

ECE 595, Section 10  
Numerical Simulations  
Lecture 17: Applications of the Beam  
Propagation Method II

Prof. Peter Bermel

February 18, 2013

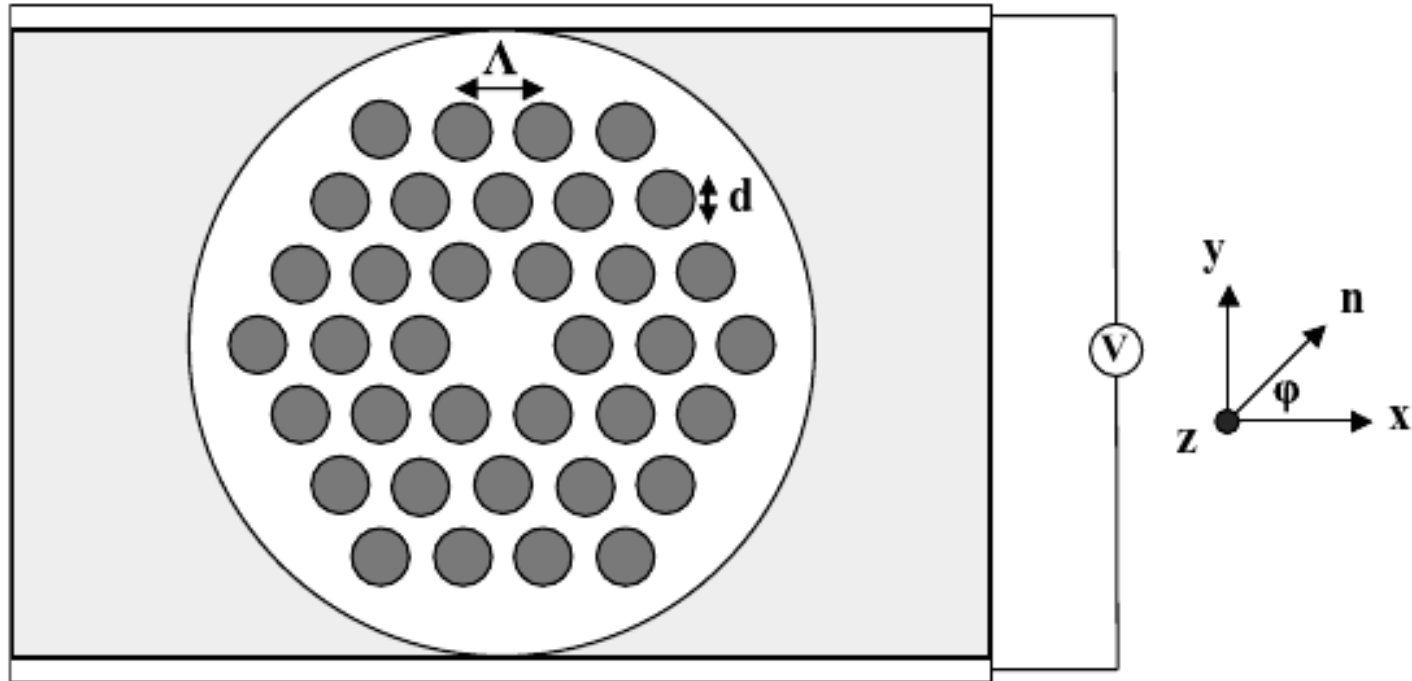
# Outline

- Recap from Friday
- Applications of Beam Propagation Method
  - Tunable Photonic Crystal Fibers
  - Electro-Optic Modulator
  - Electro-Optic Switch

# Recap from Friday

- BPM Mode Solver
- Vectorial BPM Applications:
  - Waveguide
  - Photonic Crystal Fiber

