

ECE 595, Section 10
Numerical Simulations
Lecture 37: MEEP Tutorial III

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April 12, 2013

Recap from Wednesday

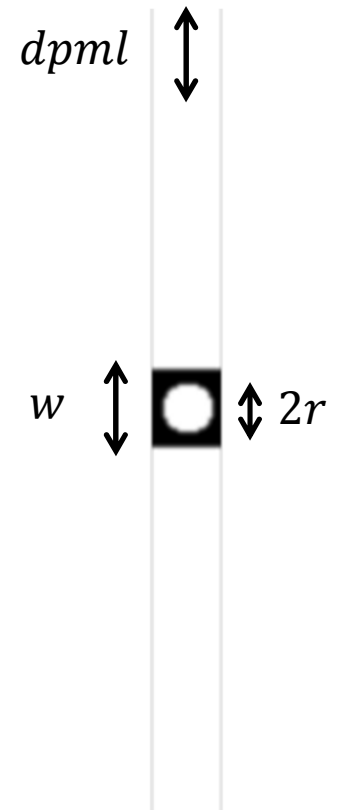
- Examples:
 - Multimode ring resonators
 - Isolating individual resonances
 - Kerr nonlinearities
 - Quantifying third-harmonic generation

Outline

- Recap from Wednesday
- Photonic Crystal Waveguides:
 - Photonic Bandstructure
 - Defect Resonant Modes
 - Waveguide Transmission

Photonic Bandstructure

```
(define-param eps 13) ; dielectric constant of waveguide
(define-param w 1.2) ; width of waveguide
(define-param r 0.36) ; radius of holes
(define-param sy 12) ; size of cell in y direction (perp. to wvg.)
(define-param dpml 1) ; PML thickness (y direction only!)
(set! geometry-lattice (make lattice (size 1 sy no-size)))
(set! geometry (list (make block (center 0 0)
    (size infinity w infinity)
    (material (make dielectric (epsilon eps))))
    (make cylinder (center 0 0) (radius r)
    (height infinity) (material air))))
(set-param! resolution 20)
(set! pml-layers (list (make pml (direction Y) (thickness dpml))))
```

