SAND2017-0431C

Topological Photonics Research at Sandia Labs

Ganapathi Subramania

Collaborators: P. Duke Anderson[*+], Daniel D. Koleske[*]

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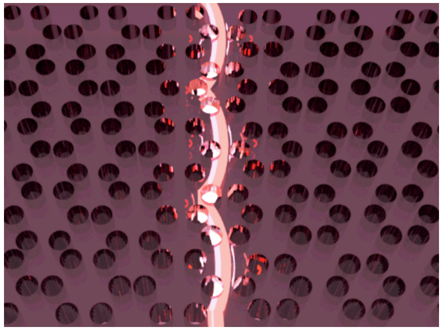

Jan 8-13, 2017
Physics of Quantum Electronics
Snowbird, UT

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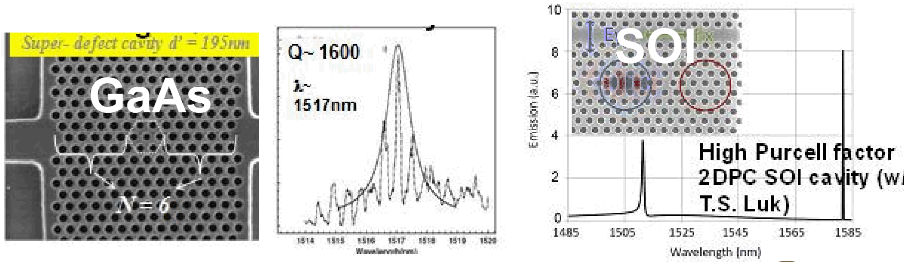
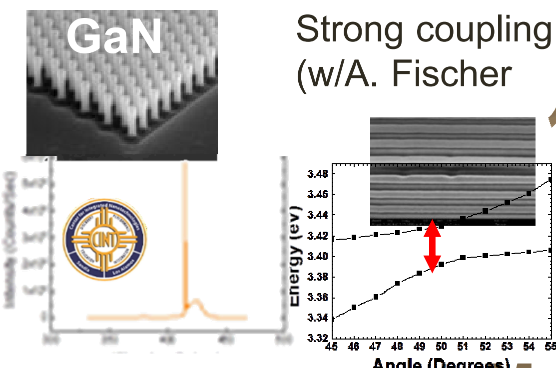
Nanophotonics Activity

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



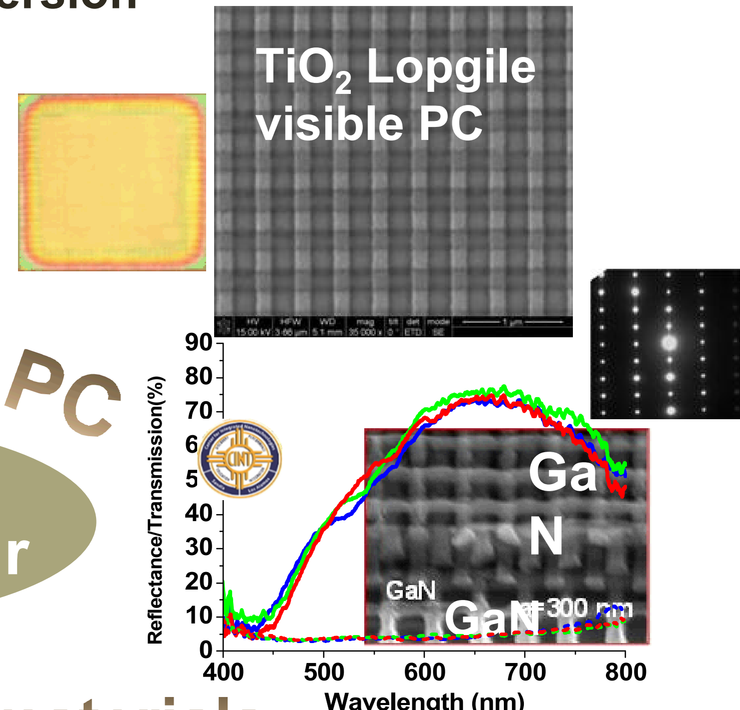


GaN 2DPC laser w/ G. Wang, I. Brener

1,2D PC

3D PC

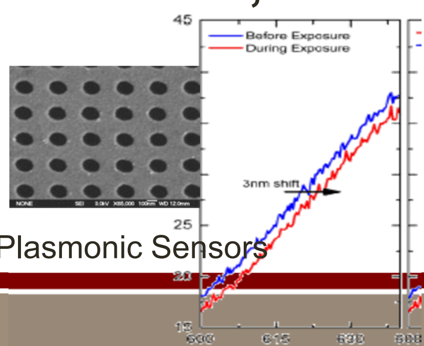
Photonic Nanostructur



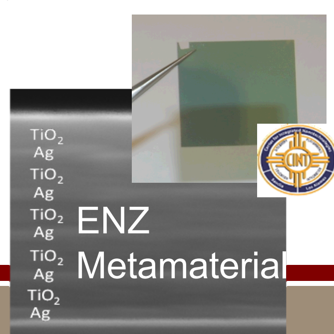
(w/ G.Wang, A. Fischer, D. Koleske)

Metal optics and Metamaterials

Ultrasubwavelength light control, Detection, Sensing , Nanocircuitry

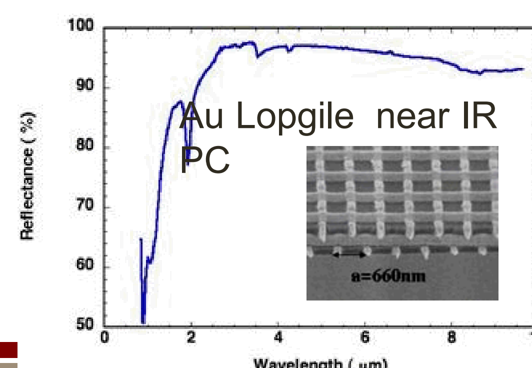


Plasmonic Sensors



ENZ Metamaterial

Double groove Metal Nanostructure



Au Lopgile near IR PC

Outline

- Introduction
- Designs for photonic spin hall effect
  - Modified honeycomb lattice
  - Rod vs. Hole array structure
- Fabrication approach
  - Passive devices
  - Active devices
- Summary and Future directions