# Tunable PhC Fiber

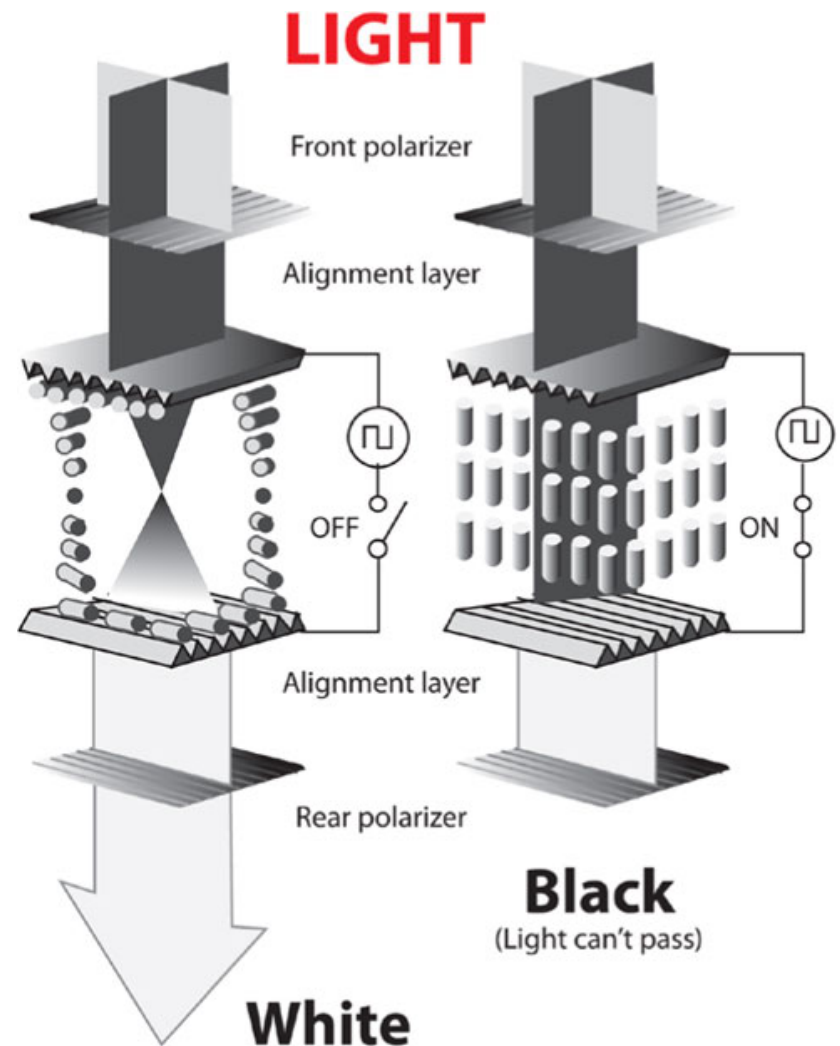


S. Obyaya, "Computational Photonics" (Wiley, 2010)

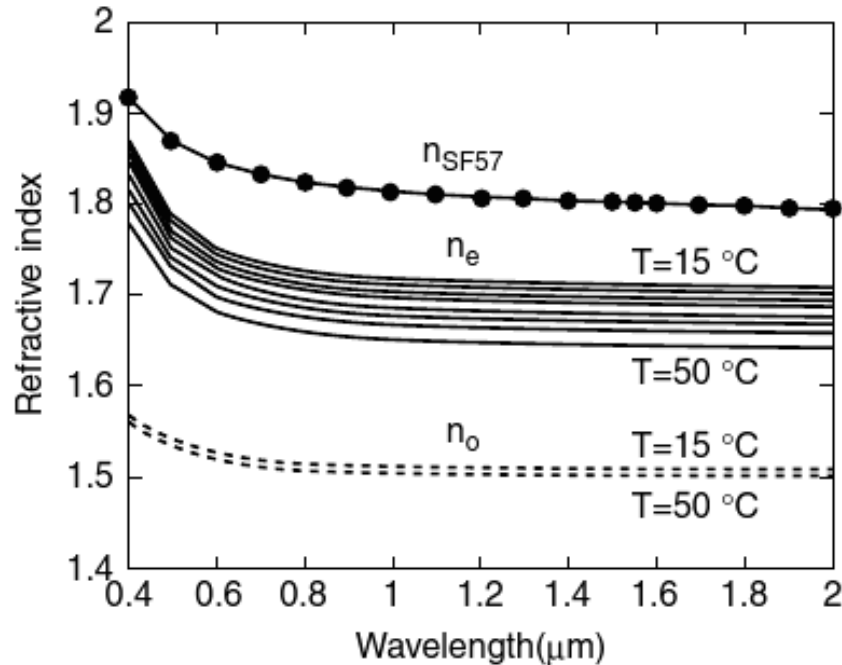
- Cross-section of a PhC fiber filled with electrostatically tunable liquid crystals

# Liquid Crystals

- Liquid crystals consist of many stiff molecules
- LC order in between that of liquids and crystals
- LCs have a uniaxial dielectric function:
$$\epsilon_{ij} = \epsilon_o + \delta\epsilon \hat{n}_i \hat{n}_j$$
- The director is oriented along applied electrostatic fields



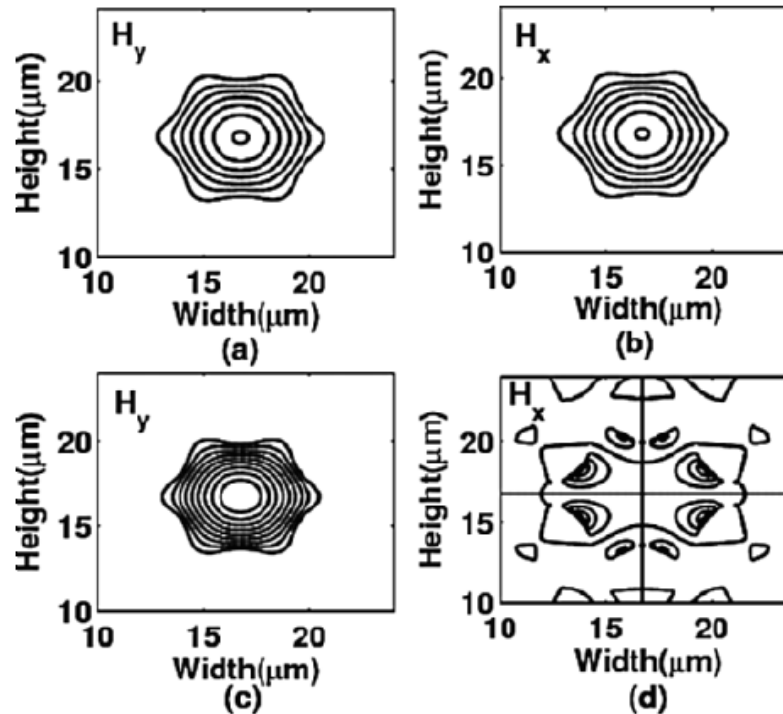
# Tunable PhC Fiber



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Variation of LC refractive indices both on and off-axis, consistent with normal dispersion

