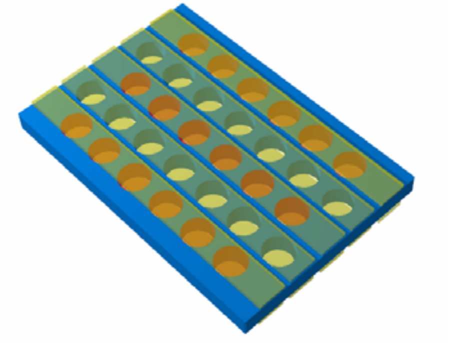
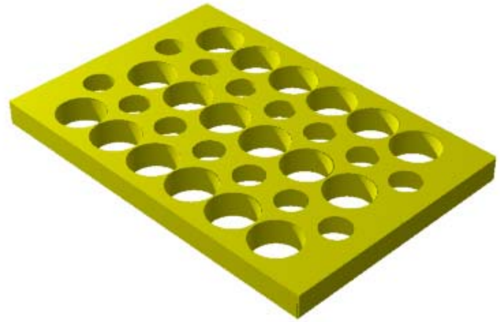
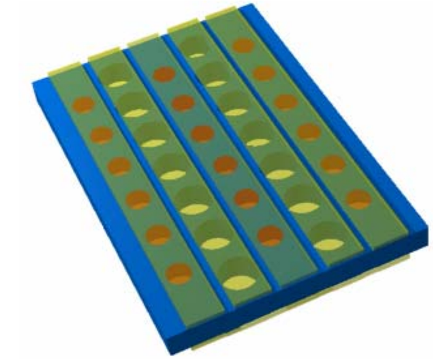

Photonic Crystal Superlattices

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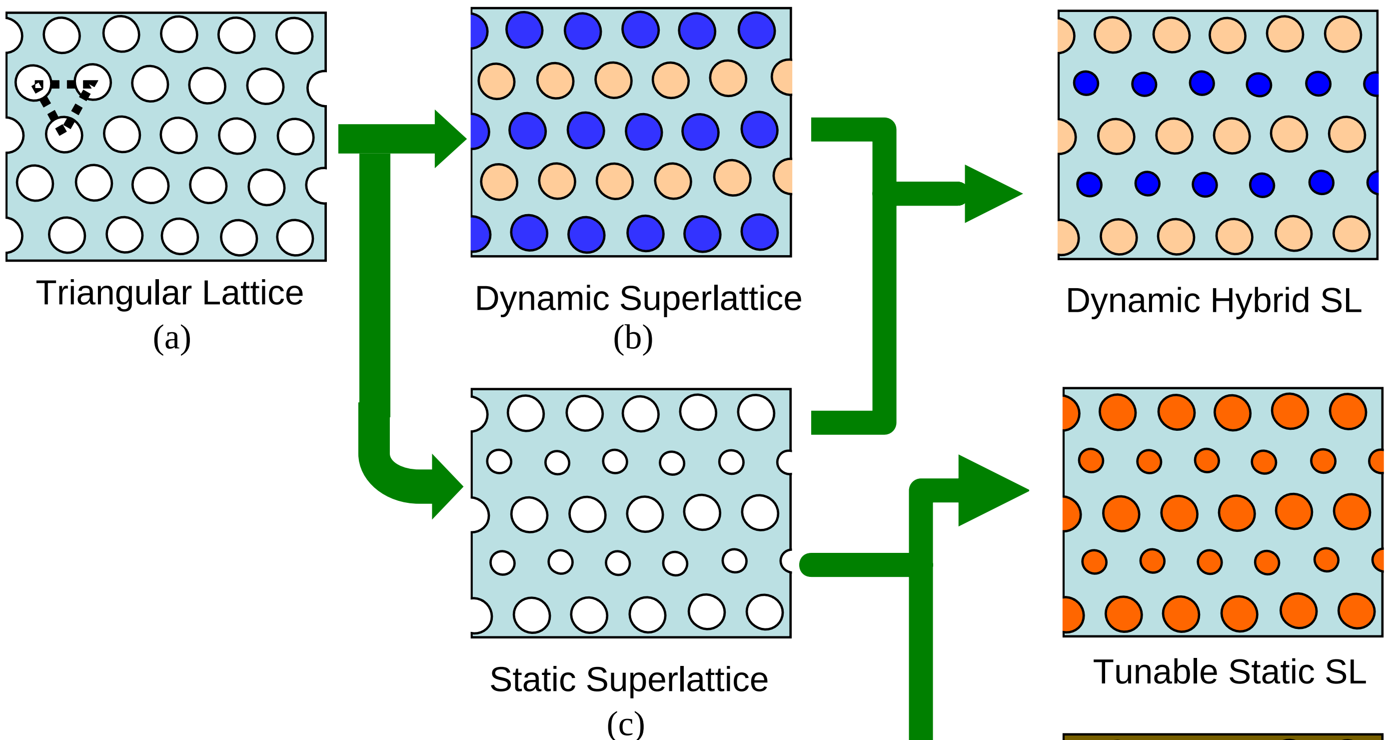
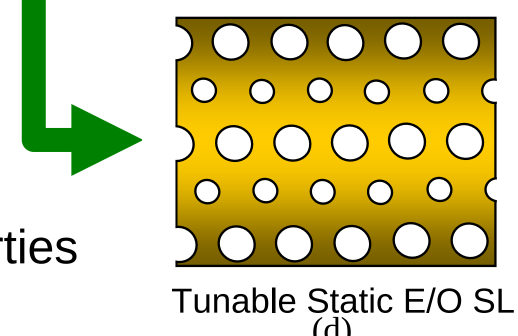
Outline

