Multi-Mode Interference (MMI) Couplers

IN252: End-Semester Project

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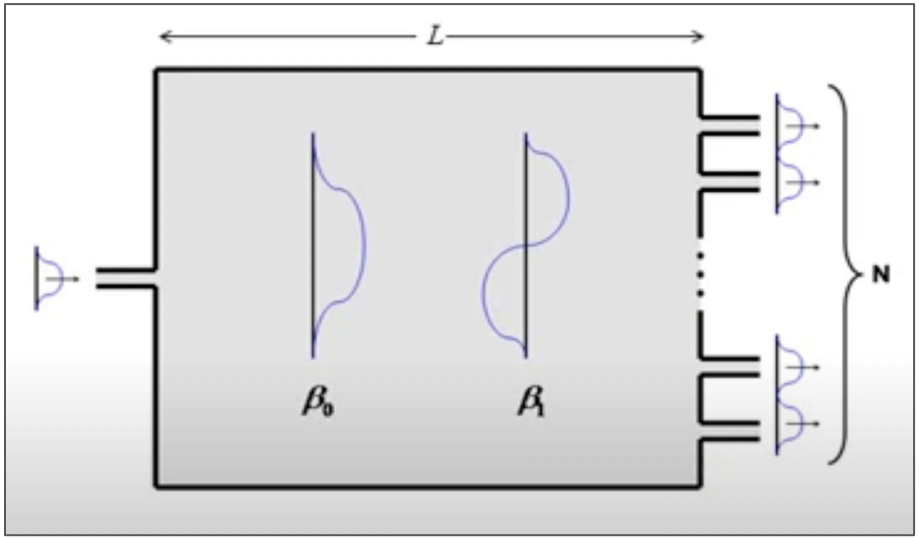
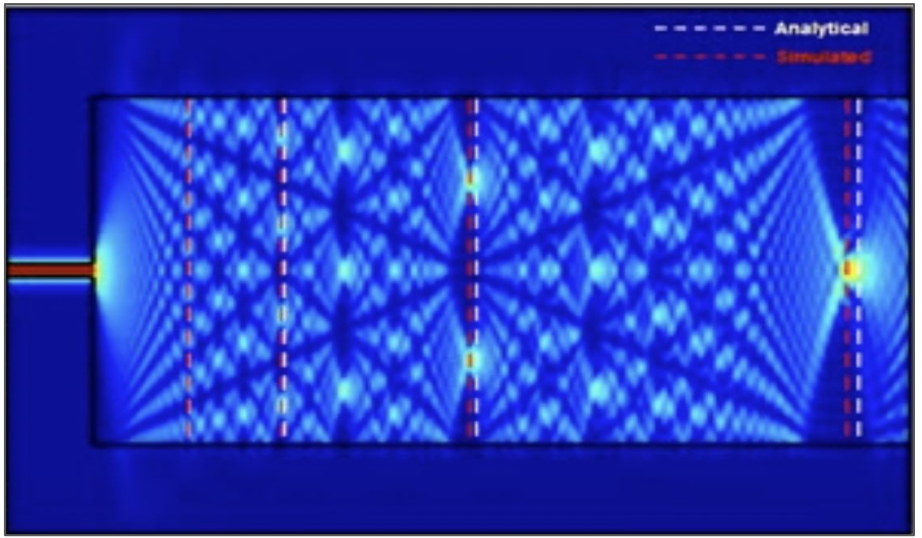
MULTI MODE INTERFERENCE



