Silicon-Organic-Hybrid Independent, Simultaneous Dual-Polarization Modulator: Device Theory and Design

Y. D'Mello*[1] , M. Hui[1] , J. Skoric[1] , M. Haines[1] , A. Kirk[1] , M. Andrews[2] , D. Plant[1]

1. Department of Electrical and Computer Engineering, McGill University, Montreal, Canada

2. Department of Chemistry, McGill University, Montreal, Canada

*Yannick.DMello@mail.McGill.ca

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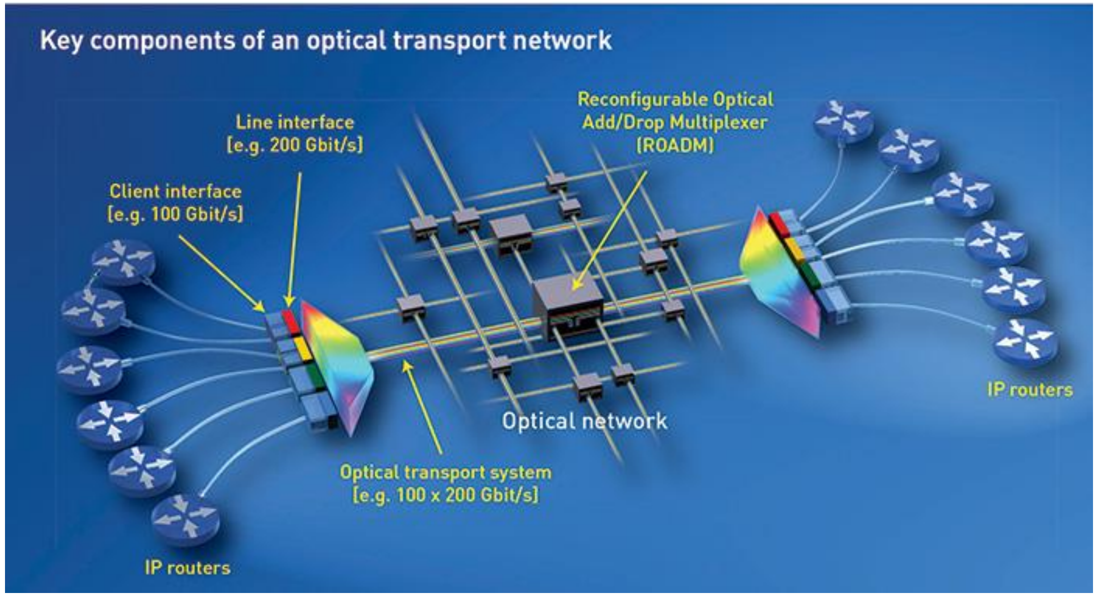
    - Interaction Length
    - Applied electric field
    - Dual modulation
- Future Work

Telecommunication

- Generating 1’s and 0’s
- Signal Processing
  - Nyquist: $f_{carrier} = 2f_{signal}$
  - Shannon:
    - Send-transmit-receive
    - Chip-AON-chip
- Always a need for higher bandwidth & speed



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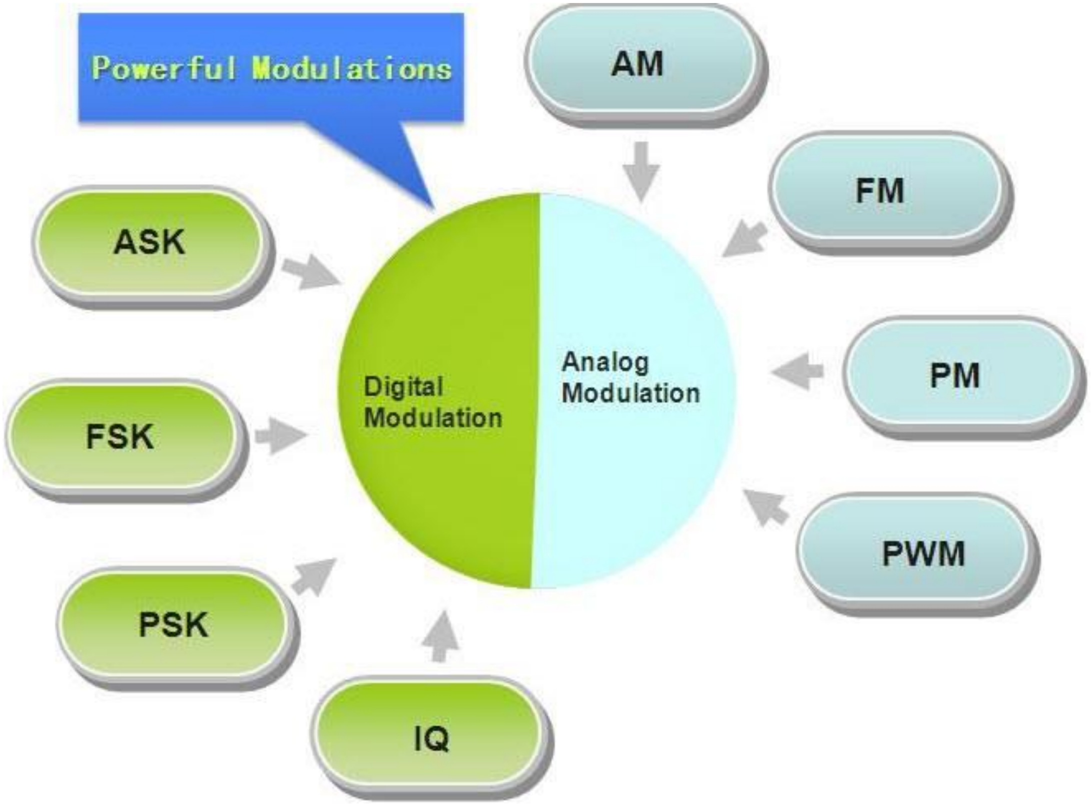
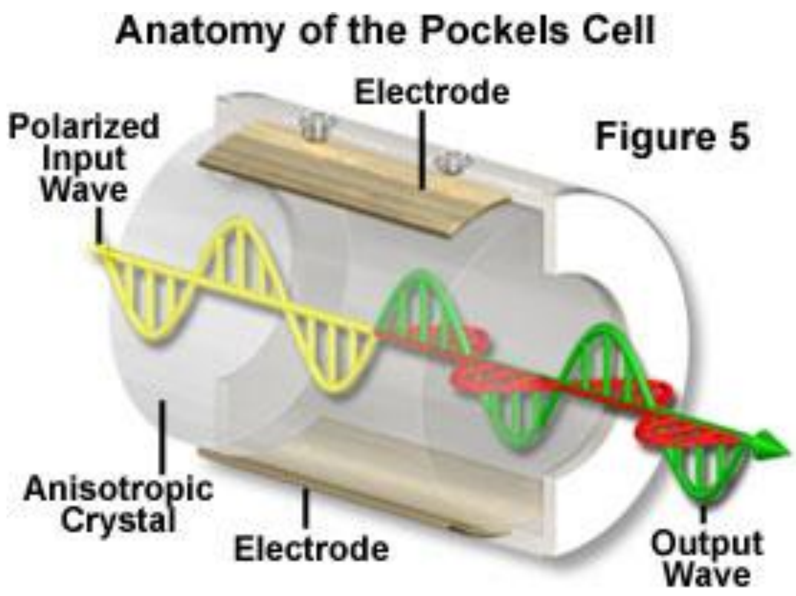
Modulators



https://www.edgefx.in/wp-content/uploads/2014/09/9-27-2014-12-30-50-PM.jpg

- Occupy the largest area on a nanophotonic chip
- Analog Modulation techniques
  - Amplitude
  - Frequency
  - Phase

Pockels Effect



http://www.olympusmicro.com/primer/java/pockelscell/pockelsceljavafigure1.jpg

- 2^{nd} order nonlinear optic effect

$$\vec{P} = \vec{P}_0 + \varepsilon_0\left(\chi^{(1)}\vec{E} + \chi^{(2)}\vec{E}:\vec{E} + \chi^{(3)}\vec{E}:\vec{E}:\vec{E} + \cdots\right)$$

