ECE 595, Section 10
Numerical Simulations
Lecture 16: Applications of the Beam Propagation Method

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February 15, 2013

Outline

- Recap from Wednesday
- BPM Mode Solver
- Vectorial BPM Applications:
  - Waveguide
  - Photonic Crystal Fiber

BPM Mode Solver

- Can extend BPM method to solve for modes, by propagating in the imaginary direction
- First, drop all derivatives in BPM equation:

$$[K]\{h_{t,l}\} = -\gamma^2[M]\{h_{t,l}\}$$

- Second, write down next step in z:

$$\{h_{t,l}\}_{k+1} = \frac{-2\gamma - 0.5\Delta z k_o^2\left(n_{\mathit{eff},\ell}^2 - n_o^2\right)}{-2\gamma + 0.5\Delta z k_o^2\left(n_{\mathit{eff},\ell}^2 - n_o^2\right)}\{h_{t,l}\}_k$$

- Third, substitute special value of Δz:

$$\Delta z \approx j\frac{4n_o}{\left(n_{\mathit{eff},\ell}^2 - n_o^2\right)k_o}$$

BPM Mode Solver

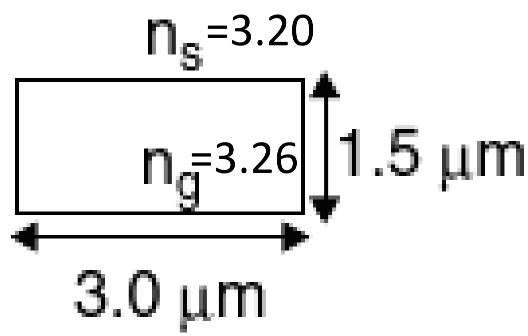
- Since Δz initially unknown, assume largest index possible, and decrease it as needed
- Will eventually converge to correct answer and effective refractive index:

$$n^2_{eff,\ell,k} = \frac{\{h_t\}^*_k[K]_k\{h_t\}_k}{k_o^2\{h_t\}^*_k[M]_k\{h_t\}_k}$$

- Can use Gram-Schmidt normalization procedure to find higher-order modes:

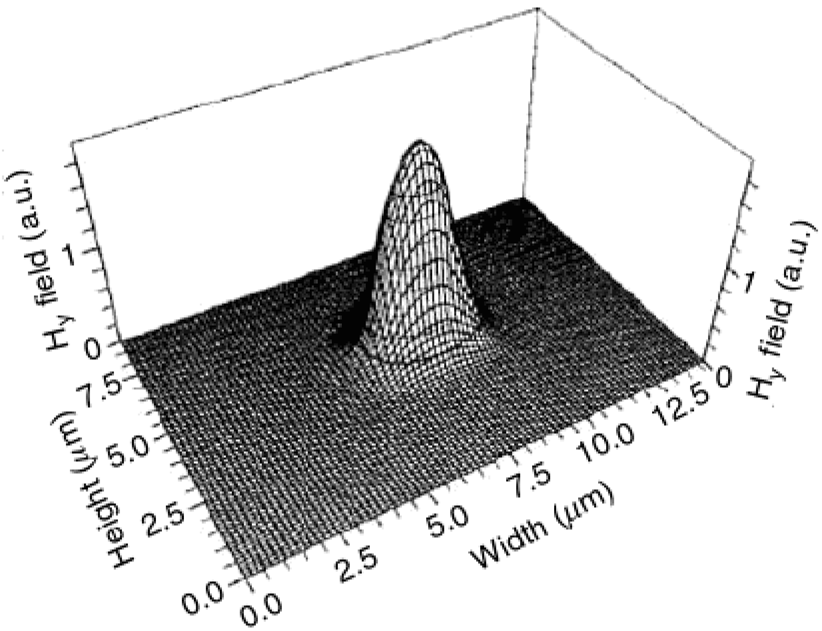
$$\{h_t\}_{1,new} = \{h_t\}_1 - \sum_{\ell=1}^{i-1} \frac{\{h_{t,l}\}^*[M]\{h_t\}_1}{\{h_{t,l}\}^*[M]\{h_{t,l}\}}\{h_{t,l}\}$$