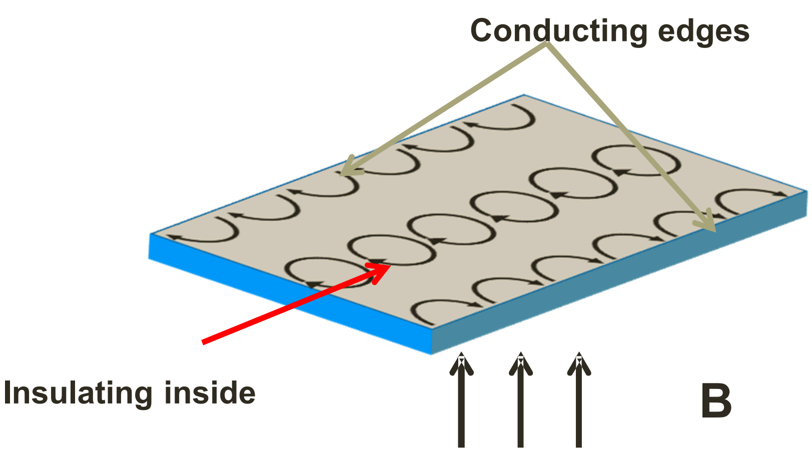
Topological Systems in Electronics

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

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

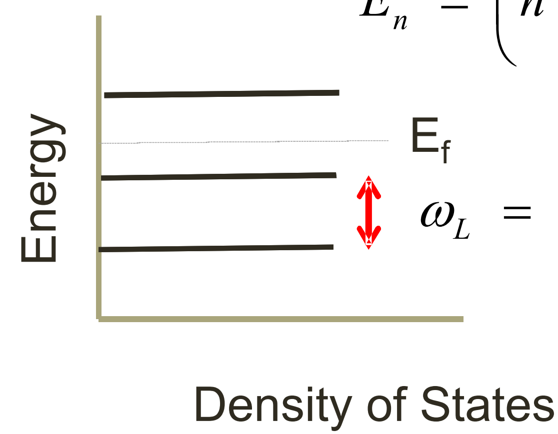
- Discrete highly degenerate Landau Levels
- Conducting edge states within insulator gap
- Topologically protected "one way" electronic transport

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



Landau Levels

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

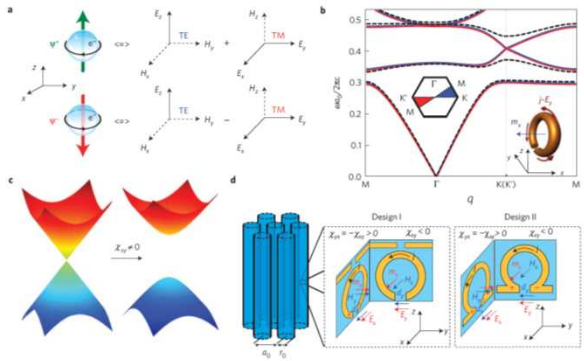


$$\omega_L = \frac{eB}{m}$$

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

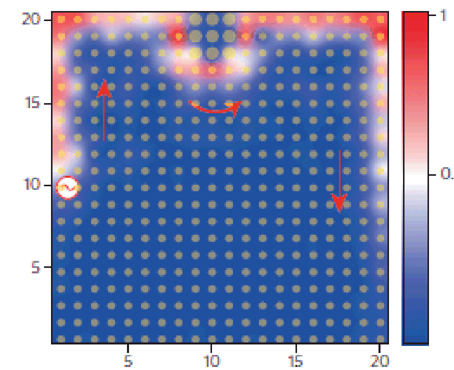
http://jqi.umd.edu/glossary/quantum-hall-effect-and-topological-insulators

Topological Photonics Research Activities

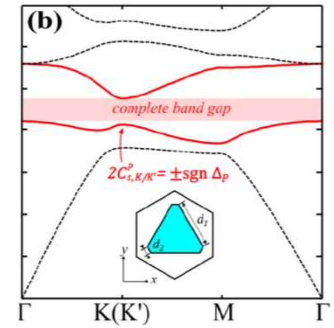


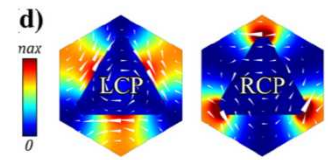
A. B. Khanikaev et.al. Nat Mater **12** (3), 233-239 (2013).

Simulation of Oneway edge transport



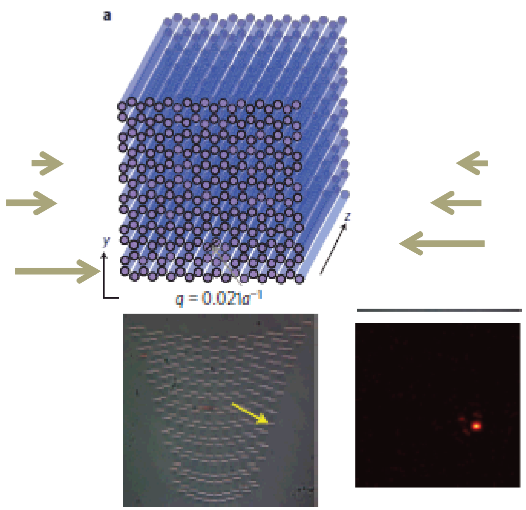
K.Fang, Z. Yu , S.H.Fan , **Nat. Phot. 6 ,** (2012)





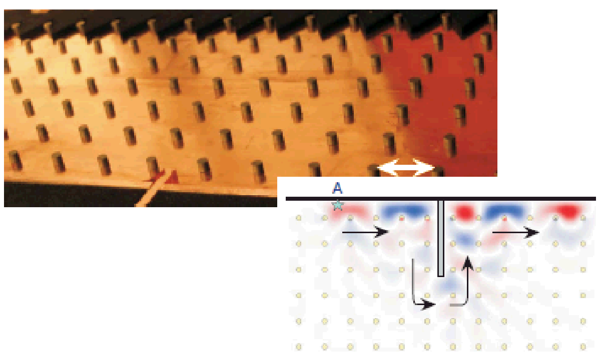
M. Tzuhsuan and S. Gennady, New Journal of Physics **18** (2), 025012 (2016).

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

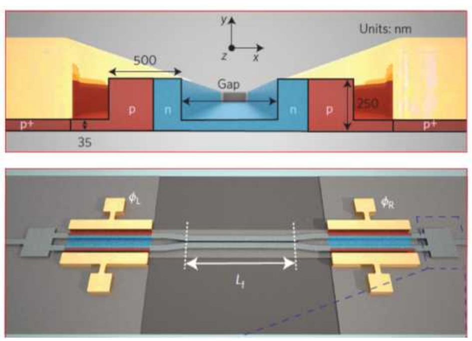


M.Rechtsman et.al. **Nat. Phot. 7** (2013) *E*

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



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



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

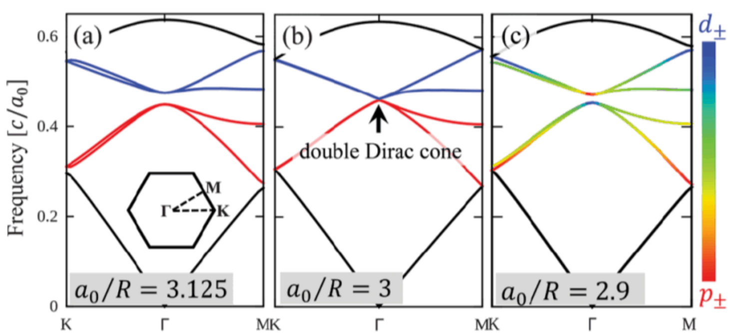
Topological Photonics Spin Hall in Dielectric PC