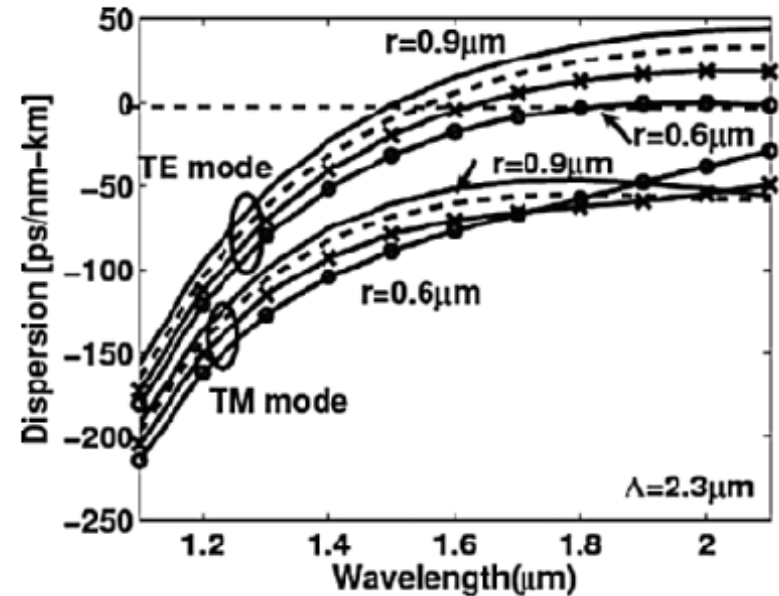
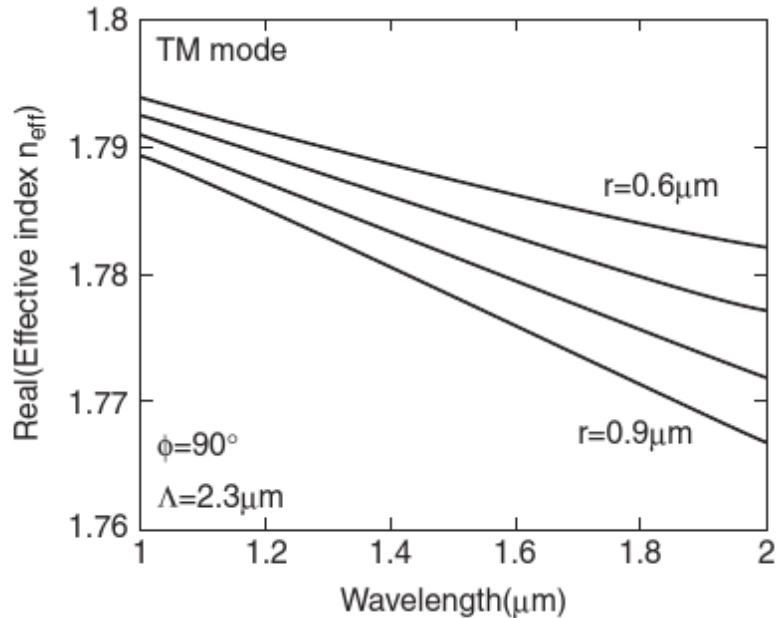
# Tunable PhC Fiber



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Dominant and non-dominant HE (quasi-TE) modes for tunable PhC fiber

# Tunable PhC Fiber

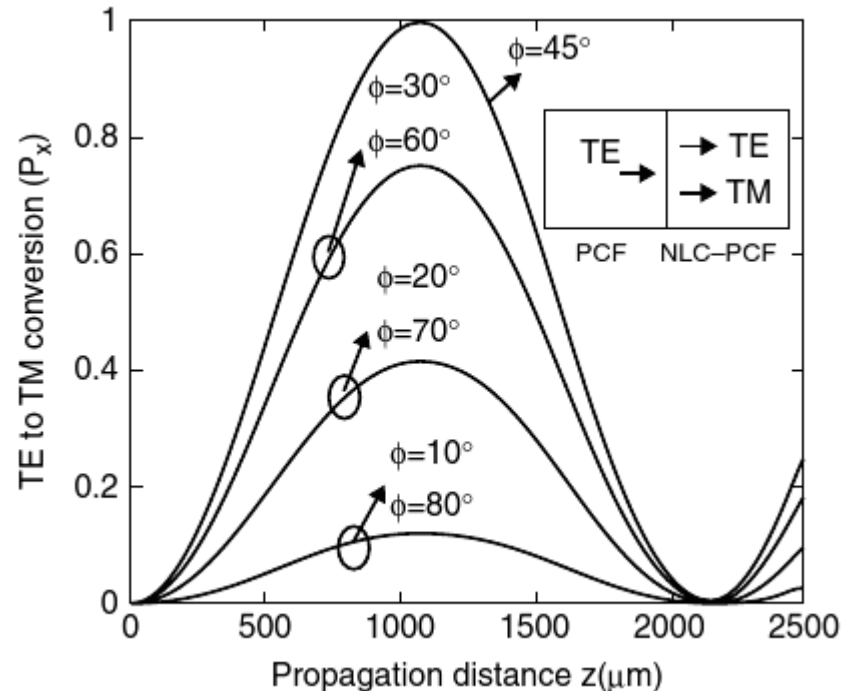


S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Wavelength dependence of the effective index (left) and dispersion (right)