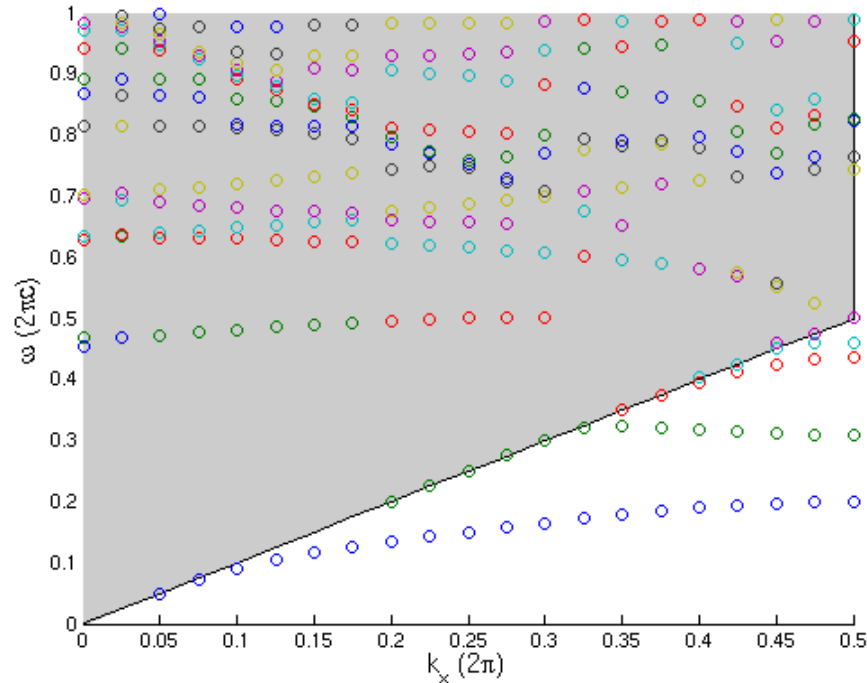


Our 1x12
unit cell

Photonic Bandstructure

```
(define-param fcen 0.25) ; pulse center frequency
(define-param df 1.5) ; pulse frequency width
(set! sources (list (make source (src
    (make gaussian-src (frequency fcen)
        (fwidth df))) (component Hz) (center 0.1234 0))))
(set! symmetries (list (make mirror-sym (direction Y) (phase -
1))))
(set-param! k-point (vector3 0.4 0))
(run-sources+ 300 (after-sources (harminv Hz (vector3 0.1234)
fcen df)))
(define-param k-interp 19)
(run-k-points 300 (interpolate k-interp (list (vector3 0)
(vector3 0.5))))
```

Photonic Bandstructure

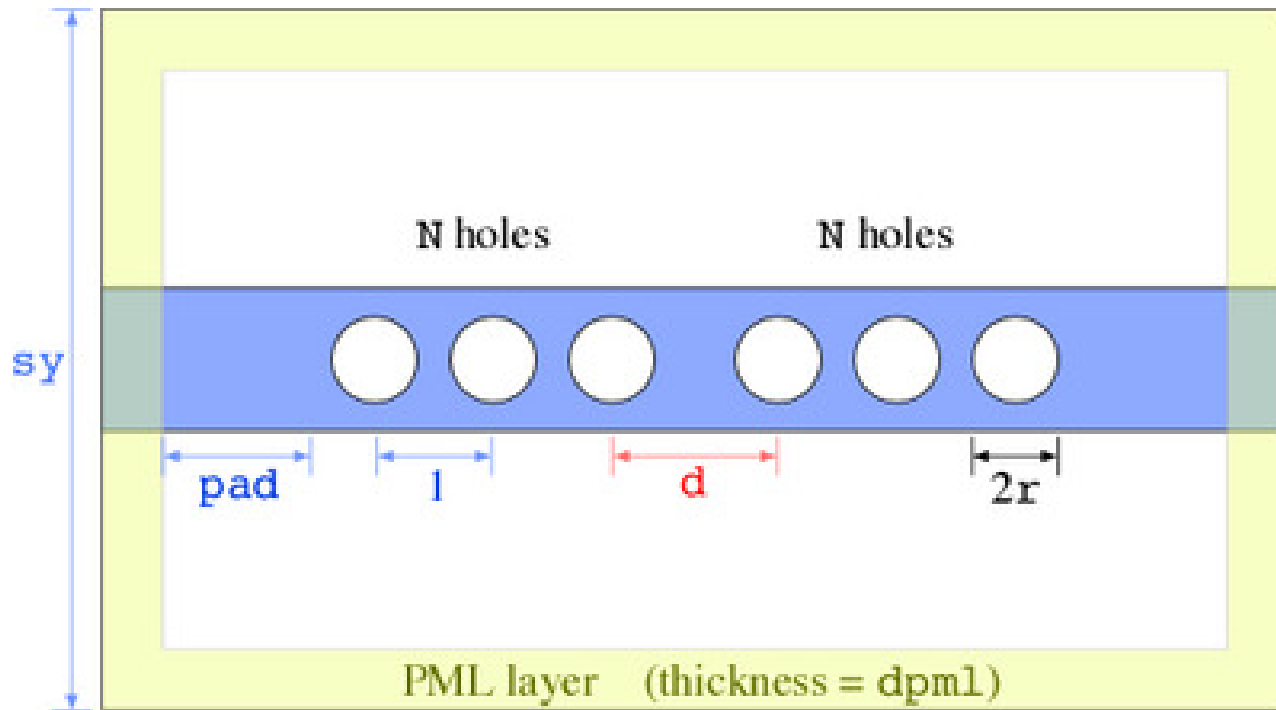


- Output frequencies at each k_x – for example:
freqs:, 14, 0.325, 0.0, 0.0, 0.171671252741341, 0.319717964514696,
0.323470450791478
freqs-im:, 14, 0.325, 0.0, 0.0, -8.74808991364674e-8, 1.82230861728163e-4,
0.00144227925408331
- Extract frequency lines via grep:
unix% meep holey-wvg-bandsctl | tee holey-wvg-bands.out
unix% grep freqs: holey-wvg-bands.out > fre.dat
unix% grep freqs-im: holey-wvg-bands.out > fim.dat