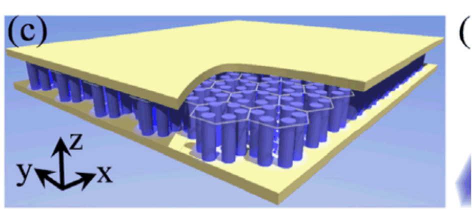
PRL 114, 223901 (2015) PHYSICAL REVIEW LETTERS week ending 5 JUNE 2015

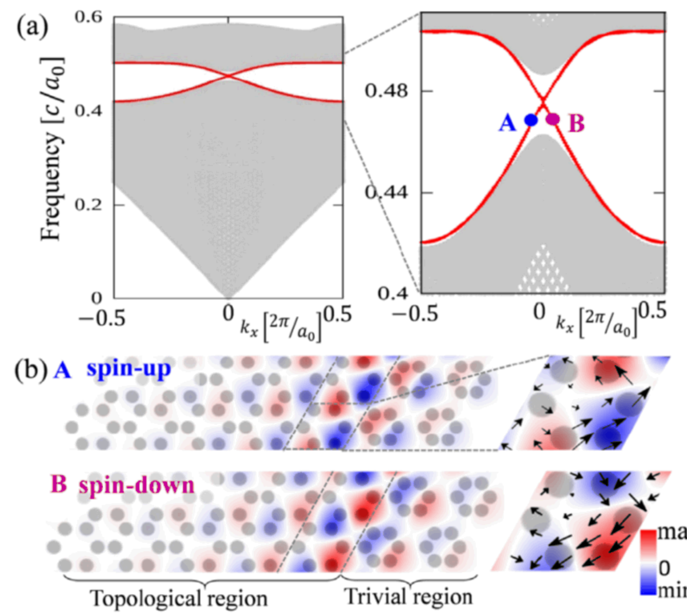
Scheme for Achieving a Topological Photonic Crystal by Using Dielectric Material

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)





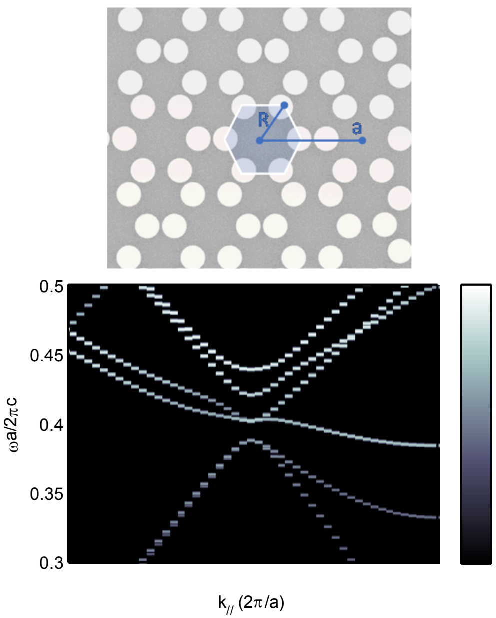


Modified honeycomb lattice of dielectric rods

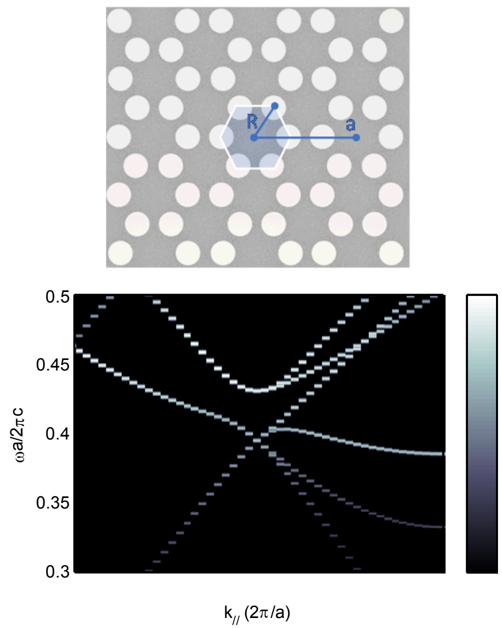
Sandia National Laboratories

Photonic Bandstructures for Modified Honeycomb Lattices

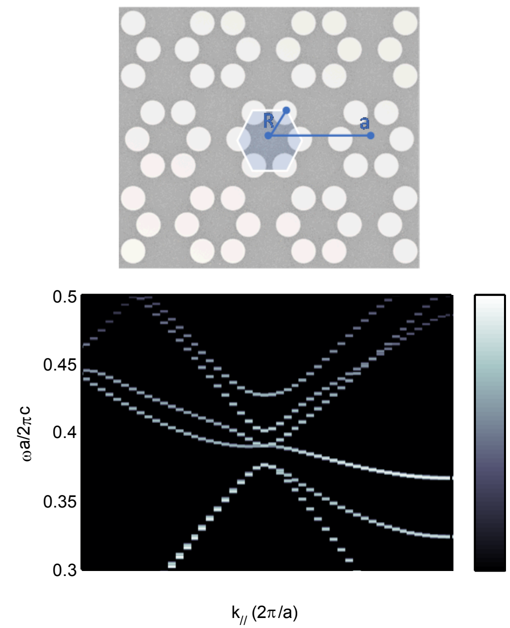
- Holes in dielectric design can be useful for optical frequency photonics applications



Trivial (a/R = 2.9)



Honeycomb (a/R = 3.0)



Topological (a/R = 3.2)

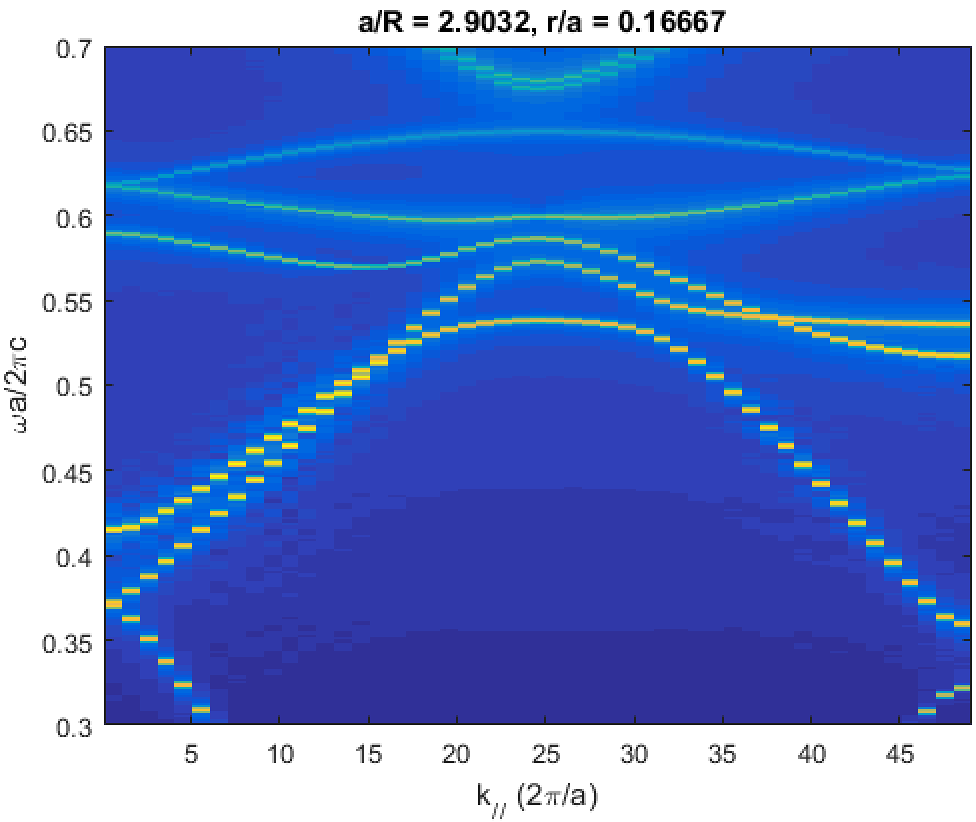
(r/a ~ 0.12)

Does not open up a band gap !