# Tunable PhC Fiber



S. Obayya, "Computational Photonics" (Wiley, 2010)

- Polarization conversion versus propagation distance  $Z$

# Electro-Optic Modulation

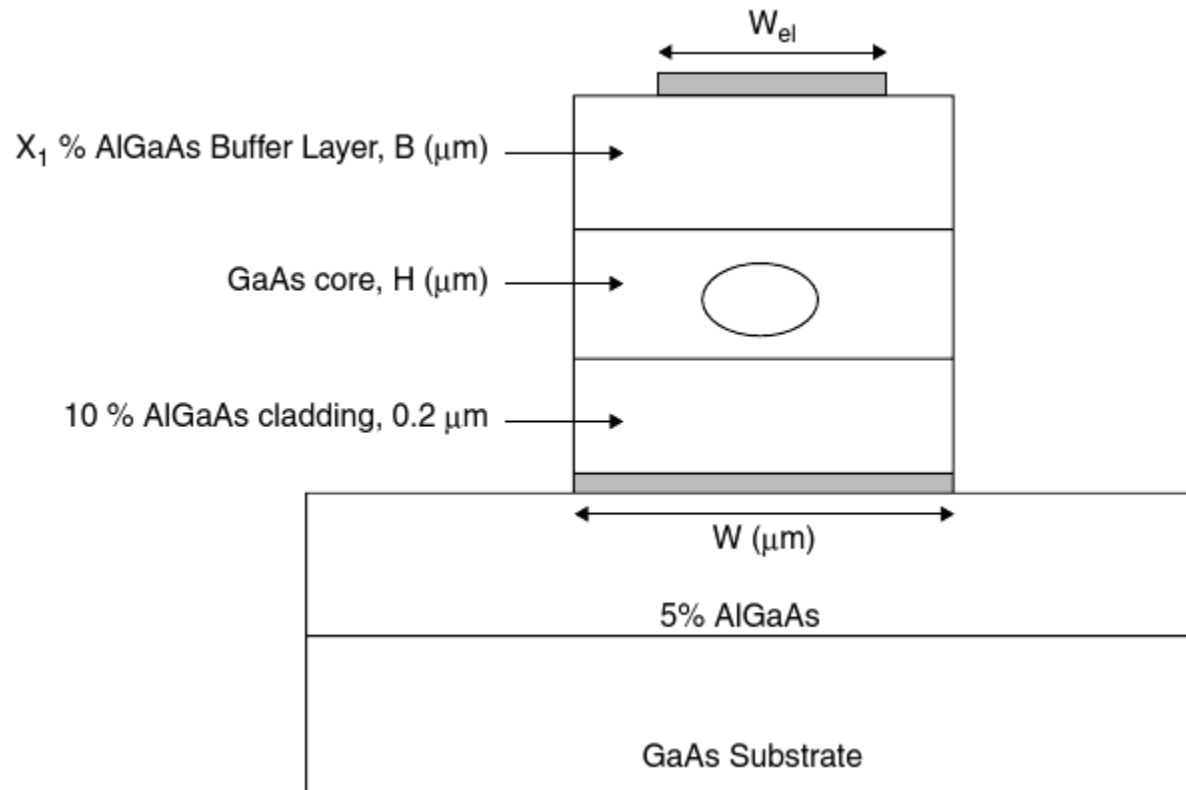
- The refractive index matrix for a Pockels medium subject to an external electric field in the xy-plane can be written as follows:

$$n = \begin{pmatrix} n_o + \delta n_{xx} & \delta n_{xy} & 0 \\ \delta n_{yx} & n_o & 0 \\ 0 & 0 & n_o - \delta n_{zz} \end{pmatrix}$$

- Where:

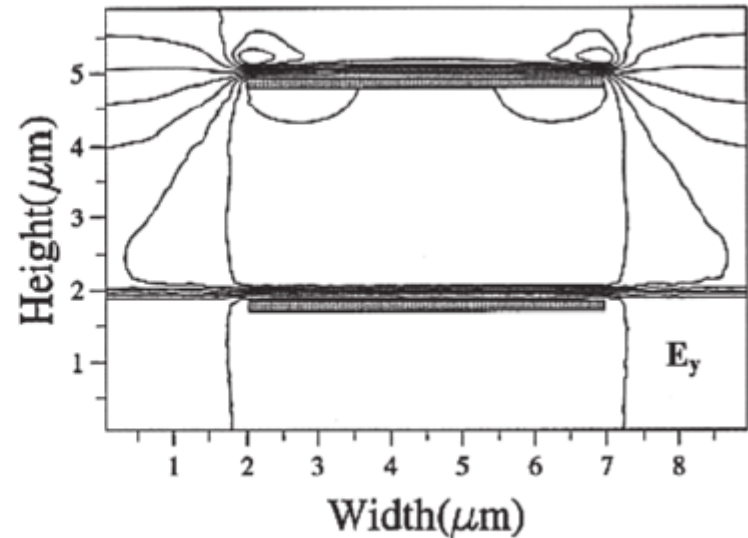
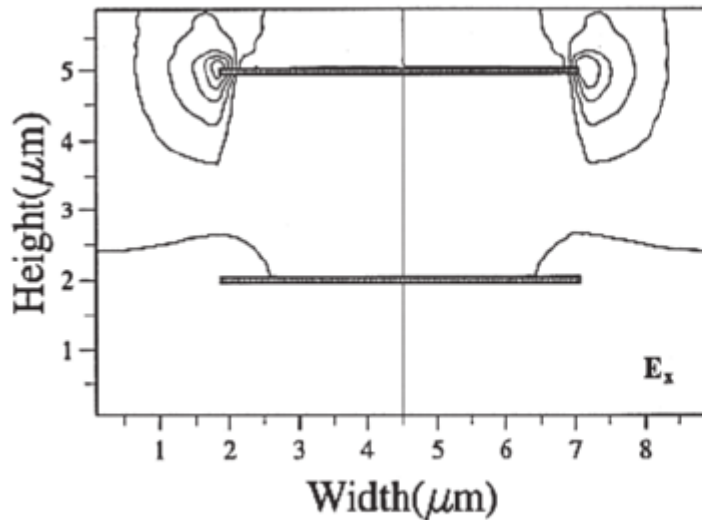
$$\delta n_{xx} = \delta n_{zz} = \frac{1}{2} n_o^3 r_{41} E_y$$
$$\delta n_{xy} = \delta n_{yx} = \frac{1}{2} n_o^3 r_{41} E_x$$

# Electro-Optic Modulator



- Schematic diagram of the electro-optic modulator, made from epitaxial GaAs/AlGaAs layers