- 1^{st} order linear electro-optic effect

$$n_d = n_{co} - \frac{1}{2}n_{co}^3 r_{ij} E_d$$

- Change in n → phase shift

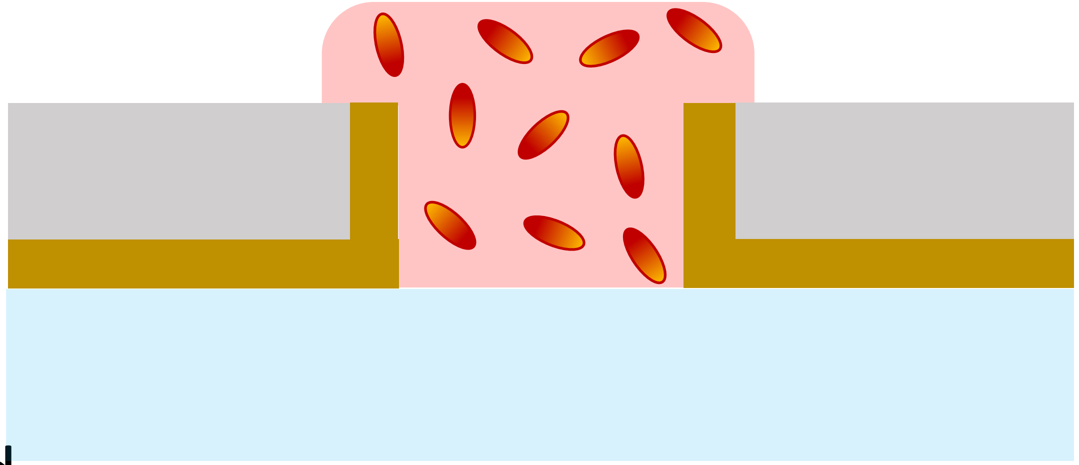
- Affected by Second Harmonic Generation

Electro-Optic Polymers

- Smart material: guest-host matrix
- Chromophores related to color
- Delocalized π-bonds asymmetrically oriented to create a dipole effect
- Applied E-field affects polarization
- Orientation can be manipulated to produce phase modulation

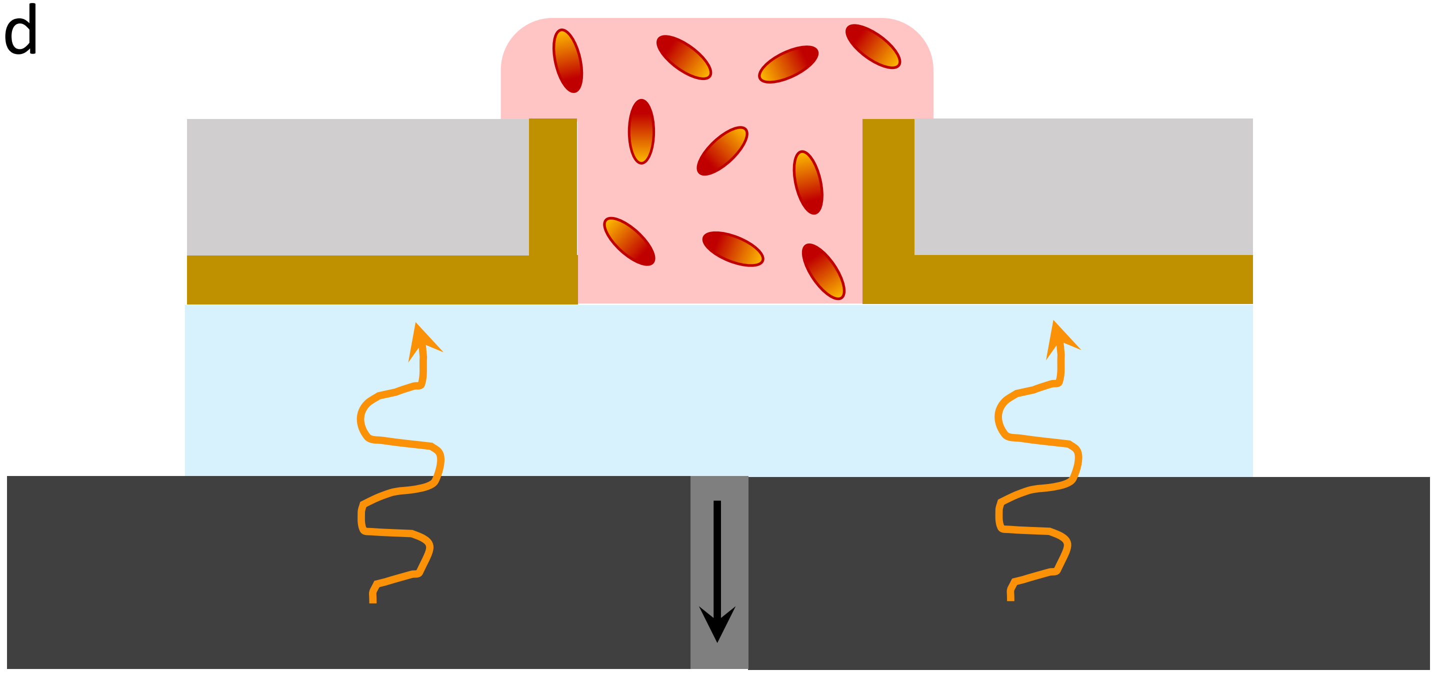
$$\vec{P} = \vec{P}_0 + \varepsilon_0\left(\chi^{(1)}\vec{E} + \chi^{(2)}\vec{E}:\vec{E} + \chi^{(3)}\vec{E}:\vec{E}:\vec{E} + \cdots\right)$$

$$\vec{M}(\vec{E}) = \vec{M}(0) + \hat{\alpha}\vec{E} + \hat{\hat{\beta}}\vec{E}:\vec{E} + \hat{\hat{\hat{\gamma}}}\vec{E}:\vec{E}:\vec{E} + \cdots$$