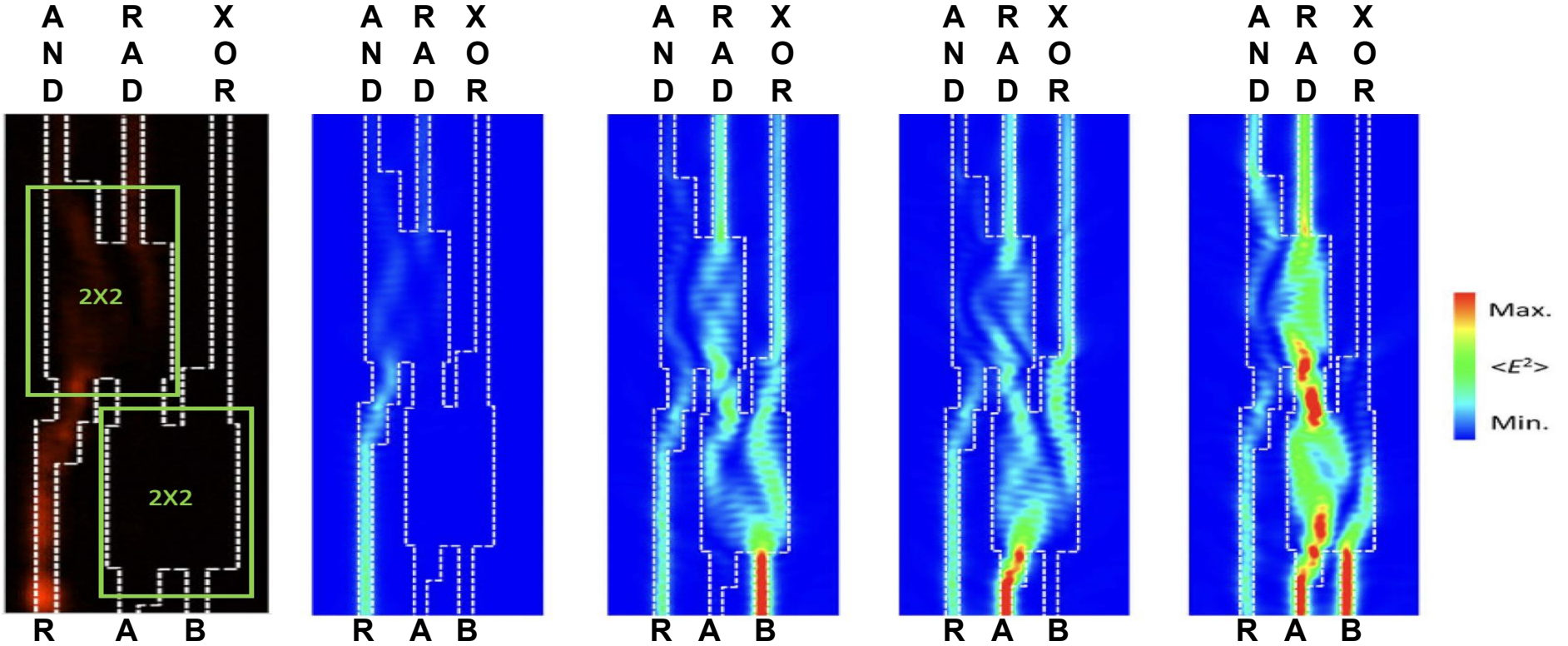


$$L_{1\times N} = \frac{3L_\pi}{4N}$$

$$L_\pi = \frac{\pi}{\beta_0 - \beta_1}$$

REF: “EM POSSIBLE LECTURES” YOUTUBE CHANNEL - EM POSSIBLE, BY DR. RAYMOND C RUMPF

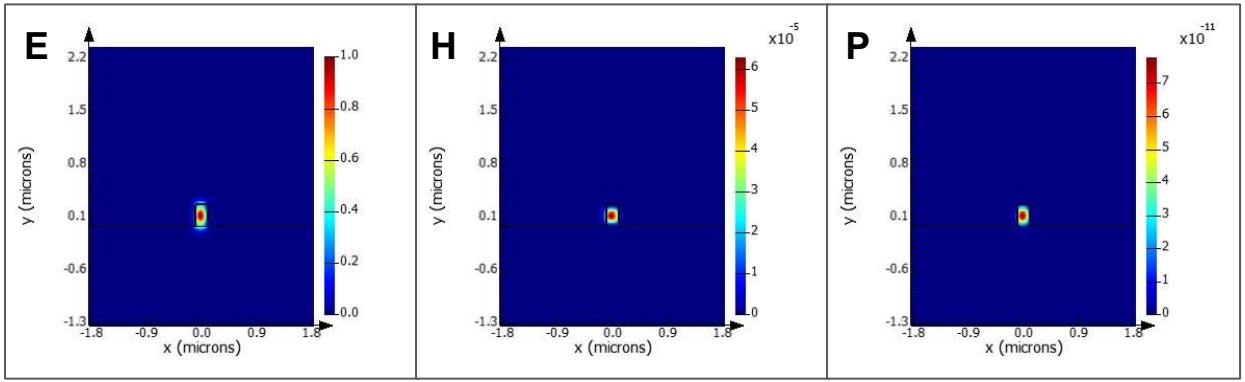
IMPLEMENTATION OF **AND** AND **XOR** GATE USING **1x1** AND **2x2** MMI COUPLER



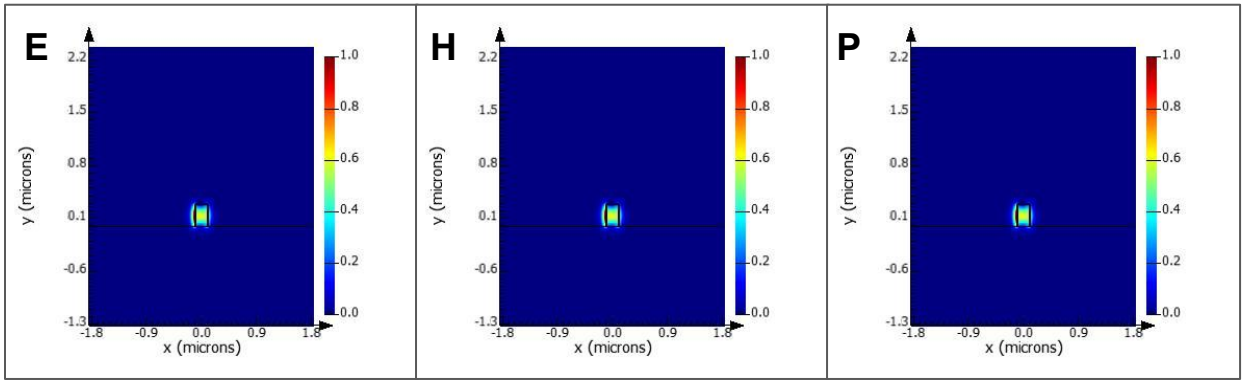
REF: Plasmonic-multimode-interference-based logic circuit with simple phase adjustment" Masashi Ota, Asahi Sumimura, Masashi Fukuhara, Yuya Ishii & Mitsuo Fukuda

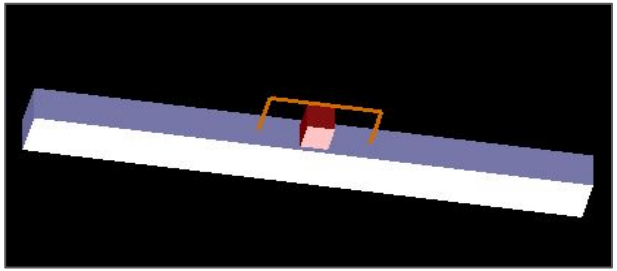
Ridge Waveguide

Mode 1



Mode 2

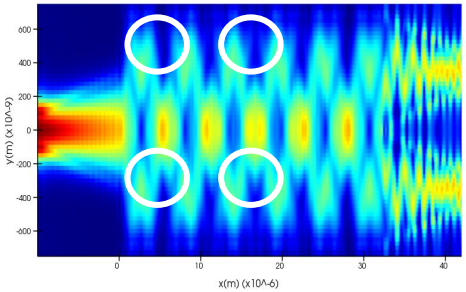


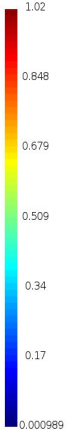


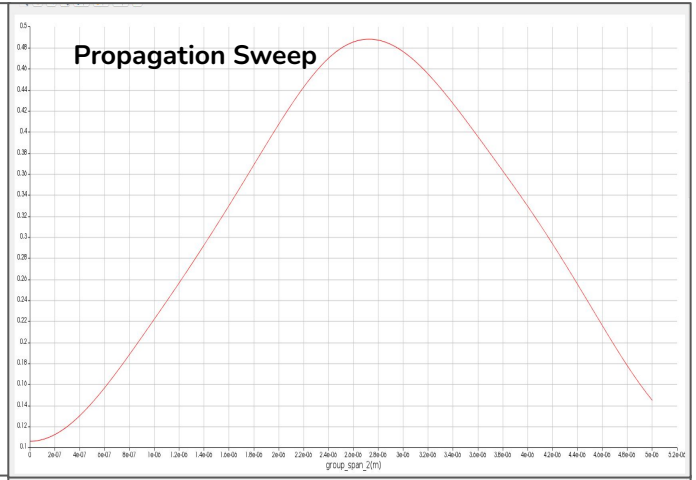
Parameter	Value
Core Material	Arsenic Triselenide
Substrate Material	PDMS
Loss (dB/cm): Mode 1	0.12312
Loss (dB/cm): Mode 2	0.11386
Core Width (μm)	0.2
Core Thickness (μm)	0.3