Defect Resonant Modes

```
(define-param eps 13) ; dielectric constant of waveguide
(define-param w 1.2) ; width of waveguide
(define-param r 0.36) ; radius of holes
(define-param d 1.4) ; defect spacing (ordinary spacing = 1)
(define-param N 3) ; number of holes on either side of defect
(define-param sy 6) ; size of cell in y direction (perpendicular to wvg.)
(define-param pad 2) ; padding between last hole and PML edge
(define-param dpml 1) ; PML thickness
(define sx (+ (* 2 (+ pad dpml N)) d -1)) ; size of cell in x direction
(set! geometry-lattice (make lattice (size sx sy no-size)))
(set! geometry (append ; combine lists of objects:
  (list (make block (center 0 0) (size infinity w infinity)
    (material (make dielectric (epsilon eps))))))
  (geometric-object-duplicates (vector3 1 0) 0 (- N 1) (make cylinder
    (center (/ d 2) 0) (radius r) (height infinity) (material air)))
  (geometric-object-duplicates (vector3 -1 0) 0 (- N 1) (make cylinder
    (center (/ d -2) 0) (radius r) (height infinity) (material air))))))
```

Defect Resonant Modes



N holes on each side surround a defect cavity of size d (in units of a)

Defect Resonant Modes

```
(set! pml-layers (list (make pml (thickness dpml))))  
(set-param! resolution 20)  
(define-param fcen 0.25) ; pulse center frequency  
(define-param df 0.2) ; pulse width (in frequency)  
(set! sources (list (make source (src (make gaussian-src  
(frequency fcen) (fwidth df))) (component Hz) (center 0 0))))  
(set! symmetries (list (make mirror-sym (direction Y) (phase -  
1)) (make mirror-sym (direction X) (phase -1))))  
(run-sources+ 400 (at-beginning output-epsilon) (after-  
sources (harminv Hz (vector3 0) fcen df)))  
(run-until (/ 1 fcen) (at-every (/ 1 fcen 20) output-hfield-z))
```

Defect Resonant Modes

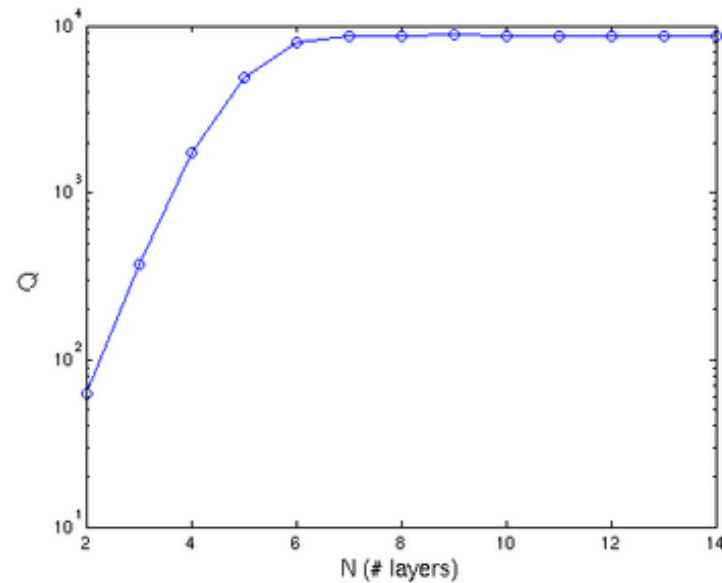


- Create a movie of defect mode over time:

```
unix% h5topng -RZc dkbluered -C holey-wvg-cavity-eps-000000.00.h5 holey-wvg-cavity-hz-*.h5
```

```
unix% convert holey-wvg-cavity-hz-*.png holey-wvg-cavity-hz.gif
```