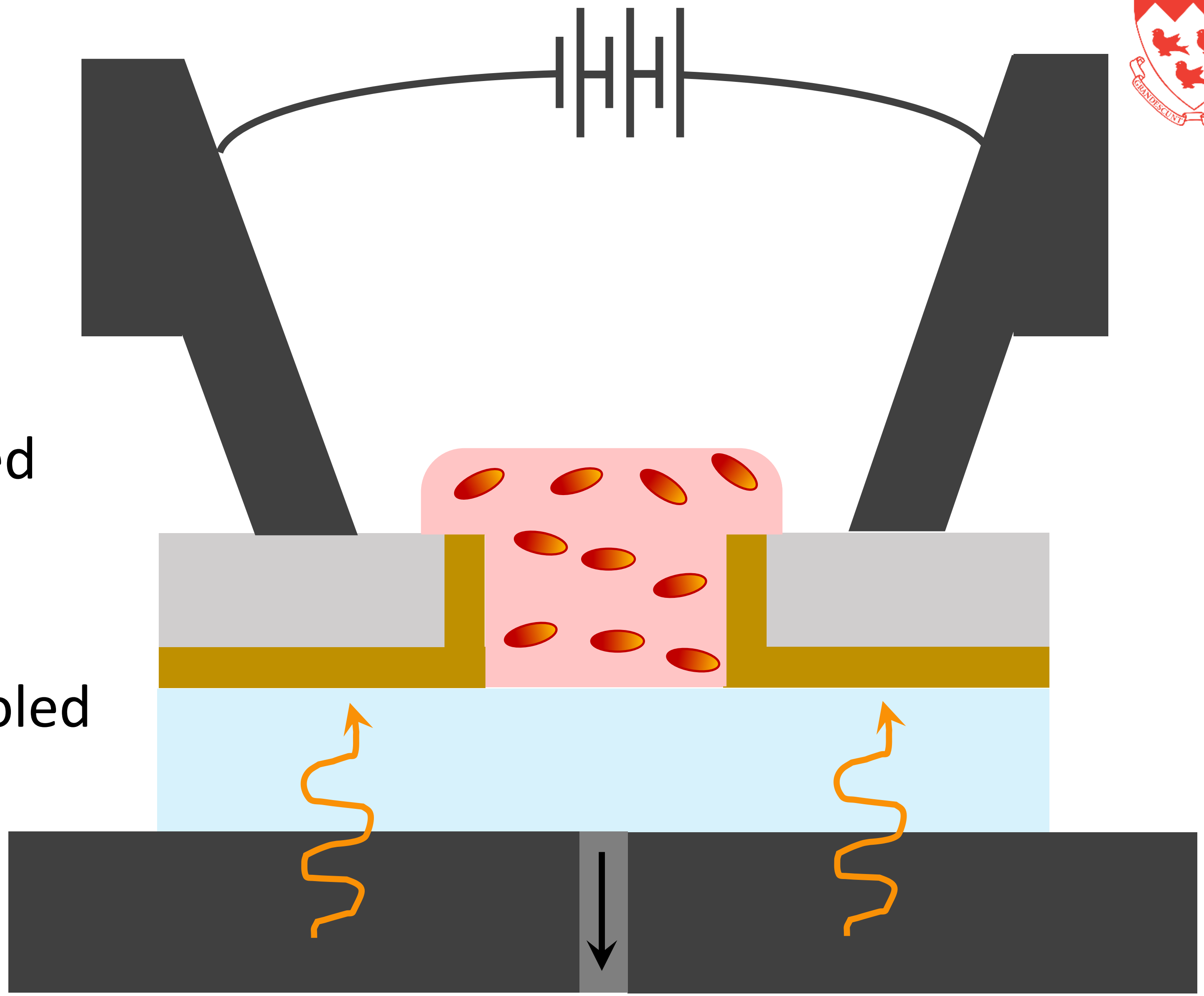
Thermal Poling

- Heat to T_g
- Annealing under electric field
- EOP is isotropic until poled

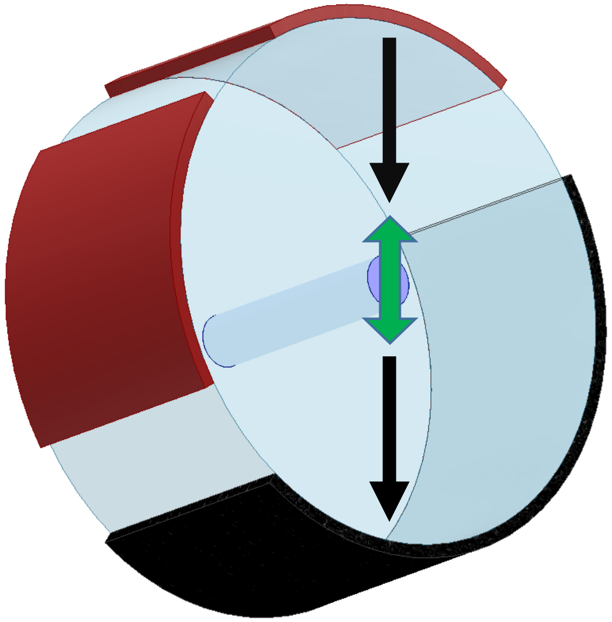


Thermal Poling

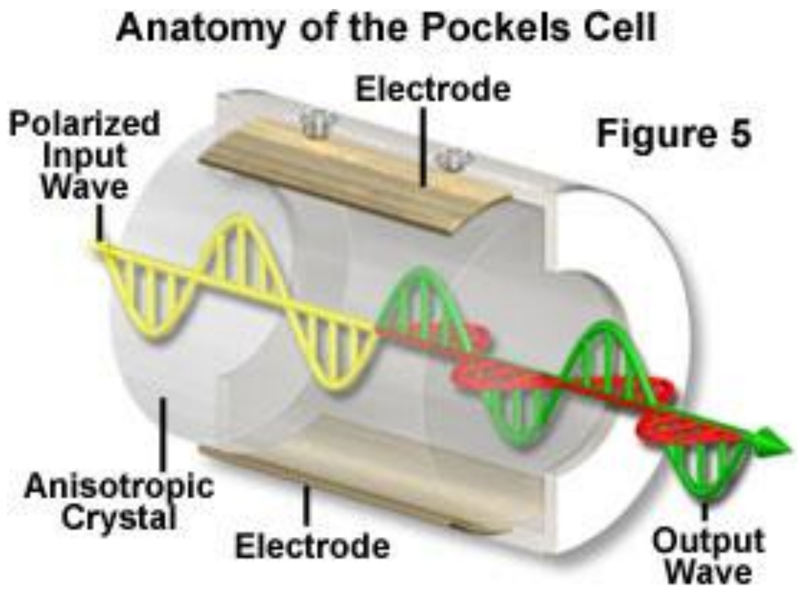
- EOP is isotropic until poled
- Poling methods
  - Corona or Electrode
- Typical modulators are poled opposite to E-signal



Dual Polarization

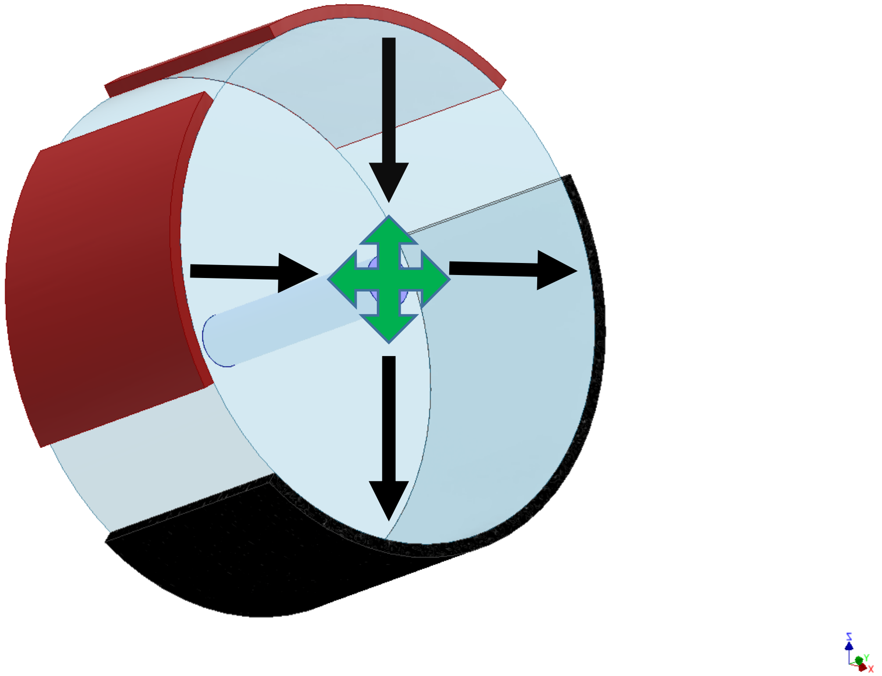


- Typical modulators interact with one polarization on-axis



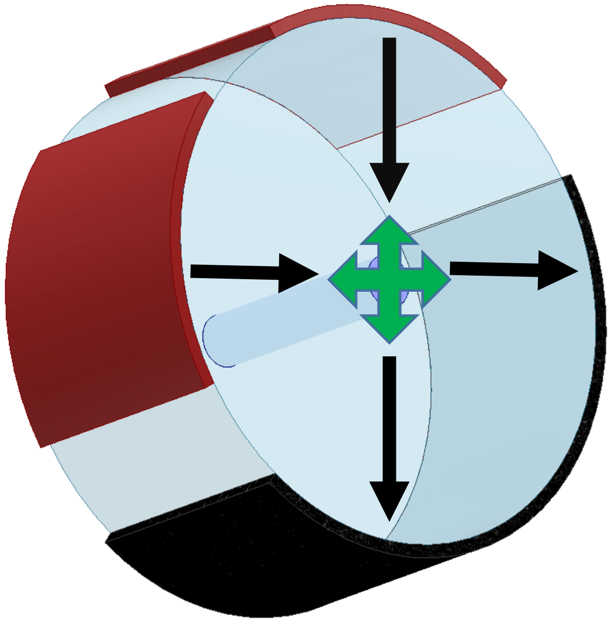
http://www.olympusmicro.com/primer/java/pockelscell/pockelscelljavafigure1.jpg