VBPM on a Waveguide: Problem Description



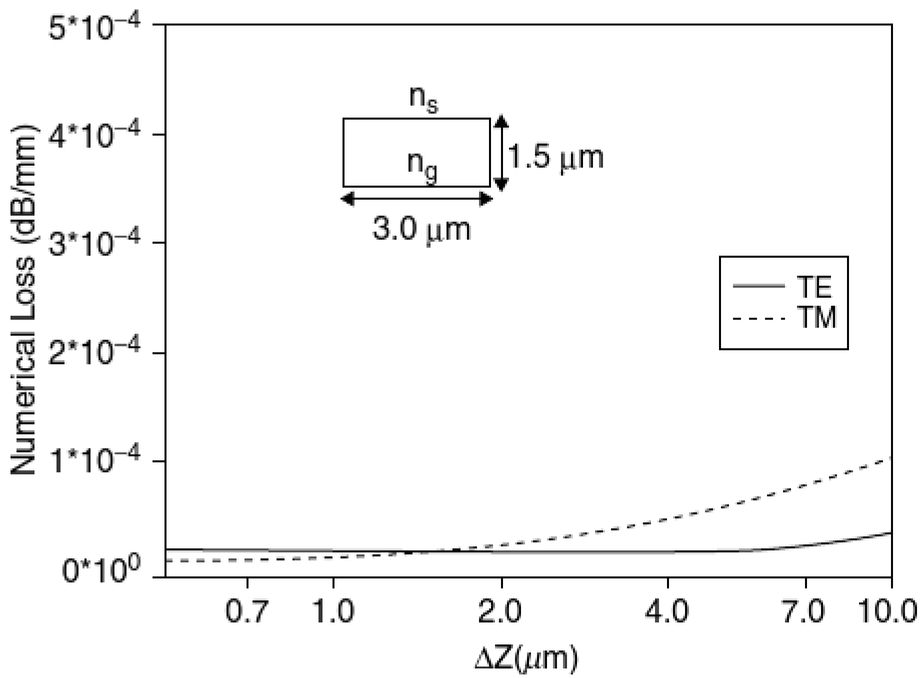
- Cross section defined above; $\lambda = 1.3\ \mu$m
- Propagation along z is semi-infinite
- Must grid space with first-order triangular elements in cross-sectional plane; choose PML to reduce reflections to 10^{-100}
- Will vary Δz for maximum effectiveness

VBPM on a Waveguide



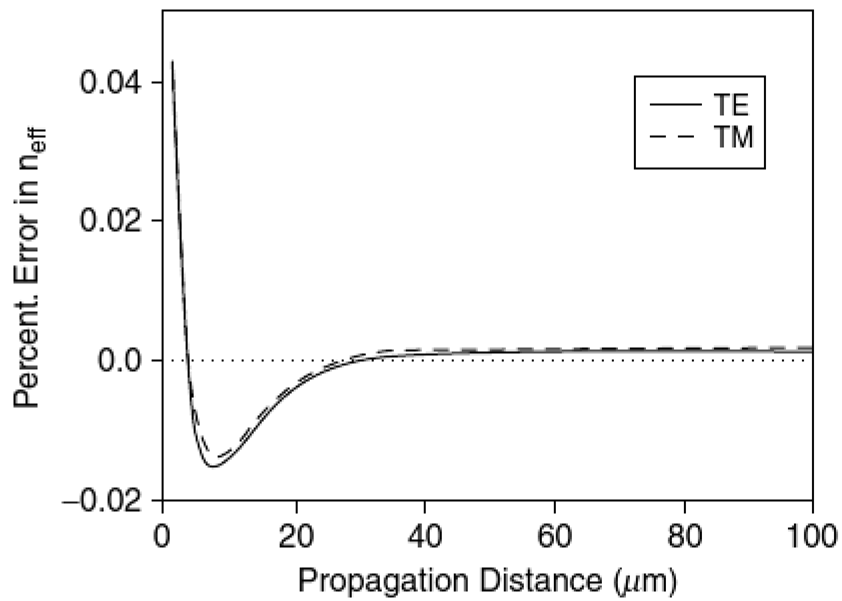
- Fundamental mode is calculated accurately with 12,800 first-order triangular elements