MMI coupler : 1 x 2

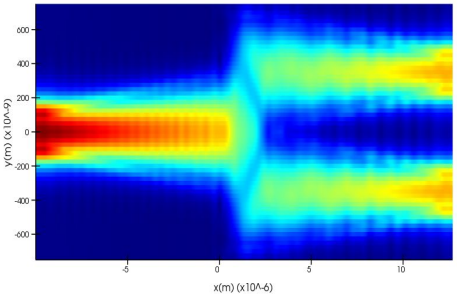
Field Profile

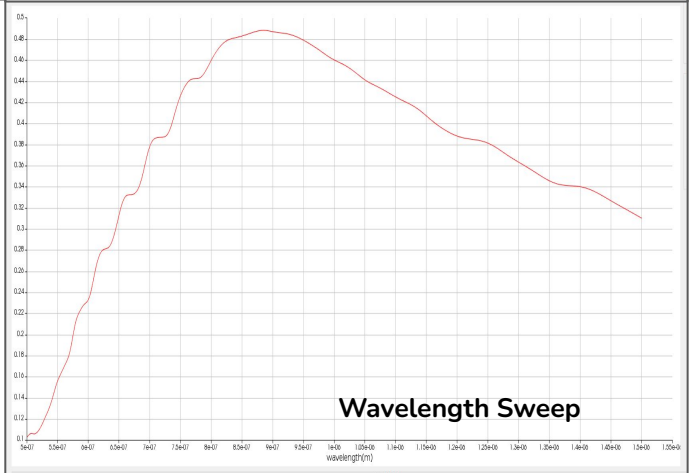






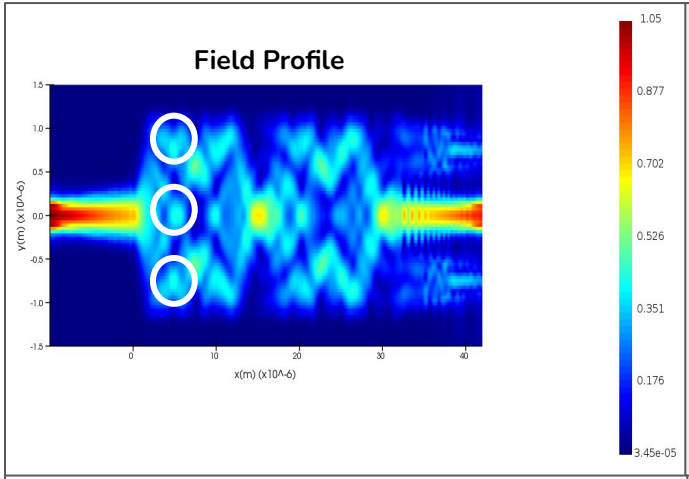
Optimal Field Profile

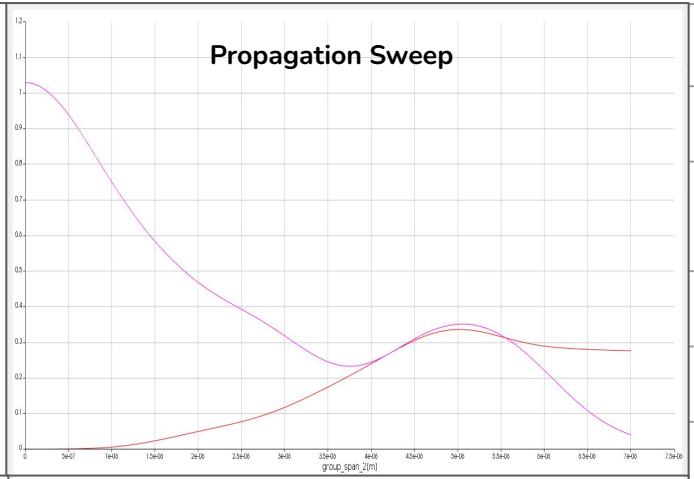


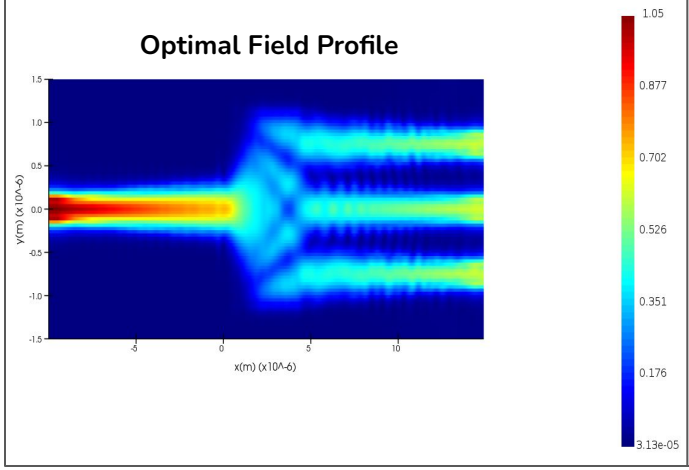


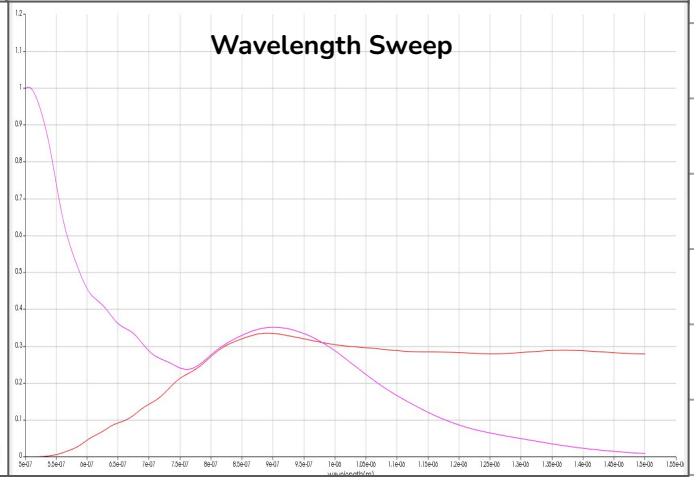
Optimal length	2.7 µm
Transmittance	0.488
Material	Arsenic Triselenide
Substrate	PDMS
Wavelength	880 nm
Coupler width	1.3 µm
Coupler length	32 µm
Separation	0.7 µm
Taper length	10 µm
Taper width	0.65 µm
Waveguide width	0.2 µm
Thickness	0.3 µm