- Introduction:
  - PC superlattice configurations
- Superlattice strength
- Effect of superlattice on:
  - Band structures
  - Field profiles
  - Dispersion contours
- Refraction using *k*-vector analysis
- Conclusions

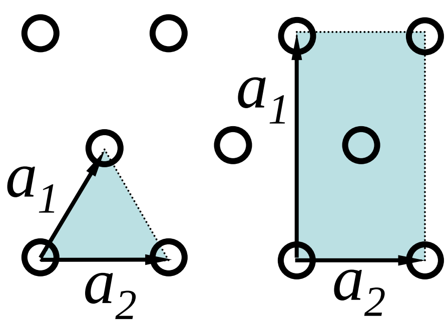
Photonic Crystal Superlattices



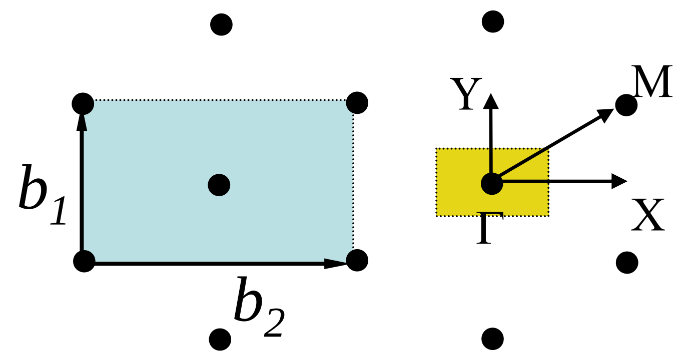


- ‘Dynamic’: Row addressing scheme to modulate n (Park *et al.*, *PECS IV* 2002)
- ‘Static’: Modulation in hole radius
- ‘Static E/O’ SL allows tunability of optical properties (Neff *et al.*, *SPIE 2004*)

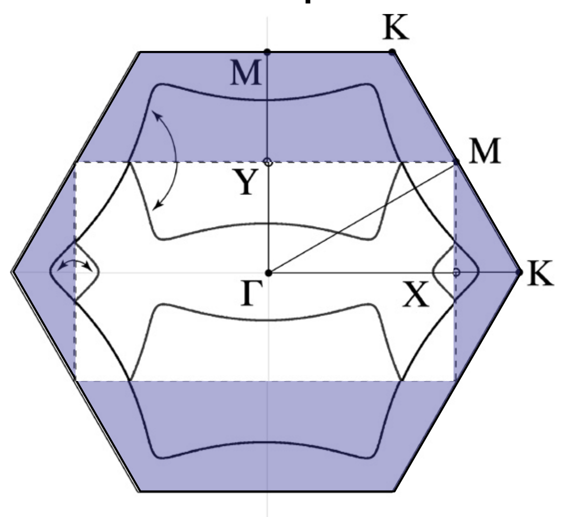
Real & Reciprocal Space



Real Space



Reciprocal Space

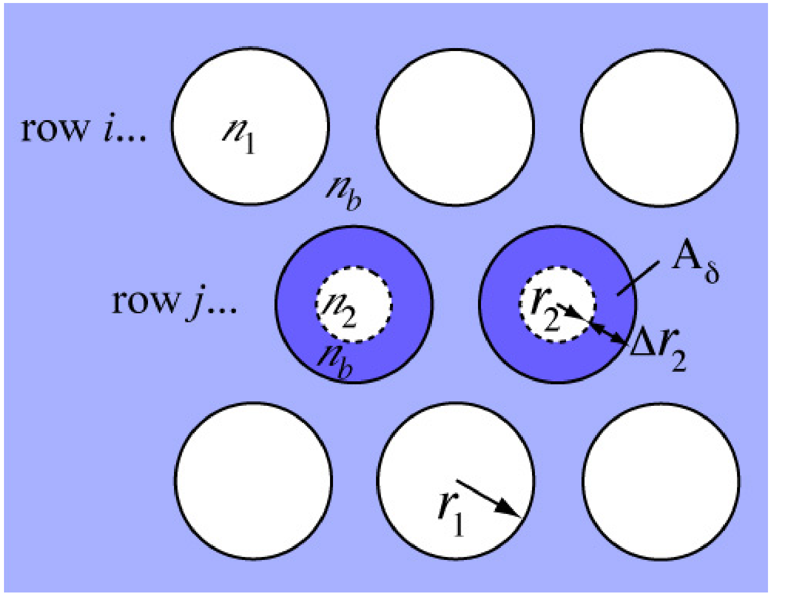


BZ Folding

- Alternating rows posses different property (Δr, Δn, or both)
- New unit cell definition with two holes per lattice point
- New BZ representation: hexagonal becomes rectangular
- BZ folding
- Symmetry reduction

Superlattice Strength: r_2/r_1

- Increasing superlattice strength accomplished by increasing Δn or Δr between rows $[i, j]$
- Effective index: quantitative value of superlattice strength of static SL for comparison with dynamic SL
  - Take amount of material added to structure by reducing r_2 hole and average the n over the area of r_1 hole
- In Si, for r_2/r_1=0.857, n_{eff}=1.654 which is Δn=0.654 between rows of holes