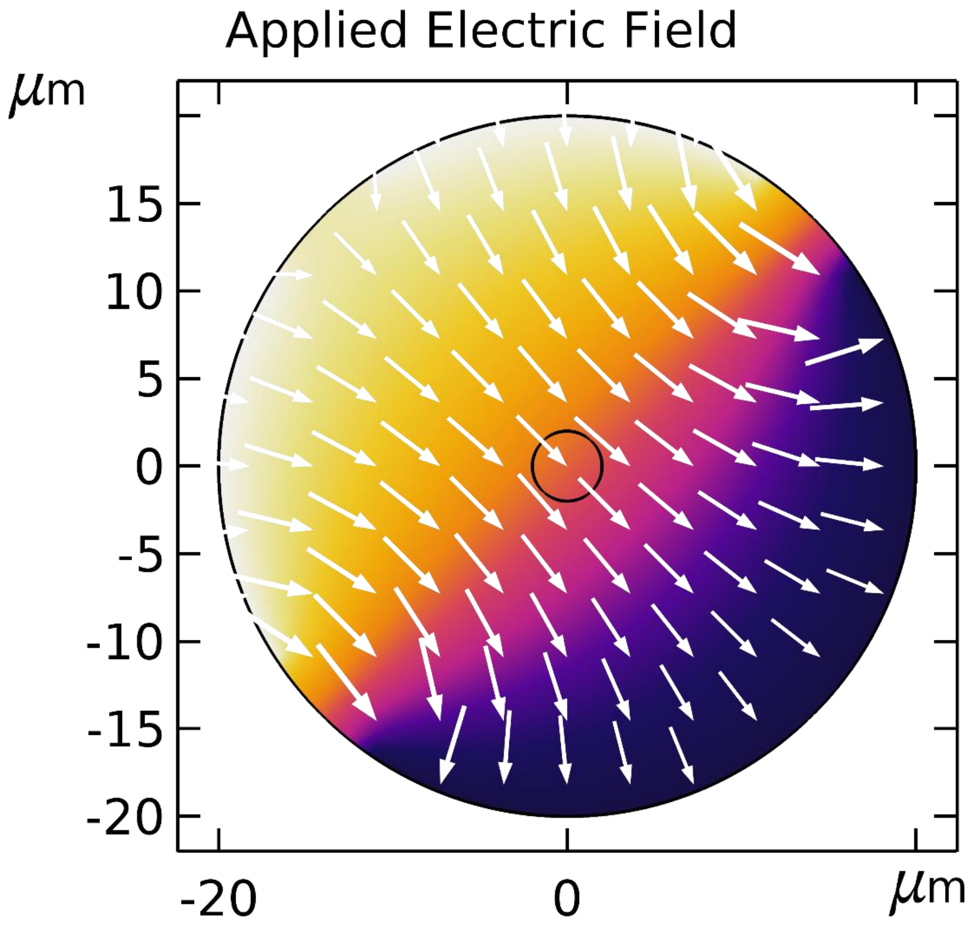
Dual Polarization



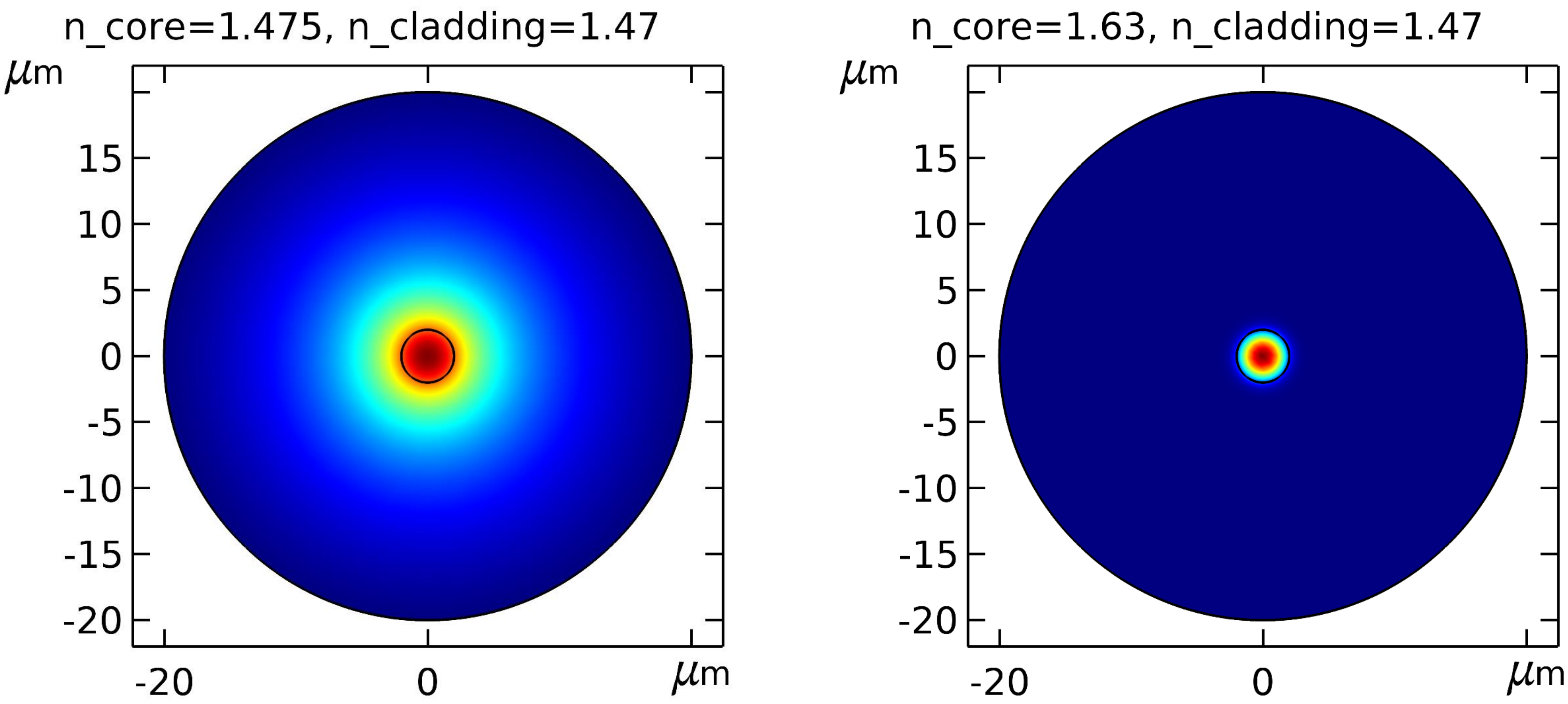
- Typical modulators interact with one polarization on-axis
- Possible to interact with orthogonal dimensions through the use of the third dimension as a degree of freedom

Electrode (Electric Field)





