Dynamic Photonic Crystal Superlattices

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Outline

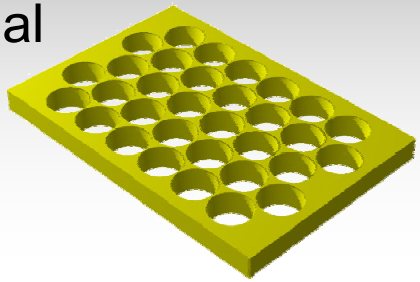
- Introduction/Motivation
- Structure & method of analysis
- 2D slab triangular lattice
  - Tunability with electo-optic materials
- New concept:
  - Superlattice photonic crystal
  - Refraction behavior
  - Switching effects
- Summary
- Acknowledgements

Introduction/Motivation

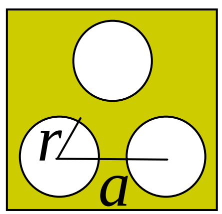
- Fabrication of 2D photonic crystals not as complicated as 3D
- Integration onto opto-electronic systems directly on common substrate
- Large refraction effects (superprism) for beam steering, signal processing, demultiplexing
- **Investigate methods to electro-optically tune these effects**
  - **Infiltrate with electro-optical or nonlinear materials (eg. liquid crystal)**
  - **Tunable refraction**
  - **Switching**

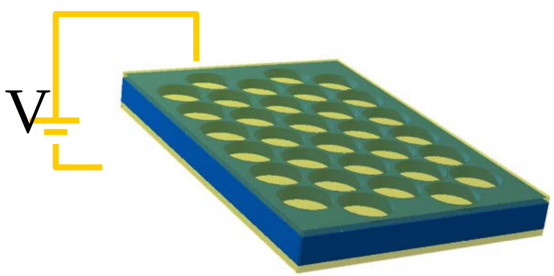
Structure & Method of Analysis

Conventional lattice



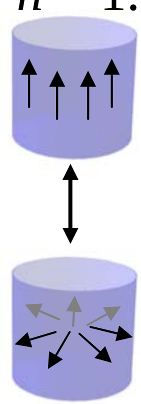
Unit cell





Infiltrated lattice

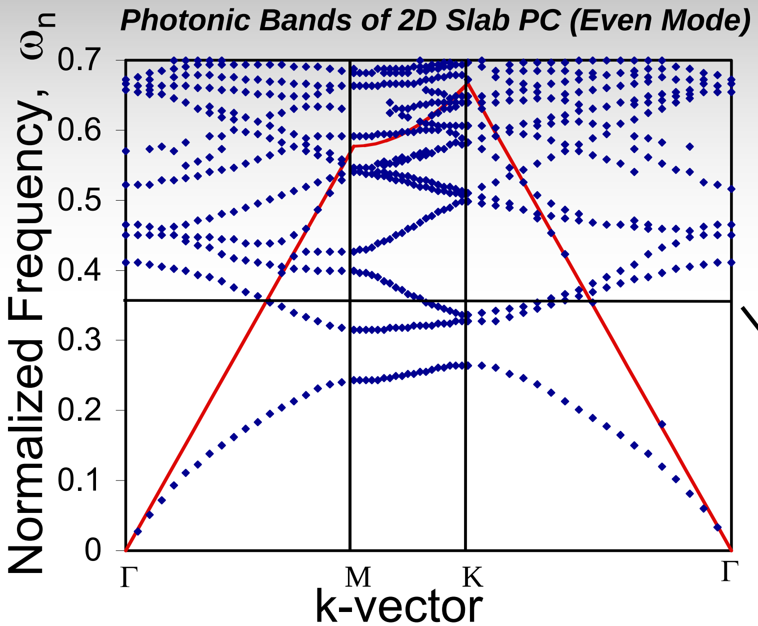
Biased
$n = 1.5$

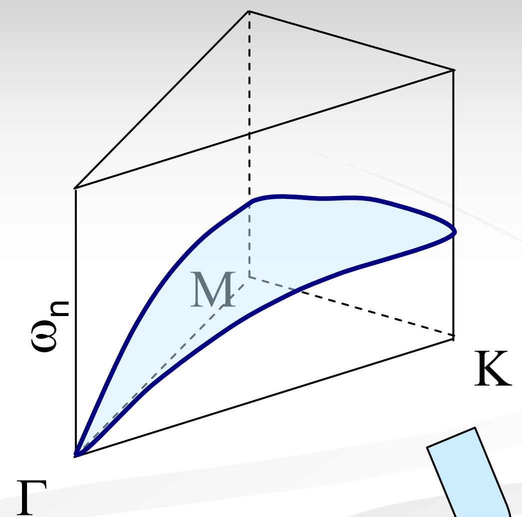


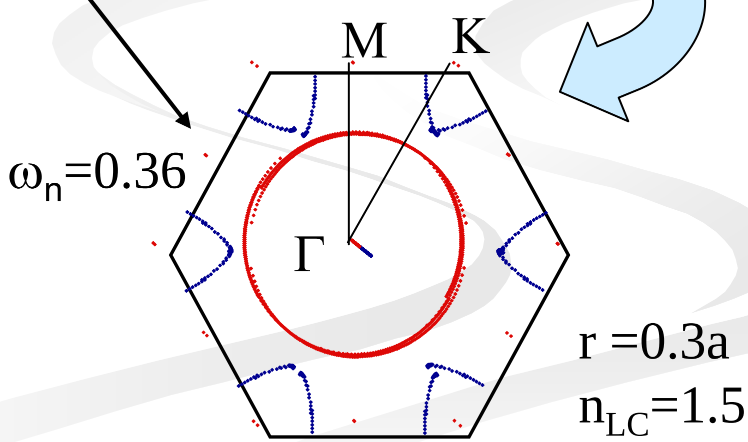
Unbiased
$n = 1.7$

- 2D Slab configuration suspended air, thickness =0.5a
- 3-D Finite difference time domain (FDTD) calculations with:
  - one mirror boundary
  - one perfectly matched layer (PML) boundary
  - four periodic boundaries
- Triangular lattice of holes
- Fill holes with electro-optic materials
  - Dynamic modification of band structure