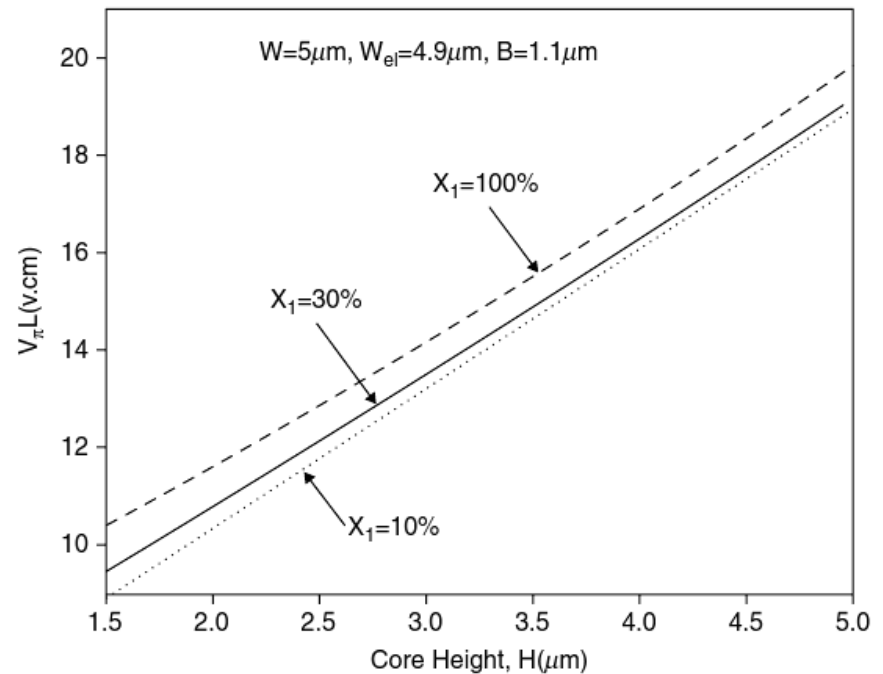
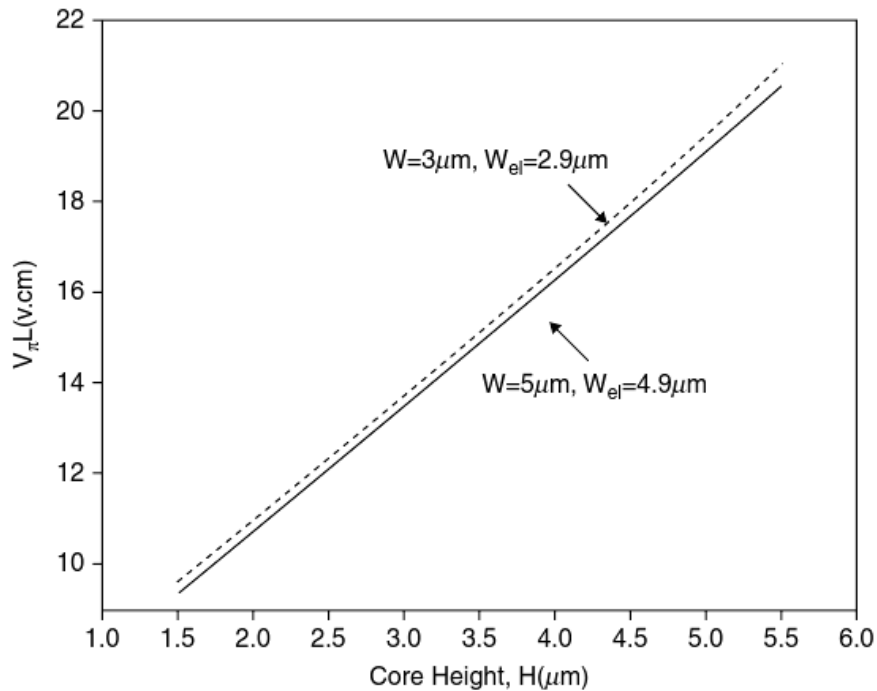
# Electro-Optic Modulator



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Electric modulation field distributions for  $E_x$  (left-hand side) and  $E_y$  (right-hand side)

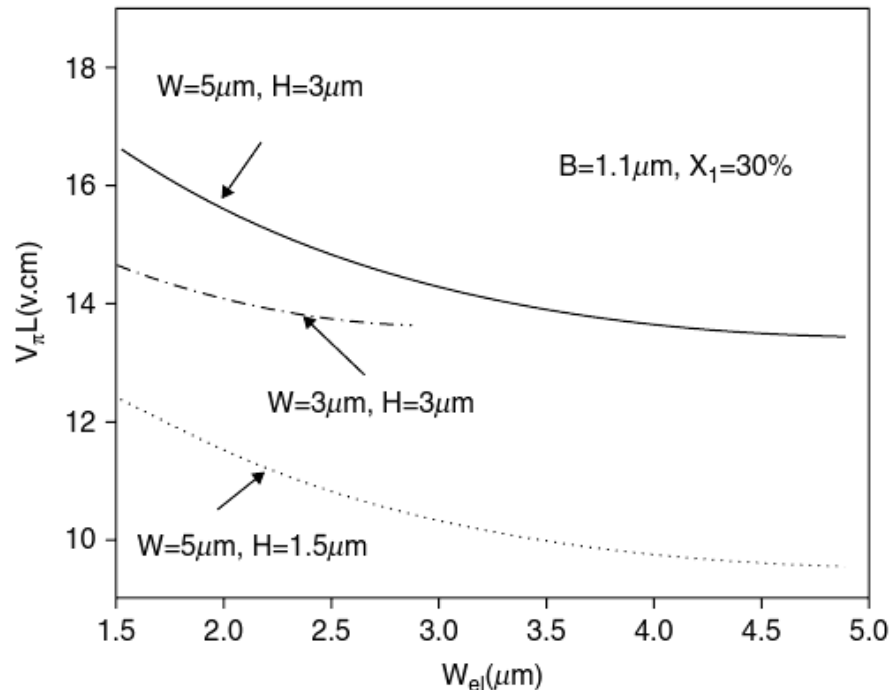
# Electro-Optic Modulator



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Key quantity  $V_{\pi}L$ , product of voltage and electrode separation necessary to create a  $\pi$  phase shift, is measured as a function of core height for a few designs