Calculated with FDTD (Lumerical ®)

Band structure for Trivial Lattice (a/R < 3.0) varying r/a

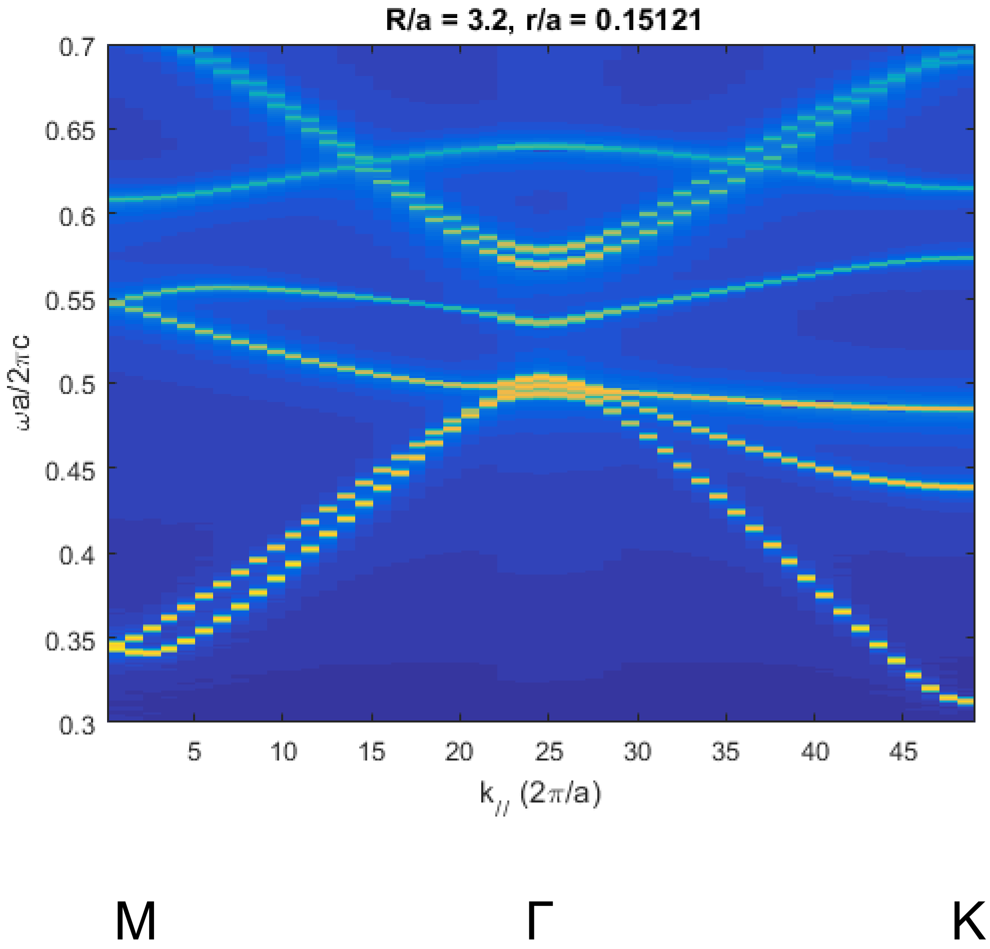
For λ = 1550 nm, a ~ 900 nm



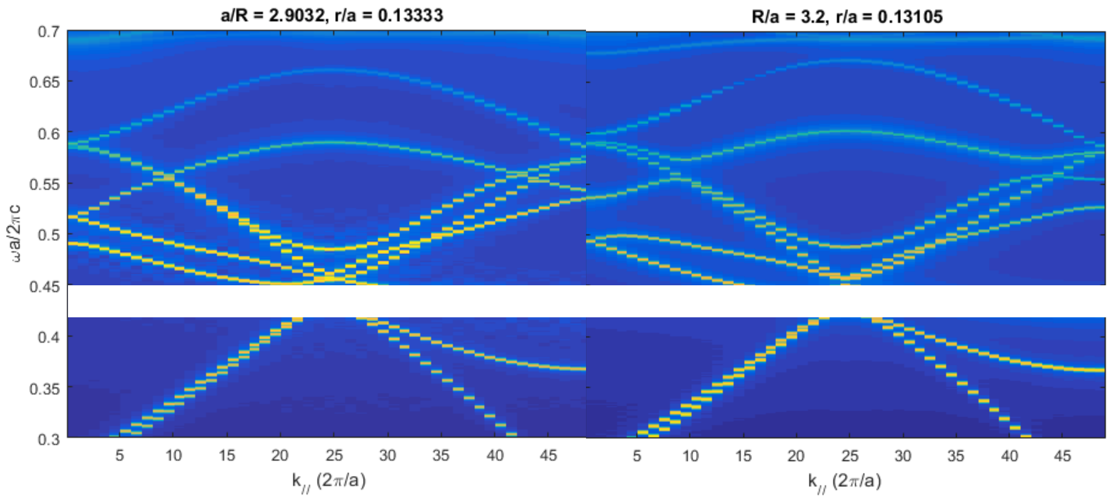
M Γ K

Band structure for Topological Lattice (a/R > 3.0) varying r/a)

For λ = 1550 nm, a ~ 900 nm



Band gap alignment for Topological/Trivial Interface



Let's assume that **a = 700 nm** and **λ = 1550 nm** ($\omega a/2\pi c \sim 0.45$)

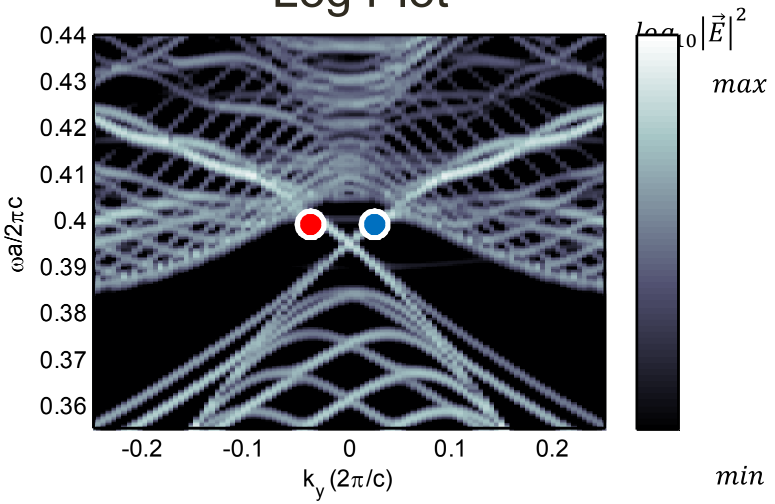
Assuming equal lattice constants: $\mathbf{R_{triv}}$ **= 241 nm** and $\mathbf{R_{top}}$ **= 218 nm**

