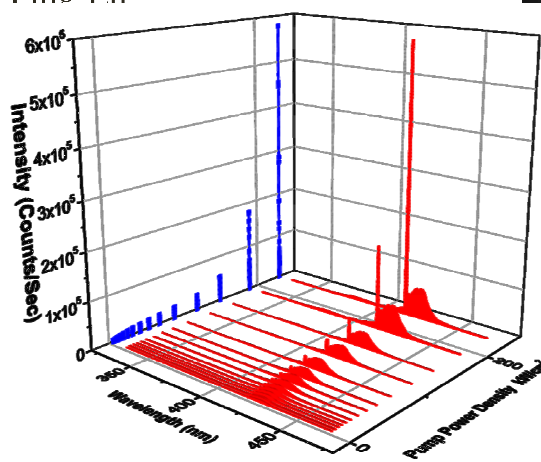
PhC nanrod array have shown excellent light emission behavior

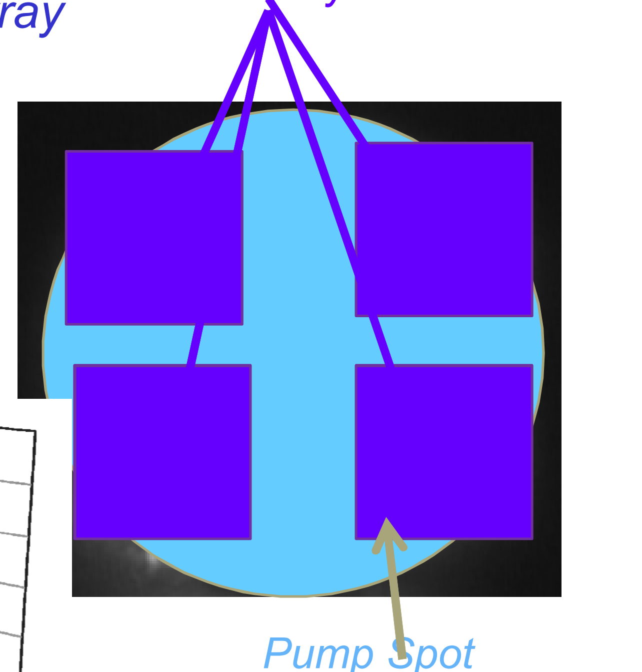
Demonstration of Lasing from PhC Array





Fabricated by using a top down approach from a planar GaN with InGaN Multiple quantum wells



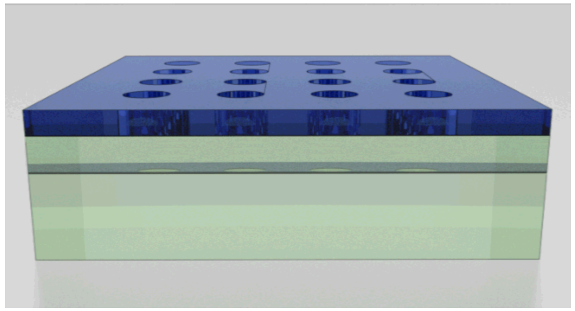


J. B. Wright et,al., Sci. Rep. **3**, 2982 (2013).

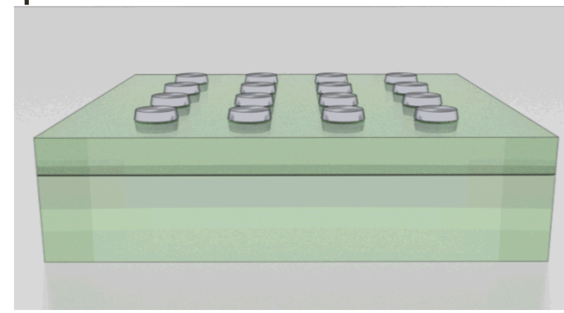
Light sources with interesting angular momentum properties ?