Confinement in a Single-Mode Fiber

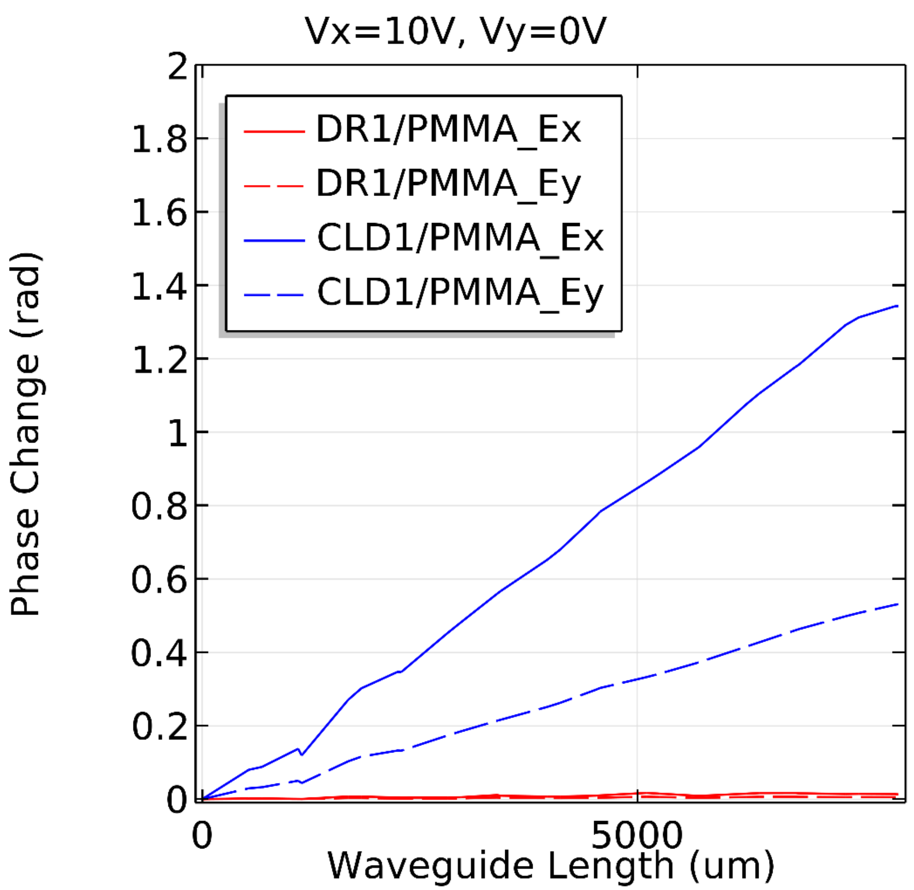


Modules & Constraints

- Electromagnetic Waves, Beam Envelopes (ewbe)
  - Define linear electro-optic effect (Pockels effect)
  - Scattering Boundary Condition: Decaying field beyond sim domain
  - Port 1: User Defined, for 45° polarized wave input
  - Matched boundary condition: Output

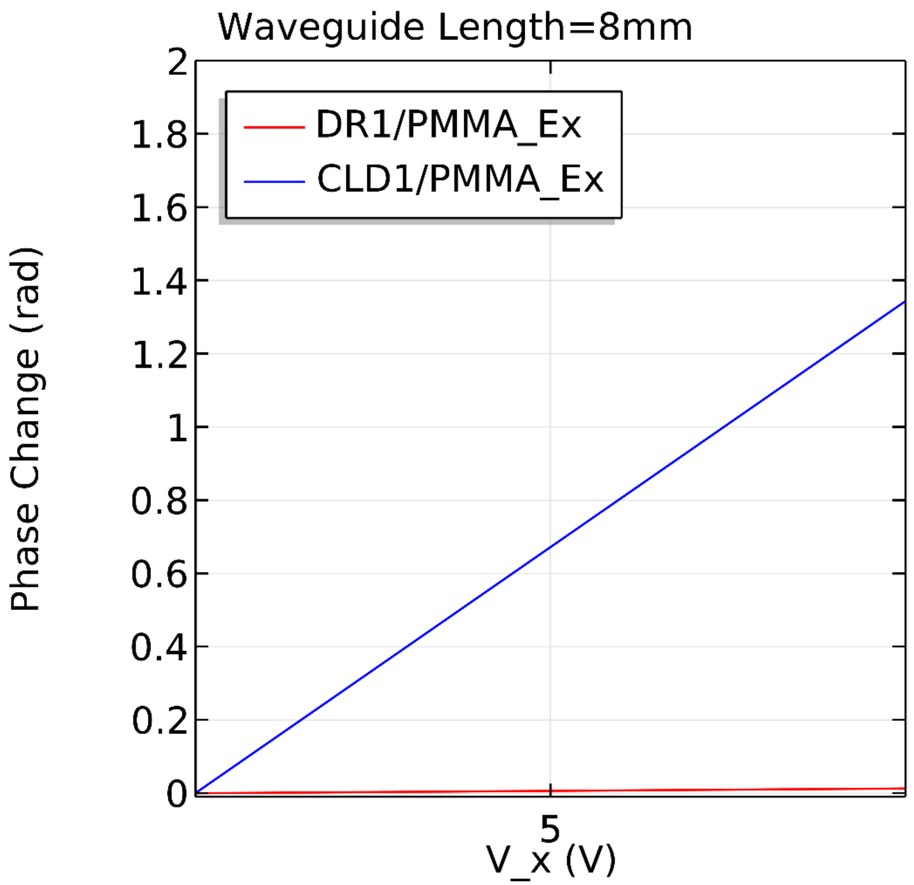
- Electrostatics (es)
  - Electric Potential 1 & 2: Apply top and side potential
  - Ground: Set uniform ground

Phase Change: Length



- Cut line 3D
- $\Delta\phi \propto L_{interaction}$
- Sinusoidal over longer interaction lengths
- Phase response can be increased with:
  - Pockels coefficient
  - Mode field overlap
  - Voltage

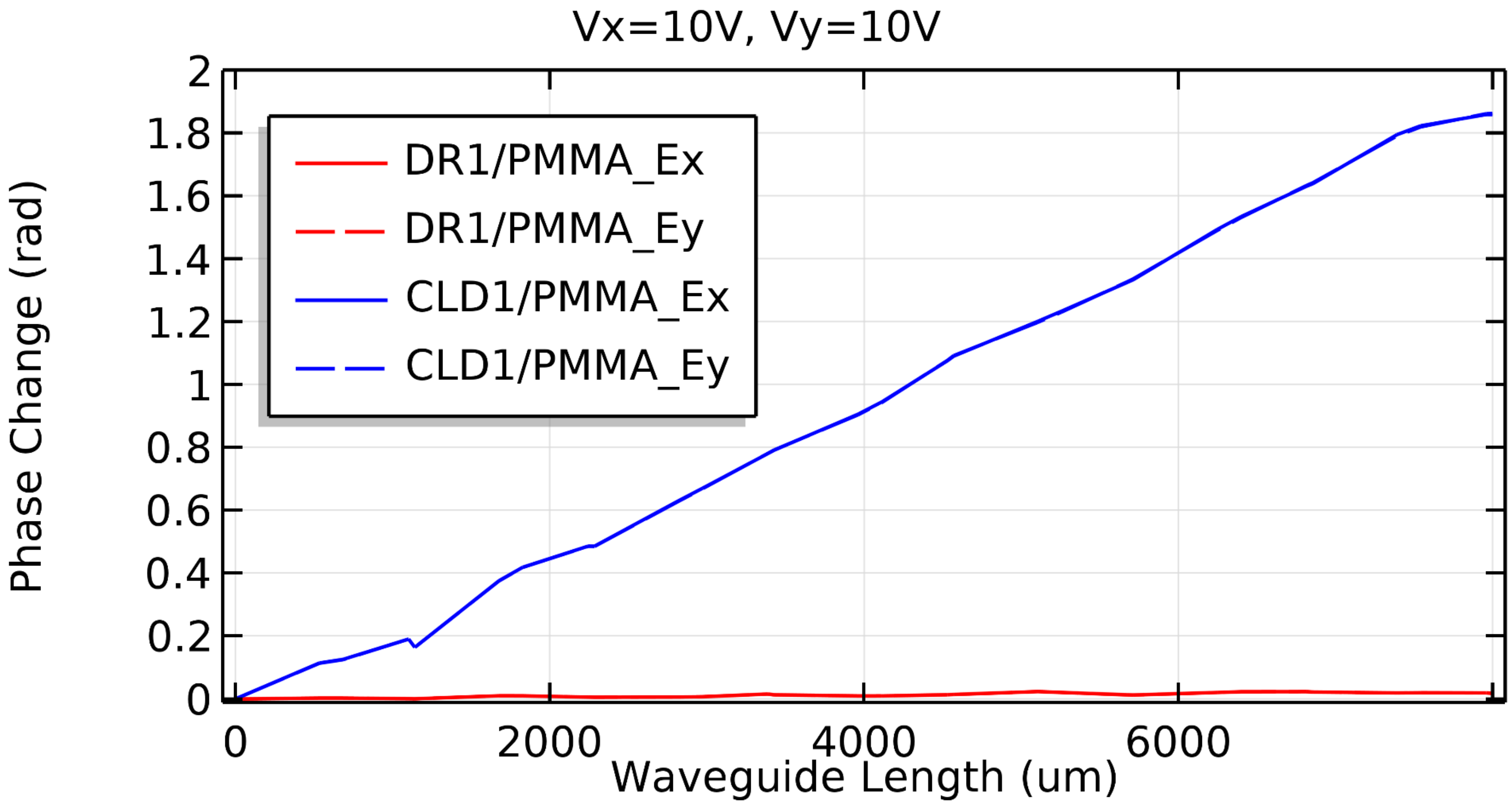
Phase Change: Applied Electric Field



- Parametric sweep
- $\Delta\phi \propto V_{modulation}$
- Sinusoidal over larger voltages