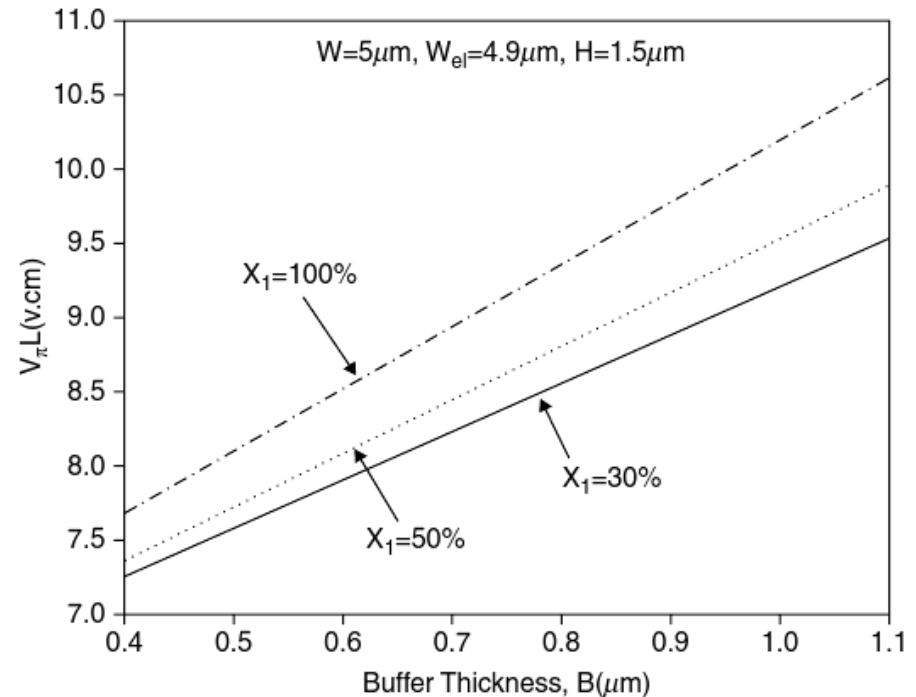
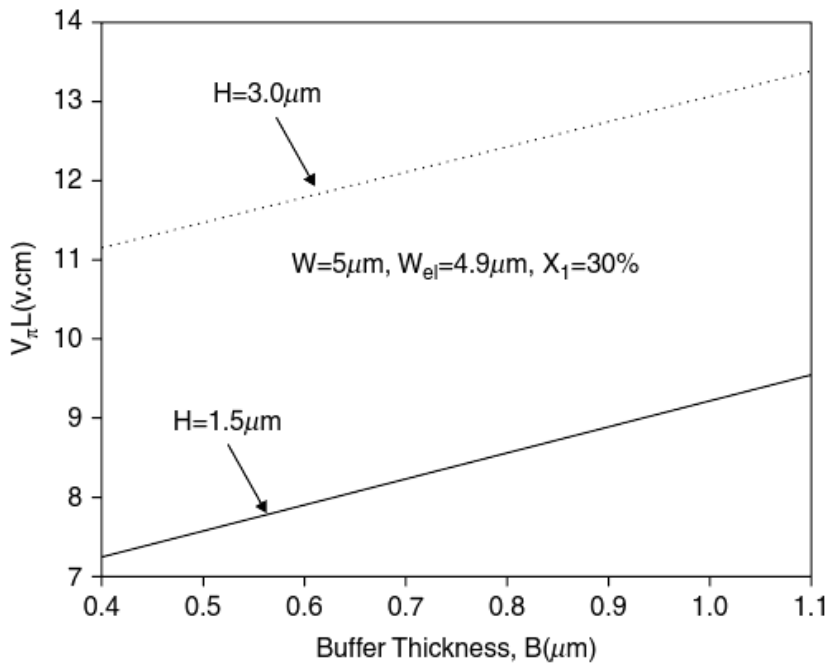
# Electro-Optic Modulator



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Here,  $V_{\pi}L$  is measured as a function of core width for several designs – greater widths are more sensitive to voltage