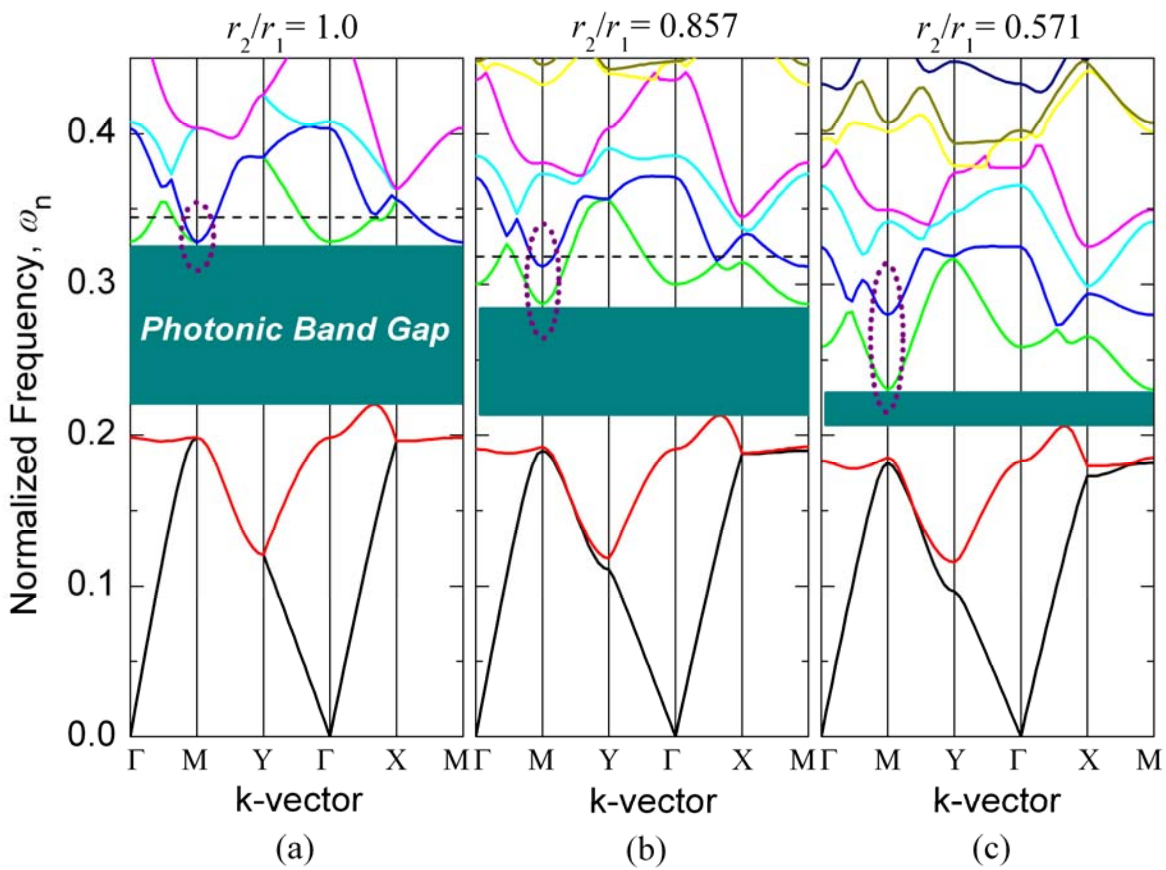


$$n_{eff} = \frac{n_b A_\delta + n_2 A_2}{A_1}$$

$$= n_b \left(1 - \left(\frac{r_2}{r_1}\right)^2\right) + n_2 \left(\frac{r_2}{r_1}\right)^2$$

Effect of SL Strength on Band Structure (Δr)

TE polarization

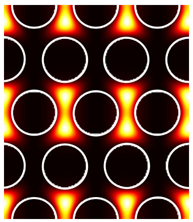


- Decreasing r_2 increases amount of material in structure
- Stronger effect on air bands than dielectric bands
- Shifts bands to lower frequencies
- Decreases width of PBG
- Increases band splitting
- Similar effect in dynamic superlattice when changing Δn

Magnetic Field Power (Δr)