Fabrication procedure in GaN

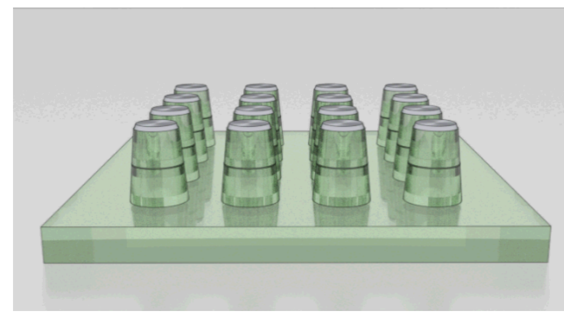
EBL pattern in PMMA

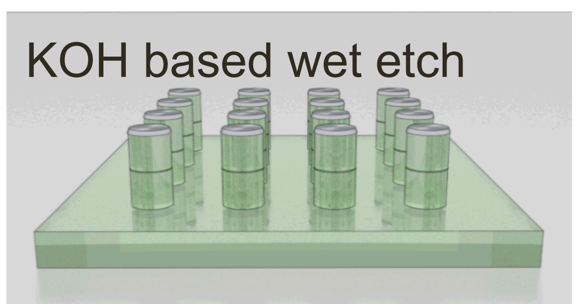


Ni evaporation and lift-off

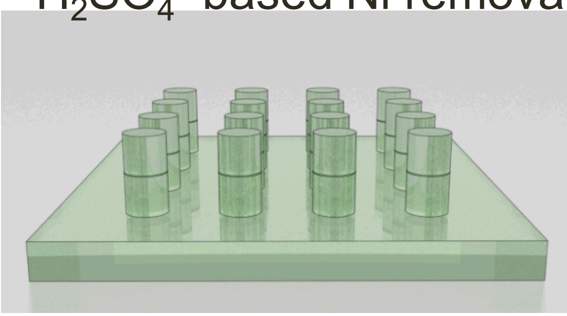


Cl2 based dry etch





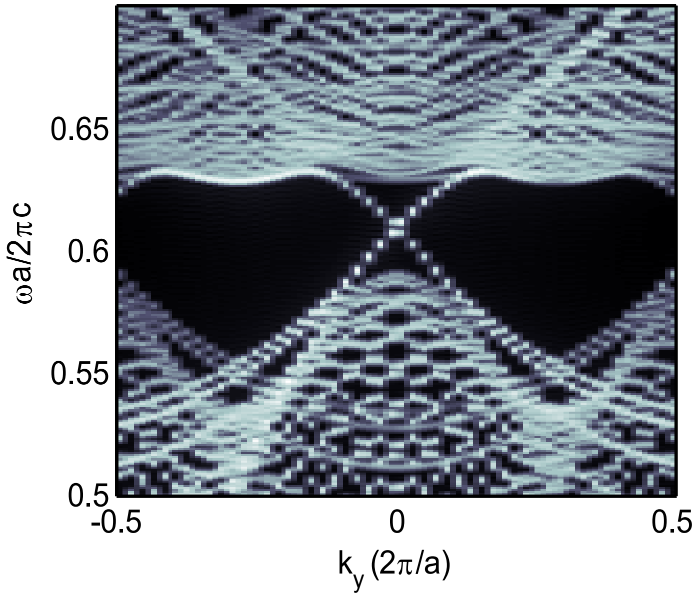
H_2SO_4–based Ni removal

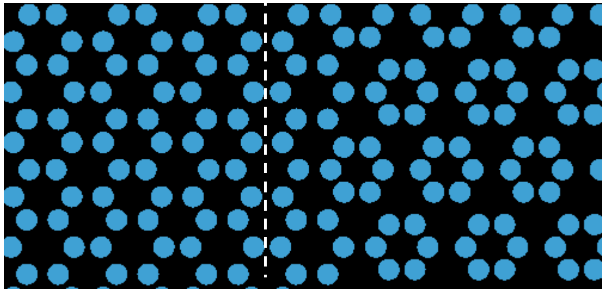


Topological edge state in honeycomb lattice structure in III-Nitride