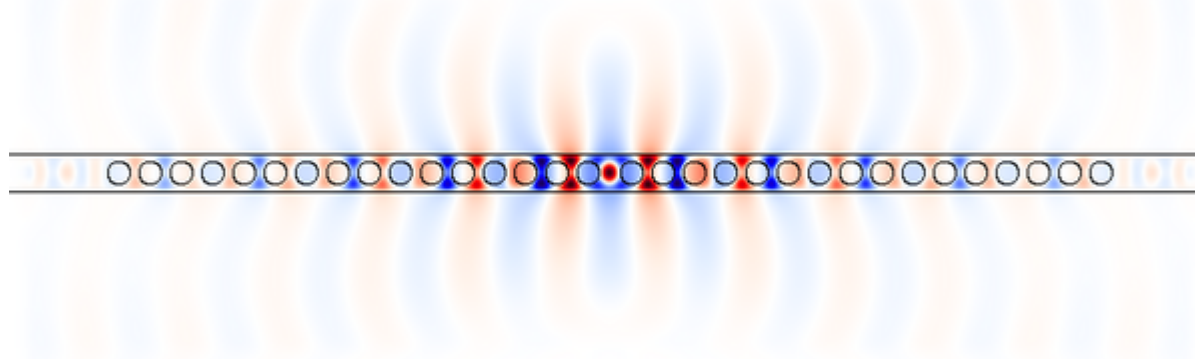
Defect Resonant Modes



- Determine quality factor versus number of holes:
unix% meep N=4 compute-mode?=true holey-wvg-cavityctl |grep harminv
unix% meep N=5 compute-mode?=true holey-wvg-cavityctl |grep harminv
...

Defect Resonant Modes

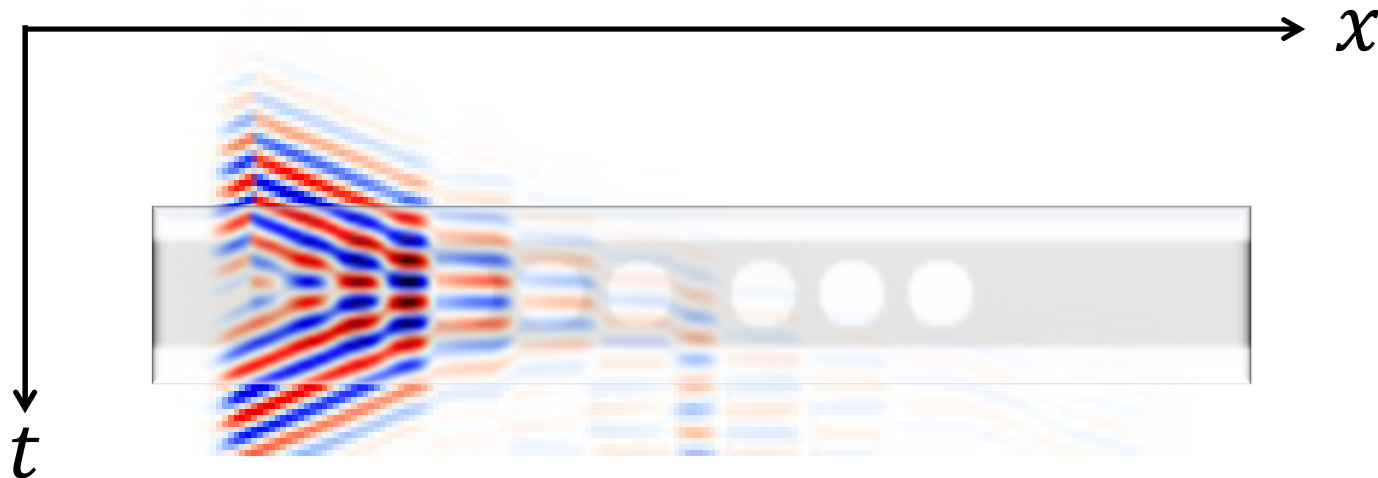
- For large N , a second mode is observed...
harminv0:, frequency, imag. freq., Q, |amp|, amplitude, error
harminv0:, 0.235201161007777, -1.34327185513047e-5,
8754.78631184943, 9.83220617825986, 6.83285024080876-
7.06996717944934i, 3.03237056700397e-9
harminv0:, 0.328227374843021, -4.6405752015136e-4,
353.649451404175, 0.134284355228178, -0.131856646632894-
0.0254187489419837i, 4.11557526694386e-7
- Generate field profile in time for extended mode at band edge:
unix% meep sy=12 fcen=0.3282 df=0.01 N=16 holey-wvg-cavityctl