MMI coupler : 1 x 3



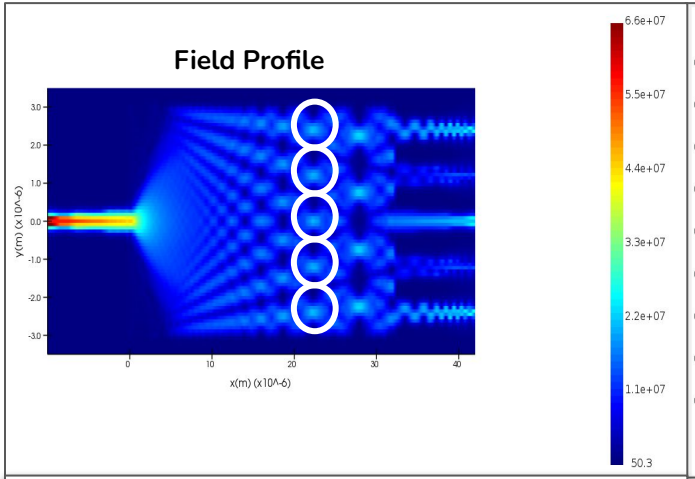


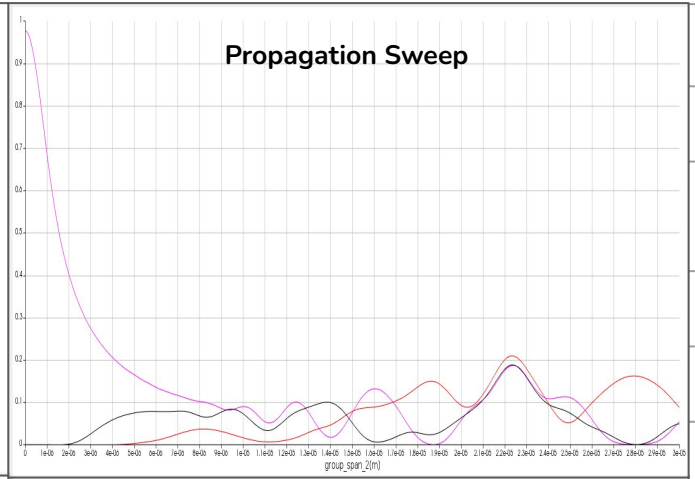


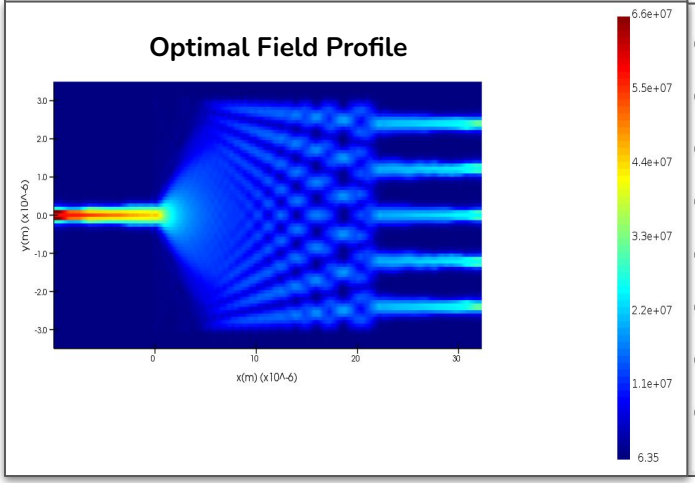


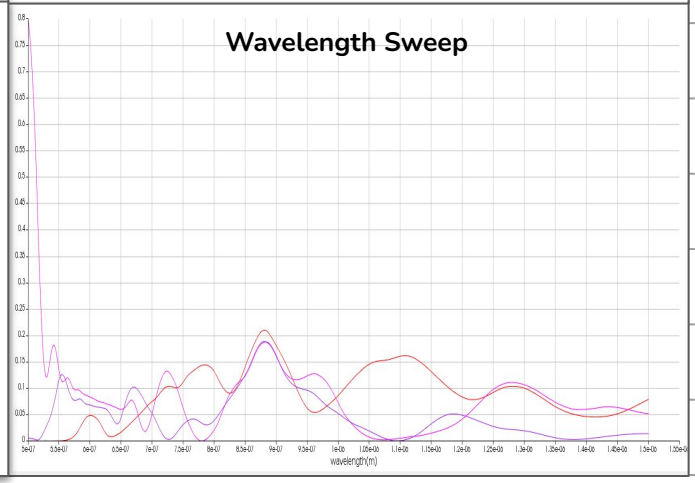
Optimal length	4.9 µm
Transmittance	0.32
Material	Arsenic Triselenide
Substrate	PDMS
Wavelength	880 nm
Coupler width	3 µm
Coupler length	32 µm
Separation	1.5 µm
Taper length	10 µm
Taper width	0.65 µm
Waveguide width	0.2 µm
Thickness	0.3 µm

MMI coupler : 1 x 5



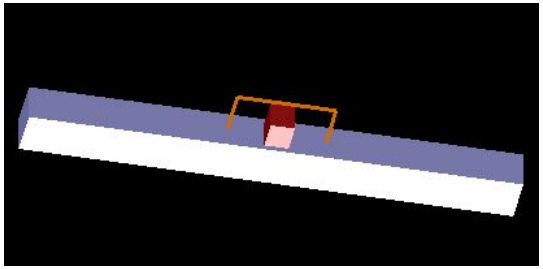






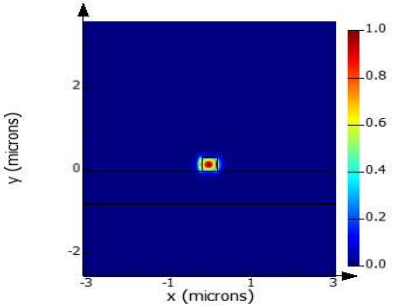
Optimal length	22.28 μm
Transmittance	0.19
Material	Arsenic Triselenide
Substrate	PDMS
Wavelength	880 nm
Coupler width	7 μm
Coupler length	32 μm
Separation	2.4 μm
Taper length	10 μm
Taper width	0.65 μm
Waveguide width	0.2 μm
Thickness	0.3 μm