- Phase response can be increased with:
  - Pockels coefficient
  - Mode field overlap
  - Interaction length

Phase Change: Dual Modulation



Future Work

- Temperature dependence – polymers
- ES module: thermal poling
- RF module: high frequency modulation
- Characterization of EOPs
- COMSOL voltage dependence stress simulation
- Decreasing footprint of device
- Fabrication techniques
- Boundary Element Method

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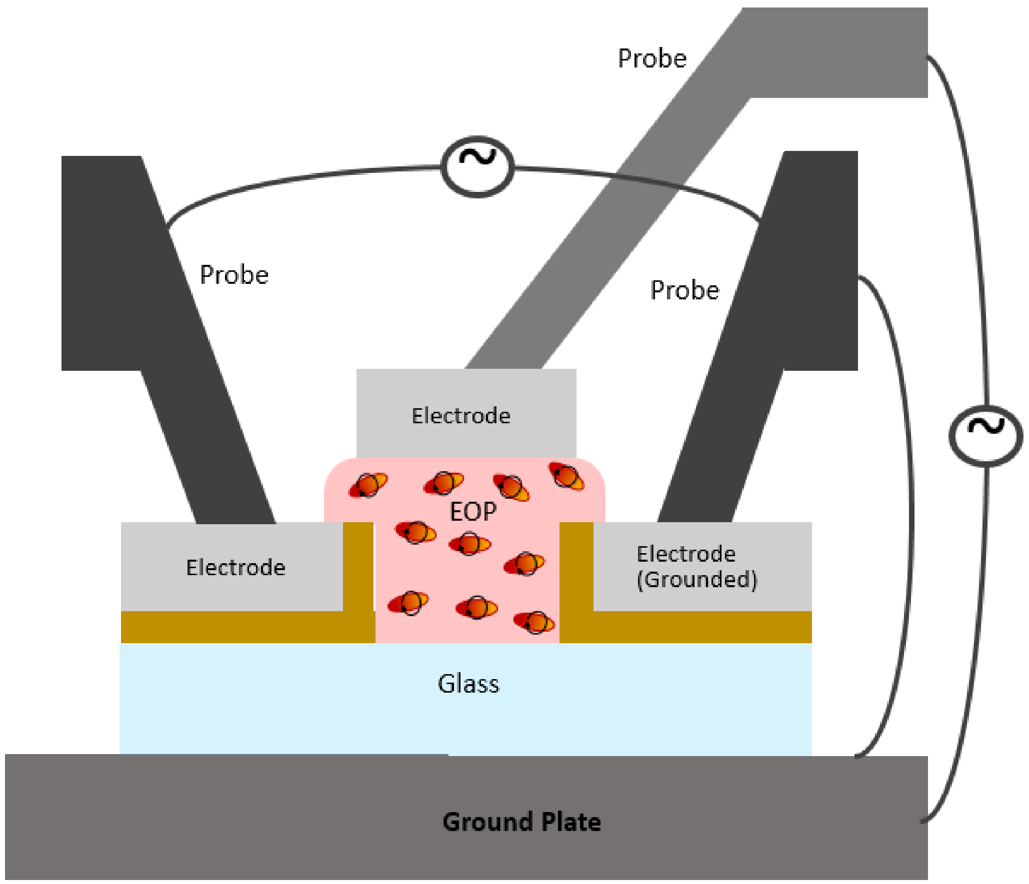
Si-EPIC CREATE

Thank You

Yannick.DMello@mail.McGill.ca

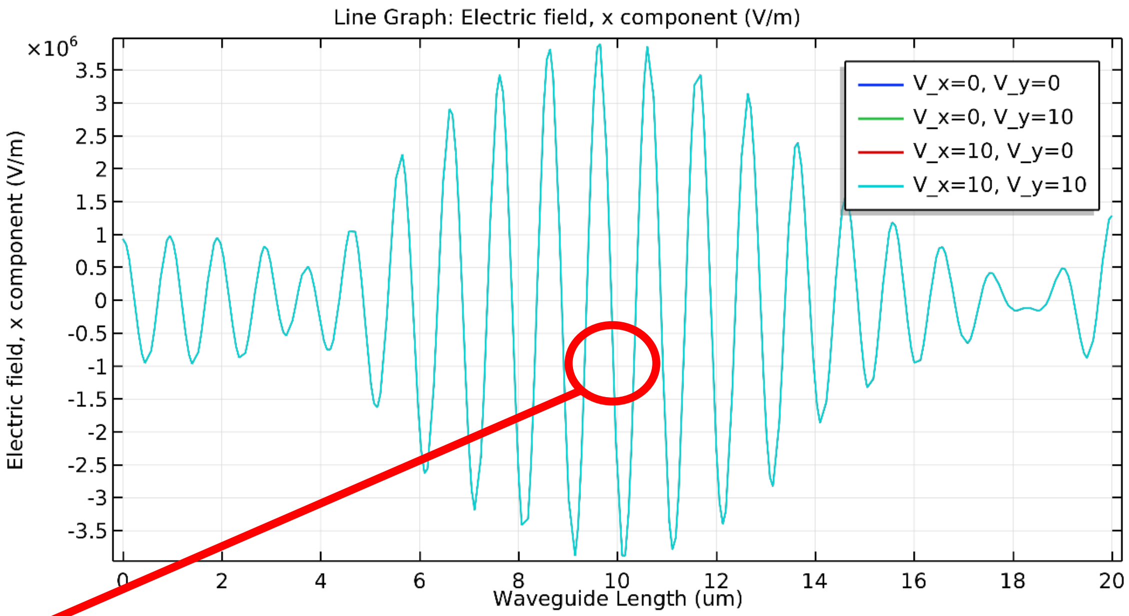
For more information, visit our poster!