Waveguide Transmission

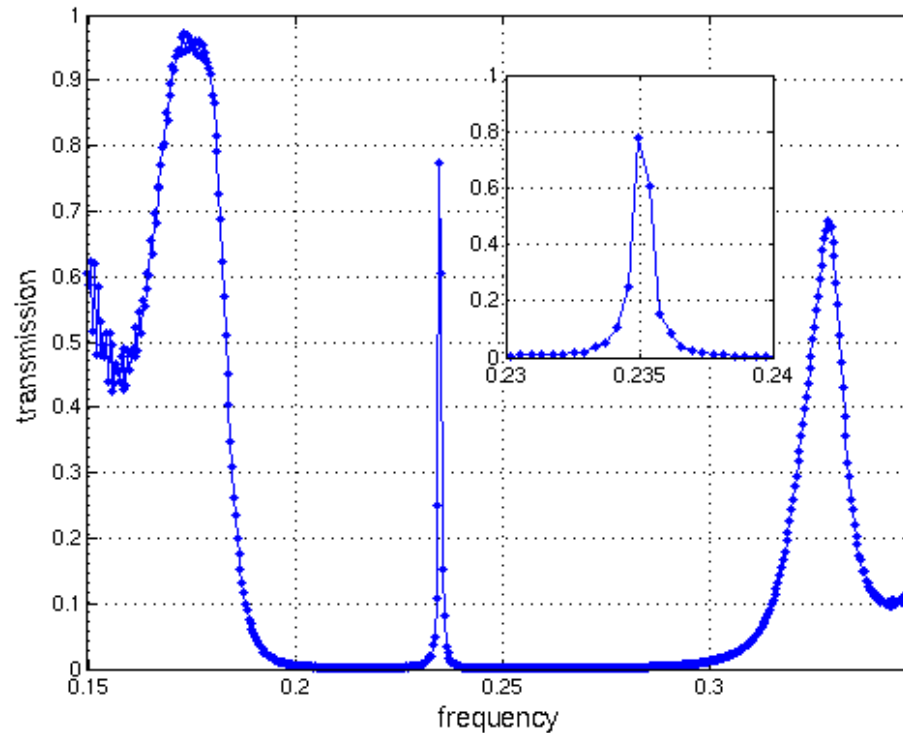
```
(define-param nfreq 500) ; num. frequencies at which to compute flux
(set! sources (list (make source (src (make gaussian-src
    (frequency fcen) (fwidth df))) (component Ey)
    (center (+ dpml (* -0.5 sx)) 0) (size 0 w))))
(set! symmetries (list (make mirror-sym (direction Y) (phase -1))))
(define trans ; transmitted flux
    (add-flux fcen df nfreq
        (make flux-region (center (- (* 0.5 sx) dpml 0.5) 0) (size 0 (* w 2)))))
(run-sources+ (stop-when-fields-decayed 50 Ey (vector3 (- (* 0.5 sx) dpml 0.5)
    0) 1e-3)
    (at-beginning output-epsilon)
    (during-sources (in-volume (volume (center 0 0) (size sx 0)) (to-
    appended "hz-slice" (at-every 0.4 output-hfield-z))))))
(display-fluxes trans) ; print out the flux spectrum
```

Waveguide Transmission



- View H_z field over space and time:
unix% meep holey-wvg-cavity.ctl | tee holey-wvg-cavity.out
unix% h5topng holey-wvg-cavity-eps-000000.00.h5
unix% h5topng -Zc dkbluered holey-wvg-cavity-hz-slice.h5

Waveguide Transmission



- Transmission spectrum computed as ratio:
unix% meep N=0 holey-wvg-cavityctl | tee holey-wvg-cavity.out0
unix% grep flux1: holey-wvg-cavity.out > flux.dat
unix% grep flux1: holey-wvg-cavity.out0 > flux0.dat
unix% divide2.pl flux0.dat flux.dat > flux-q.dat

Next Class

- Is on Monday, April 15
- Next time: in-class final project presentations!