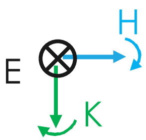
Modeling

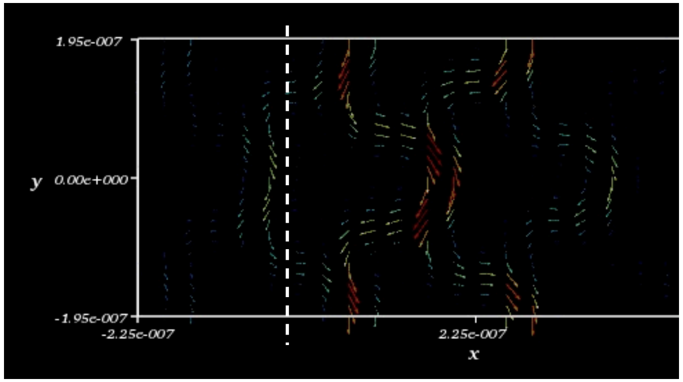
Band Structure



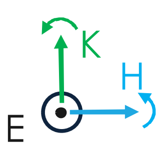


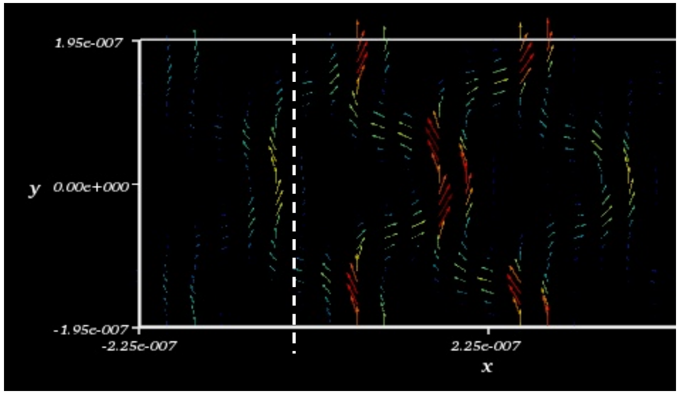
Spin-down state
a/λ = 0.618



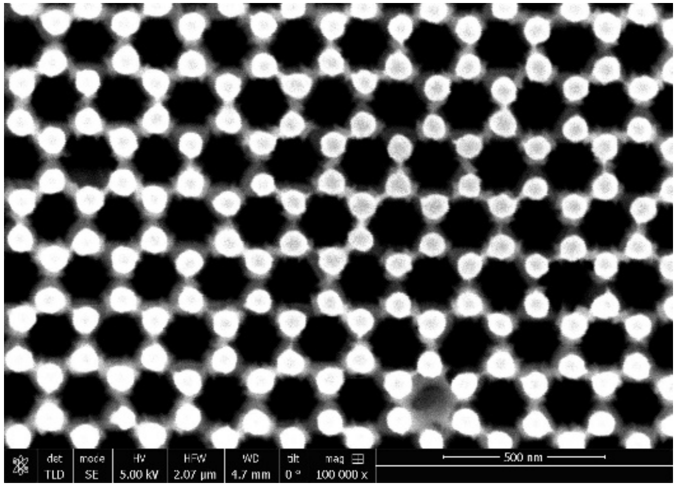


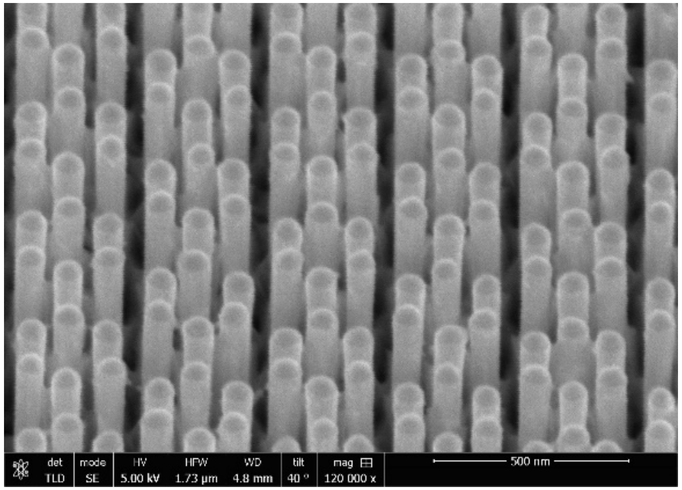
Spin-up state
a/λ = 0.60

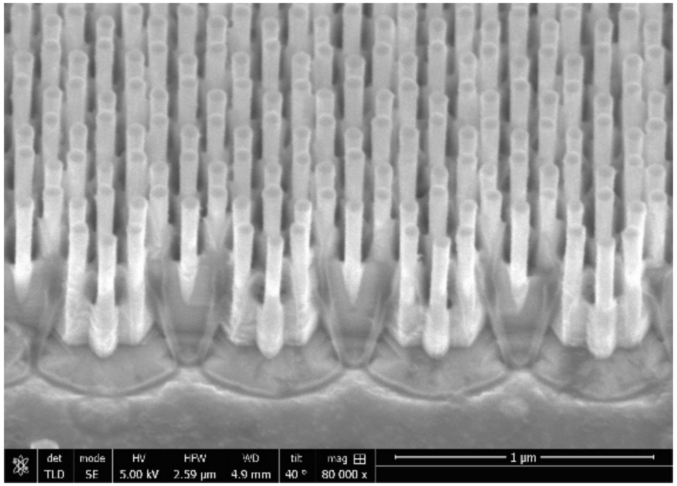




Topological/Trivial lattice interface structure in III-Nitride