Lastly, $\mathbf{d_{triv}}$ **= 187 nm** and $\mathbf{d_{top}}$ **= 183 nm**

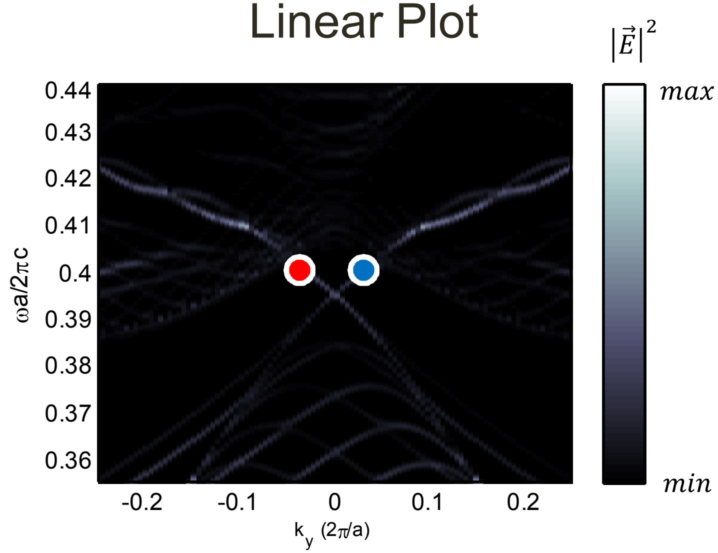
Band structure for Topological/Trivial Zig-zag Interface

R_{triv}/a = 0.312, R_{top}/a = 0.344, r/a = 0.12, a = 700 nm

Log Plot

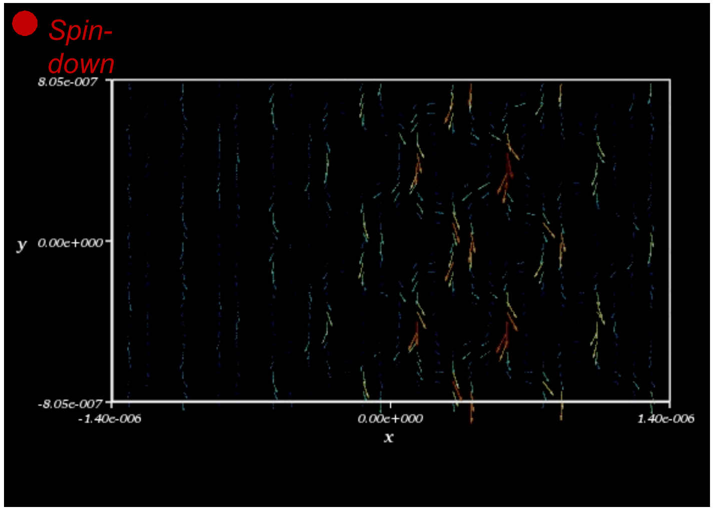


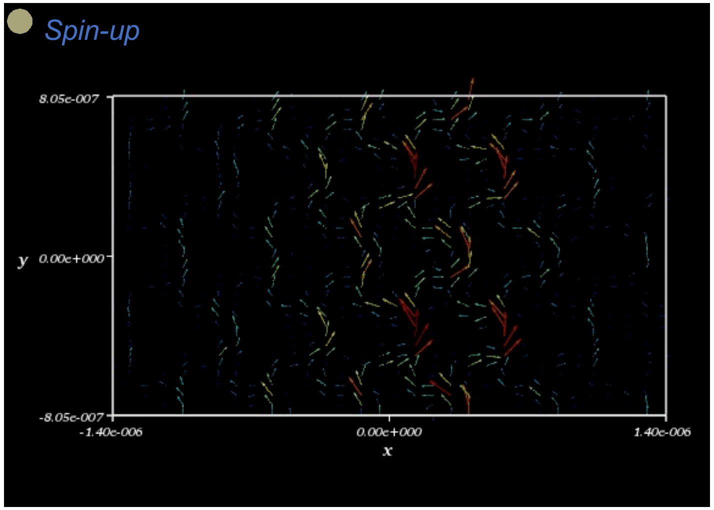
Linear Plot



- Crossing unidirectional edge states are observed
- Other modes show up in the band structure as well

Power/Vector Plots of Edge States



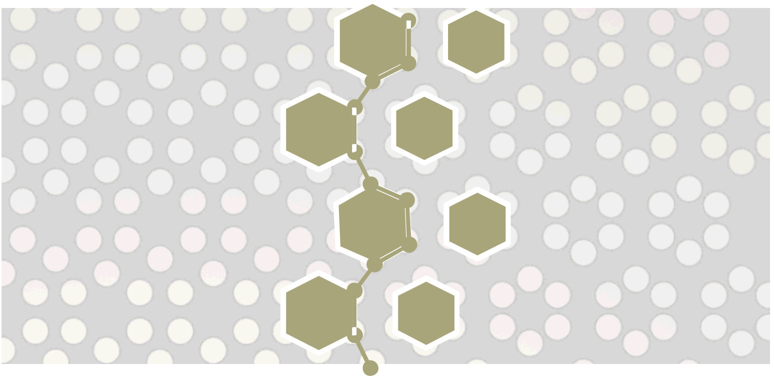


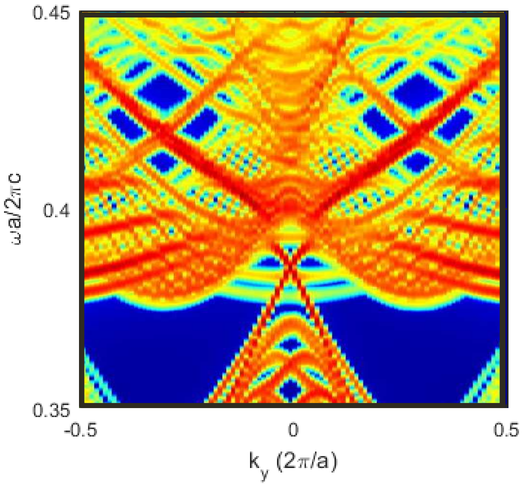
Band structure for Topological/Trivial Armchair Interface

