Numerical Analysis and Optimization of a Multi-Mode Interference Polarization Beam Splitter

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COMSOL CONFERENCE
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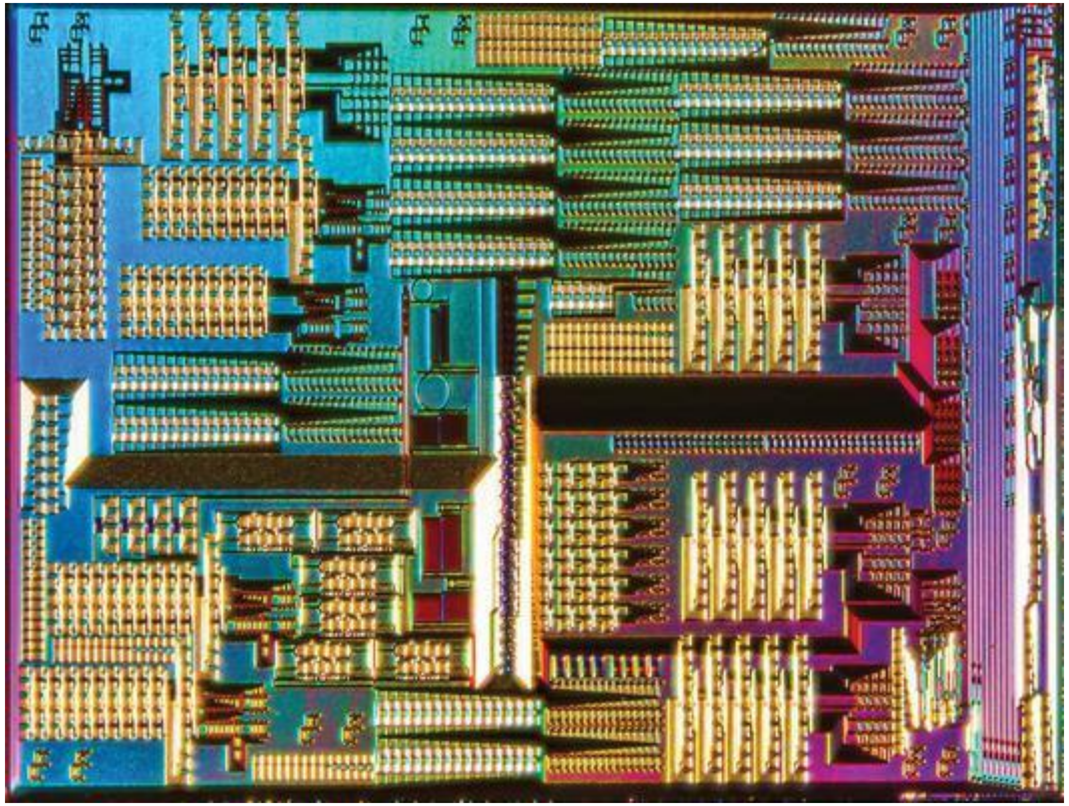
Outline

- Introduction to Silicon Photonics
  - Polarization sensitivity
  - Modes in a Si waveguide
- Theory and Concept
  - Polarization splitters
  - Effect of variations in photonics nanofabrication
  - Multi-Mode Interference (MMI)
- Simulation Set-up
  - Modules and constraints
  - Multi-mode waveguides
  - Device geometry
- Results
  - TM optimization
  - TE optimization
  - Spectral response
- Future Work

Silicon Photonics

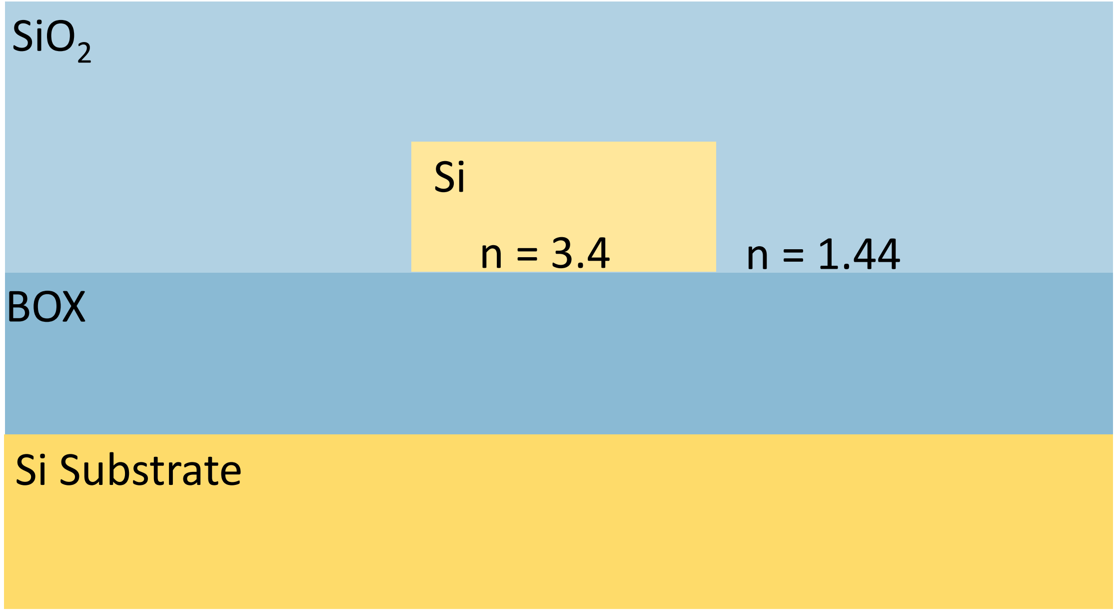
- Integrated solution to photonic systems and circuits
- Intra-datacenter signal processing - routing, switching, modulation
- CMOS compatible, non-toxic
- Robust
- Compact devices due to high index ratio