Triangular Lattice



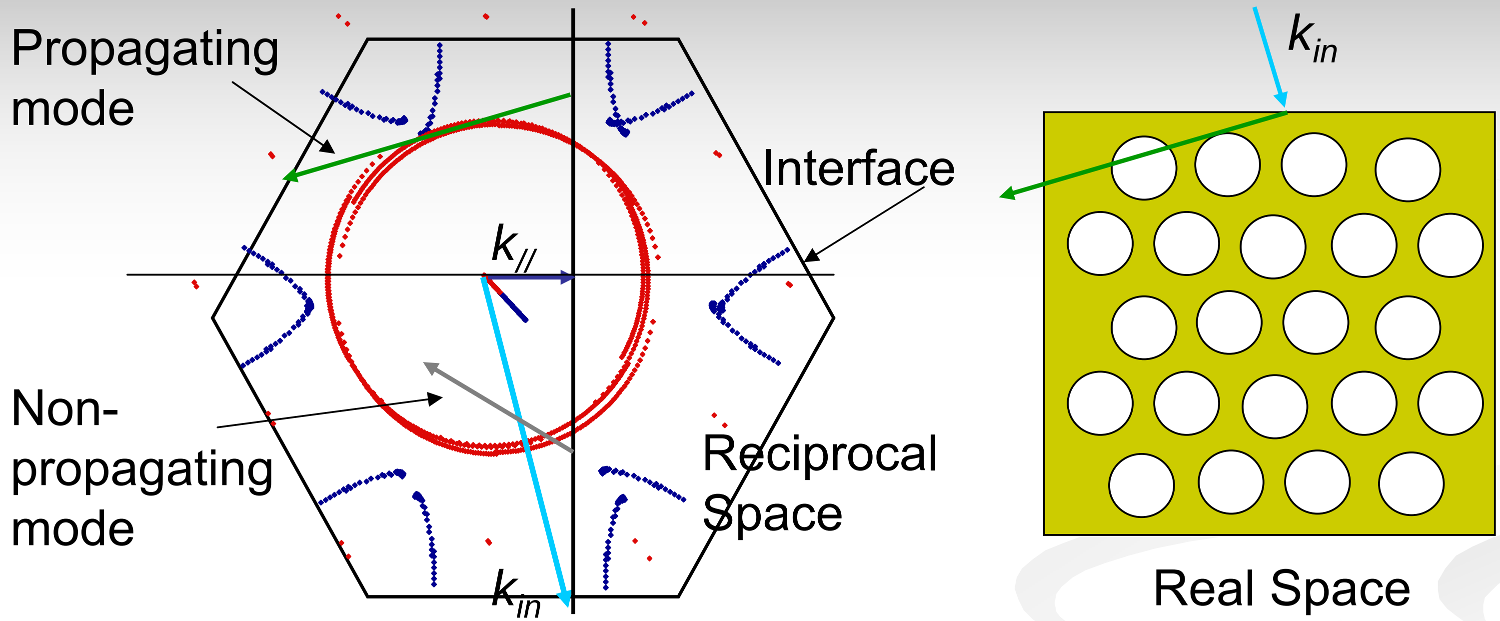




‘Cone shaped’ curve

- Holes filled with LC
  - $1.5 \le n \le 2.1$
- Silicon slab, n=3.46
- Even mode