Ribbon/Interface Photonic Band Structure

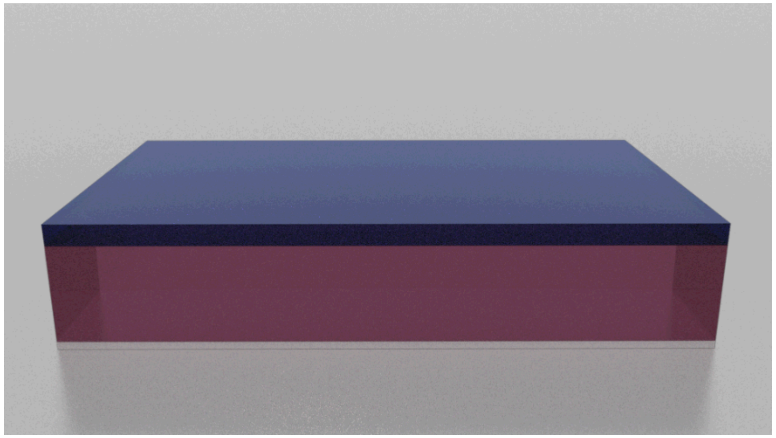
$R_{triv}/a = 0.312$, $R_{top}/a = 0.344$, $r/a = 0.12$, a = 700 nm

ArmChair-like Interface

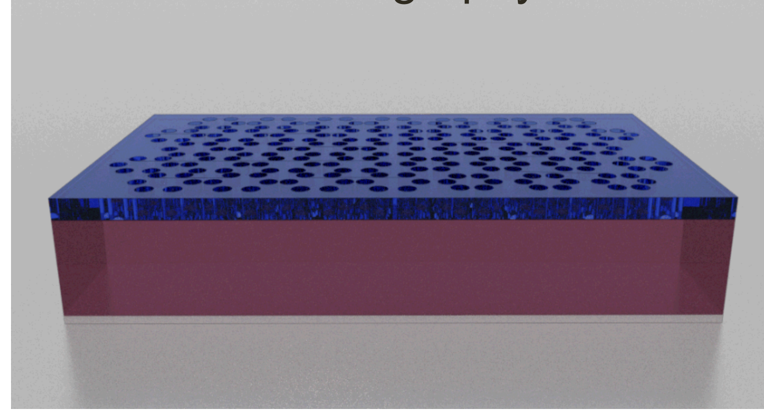




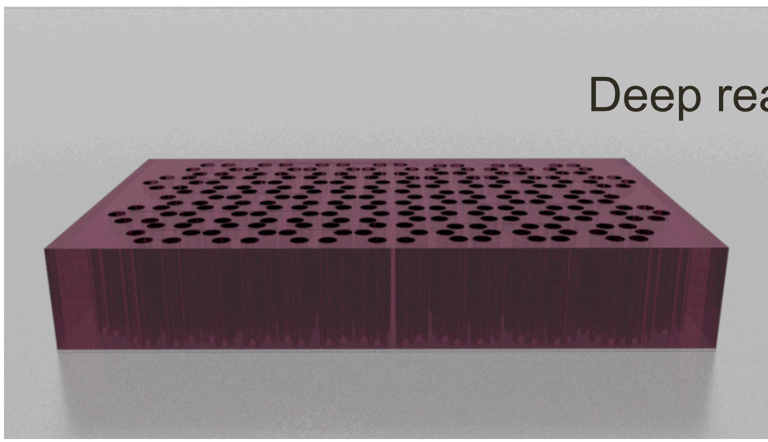
Fabrication on Thick Si using deep etch

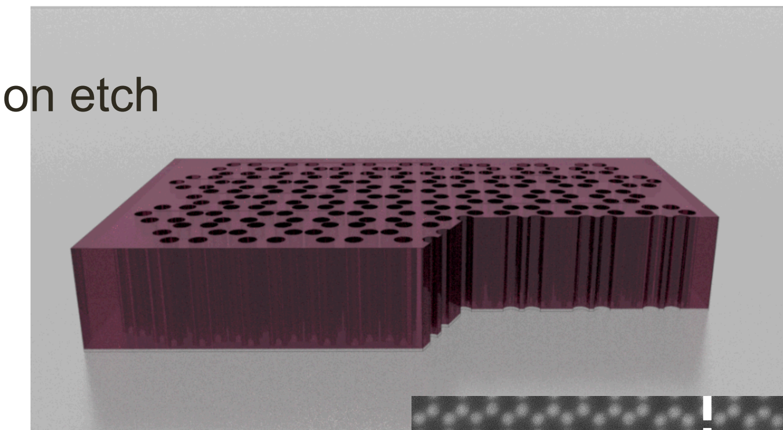


Ebeam Lithography Pattern

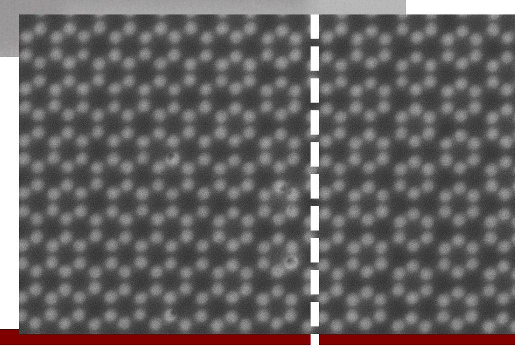


Deep reactive Ion etch





SEM image

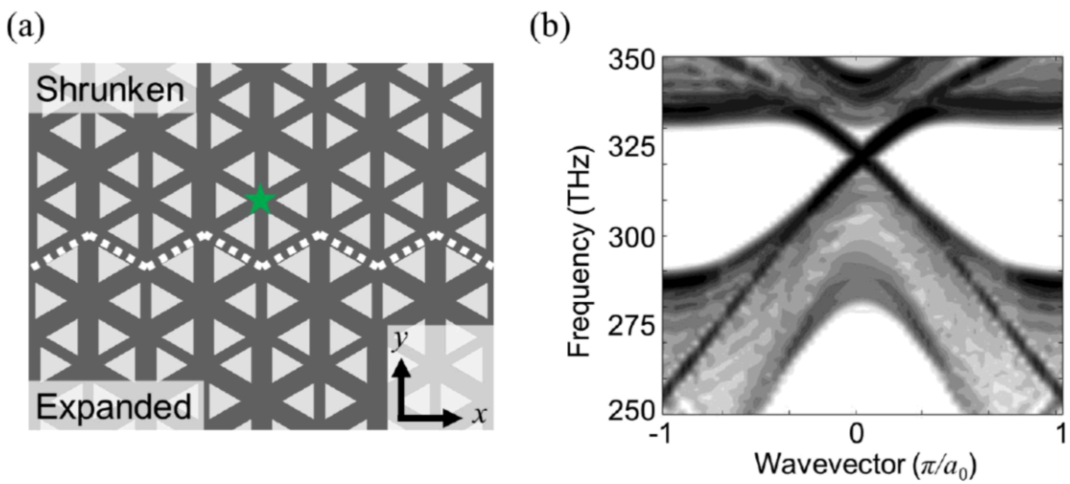


Alternate possibilities …

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]