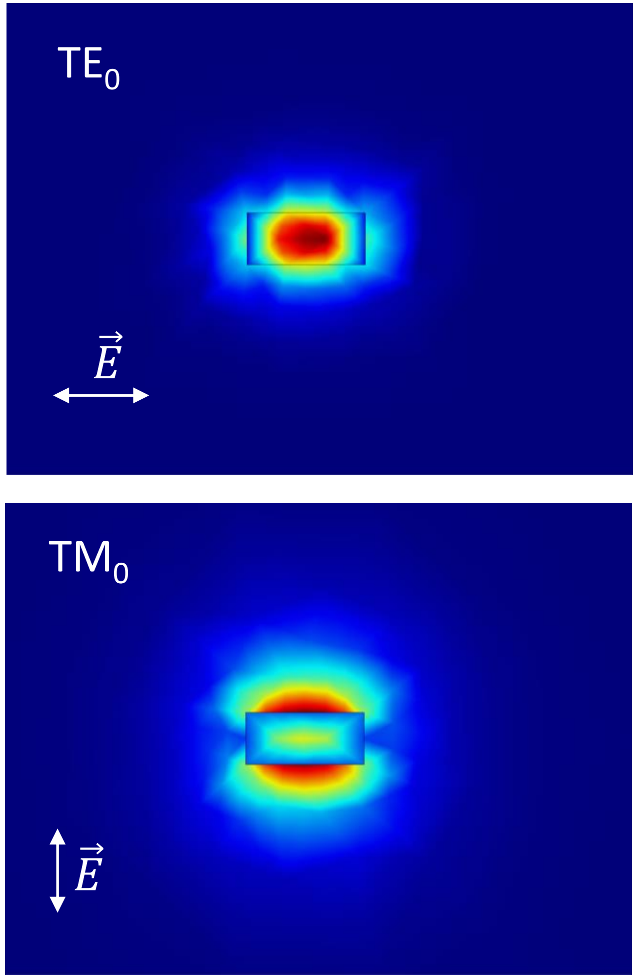


“Silicon photonic chip” © 2014 Lukas Chrostowski, reproduced with permission

Modes: Refractive Index

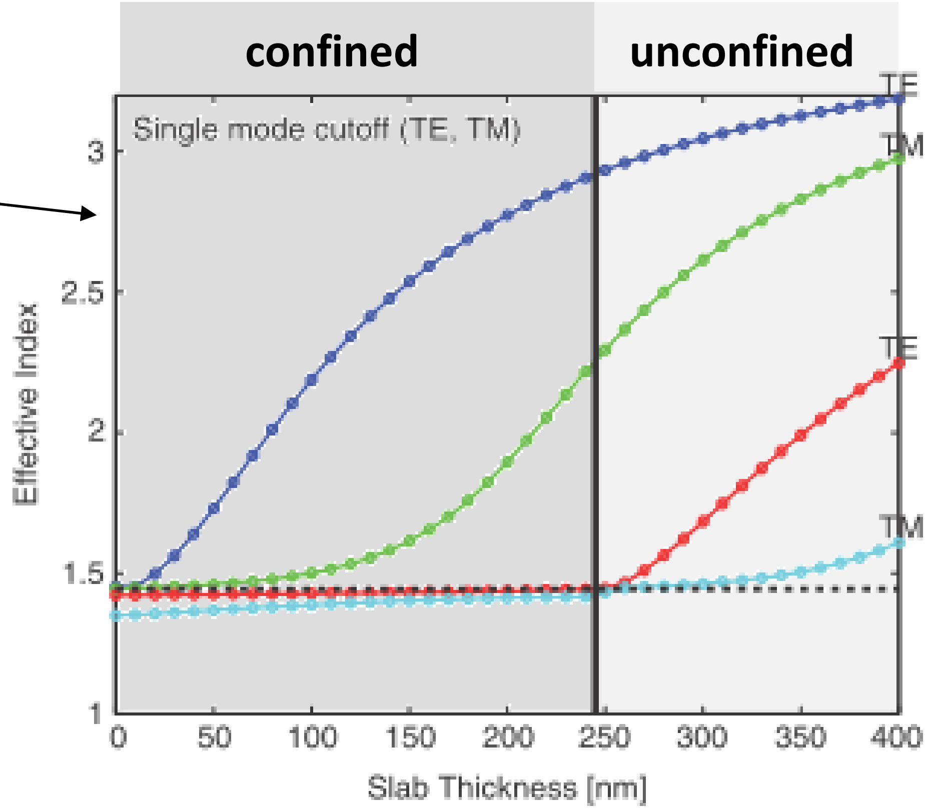
- Si/SiO2 – core/cladding
  - High core/cladding index ratio
- Mode confinement -> TE, TM





Modes: Polarization Sensitivity

- Dispersion relation
- Orthogonal polarizations no longer degenerate
- High refractive index contrast + birefringence = strong polarization sensitivity
- Devices cater to TE or TM



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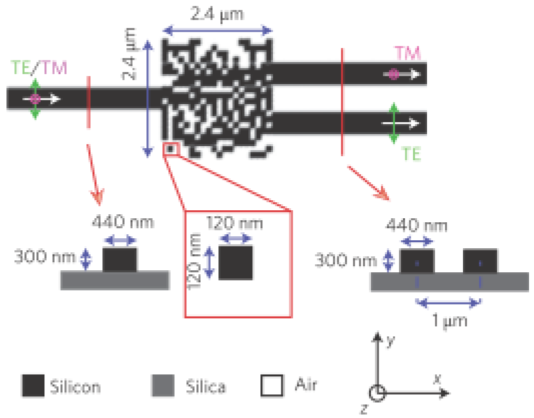
Polarization Splitters (e.g.)



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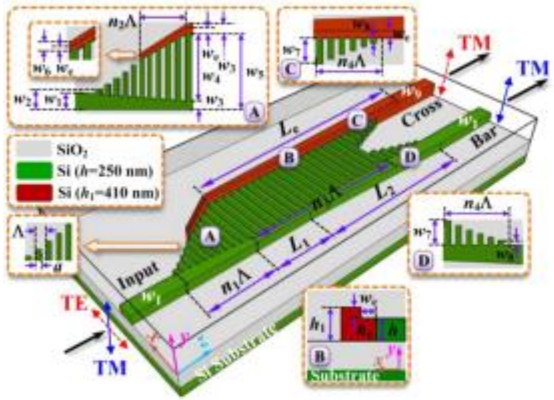

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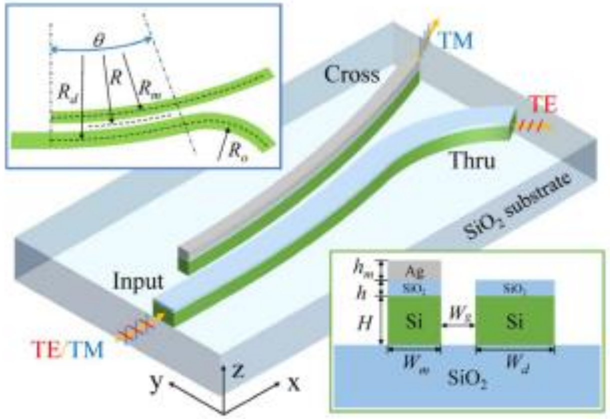

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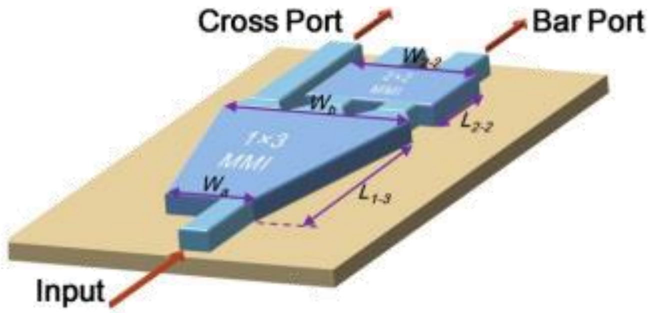

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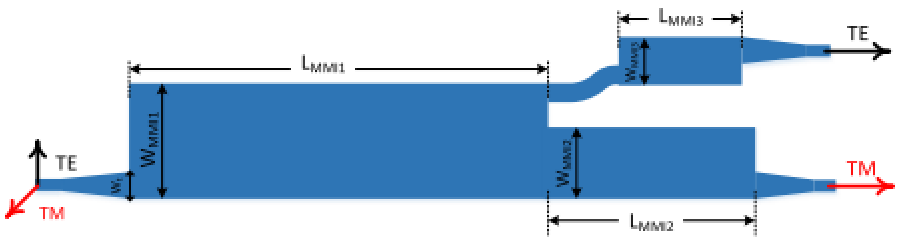

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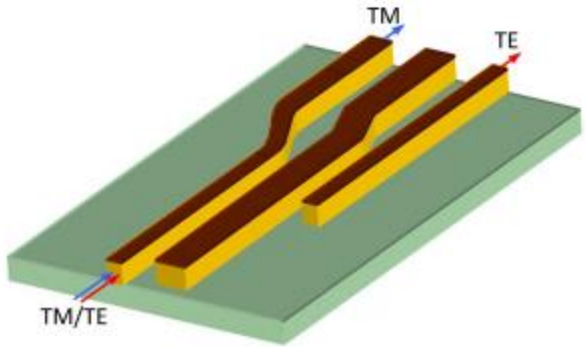