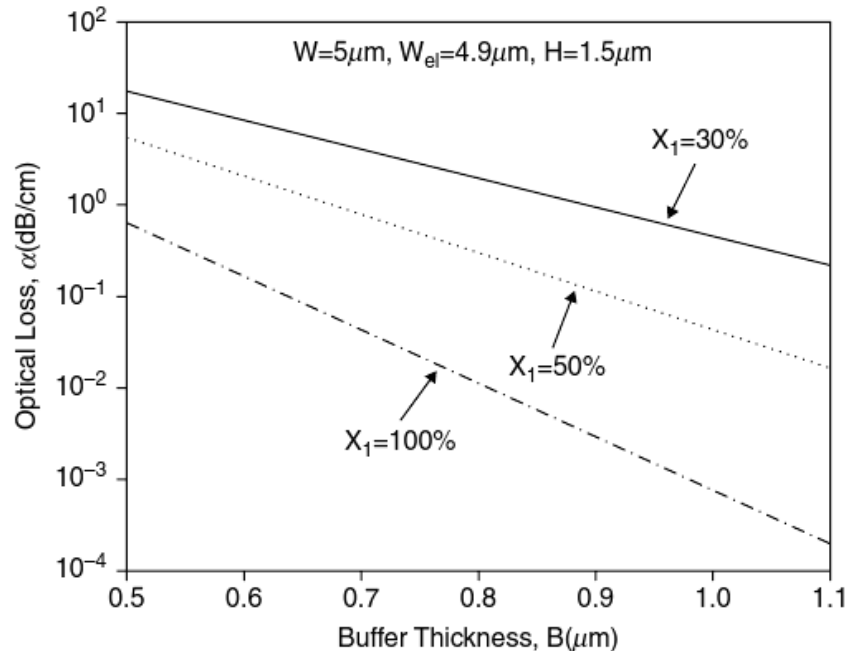
# Electro-Optic Modulator



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Here,  $V_{\pi}L$  increases with buffer thickness, caused by diminishing field strength in the core region

# Electro-Optic Modulator

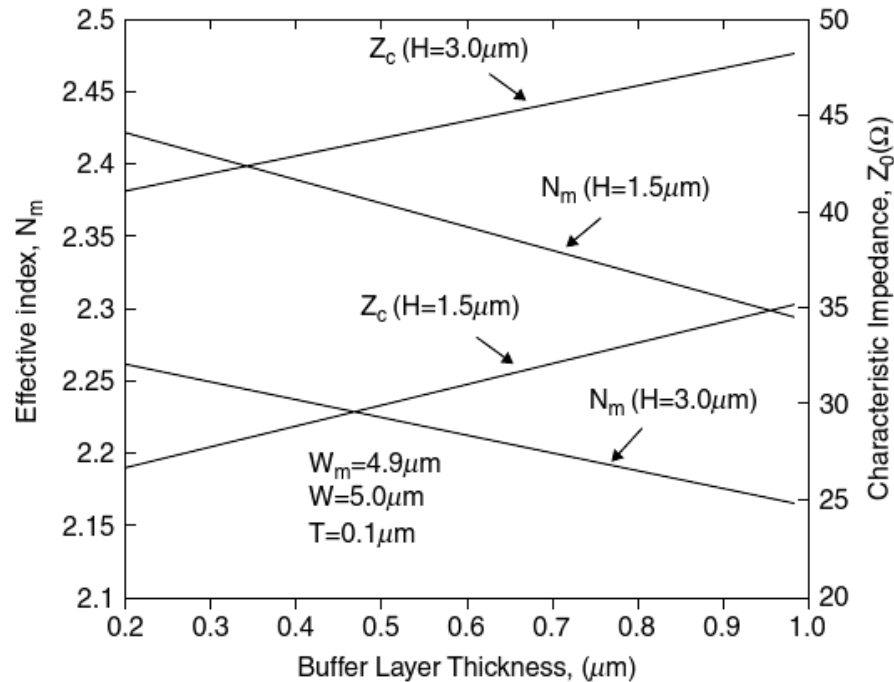


S. Obyaya, "Computational Photonics" (Wiley, 2010)

- On the other hand, optical loss decreases with buffer thickness increases for similar reasons



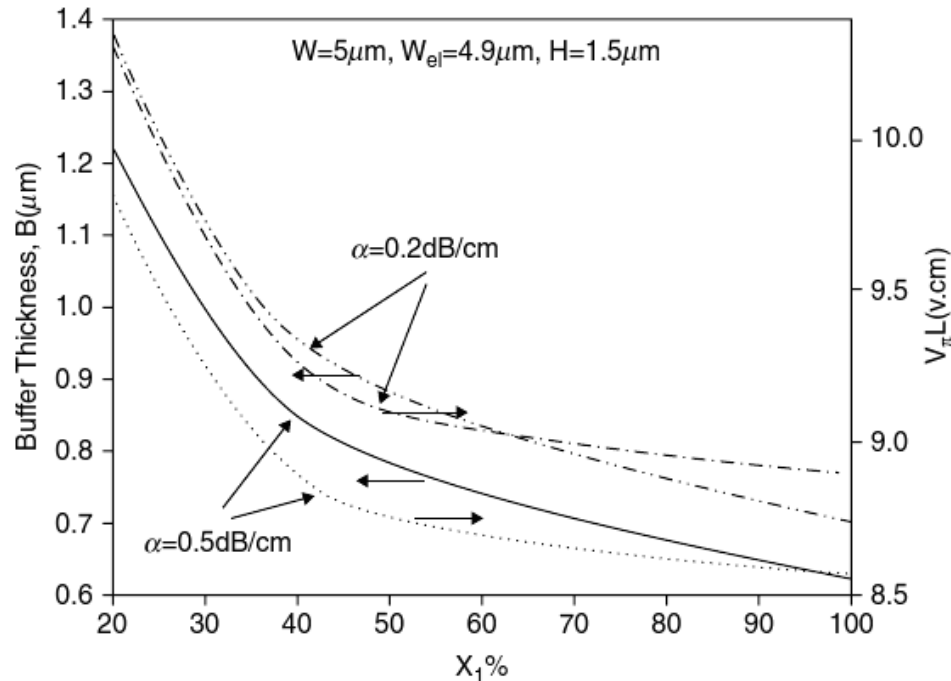
# Electro-Optic Modulator



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Effective impedance of microwaves and refractive index of IR signals cross over only at selected buffer thicknesses that vary greatly with core height