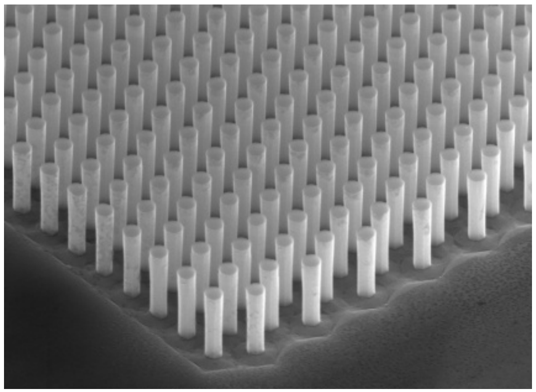


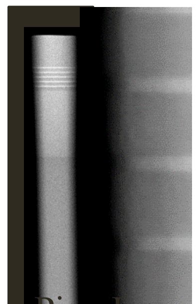
Fabrication could be challenging

Topological structure in active material systems

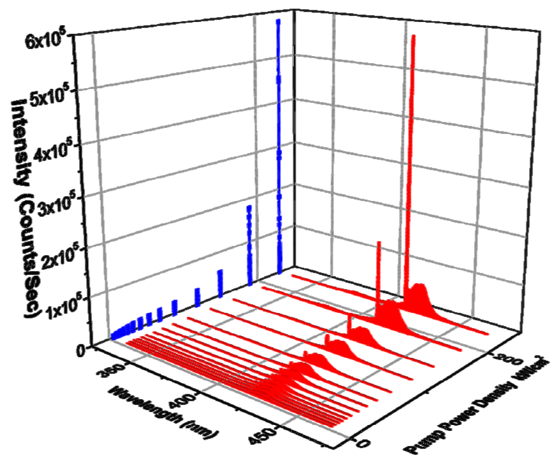
III- nitride material with InGaN Quantum wells

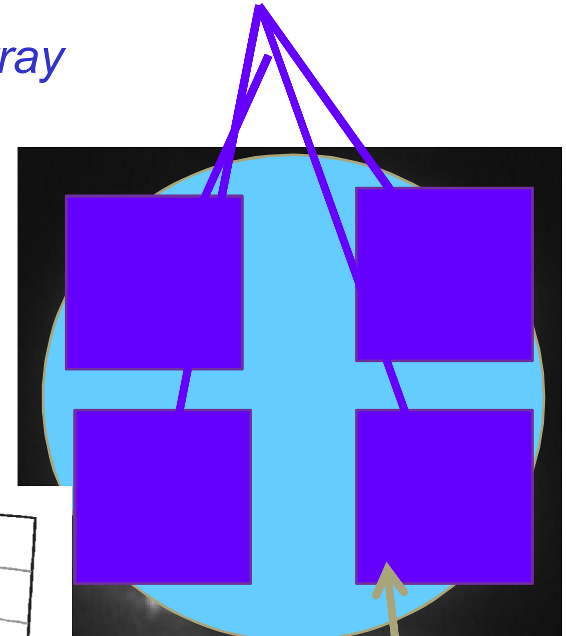
Demonstration of Lasing from PhC Array





Ping Lu, Sandia

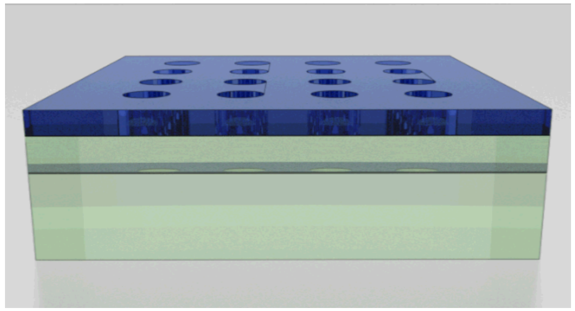




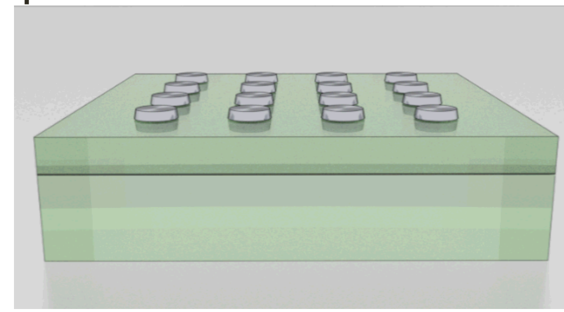
Light sources with interesting angular momentum properties ?