VBPM on a Waveguide



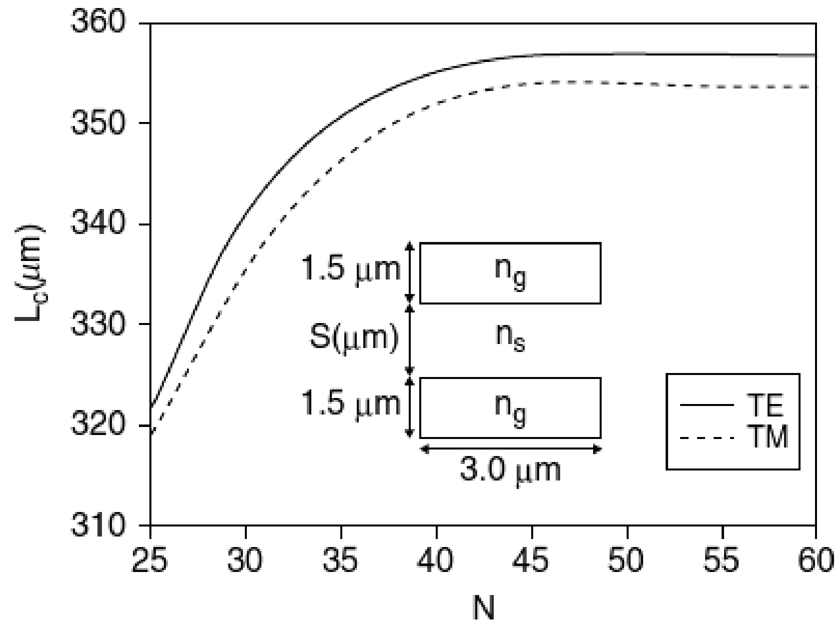
- Propagation step size in *Z*, known as ΔZ, should equal transverse dimensions for best accuracy

VBPM on a Waveguide: Longitudinal Imaginary Propagation



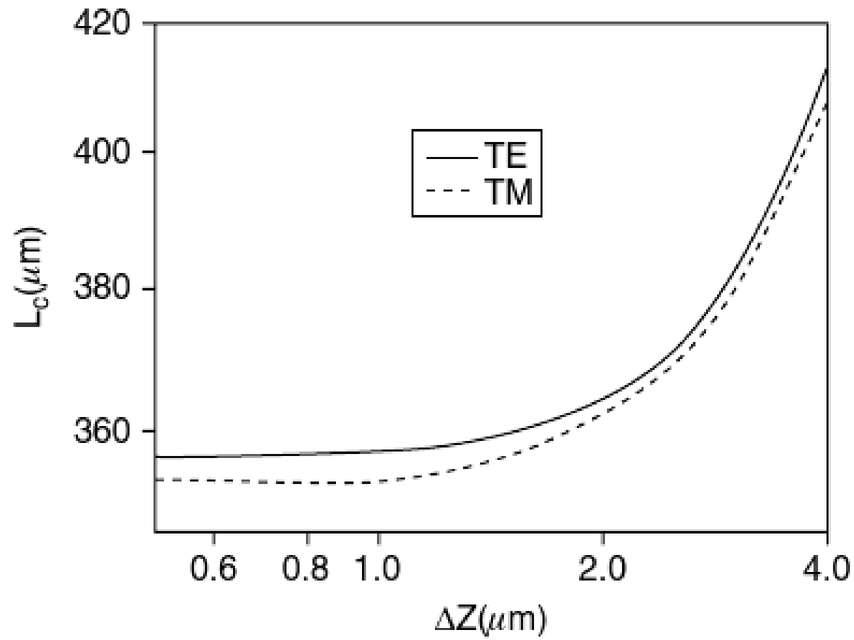
- With optimal step size, can solve the fundamental mode of both polarizations in a pretty modest number of steps!