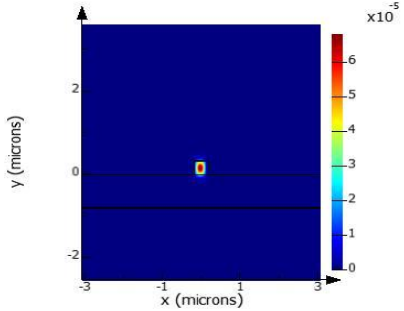
Ridge Waveguide

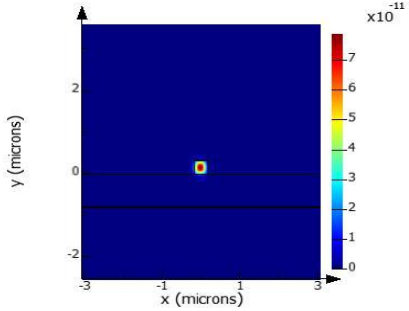


Core width	0.36 μm
Core thickness	0.34 μm
Material	Arsenic triselenide
Substrate	PDMS
Loss : Mode 1	0.5184 dB/cm
Loss : Mode 2	0.68918 dB/cm

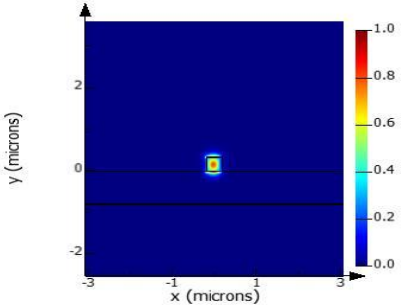
Mode 1

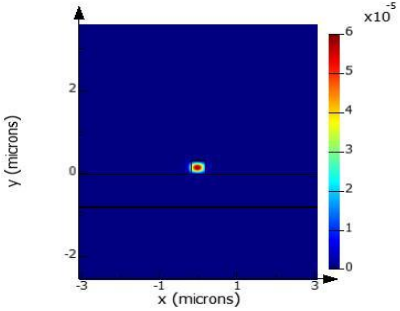


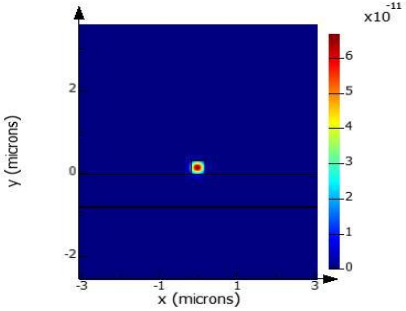




Mode 2





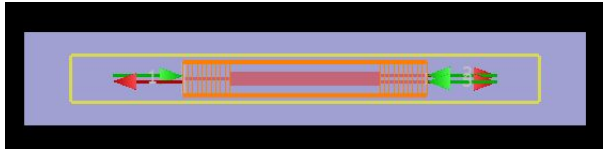


E Field Intensity

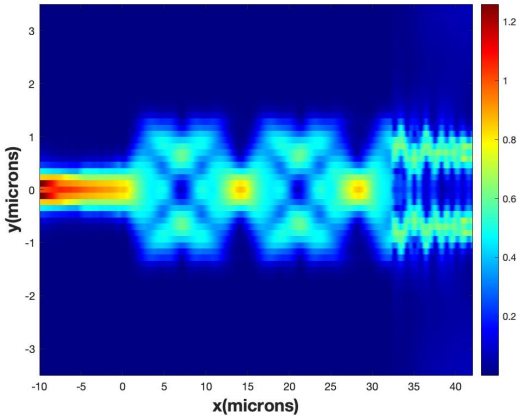
H Field Intensity

Energy Density

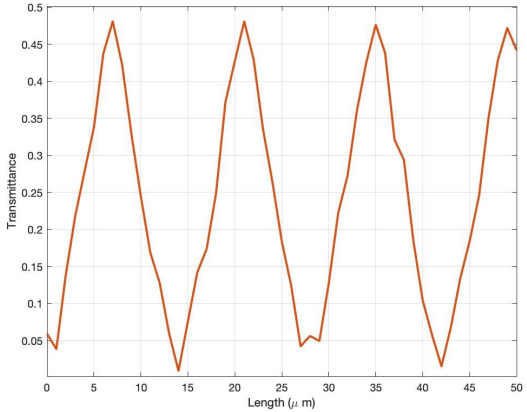
MMI coupler : 1 x 2



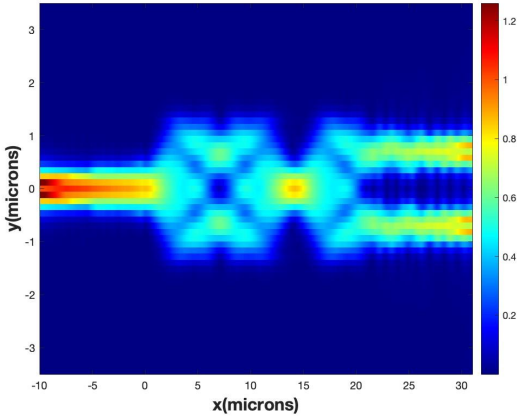
Field Profile



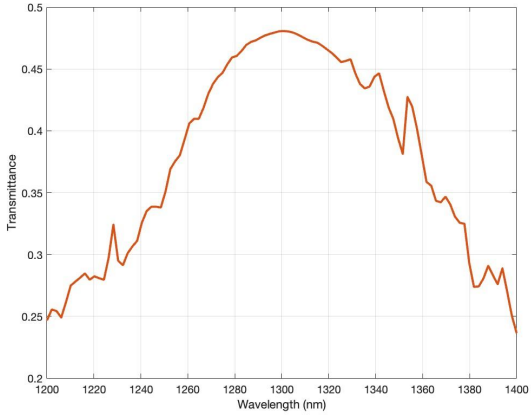
Propagation Sweep



Optimal Field Profile

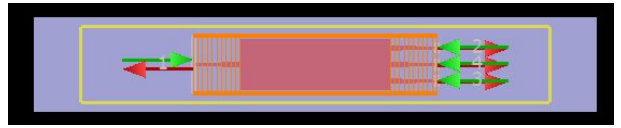


Wavelength Sweep

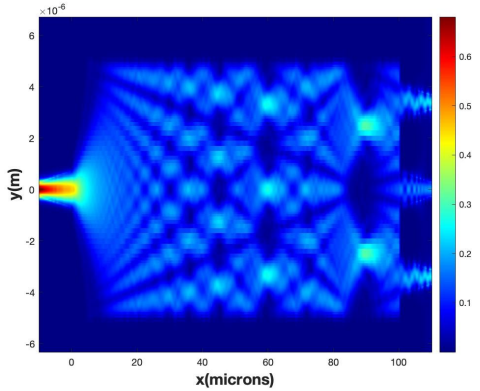


Optimal length	7 μm
Transmittance	0.481
Material	Arsenic triselenide
Substrate	PDMS
Wavelength	1300 nm
Coupler width	2.6 μm
Coupler length	32 μm
Separation	1.4 μm
Taper length	10 μm
Taper width	1 μm
Waveguide width	0.36 μm
Z span	0.35 μm