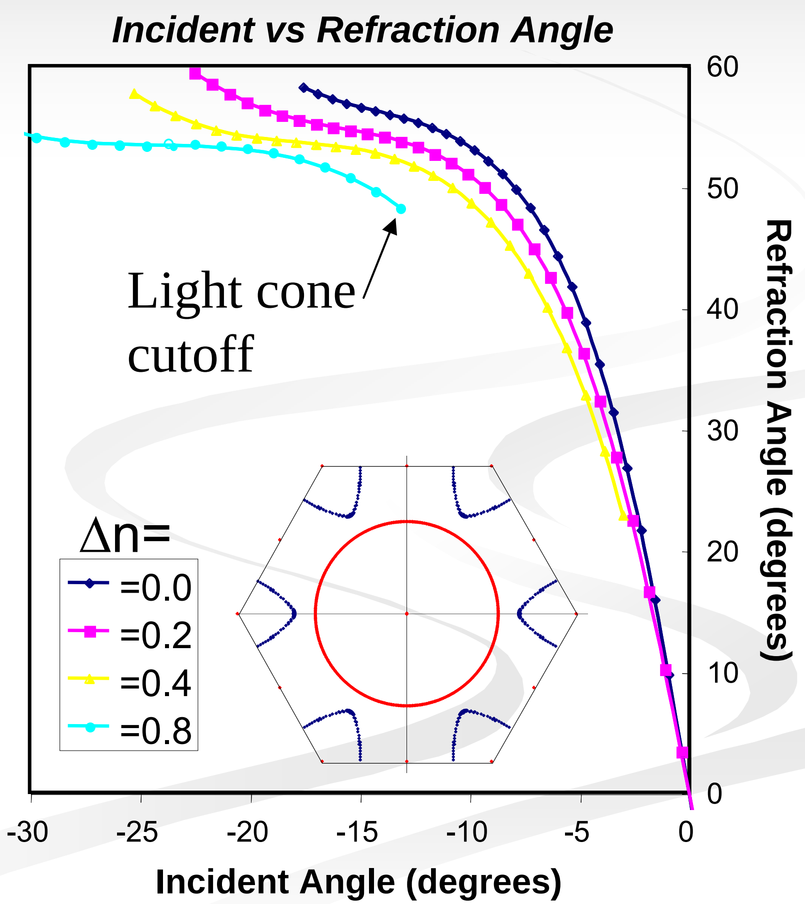
Refraction in PCs



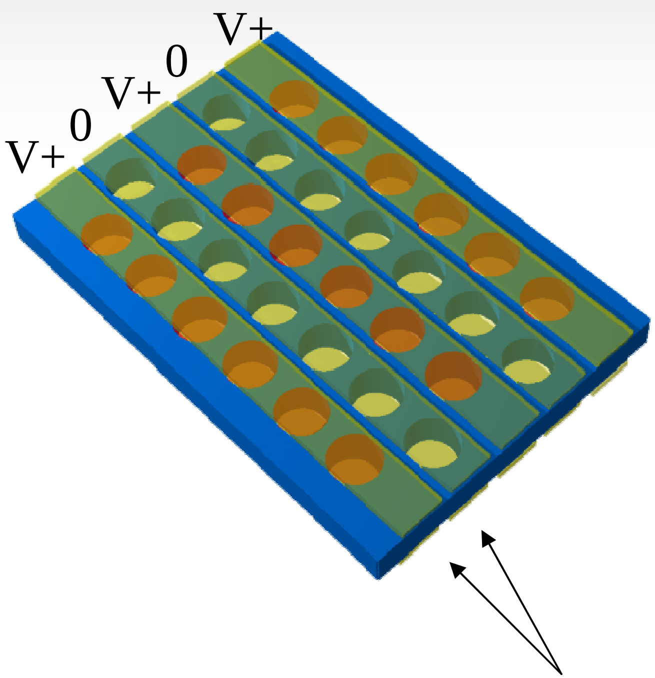
- Refraction angle determined by dispersion curve
- Conservation of tangential wave vector component, $k_{//}$, at the interface
- Final direction of travel is normal to the dispersion curve at intersection

Regular Triangular Lattice: Cone Shaped Curve

- Tunability ~7° at 13° incidence
- Range of operating angles 0° to ~18°
- As Δn is increased
  - Tip of cone is cut off by the light cone
  - Thus at small incident angles, modes are decaying



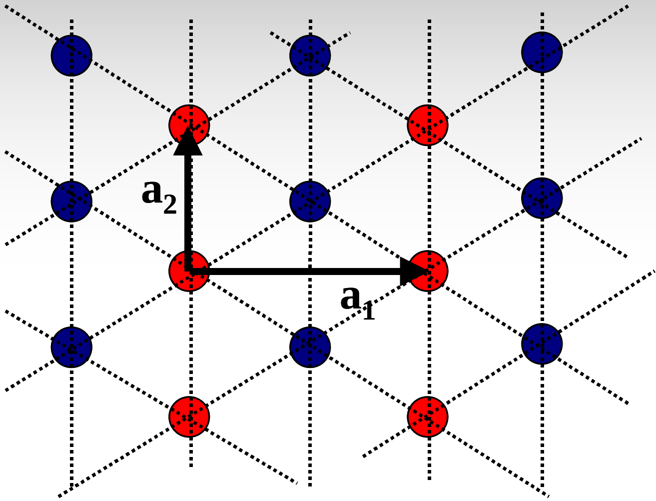
New Idea: Alternating Addressing Scheme



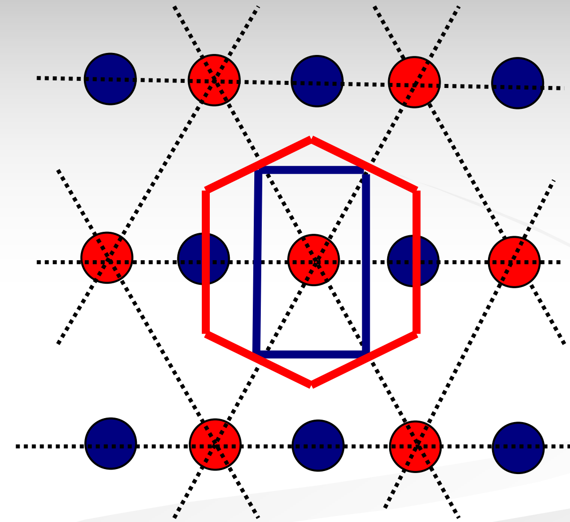
Δn = difference between refractive indices of the holes

- Address alternating rows of holes individually instead of homogeneously
- Creates superlattice with new Brillouin Zone shape
- More control over structure
- Electrical or optical biasing