Fabrication procedure in GaN

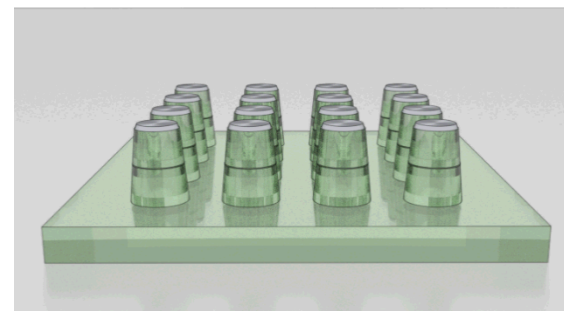
EBL pattern in PMMA

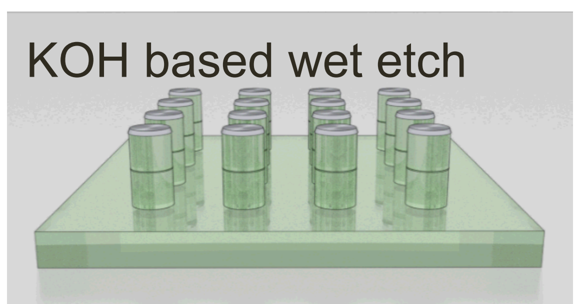


Ni evaporation and lift-off

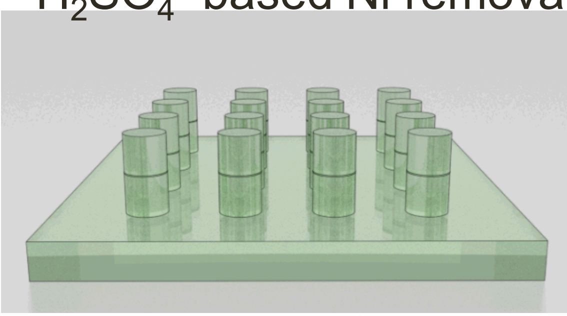


Cl2 based dry etch





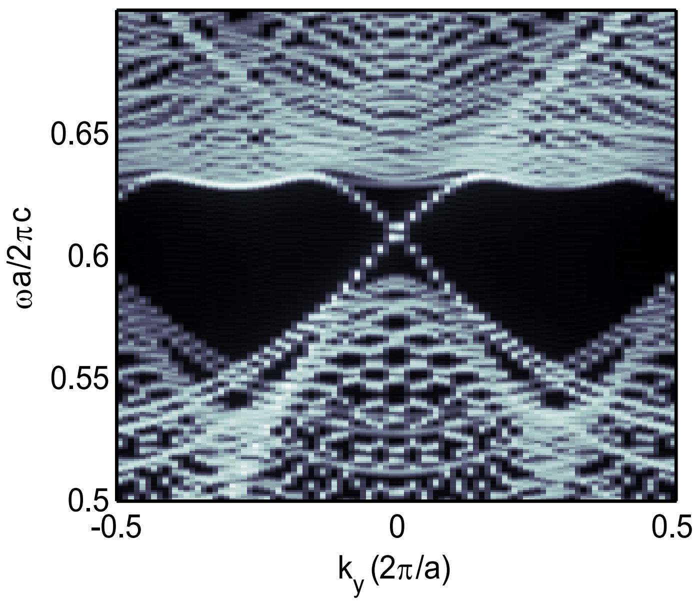
H_2SO_4–based Ni removal

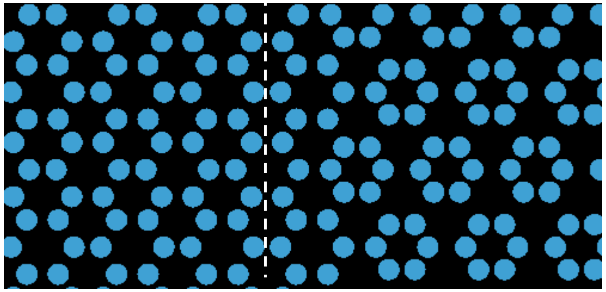


Topological edge state in honeycomb lattice structure in III-Nitride

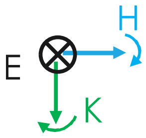
Modeling

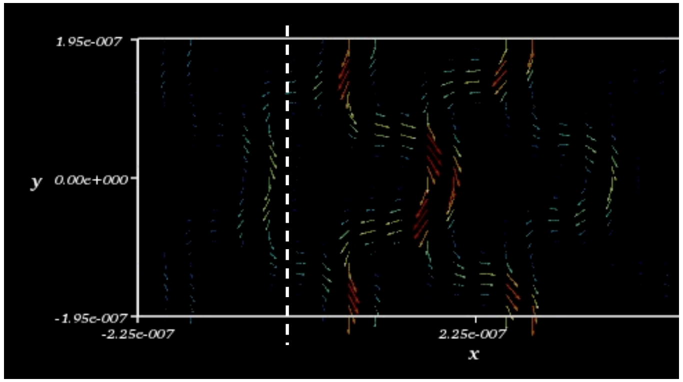
Band Structure



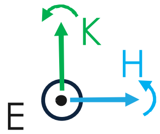


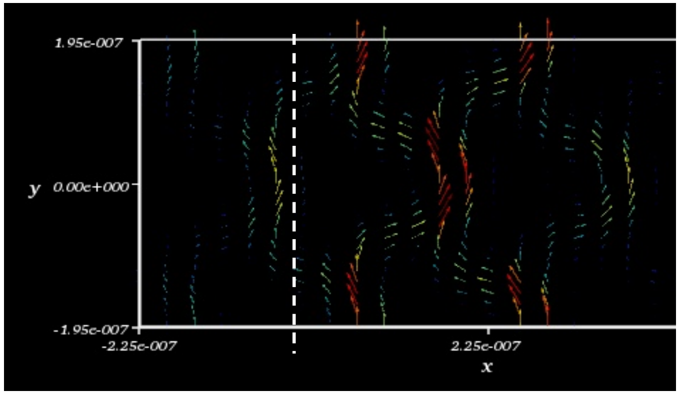
Spin-down state
a/λ = 0.618



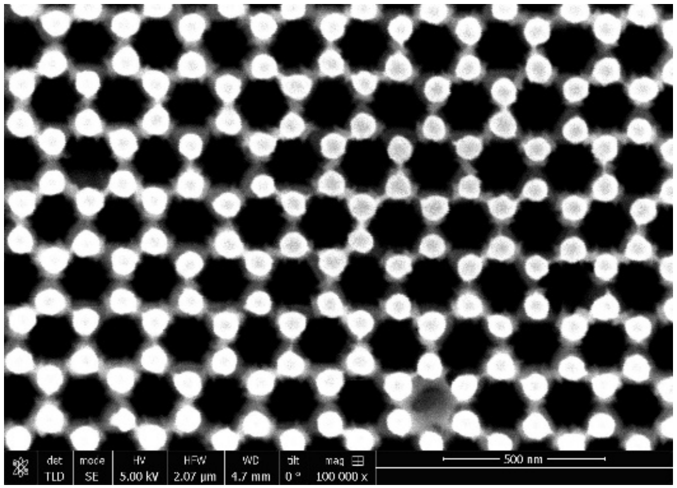


Spin-up state
a/λ = 0.60

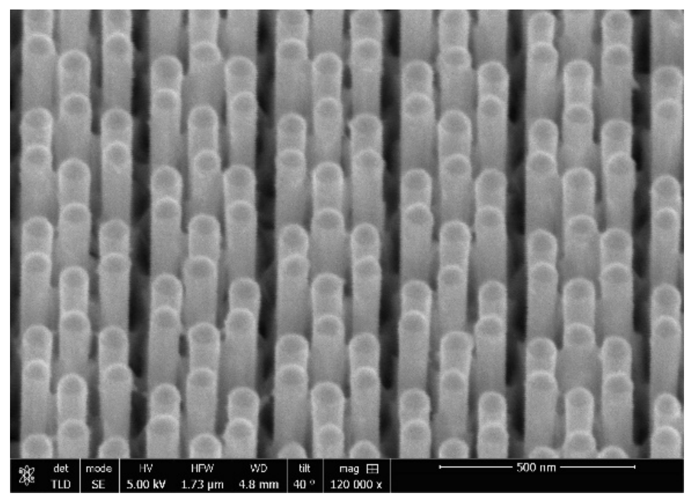


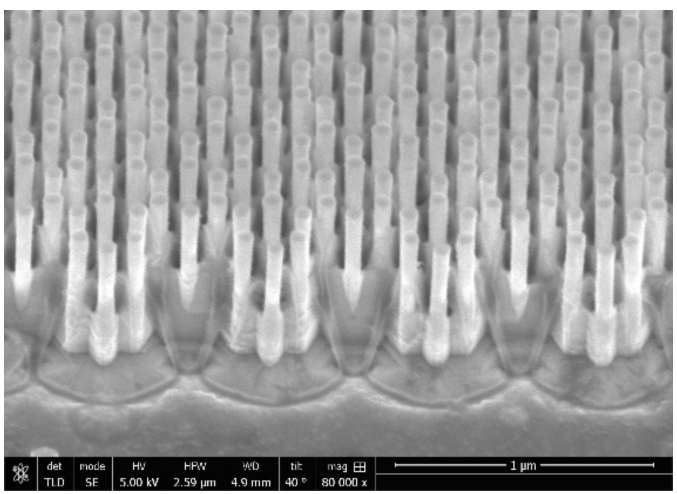


Fabricated Topological/Trivial lattice interface structure in III-Nitride



- ❑ Main challenge
  - ❑ Source polarization





Summary and Future directions

- Hole array honey comb lattice structure for photonic pseudo spin
- Fabrication in III-nitride
- Fabrication in Silicon/SOI
- Optical measurement to demonstrate pseudo spin

Thank you for your attention!

Fabrication on Silicon on Insulator (SOI) - Membrane

SOI Device Fabrication (Membrane)