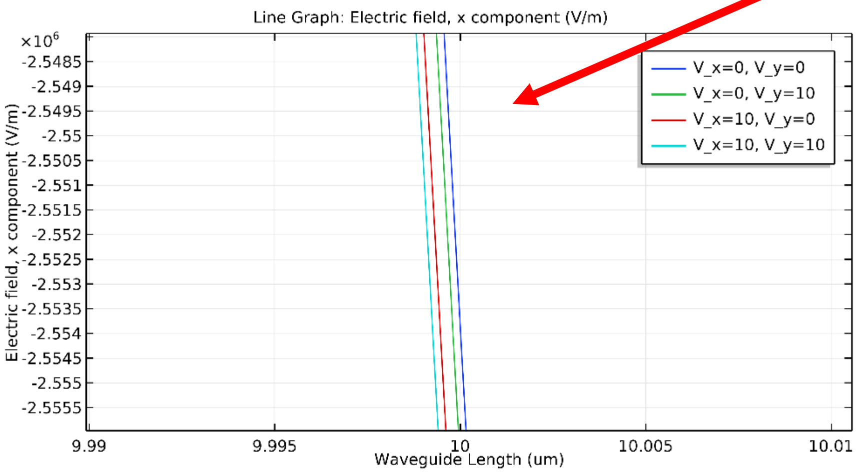
Testing DP-EOPM

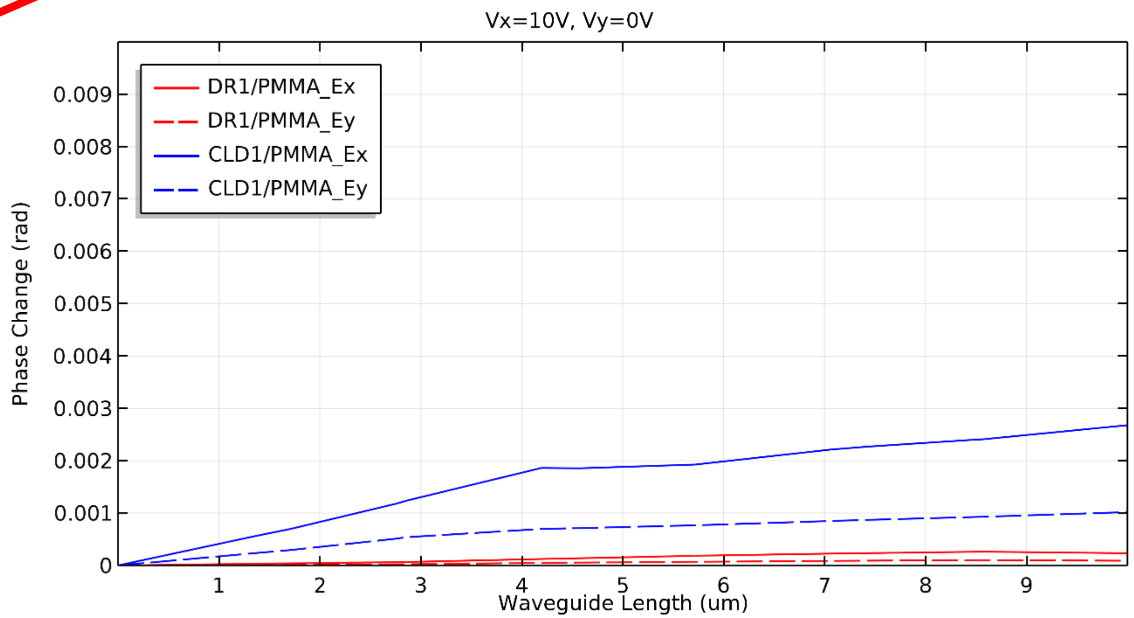


Additional Study: #1

- Reduce cladding radius
- Cladding Radius: $10\mu m$
  - Original: $20\mu m$
- Waveguide Length: $20\mu m$
  - Original: $8000\mu m$

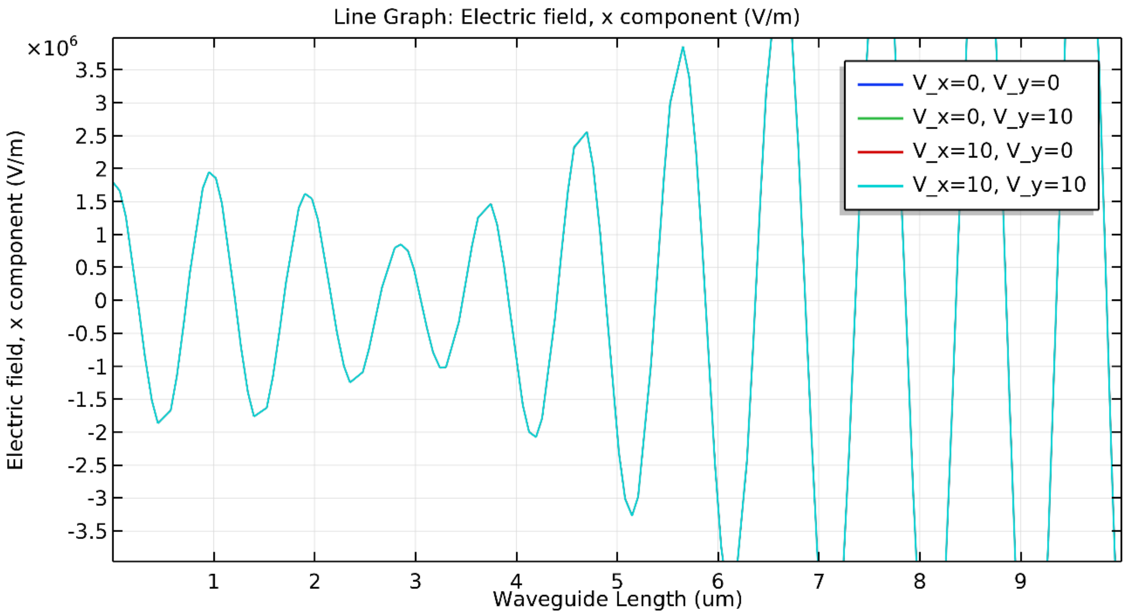


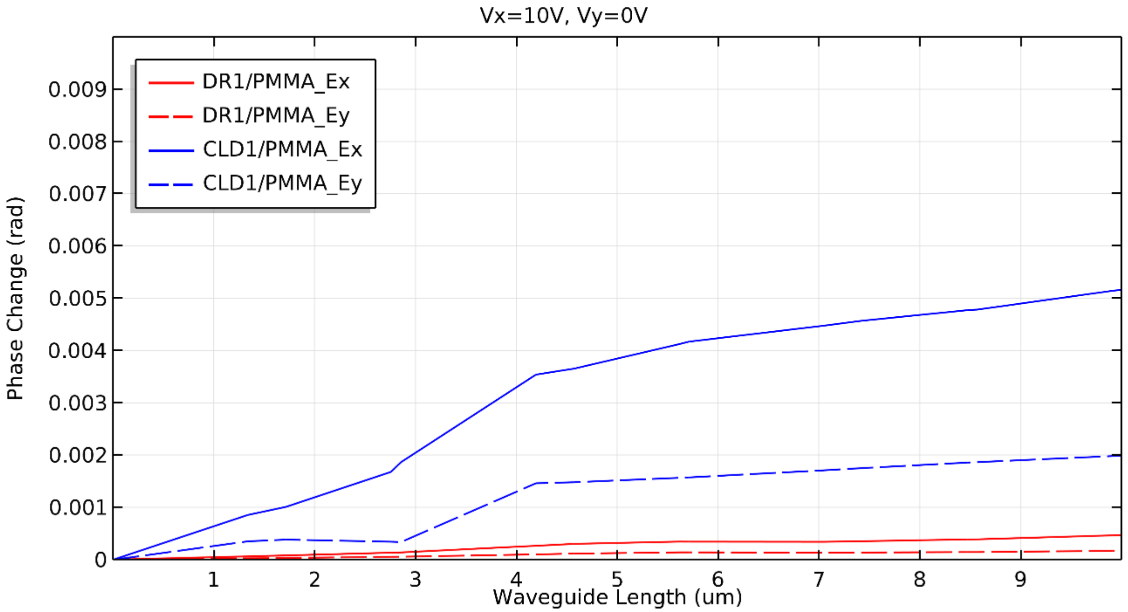




Additional Study: #2

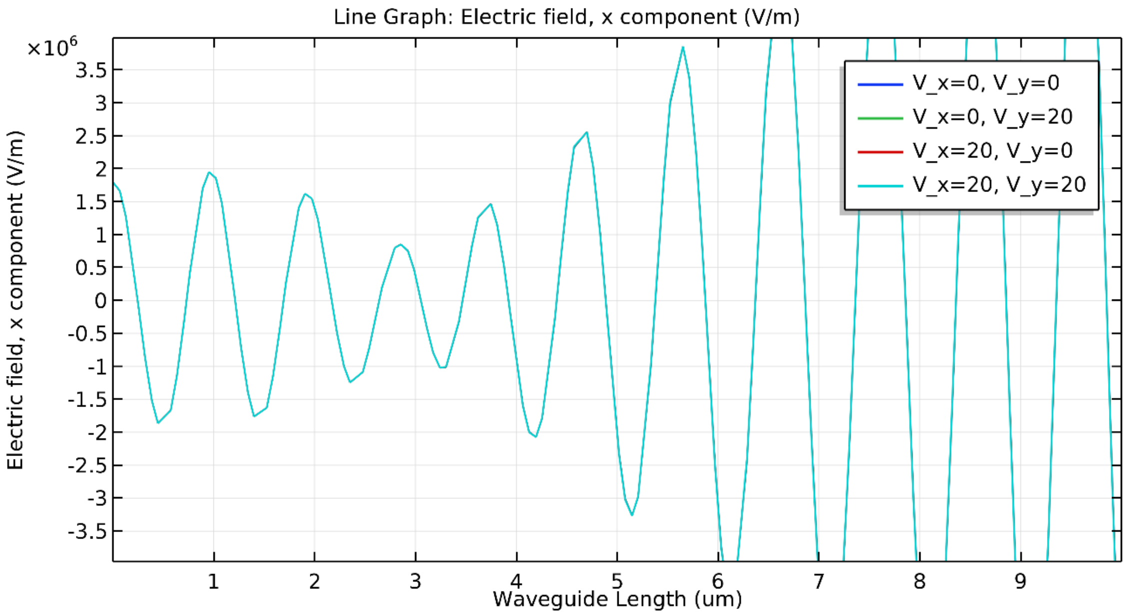
- Further reduce cladding radius
- Cladding Radius: $5\mu m$
  - Original: $20\mu m$
  - Study #1: $10\mu m$
- Waveguide Length: $20\mu m$
  - Original: $8000\mu m$