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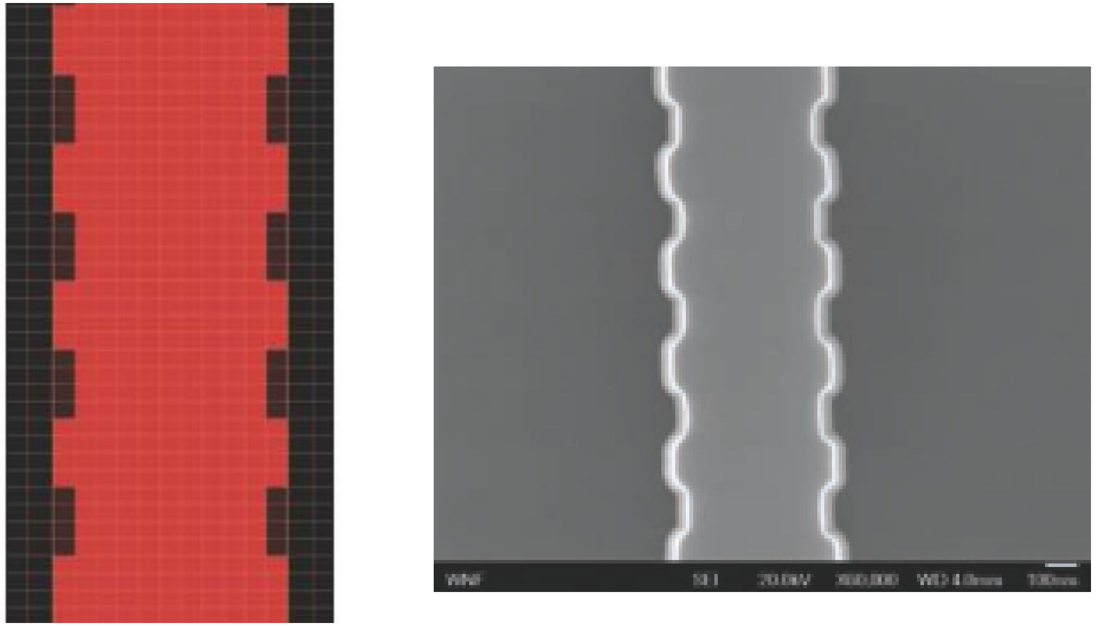
Fabrication Variations

- E-beam lithography, imperfect fabrication technique
- Variances can cause a huge change in some PBS devices
- Sidewall roughness
- MMI structures are tolerant to variation



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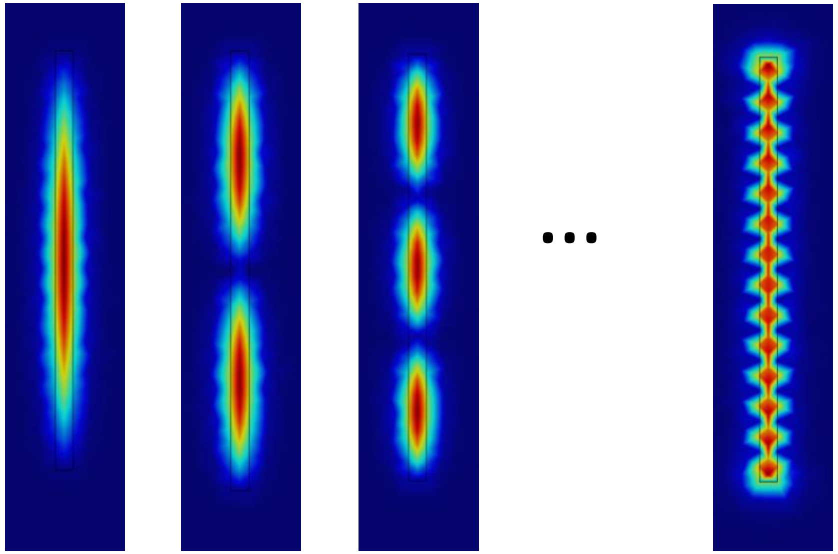
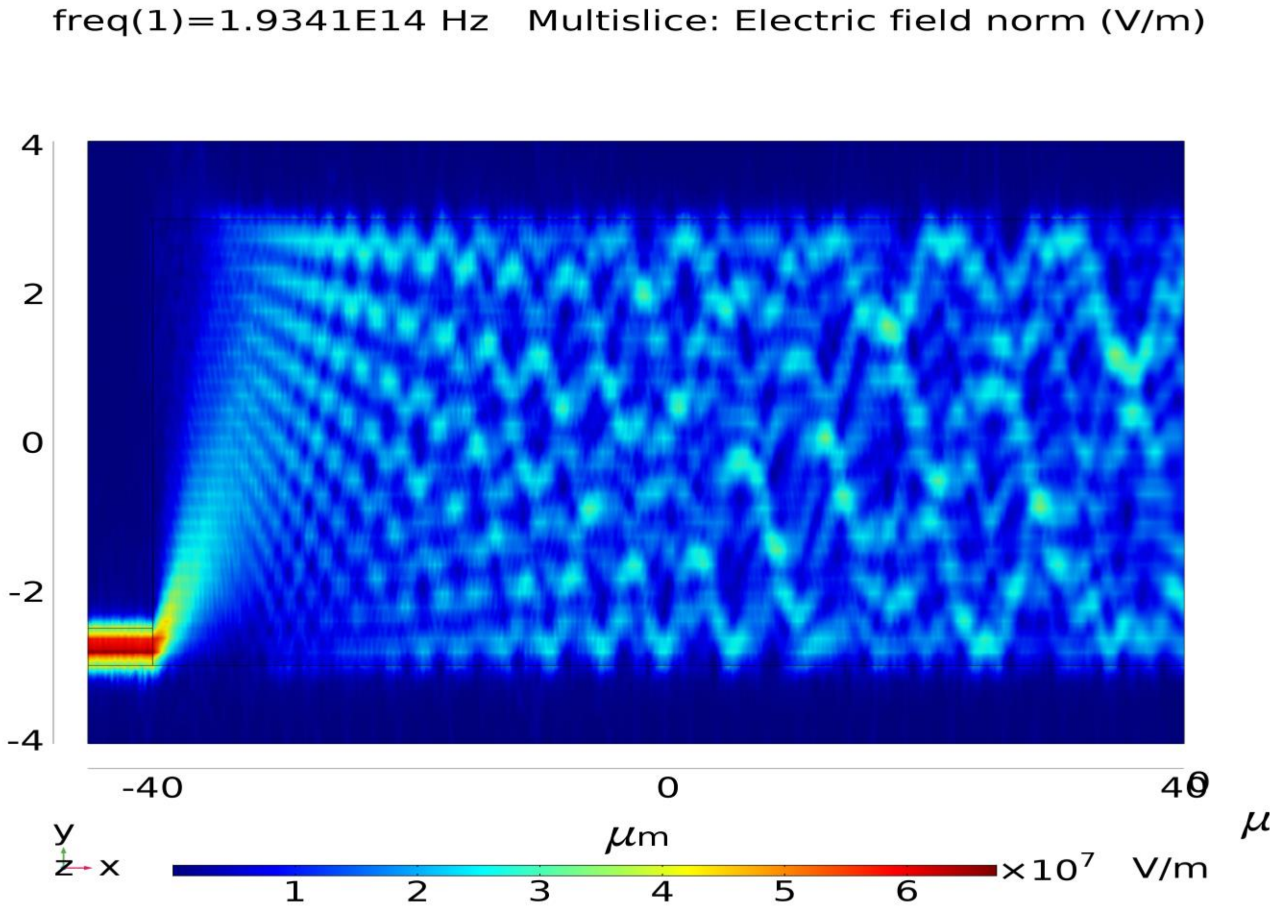
Multi-Mode Interferometer (MMI)