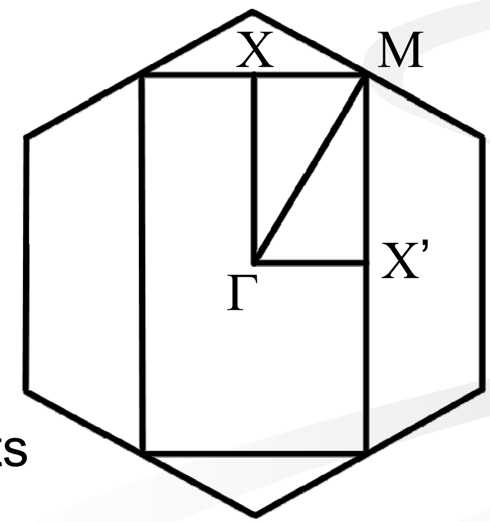
Photonic Crystal Superlattice



Need a larger unit cell with two atom basis

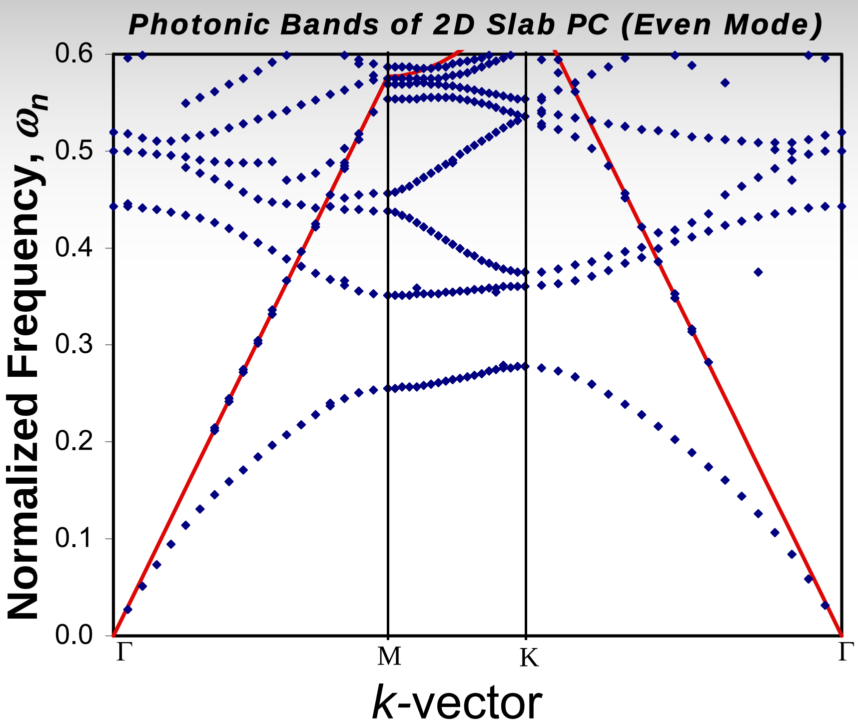


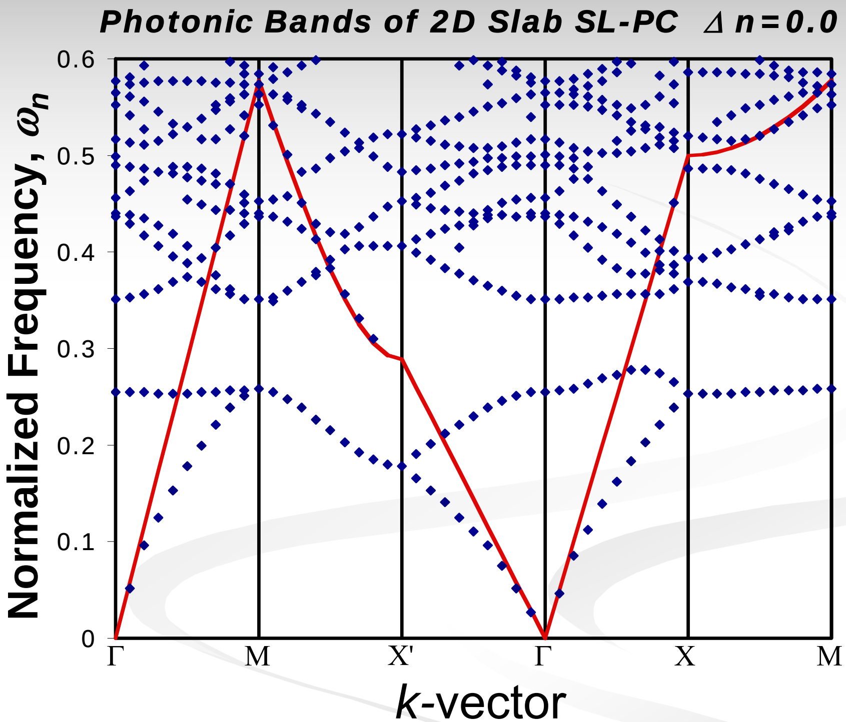
Consequent Brillouin zone



New labeling scheme for symmetry points

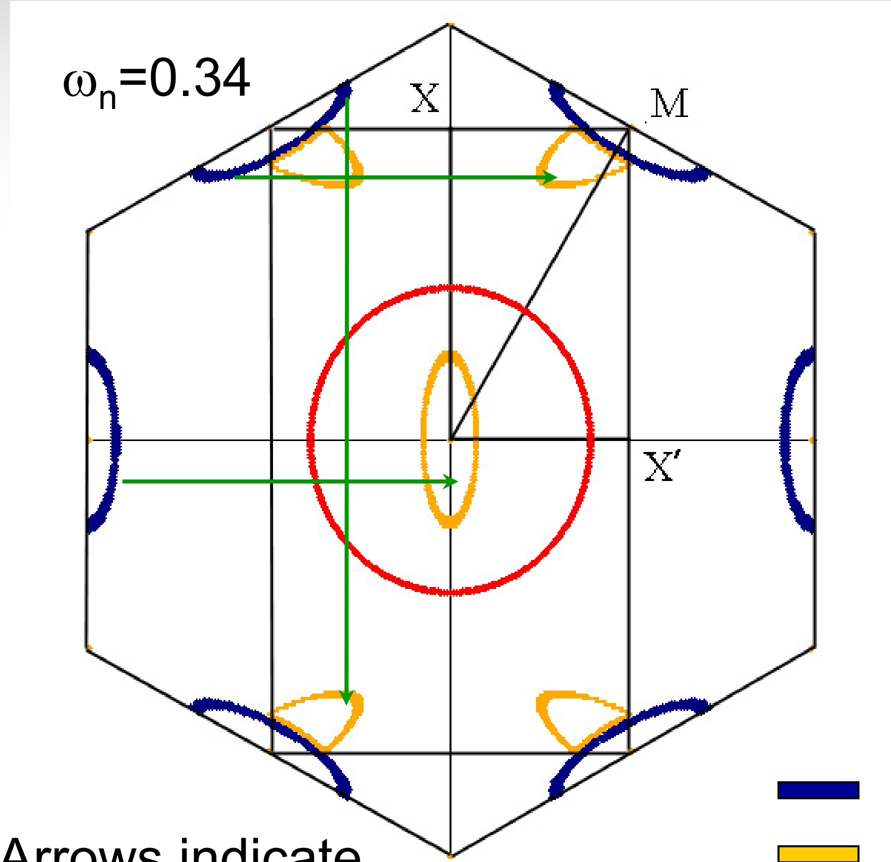
Superlattice Effect on Band Structure





- 'Artificial' Superlattice (Δn=0 between rows) to test calculation
- Bands translated according to new BZ scheme