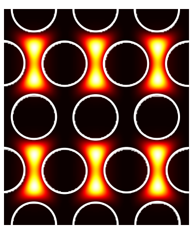
TE polarization

row *i*…
row *j*…

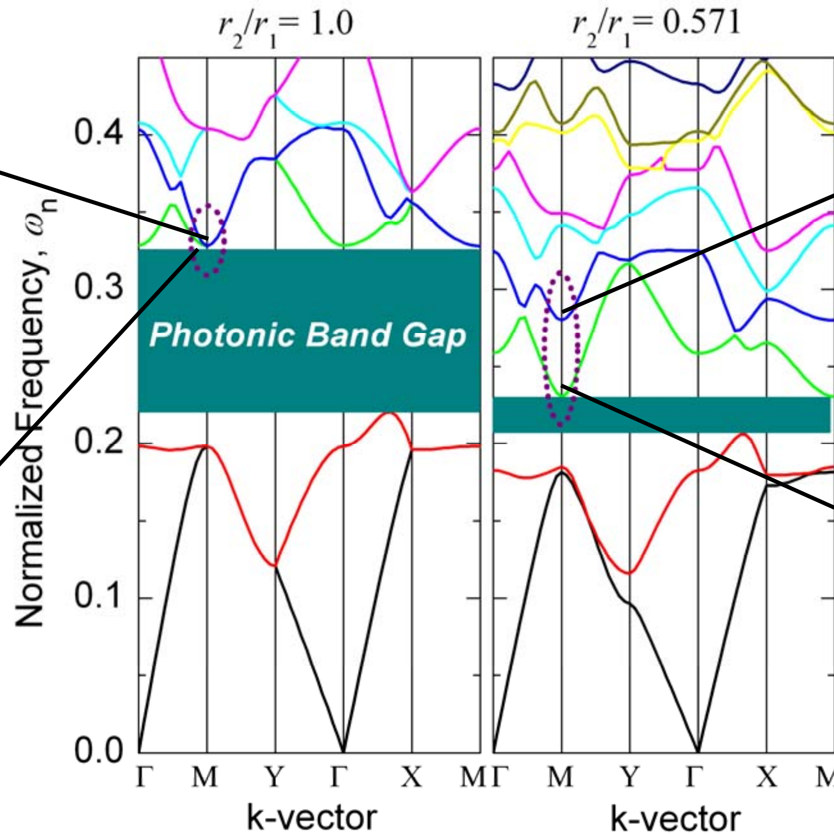


Band 4

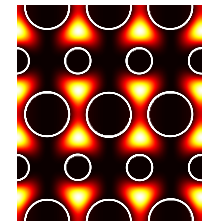
row *i*…
row *j*…



Band 3

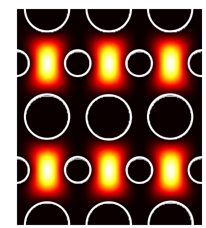


(a) (b)



…row *i*
…row *j*

Band 4



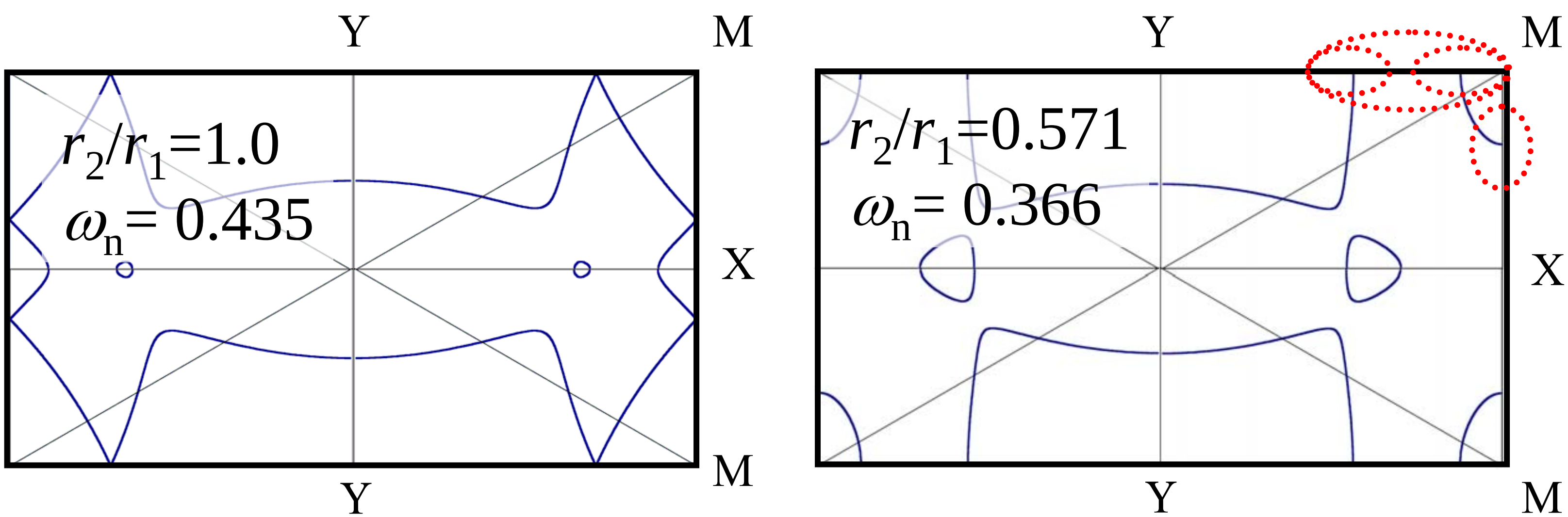
…row *i*
…row *j*

Band 3

- Degenerate modes
- Same energy density in each mode

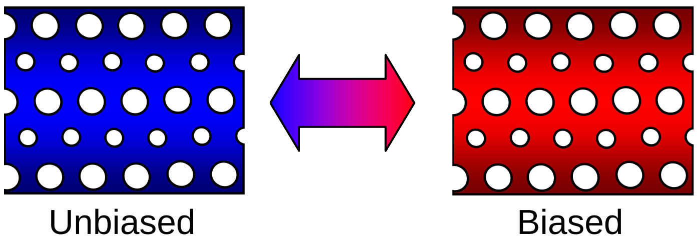
- Non-degenerate modes
- Band 4 energy > 2X Band 3