$TE_0 + TE_1 + TE_2 + \ldots + TE_n =$



Self imaging length:

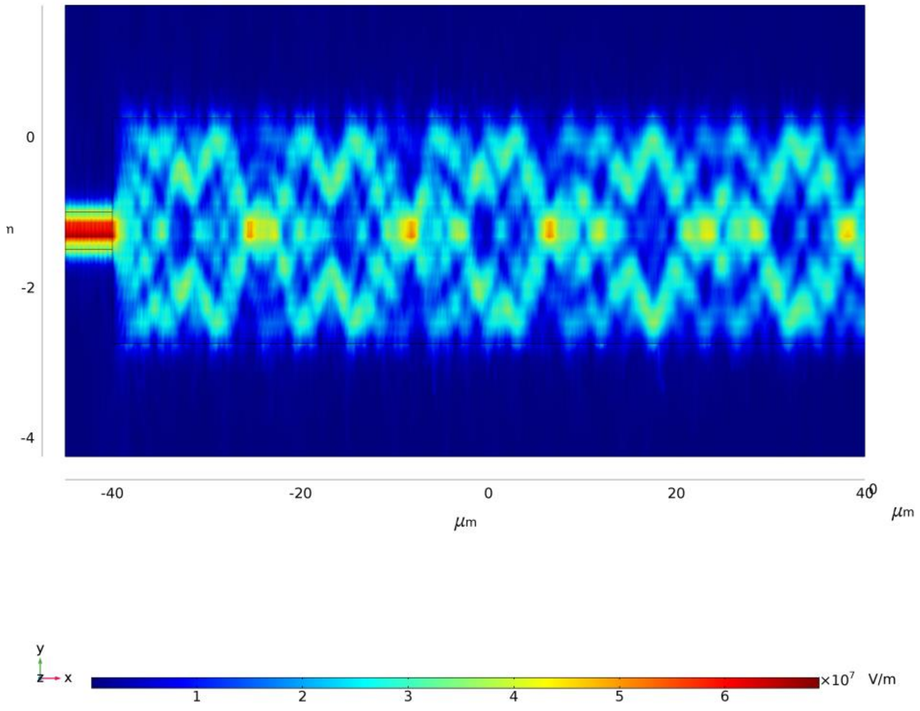
$$L_\pi \approx \frac{4n_r W_e^2}{3\lambda_0}$$

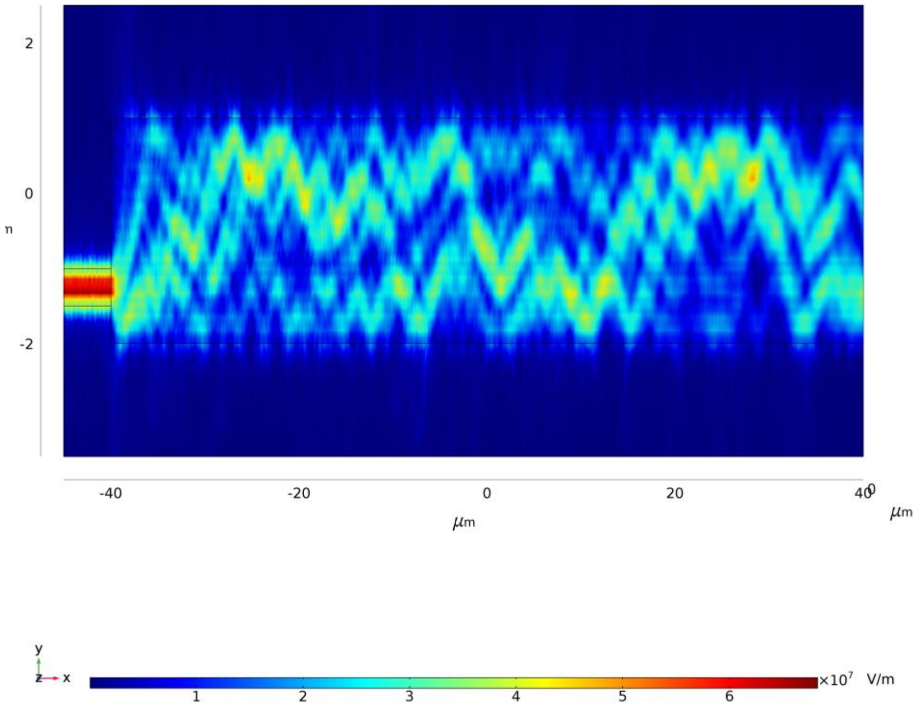


Modules & Constraints

- Wave Optics – Electromagnetic Waves, Beam Envelope (ewbe)
- Scattering boundary condition: Decaying field beyond sim domain
- Port excitation (input)
  - TE and TM separately
- Matched boundary condition (output)
  - Output issue – port causes reflections and no transmission
  - Smaller mesh needed with no port?

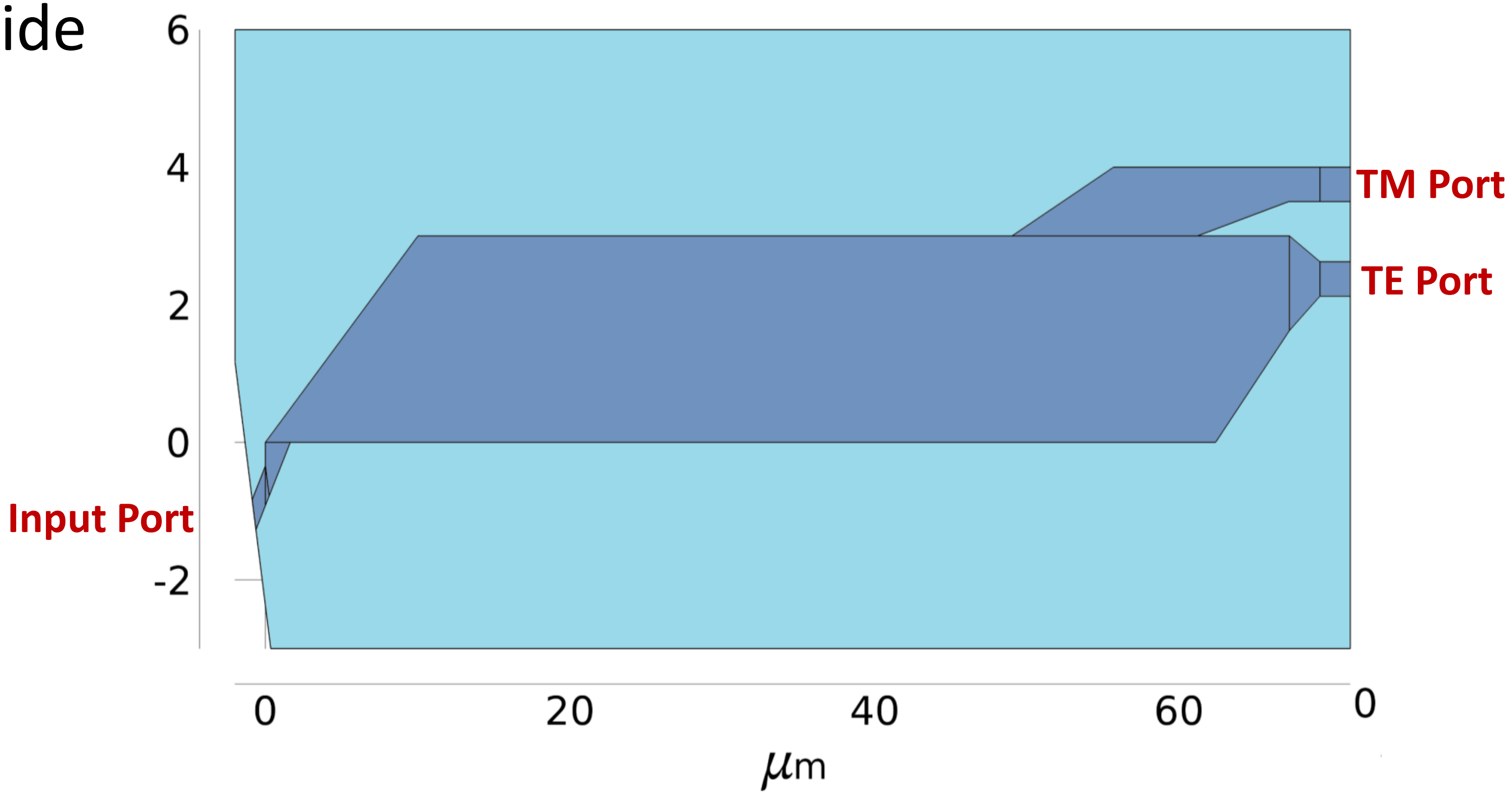
Multi-Mode Waveguide (3µm)