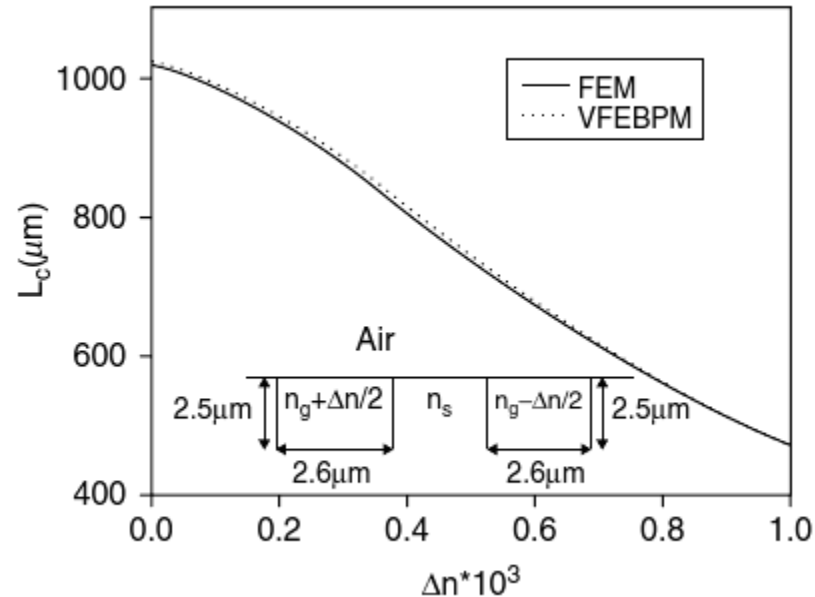
# Electro-Optic Modulator



S. Obyaya, "Computational Photonics" (Wiley, 2010)

- Here, the buffer thickness needed to achieve a given level of loss is calculated as a function of Al doping concentration  $X_f$

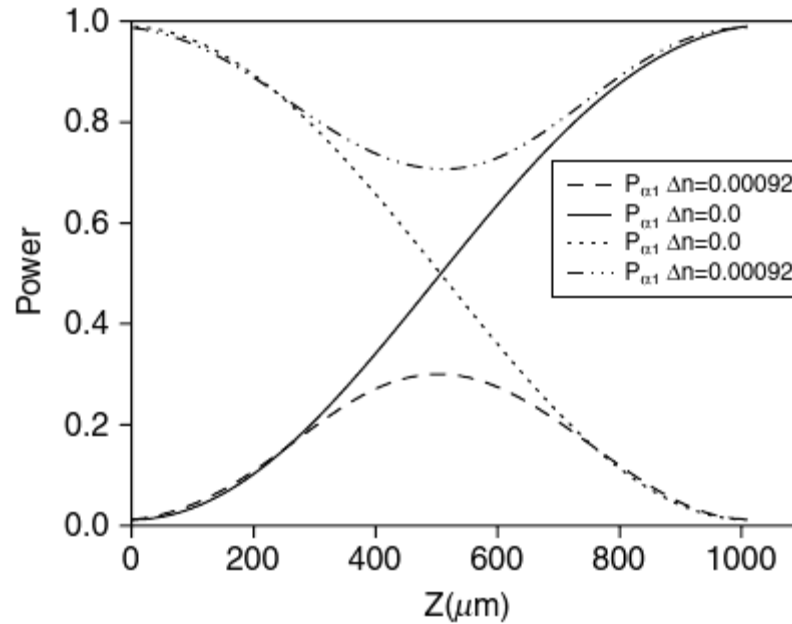
# Electro-Optic Switch



S. Obayya, "Computational Photonics" (Wiley, 2010)

- Coupling length required for power transfer decreases as a function of EO index tuning

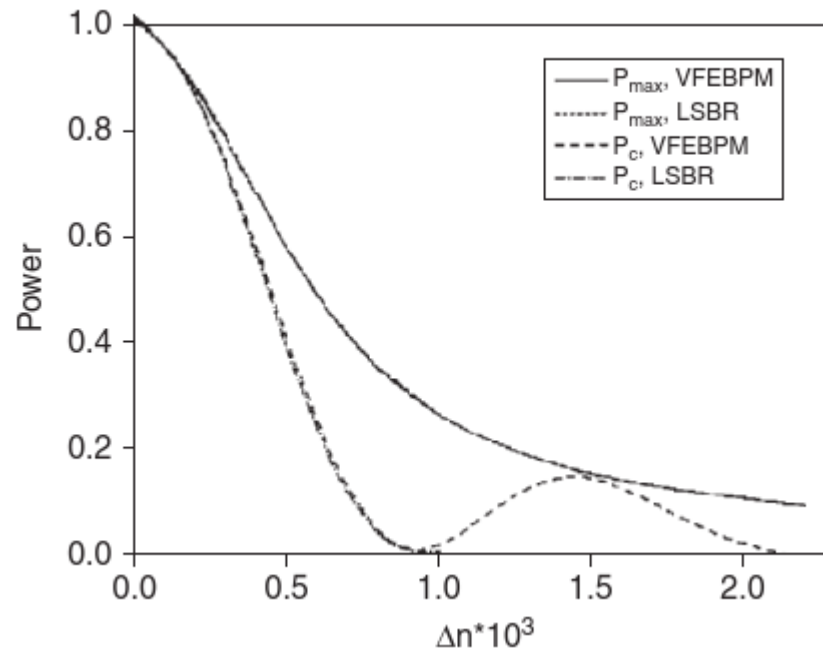
# Electro-Optic Switch



S. Obayya, "Computational Photonics" (Wiley, 2010)

- Power transferred as a function of position for waveguides both with and without EO tuning

# Electro-Optic Switch



S. Obayya, "Computational Photonics" (Wiley, 2010)

- Variation of output and maximum power transfer as a function of EO index tuning

# Next Class

- Is on Wednesday, Feb. 20
- Next time, we will cover other FEM applications in heat transfer and electronic transport