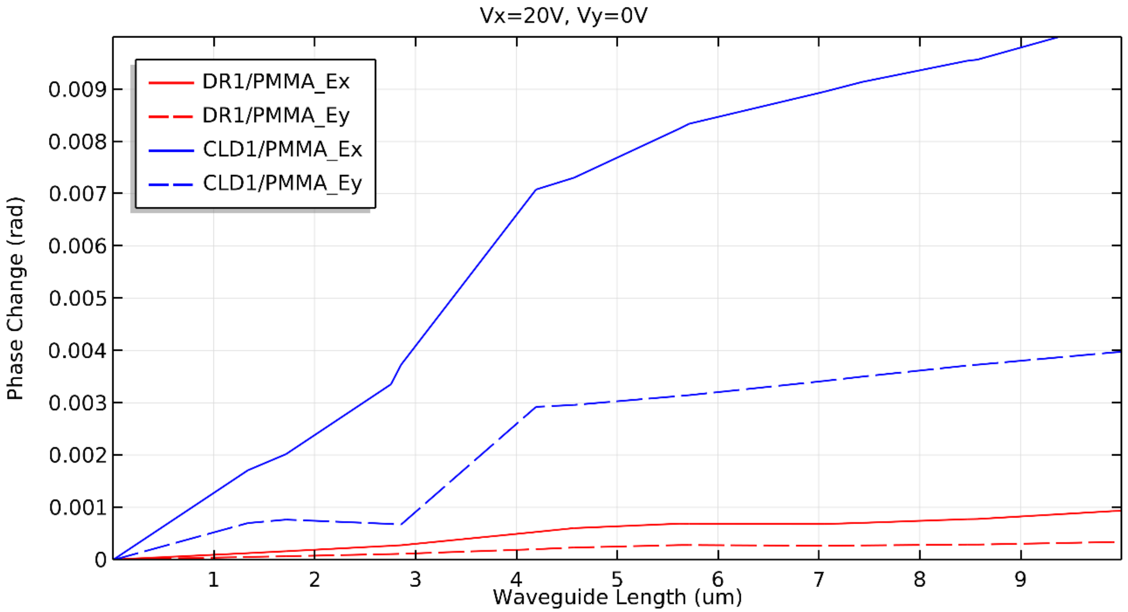




Additional Study: #3

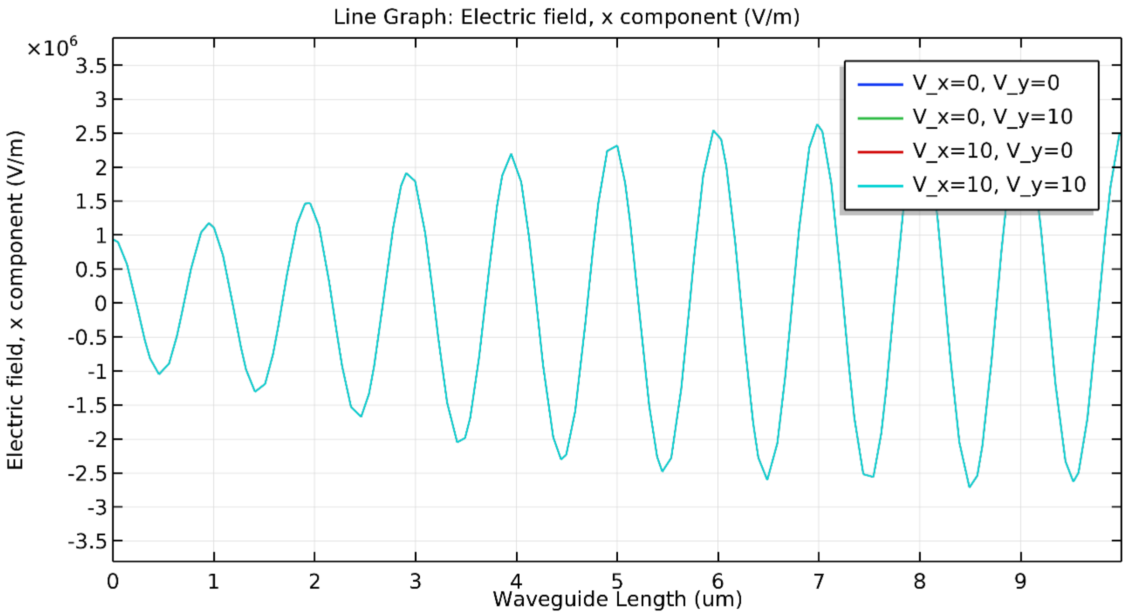
- Increasing modulation Voltage
- Voltage: 30V
  - Original: 10V
- Cladding Radius: 5μm
  - Original: 20μm
  - Study #1: 10μm
- Waveguide Length: 20μm
  - Original: 8000μm

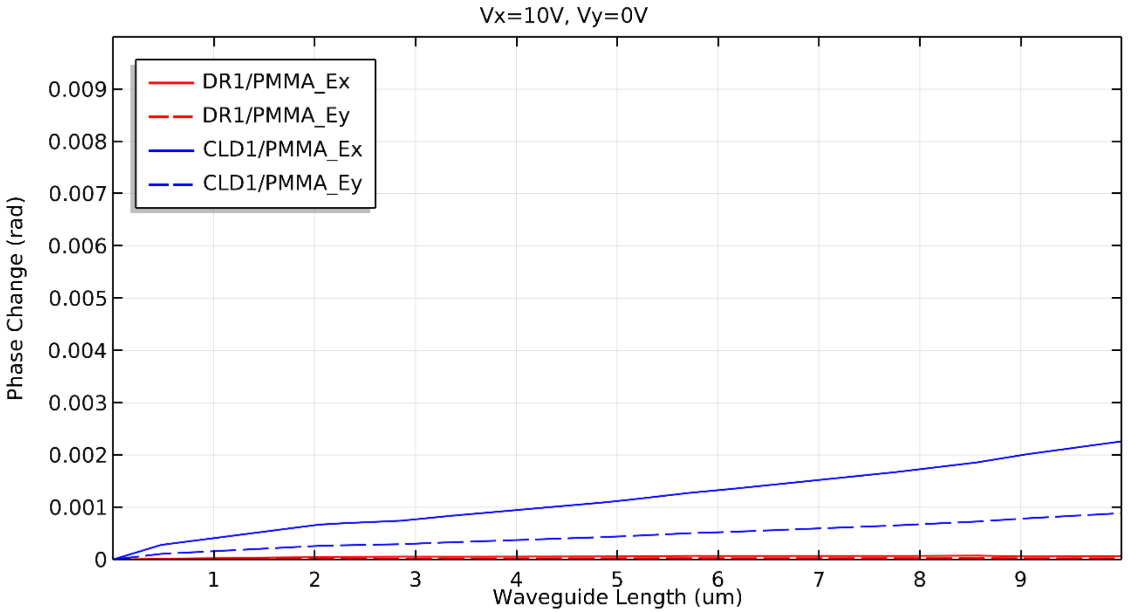




Additional Study: #4

- Single-Mode
- Voltage: 10V
- Cladding Radius: $5\mu m$
  - Original: $20\mu m$
- Core Radius: $0.8\mu m$
  - Original: $2\mu m$
- Waveguide Length: $20\mu m$
  - Original: $8000\mu m$





Additional Study: #5

- Single-Mode
- Voltage: 20V
  - Original: 10V
- Cladding Radius: 5μm
  - Original: 20μm
- Core Radius: 0.8μm
  - Original: 2μm
- Waveguide Length: 20μm
  - Original: 8000μm