Dispersion Contours: Δr

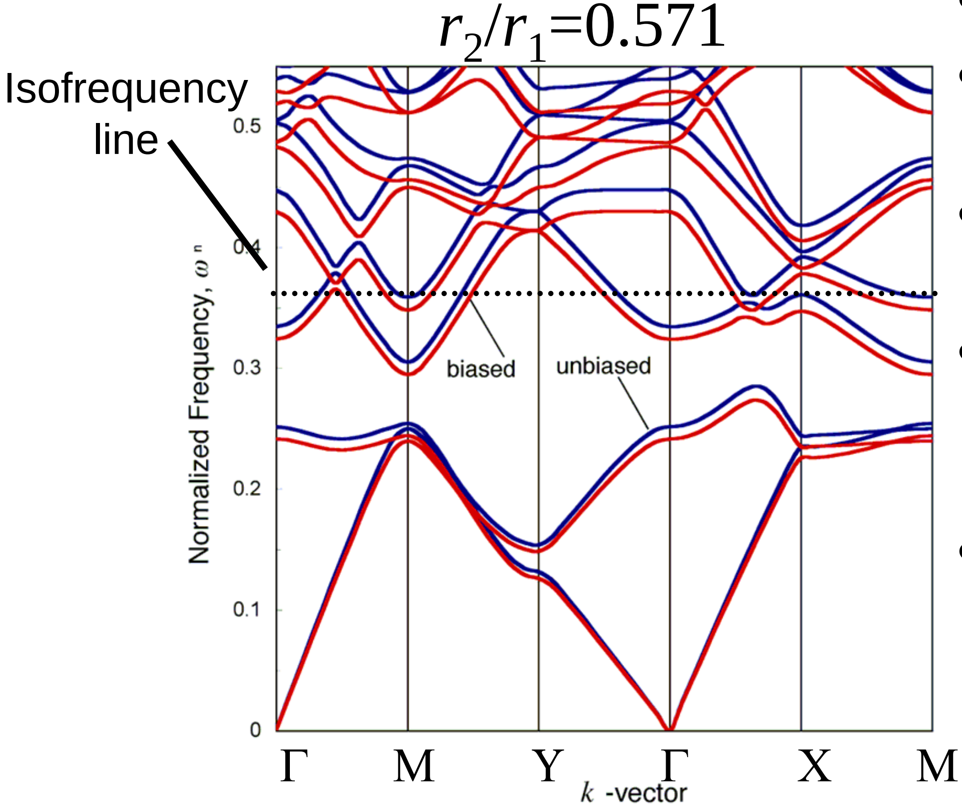


- For no radius difference, BZ folding scheme is straight forward and curves converge to a single point at BZ boundaries.
- Increased SL strength causes curves to diverge/repel at BZ boundaries.
- Small SL strength: unmodified curvature in center of BZ with high curvature near BZ boundaries
- Large SL strength: modified curvature of entire contour.

Band Structure: Bias Effects

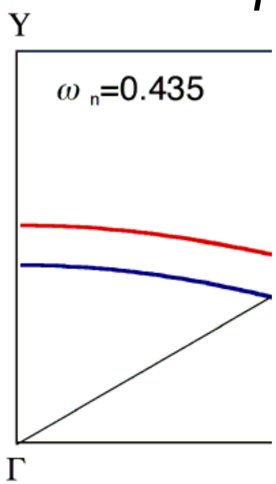


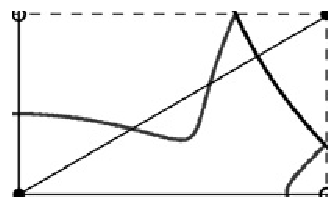
PLZT (Scrymgeour *et al.*, *APL* **82**, 3176)

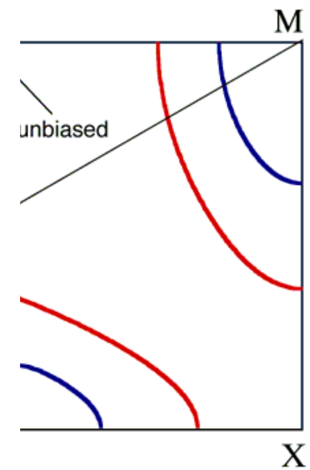


- PLZT background
- Bias of 6 V/μm
- Increase n from 2.49 to 2.598 (Δn~ 0.11)
- Moves bands to lower frequencies
- Isofrequency line intersects bands at different points
- Dispersion surface 'looks' different for unbiased/biased cases