- Results valid → band gap same, shape of bands remain intact except for some translations introduced by the superlattice

Superlattice Effect on Dispersion Diagram

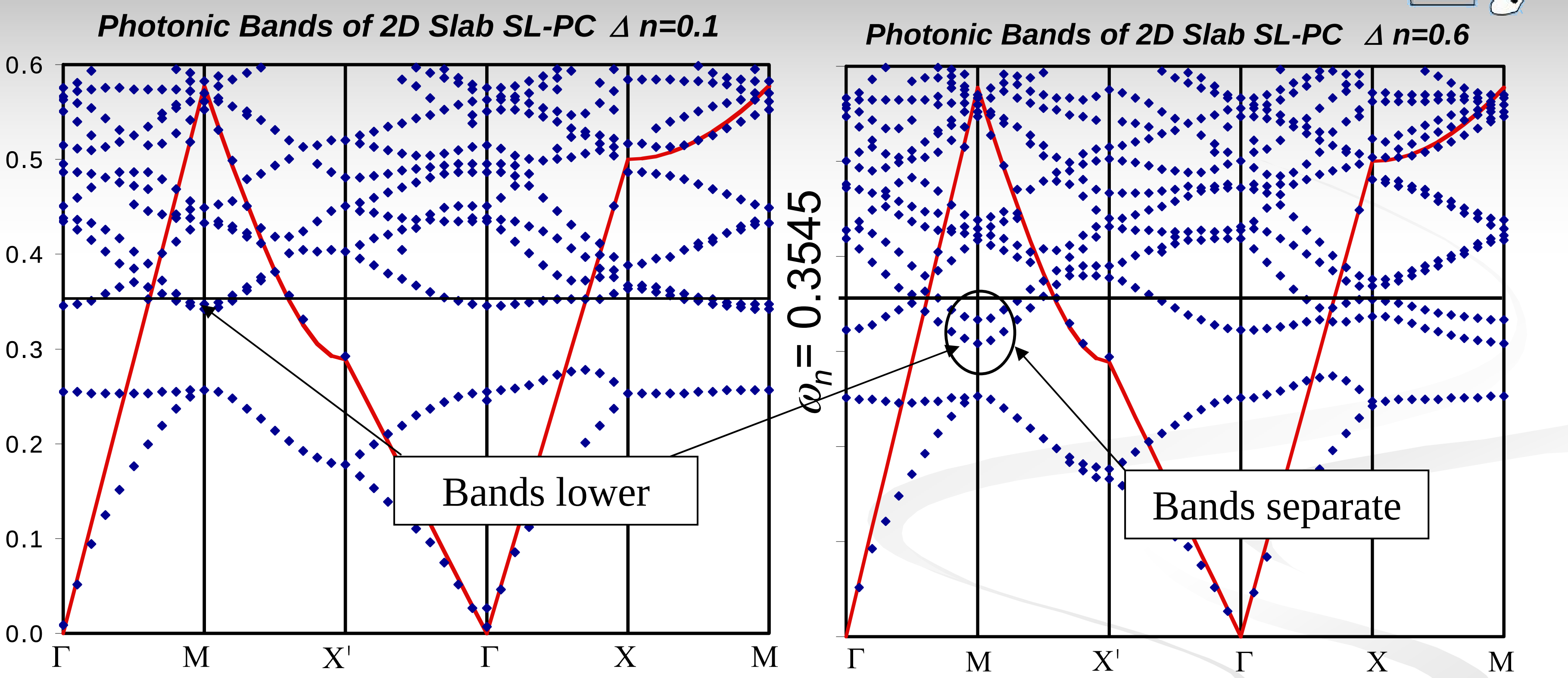


Arrows indicate translations of curves

- Additional periodicity changes shape of 1st Brillouin Zone
- No longer 6-fold symmetric
- When compared to homogeneous case, BZ appears 'folded' inward due to translation of bands
- Outcoupler/switch