VBPM on a Waveguide: Accuracy



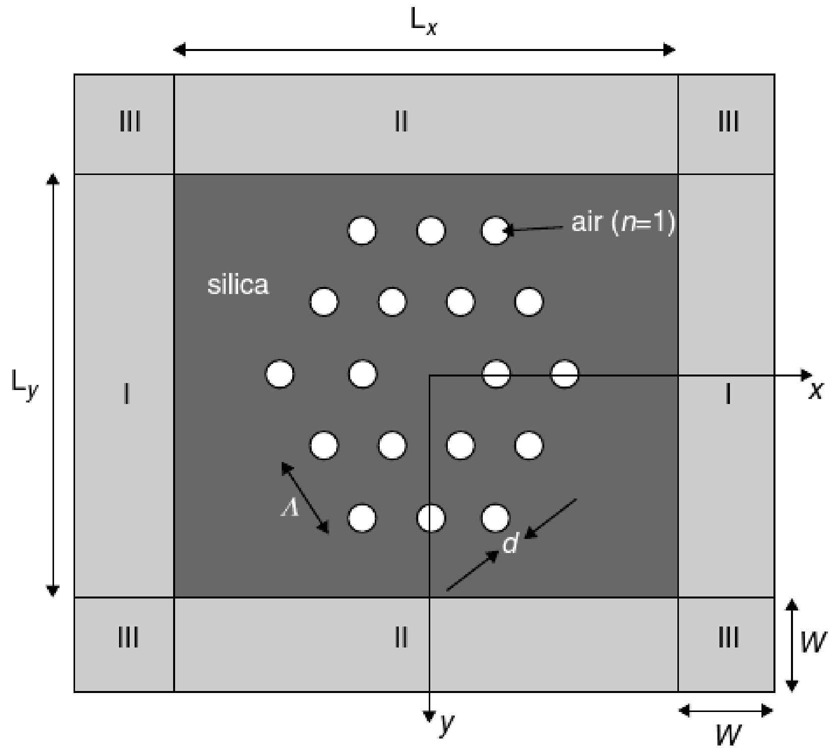
- Accuracy of calculation of waveguide coupling length as a function of mesh divisions *N*

VBPM on a Waveguide



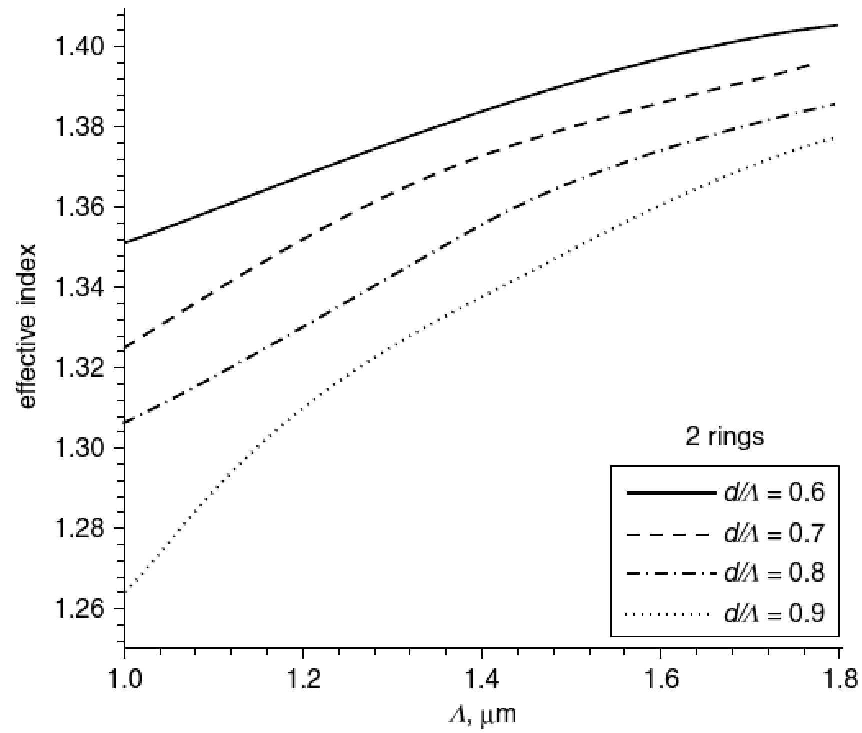
- Accuracy of coupling length as a function of ΔZ saturates below one wavelength