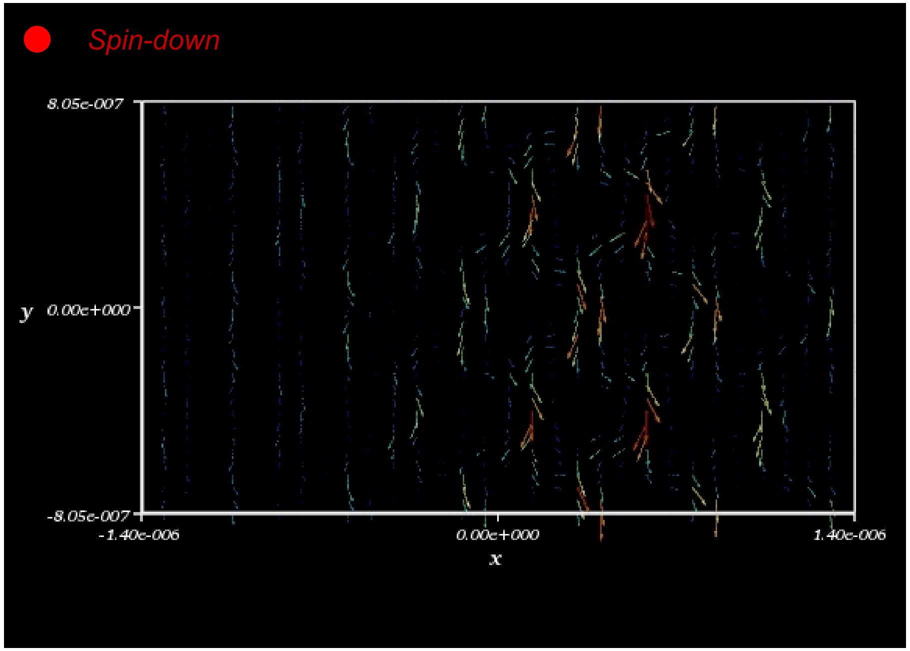


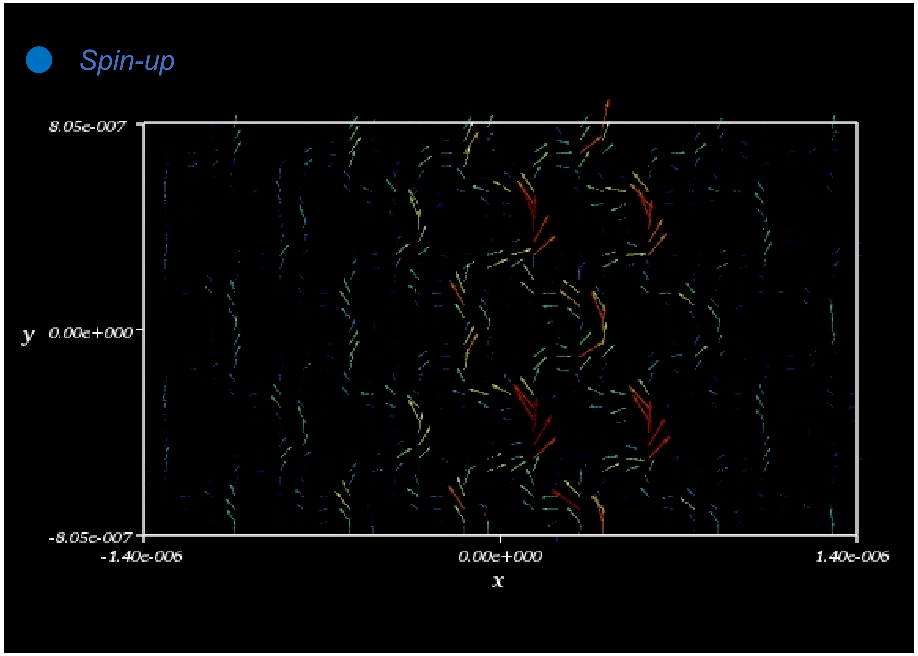


Ongoing …

- ❑ Main challenges
  - ❑ Deeper etching
  - ❑ Source polarization

Power/Vector Plots of Edge States





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

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(Received 10 February 2015; published 3 June 2015)

Modified honeycomb lattice of hexagonal cylindrical dielectric rods