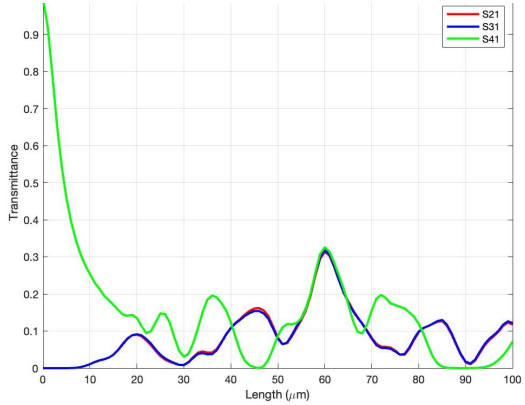
MMI coupler : 1 x 3



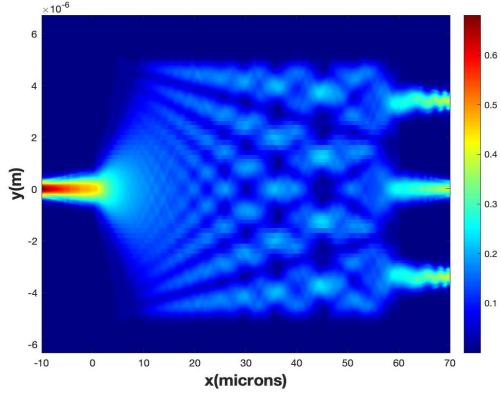
Field Profile



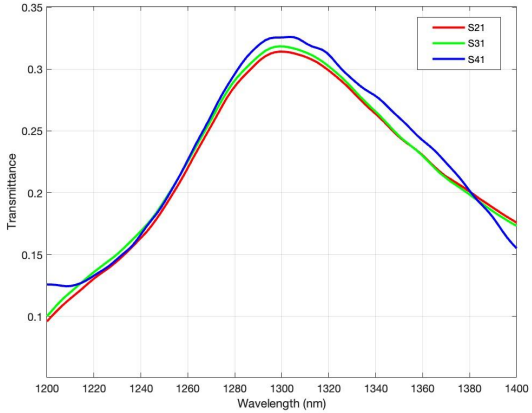
Propagation Sweep



Optimal Field Profile

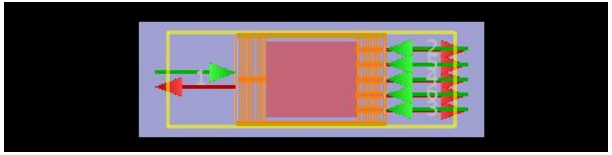


Wavelength Sweep

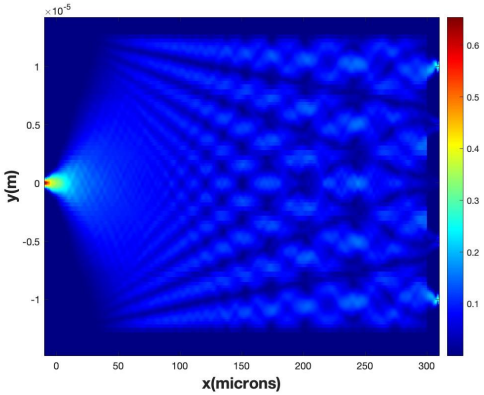


Optimal length	60 μm
Transmittance	0.325
Material	Arsenic triselenide
Substrate	PDMS
Wavelength	1300 nm
Coupler width	10 μm
Coupler length	32 μm
Separation	3.4 μm
Taper length	10 μm
Taper width	1.4 μm
Waveguide width	0.36 μm
Z span	0.35 μm