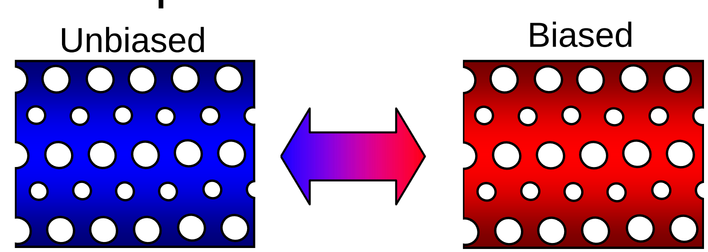
Dispersion Contours: Bias Effects



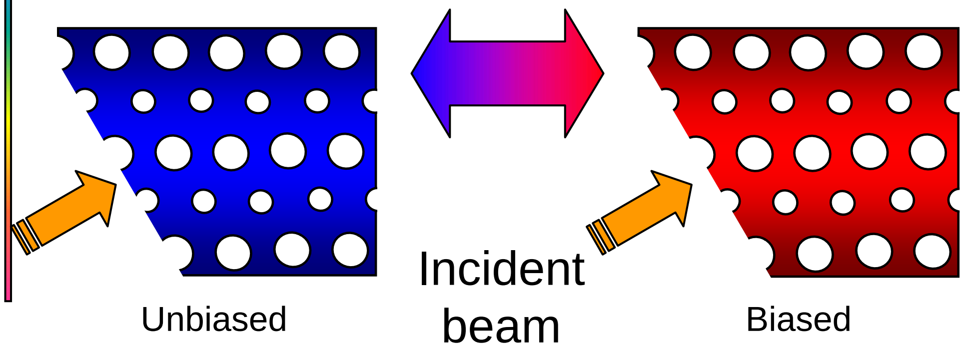




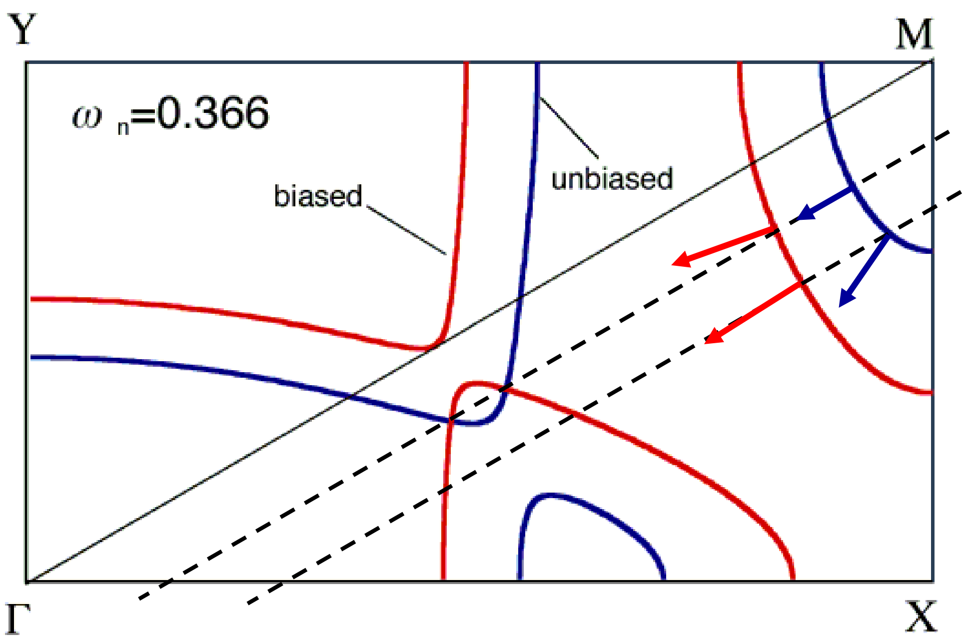
- Isofrequency plane intersecting different areas of the dispersion surface
- The contours are congruent but shifted.
- Different contours results in different optical responses
  - Refraction/Beam steering
  - Switching/Modulation
  - Dispersion