Regular lattice
Superlattice
Cutoff circle

Band Shift with Change in Δn for SL

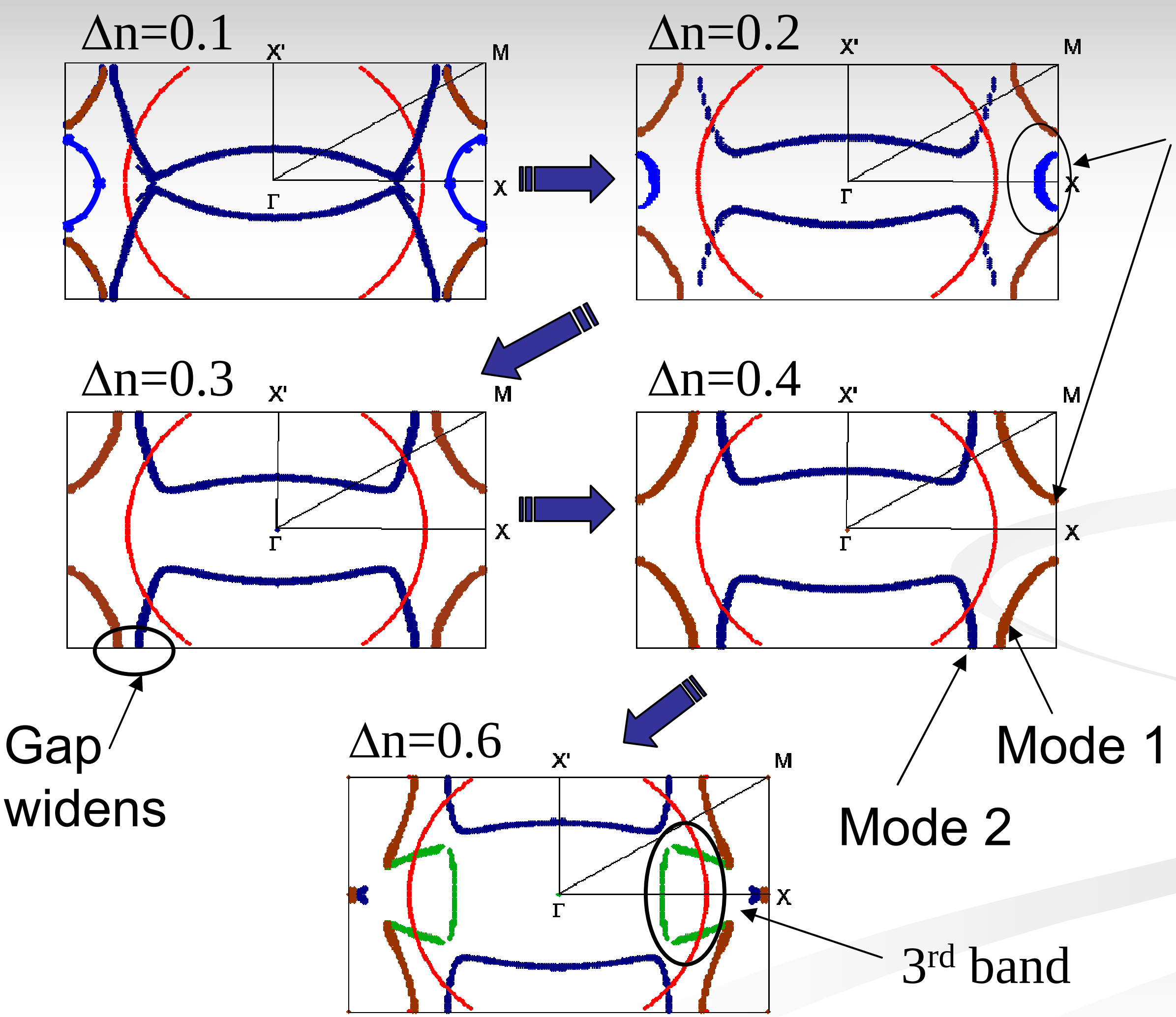


Δn=0.1

Δn=0.6

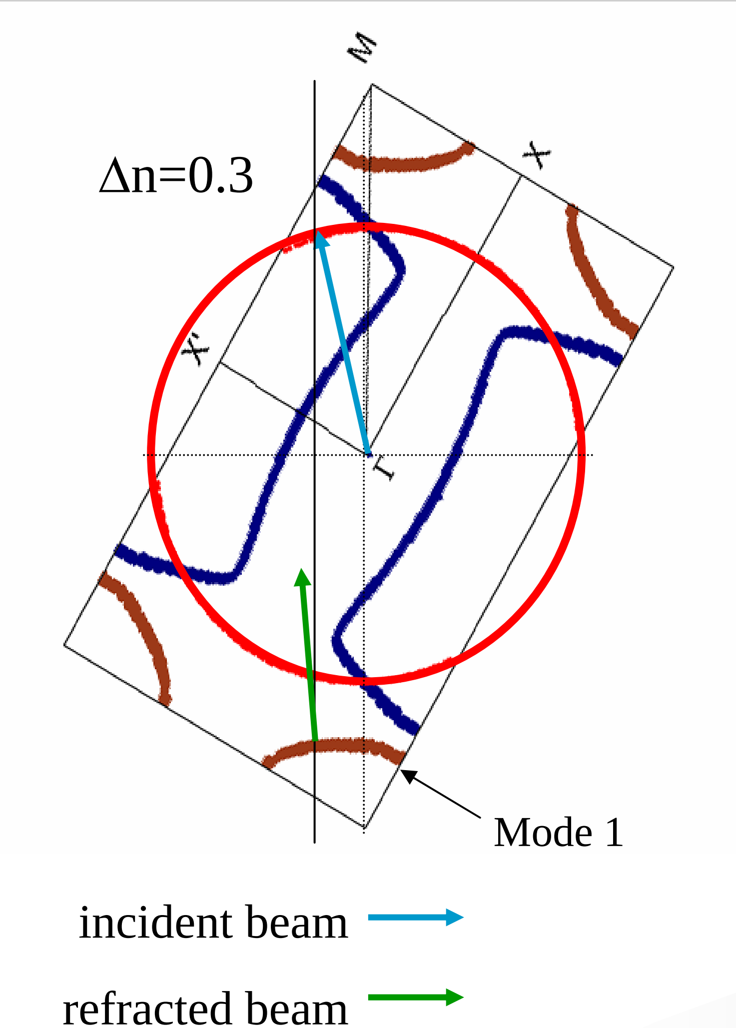
- n_{LC}=1.5 for one row
- 1.5 < n_{LC} < 2.1 for second row
- Difference in n between rows is Δn
- Bands shift to lower frequency with greater Δn.
- Separation between translated bands widen.