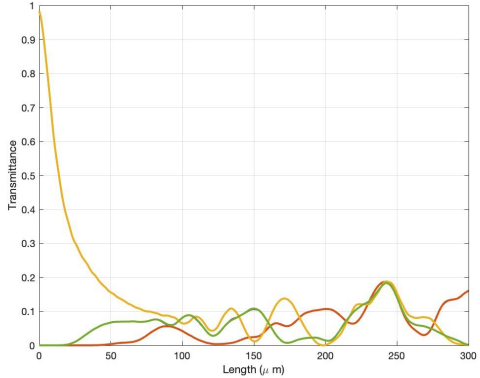
MMI coupler : 1 x 5



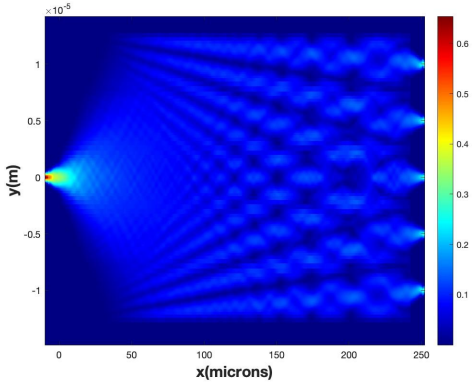
Field Profile



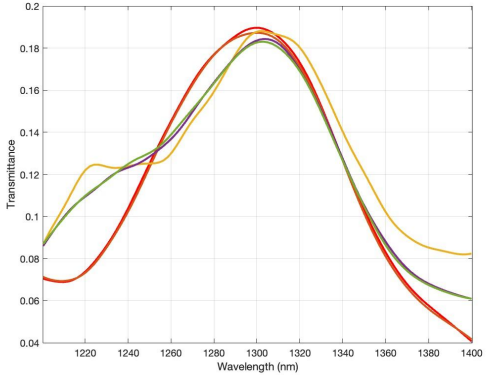
Propagation Sweep



Optimal Field Profile

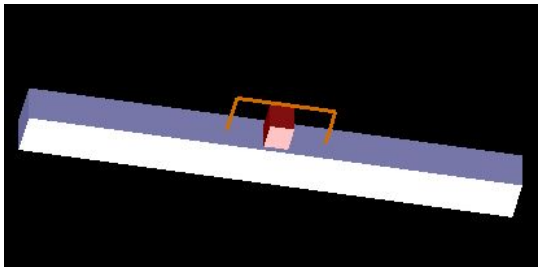


Wavelength Sweep

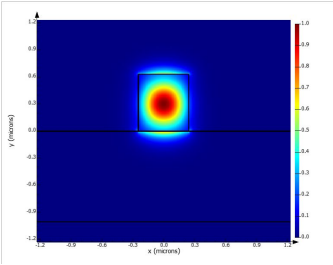


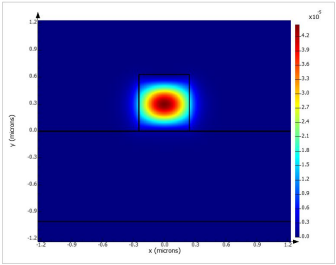
Optimal length	243 μm
Transmittance	0.183
Material	Arsenic triselenide
Substrate	PDMS
Wavelength	1300 nm
Coupler width	21 μm
Coupler length	32 μm
Separation	5.2 μm
Taper length	10 μm
Taper width	3 μm
Waveguide width	0.36 μm
Z span	0.35 μm

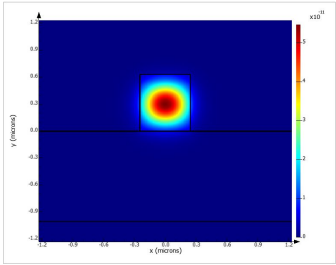
Ridge Waveguide



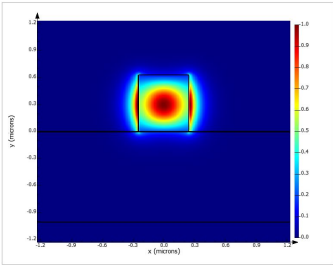
Mode 1

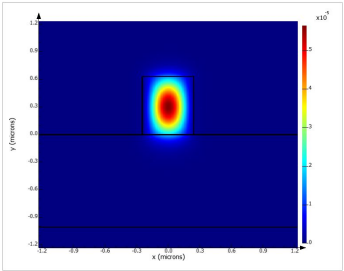


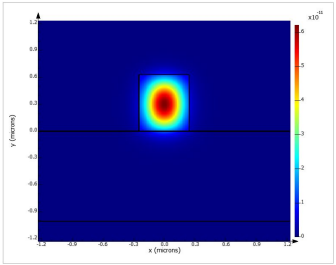




Mode 2







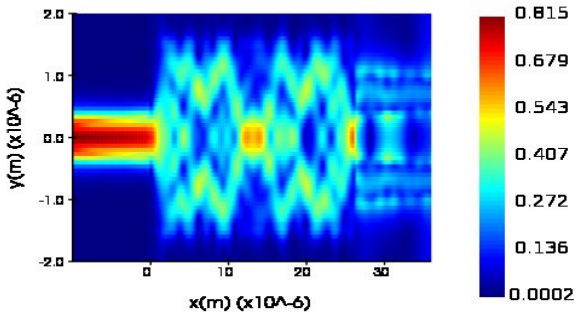
E Field Intensity

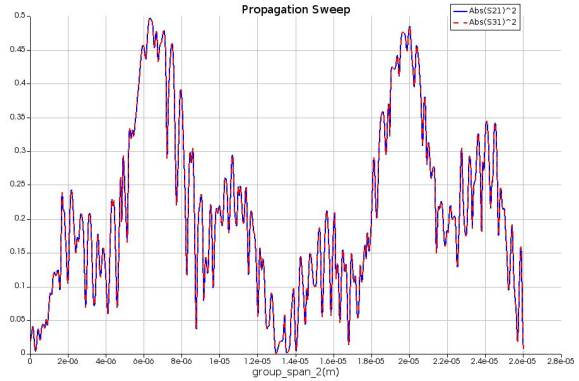
H Field Intensity

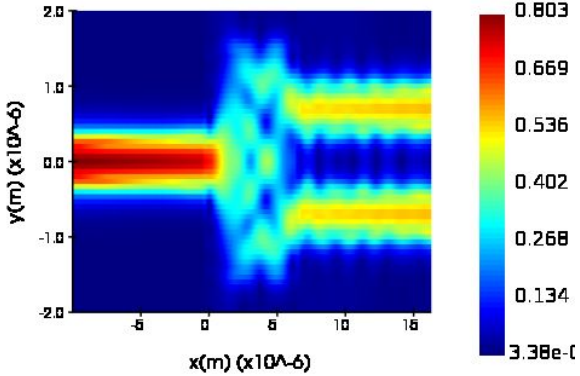
Energy Density

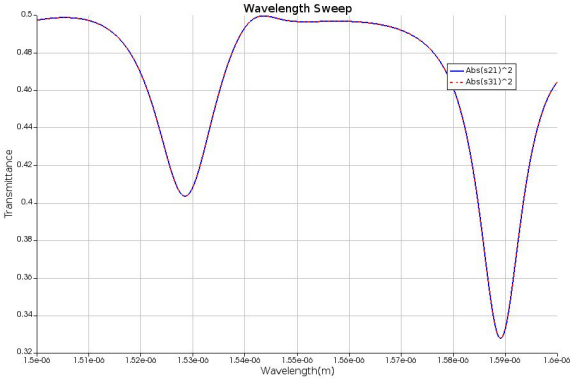
Parameter	**Value**
Core Material	Selenium (Se)
Substrate Material	PDMS
Loss (dB/cm): Mode 1	0.7632
Loss (dB/cm): Mode 2	0.0907
Core Width (μm)	0.49
Core Thickness (μm)	0.63