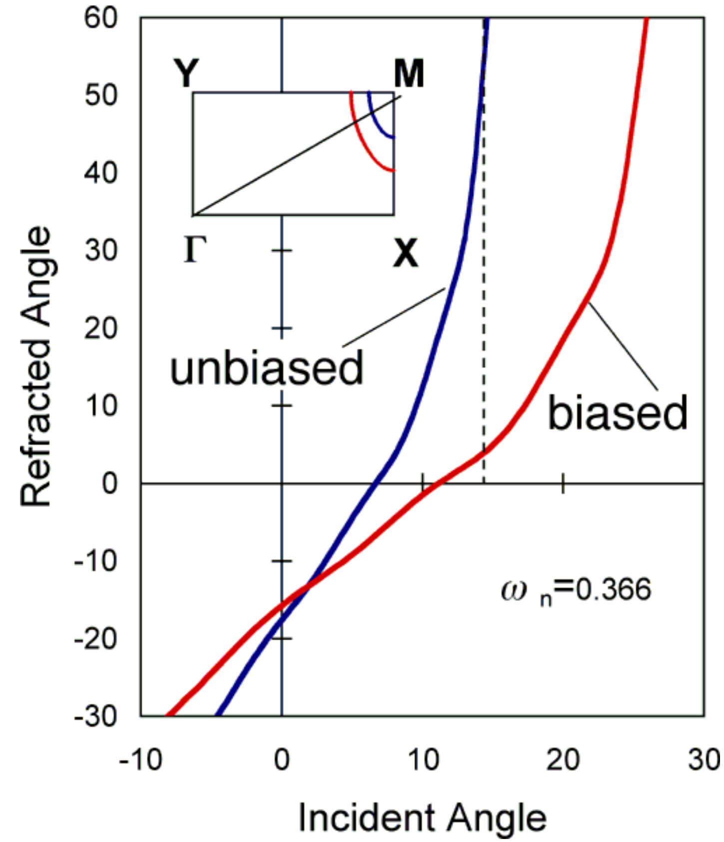
Static E/O SL



Unbiased
Incident
beam
Biased

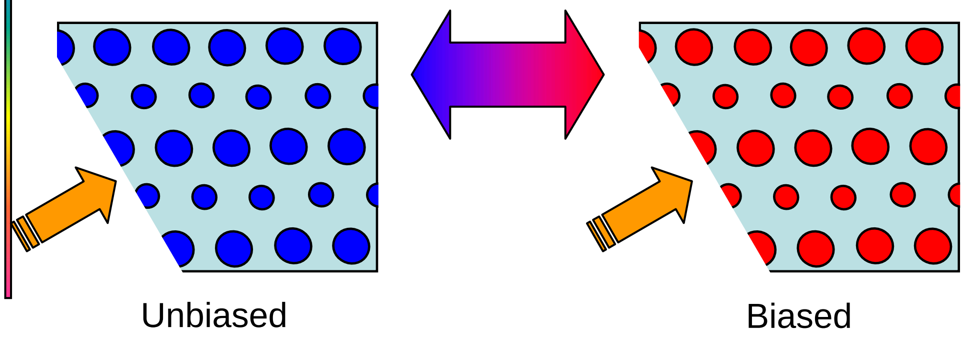


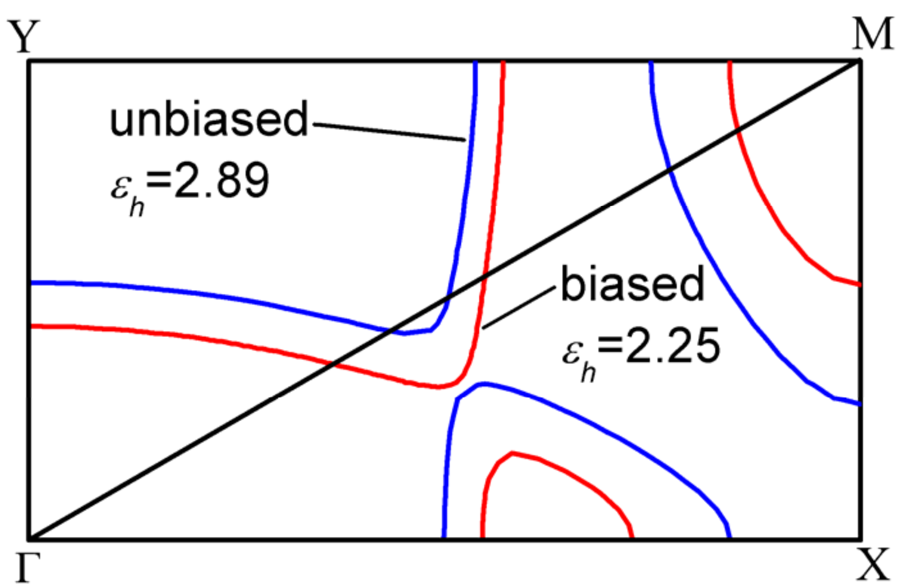
Y
M
Γ
X
ω n=0.366
biased
unbiased

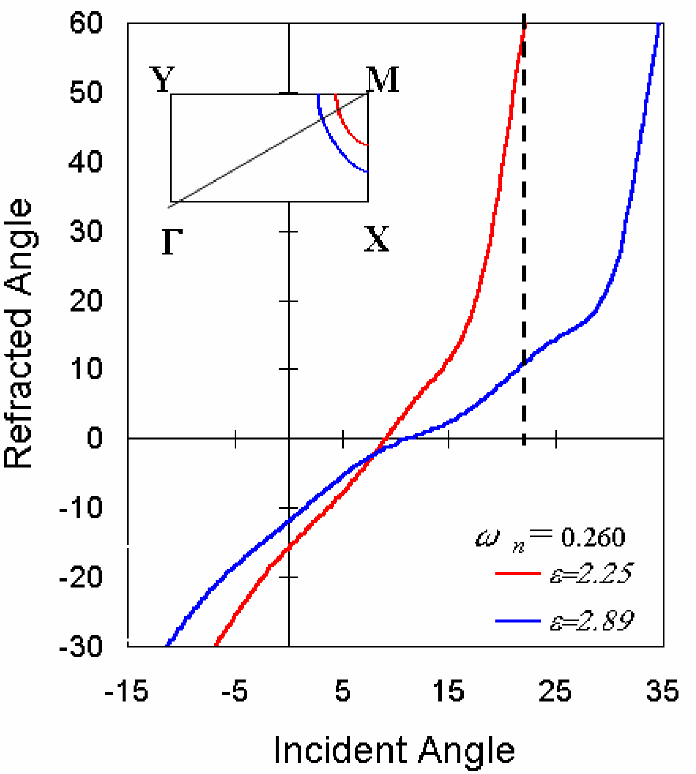


Refracted Angle
Incident Angle
60
50
40
30
20
10
0
-10
-20
-30
-10
0
10
20
30
Y
M
Γ
X
unbiased
biased
ω n=0.366