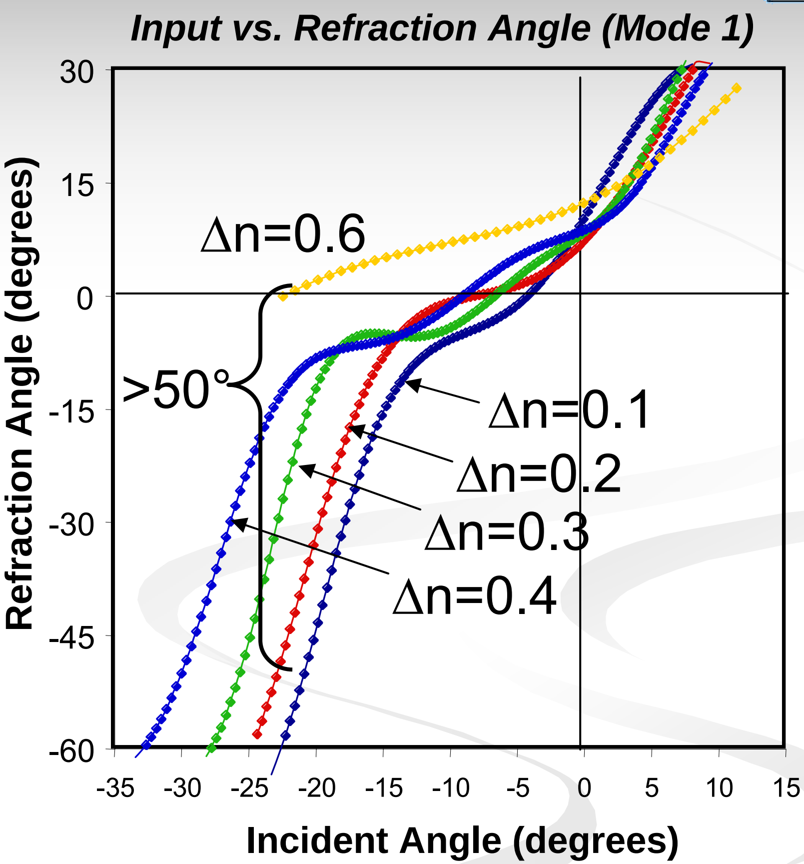
Evolution of Dispersion Curves



- As Δn is increased, the separation between certain modes in the BZ widen
- As Δn is increased, the 3rd band intersects the isofrequency line.

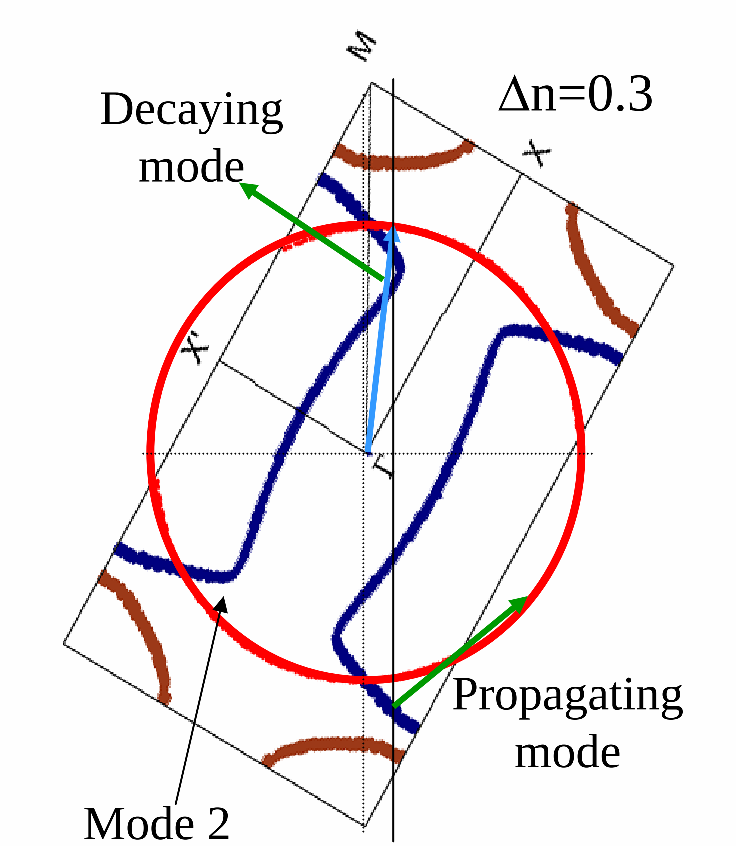
Refraction Angle (Mode 1)