VBPM on a Photonic Crystal Fiber



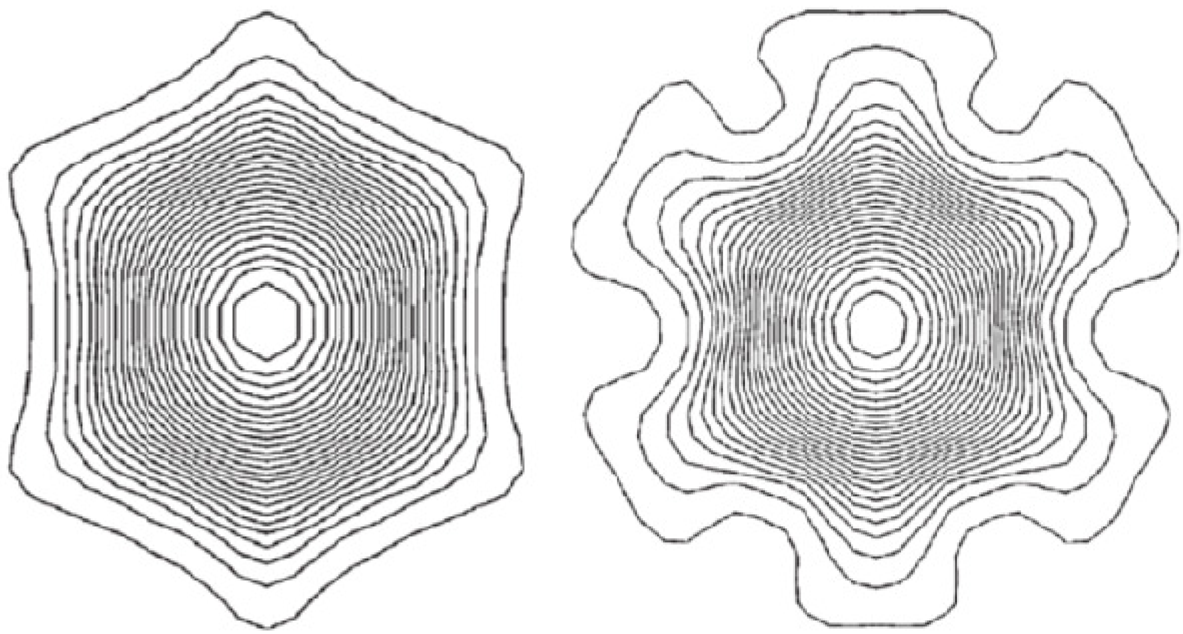
- Originally conceived of by P.J. Russell
- Confines light to core without total internal reflection!