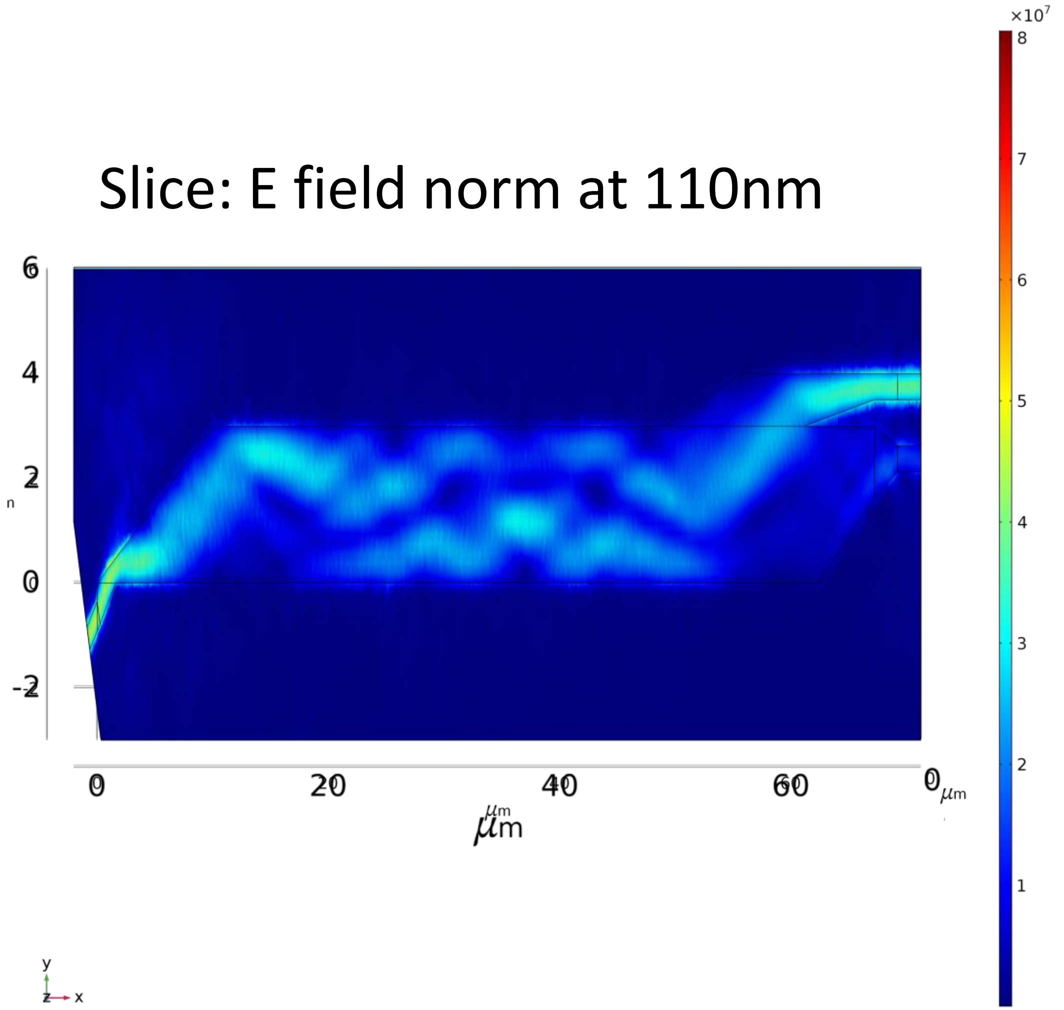
Geometry

- Angled input waveguide
- TM top port
- TE bottom port
- Tapers funnel light



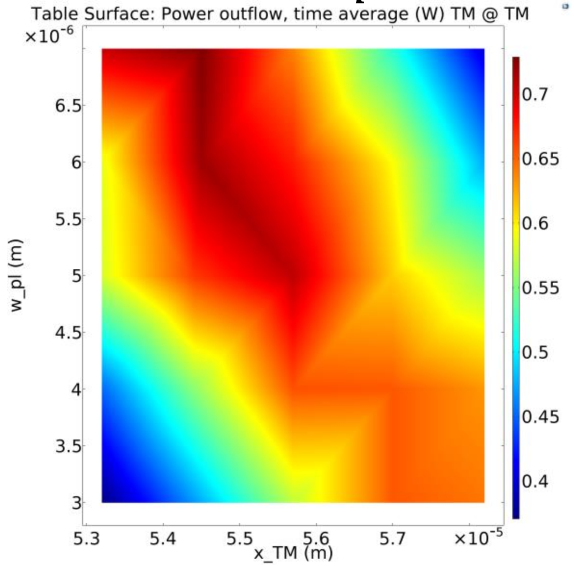
Optimization for TM

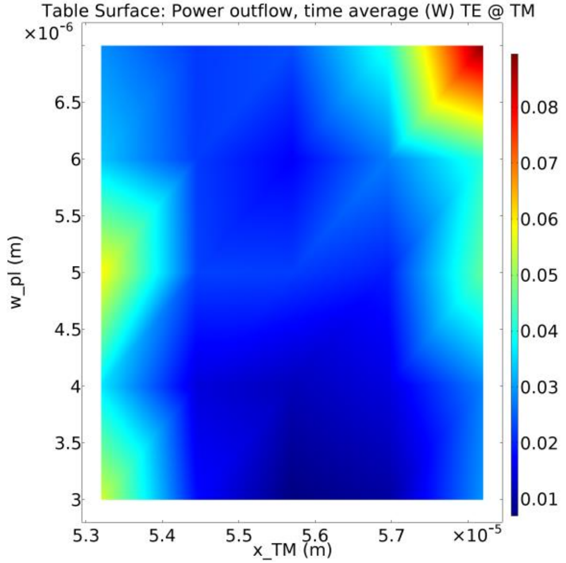
Slice: E field norm at 110nm



Parametric Sweep:

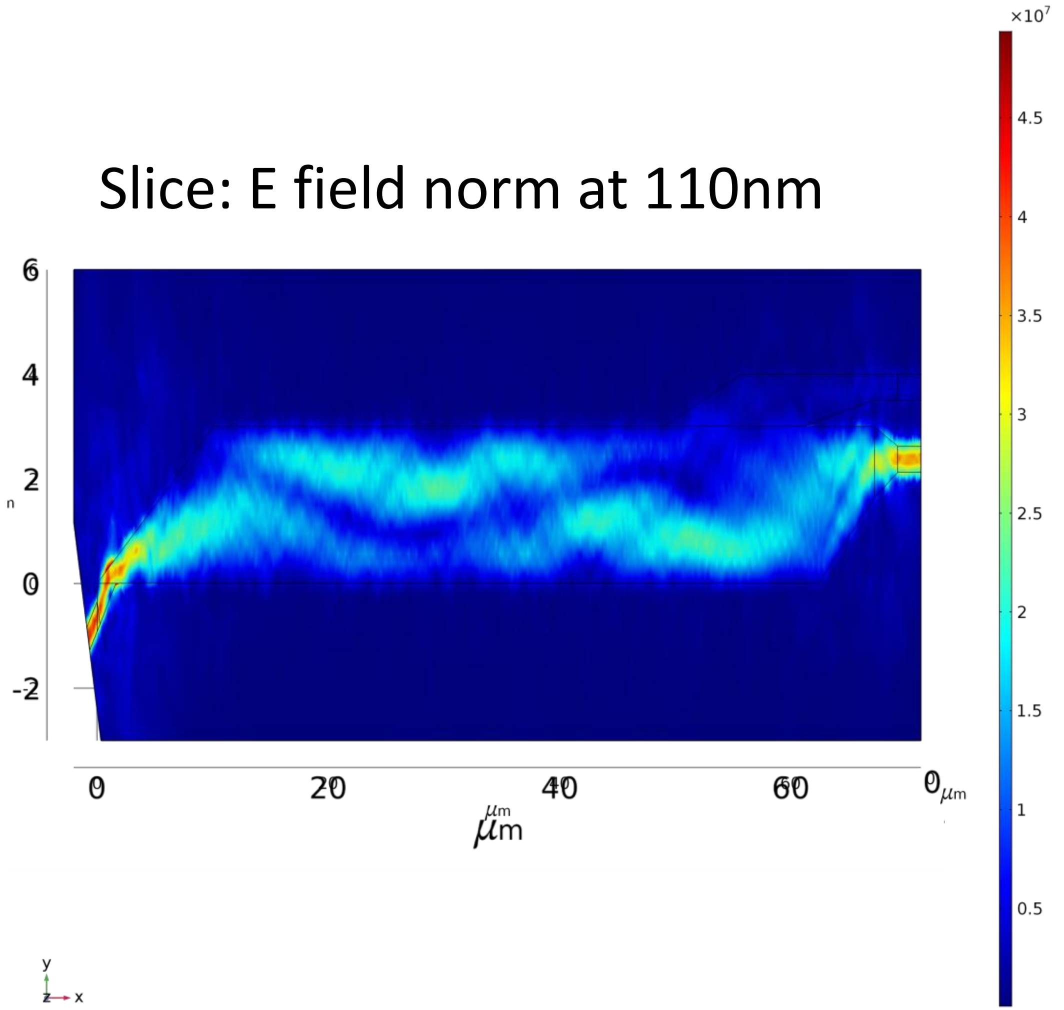
w_{pl} vs x_{TM}





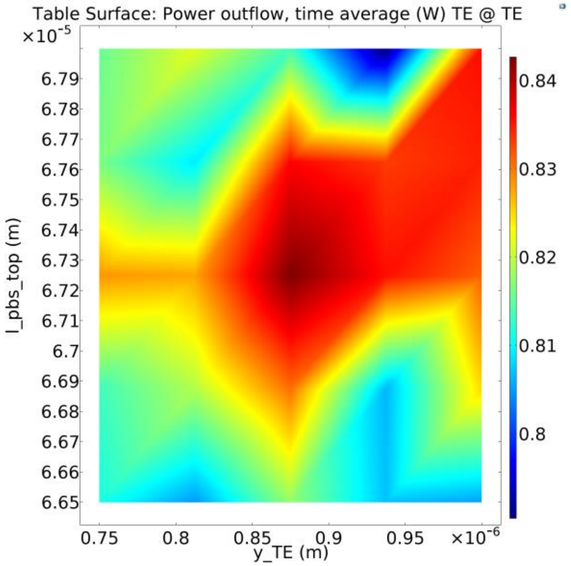
Optimization for TE

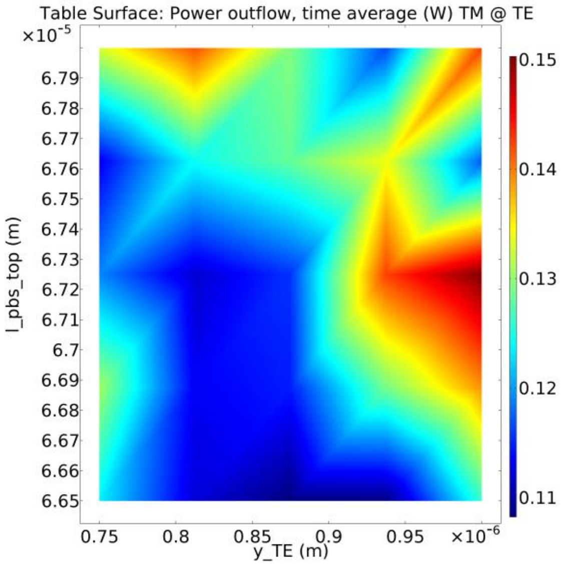
Slice: E field norm at 110nm



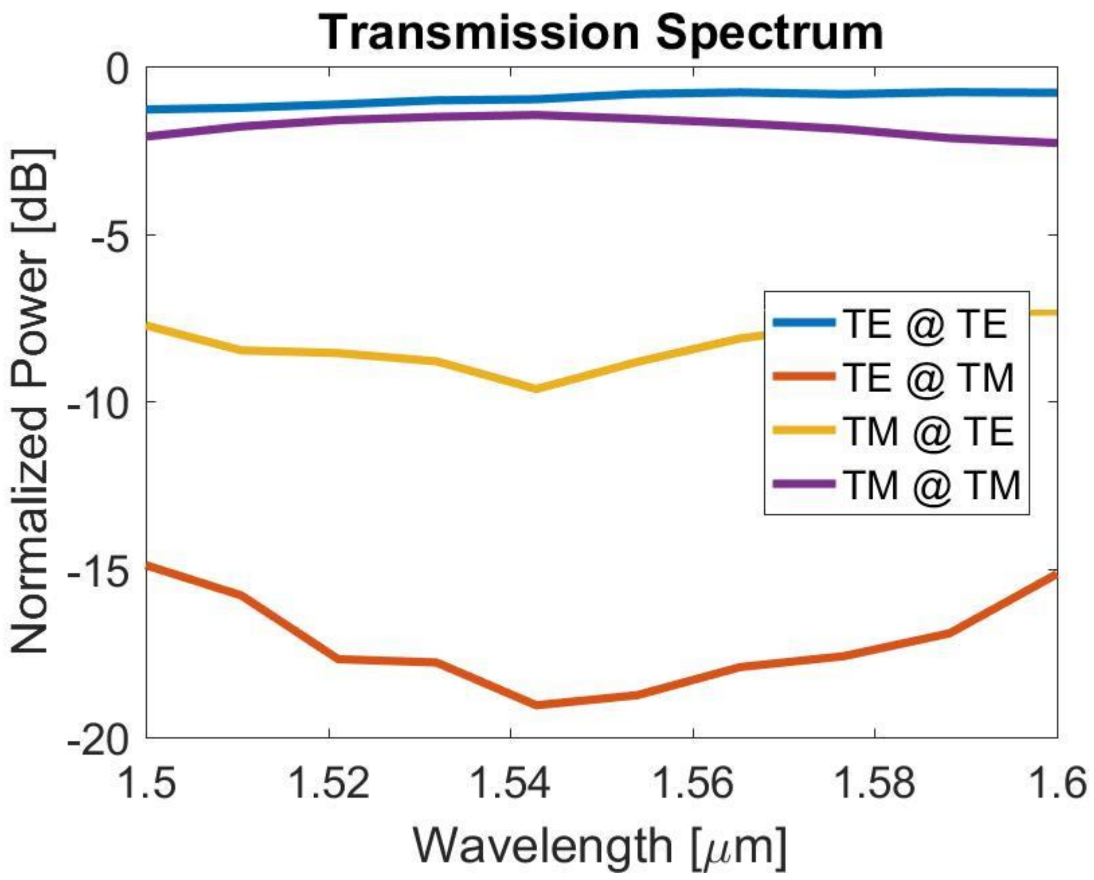
Parametric Sweep:

l_{PBS} vs y_{TE}



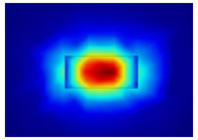


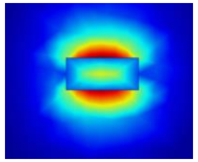
Spectral Performance Charactersitics



Mode @ Output Port	Insertion Loss (dB)
TE @ TE	0.82
TE @ TM	18.75
TM @ TM	1.56
TM @ TE *	8.81

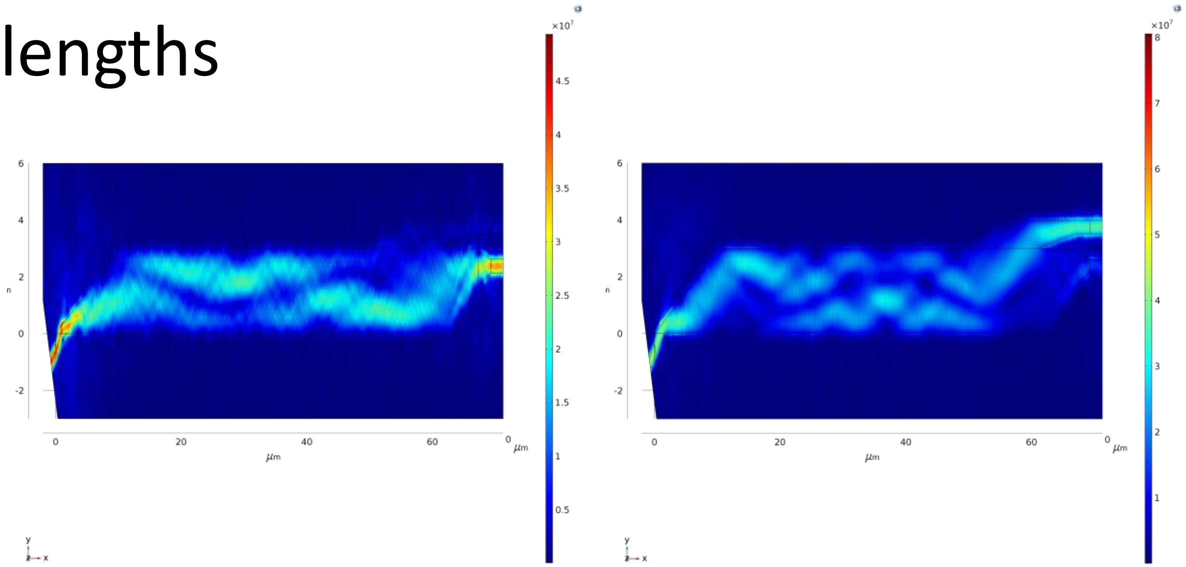
*Output waveguide bend to reduce TM @ TE





Future Work

- Fabrication
- Characterize temperature dependence in COMSOL
- Increase bandwidth
- Redesign for other central wavelengths
- Optimization module
- Boundary Element Method (?)



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McGill UNIVERSITY

CMC MICROSYSTEMS

COMSOL support

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Si-EPIC CREATE

Thank You

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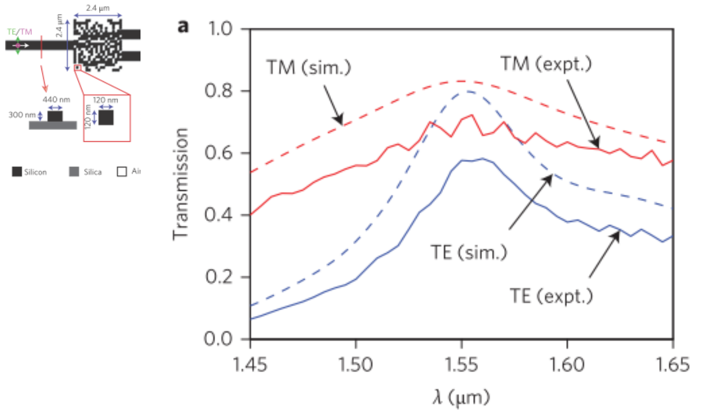
Polarization Splitters (e.g.)



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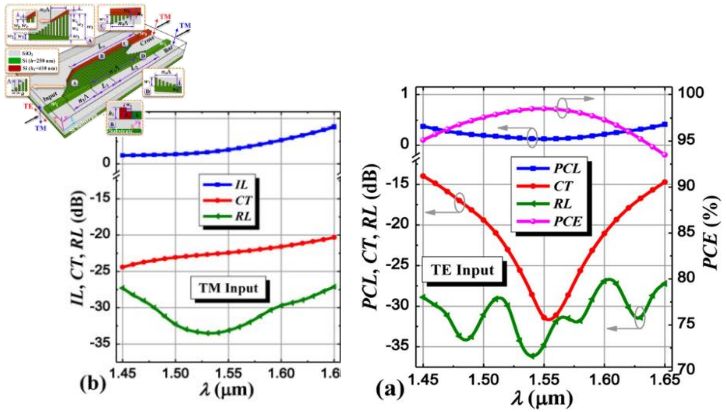

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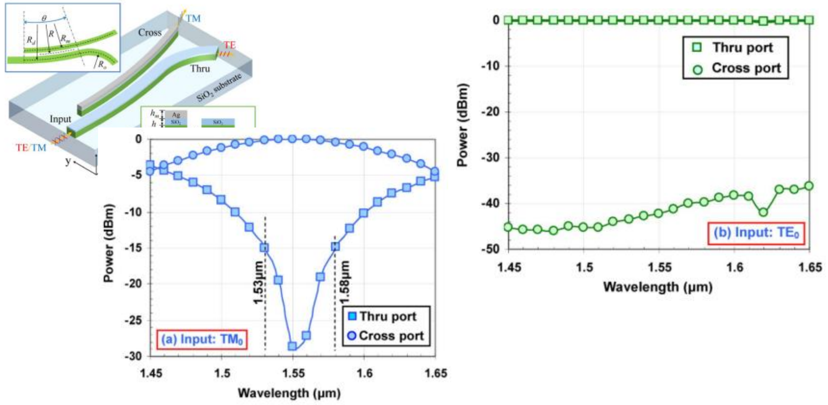