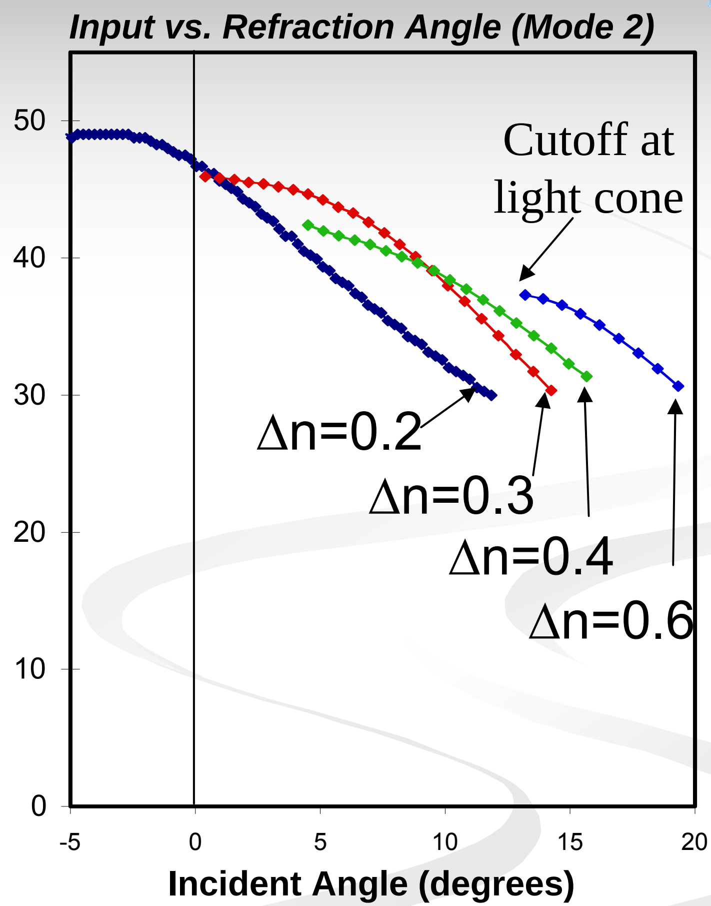




- Large tunability at negative incident angles, >50° at -20° for Δn=0.5

Refraction Angle (Mode 2)



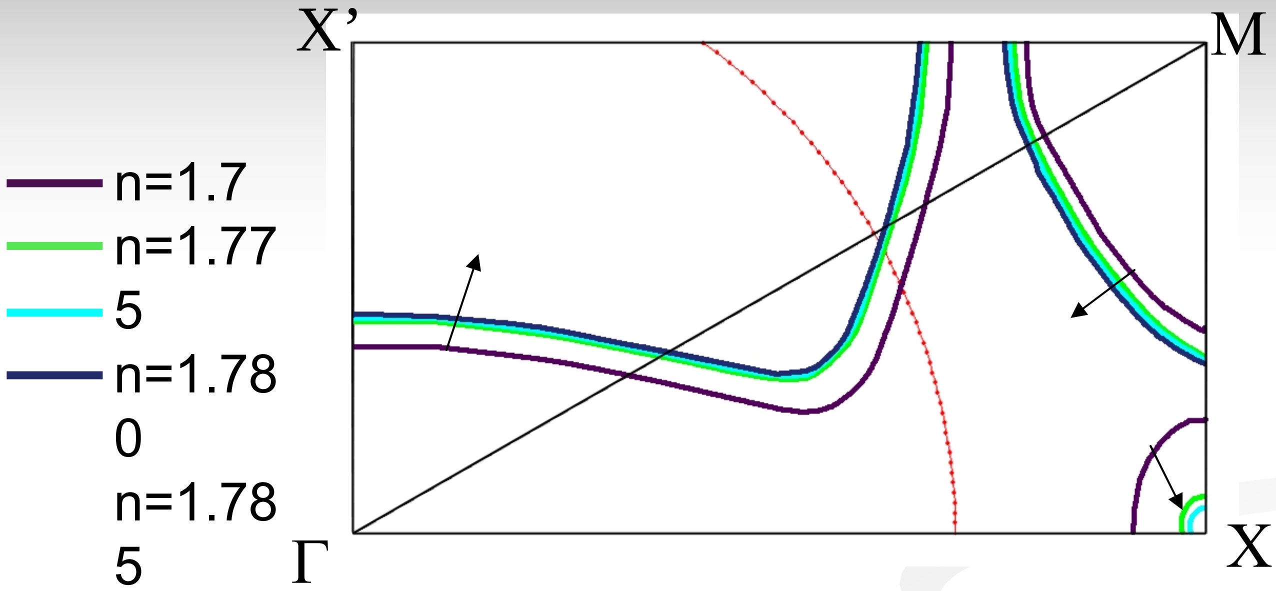


incident beam

refracted beam

- Tunability approaches 10°
- Limited range of angles due to light cone and BZ edge

Superlattice Switch



- Switch is very sensitive to small changes in Δn ~0.005
- Behavior comes from 2nd band in the band diagram
- Arrows indicate movement of dispersion curve with increasing Δn.

Summary

- 2D slab LC infiltrated regular triangular lattice
  - Beam steering approx. 10° with ~15% change in *n.*
- New superlattice configuration proposed by additional index modulation
  - Creates new allowed modes and drastic changes in dispersion
- New functionality to control optical properties
  - Improved beam steering >50°
  - Directional dependent switching, outcoupling
- Further studies required
  - Optimization of hole size & slab thickness
  - Superprism effects
  - Integration of fast non-linear materials for optical signal processing

Acknowledgements

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