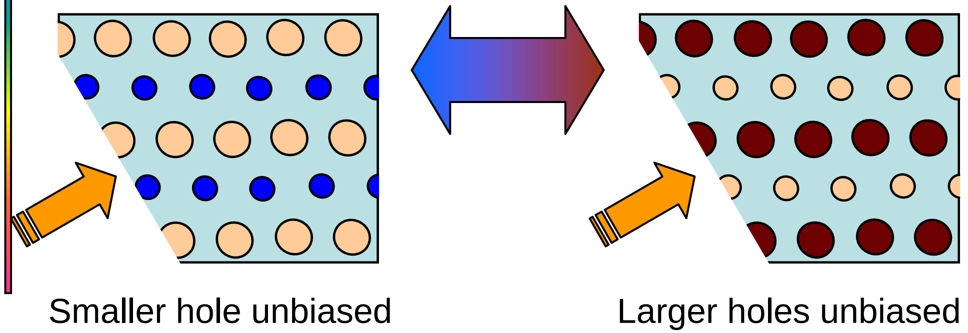
Static Infiltrated Hybrid SL

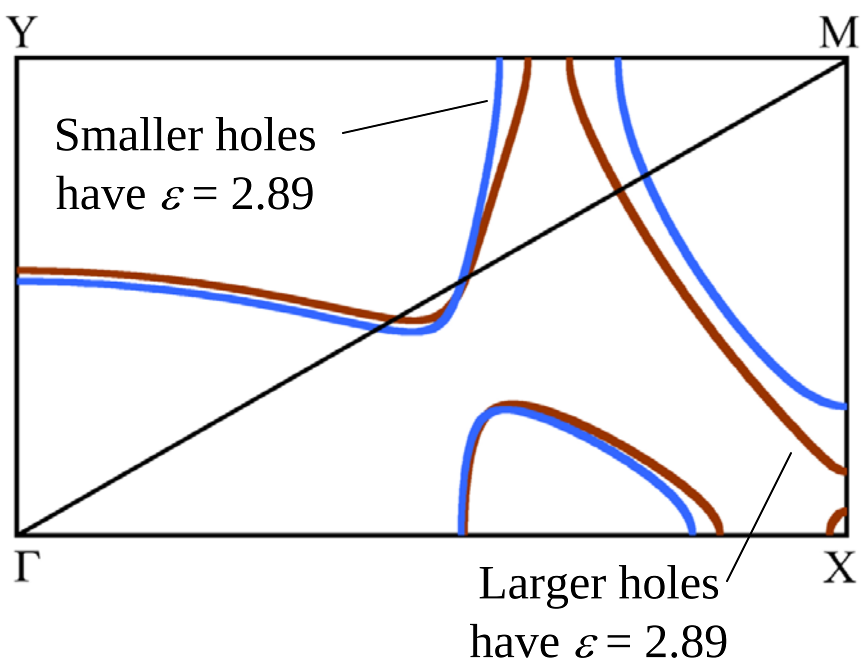


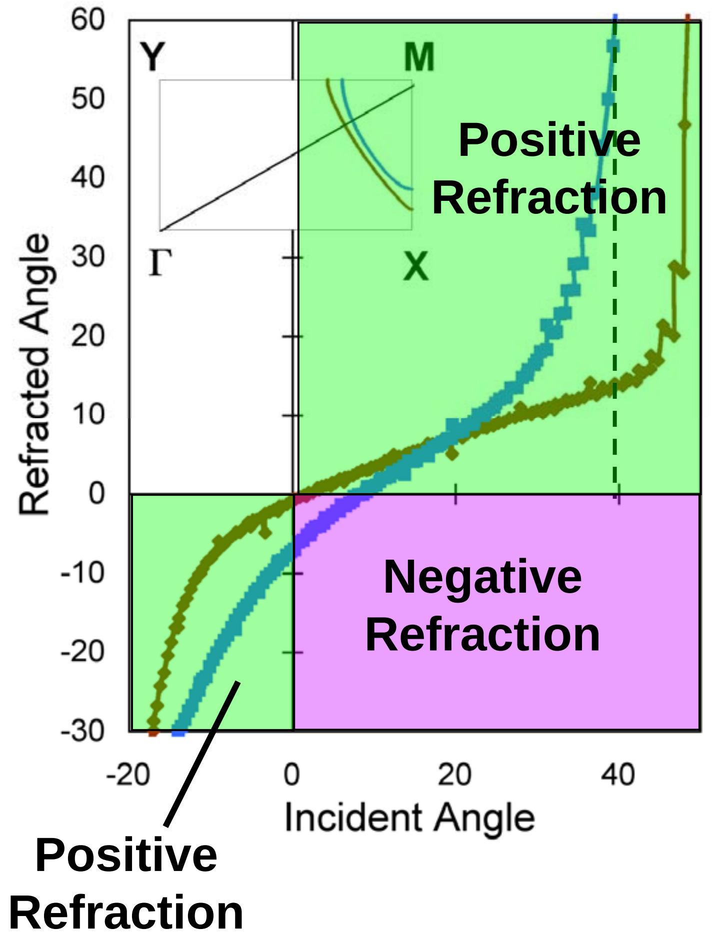




Dynamic Hybrid SL







Conclusions

- A Δr or Δn between adjacent rows of holes creates a superlattice photonic crystal.
- The superlattice lowers the symmetry of the structure causing:
  - BZ folding
  - Band splitting due to removal of modal degeneracy
  - Highly curved DCs near BZ boundaries
- Tunability of refraction accomplished by infiltration of lattice with E/O material or making background out of E/O material
- Hybrid lattice shows improvement tunability of refraction over the triangular lattice and dynamic SL.
- Greater sensitivity to Δn can be possible through optimization of hole size ratio, r_2/r_1

Acknowledgments

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