VBPM on a PhC Fiber



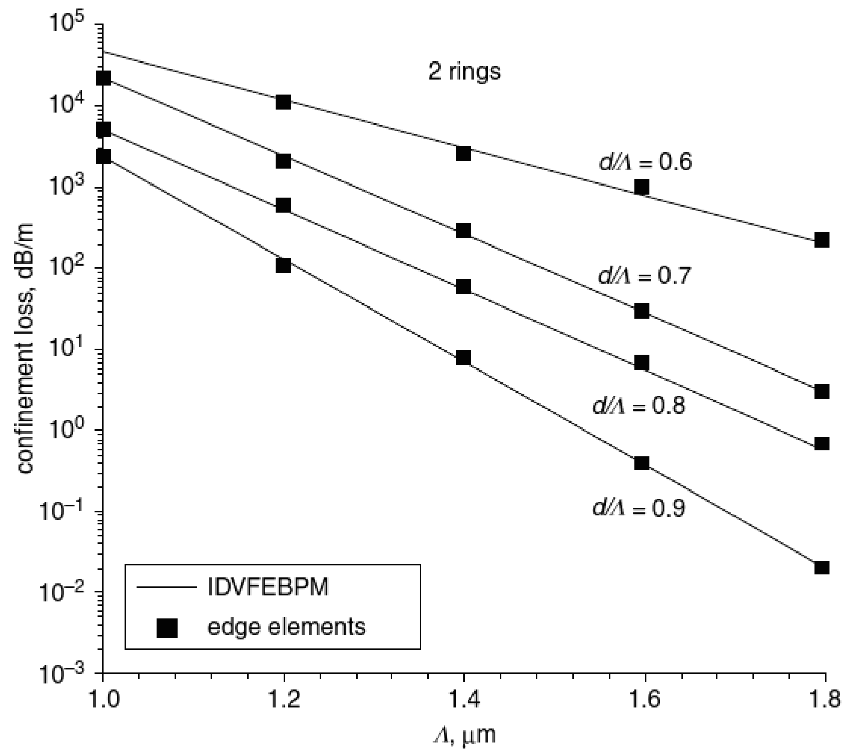
- Effective index vs. PhC period

VBPM on a PhC Fiber



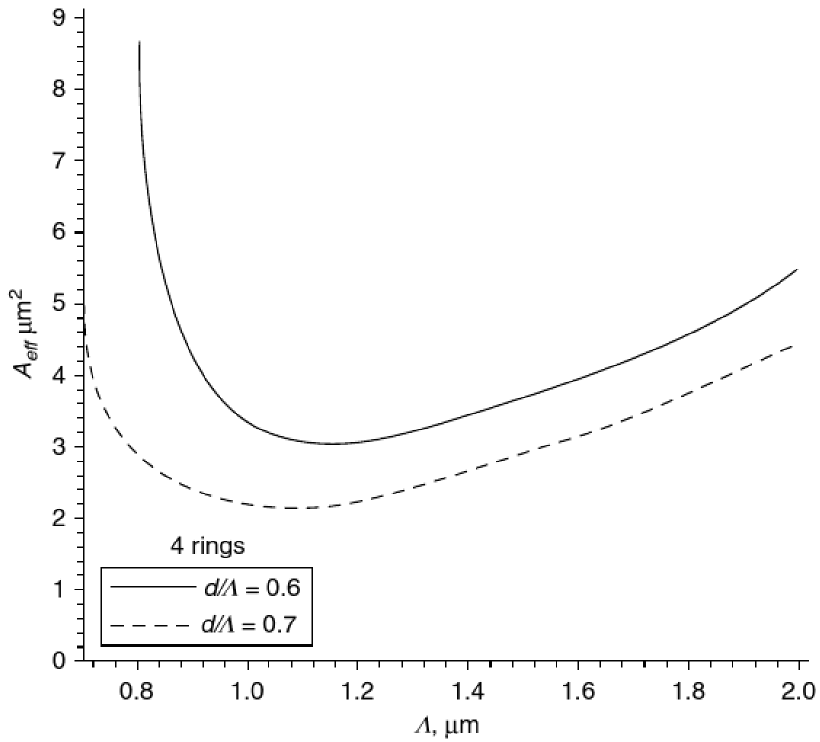
- H_y field distributions for the fundamental TE modes

VBPM on a PhC Fiber



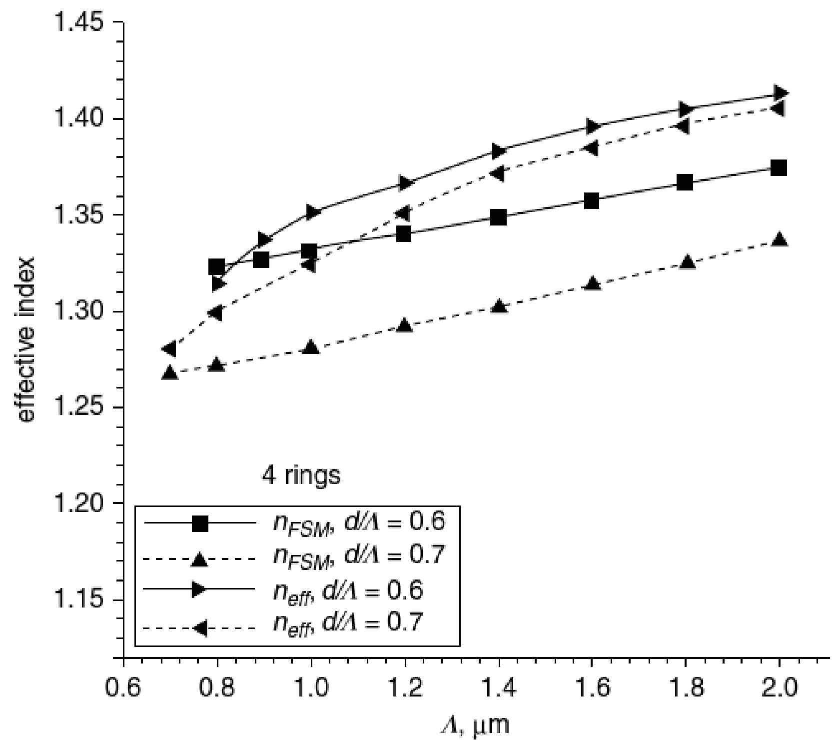
- Confinement loss decreases sharply as period Λ increases