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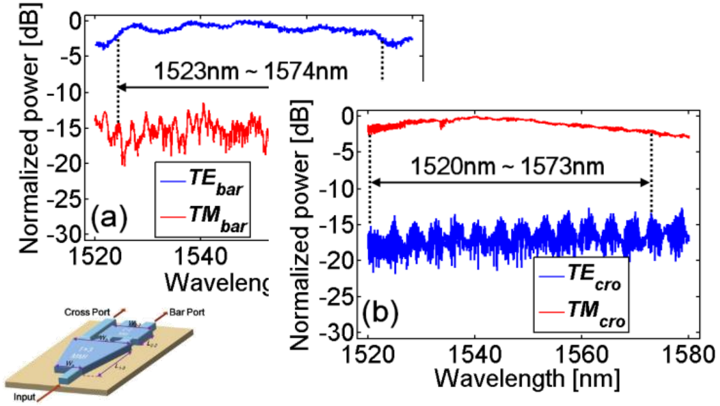

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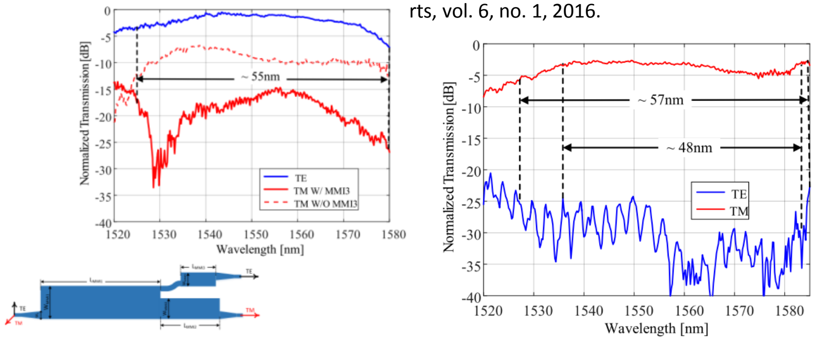

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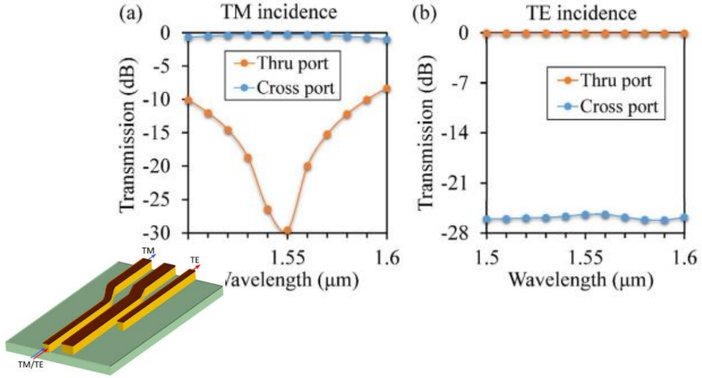

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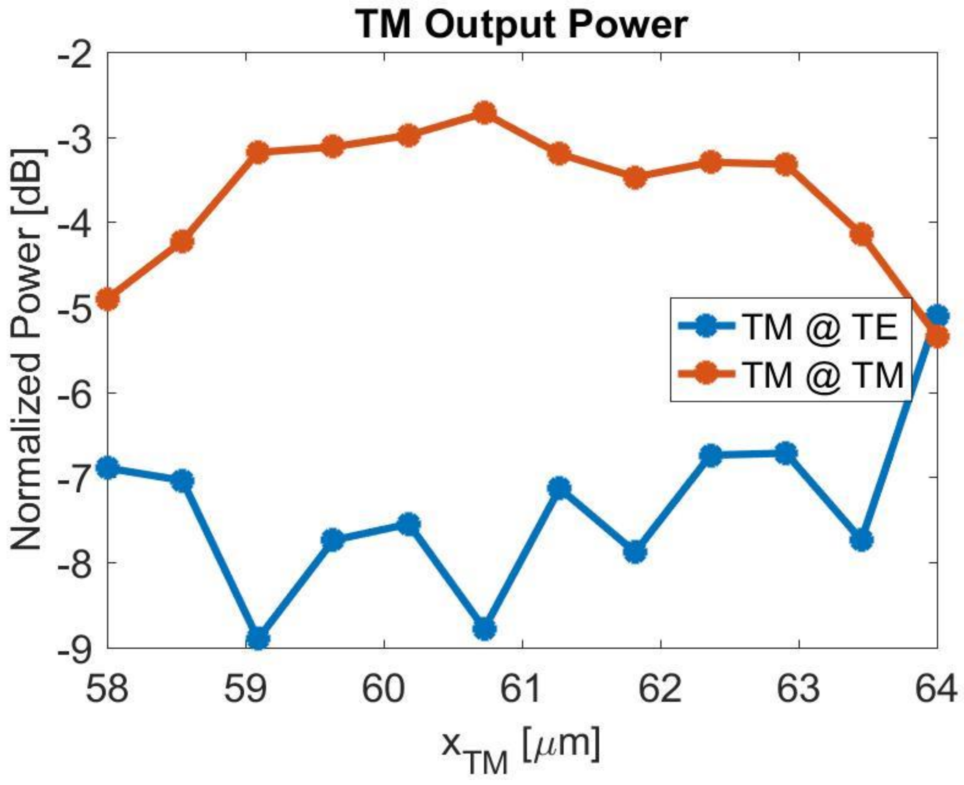
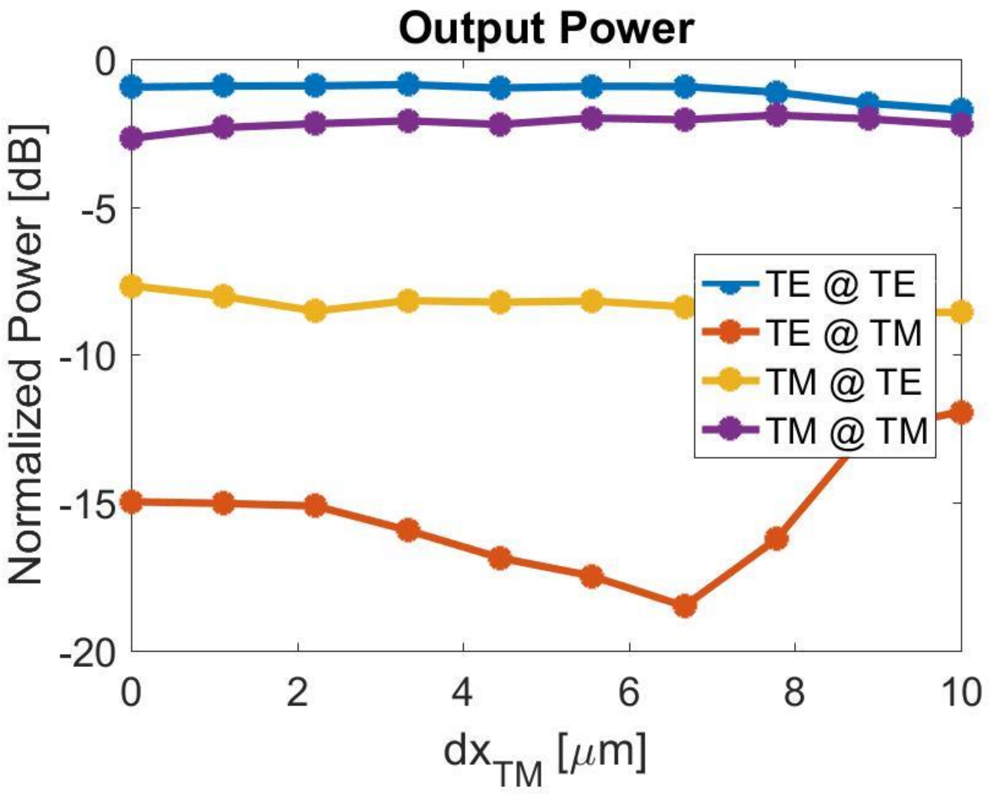
TM 1D optimization





TE 1D optimization