VBPM on a PhC Fiber



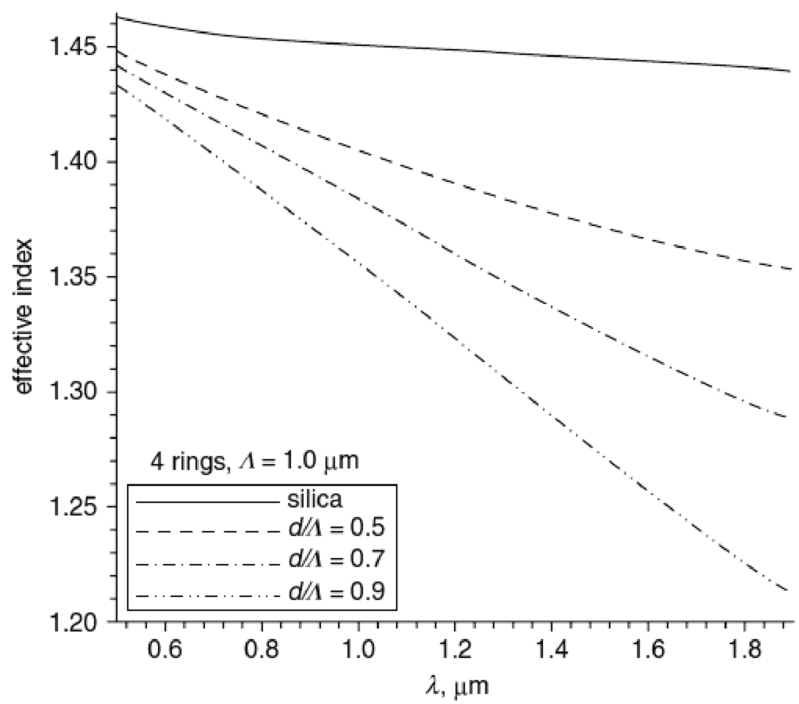
- Variation of the effective mode area with PhC period Λ

VBPM on a PhC Fiber



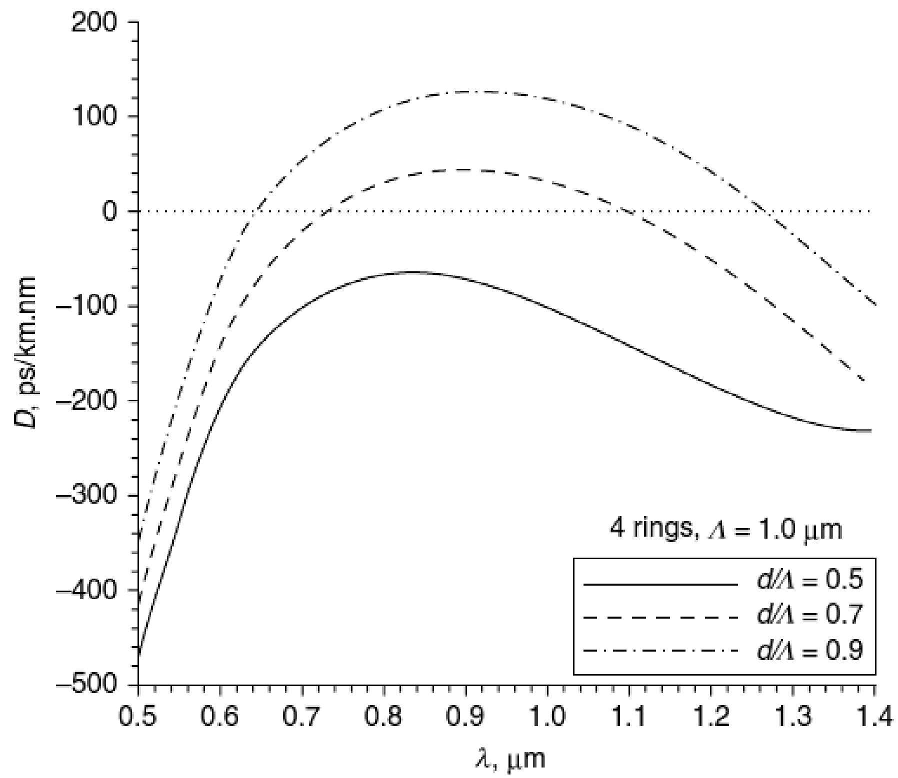
- Effective index increases modestly with increasing period Λ, indicating increased mode confinement

VBPM on a PhC Fiber



- Calculated dispersion relation (effective index versus wavelength) for a PhC Fiber

VBPM on a PhC Fiber



- Obtained dispersion $D = d^2k/d\omega^2$ from earlier data
- Note modest changes in parameters flip sign of *D*

Next Class

- Is on Monday, Feb. 18
- Next time, we shall finish the applications of BPM, and possibly cover other FEM applications
- Recommended reading: Obayya, Chapter 3