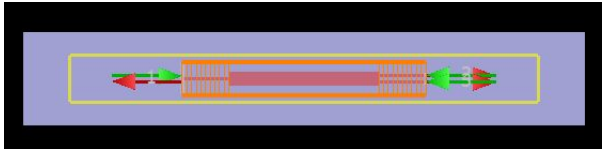
MMI Coupler: 1x2





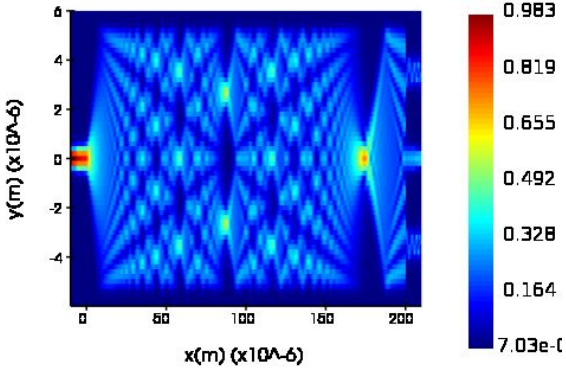


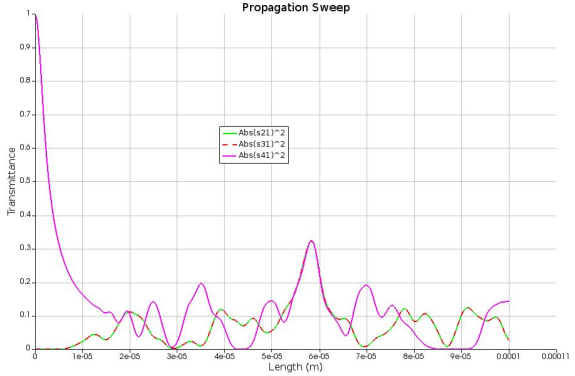


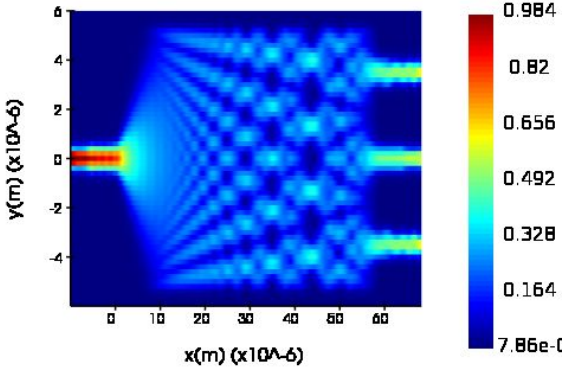


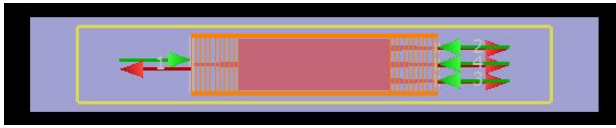
Substrate	PDMS
Material	Selenium (Se)
Coupler Length	6.3 μm
Wavelength	1550 nm
Coupler width	3 μm
Separation	3.5 μm
Taper length	10 μm
Taper width	0.7 μm
Waveguide width	0.49 μm
Coupler thickness	0.63 μm
Transmittance for length = 6.3 μm	0.497
Transmittance for wavelength=1.55 μm	0.496

MMI Coupler: 1x3



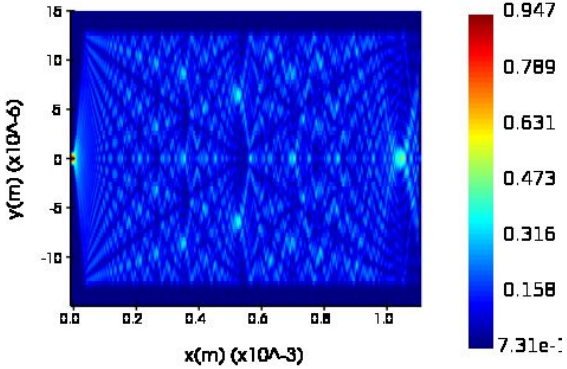


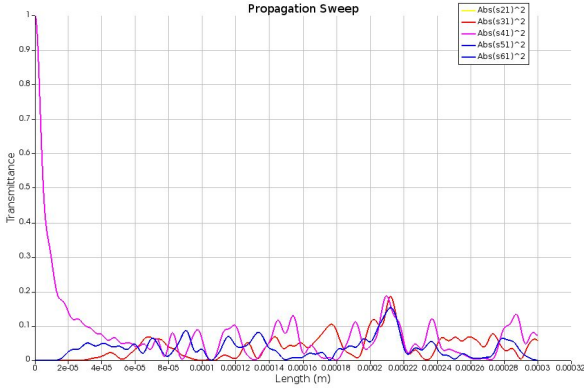


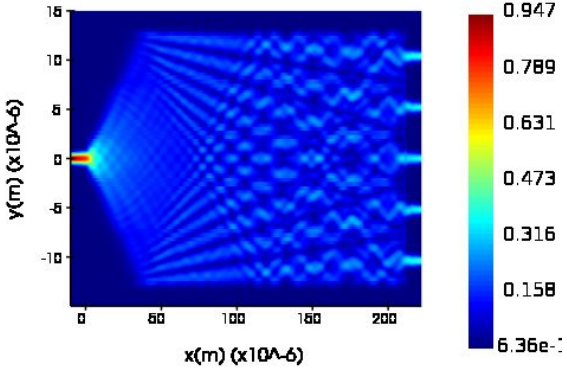


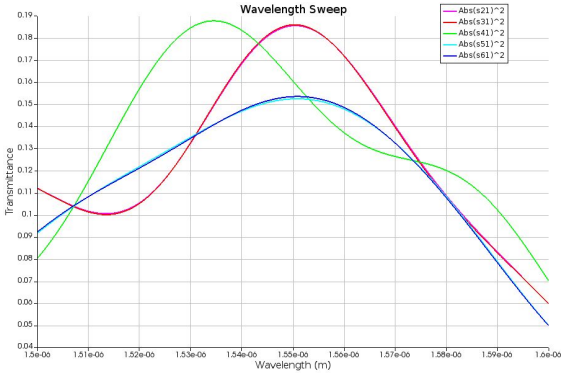
Substrate	PDMS
Material	Selenium (Se)
Coupler Length	58.2 μm
Wavelength	1550 nm
Coupler width	10.6 μm
Separation	1.4 μm
Taper length	10 μm
Taper width	0.7 μm
Waveguide width	0.49 μm
Coupler thickness	0.63 μm
Transmittance for length = 58.2 μm	0.324
Transmittance for wavelength=1.55 μm	0.323

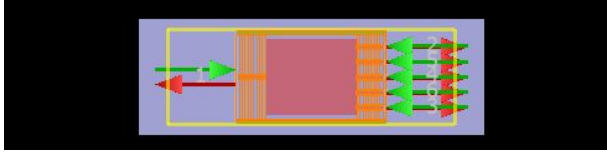
MMI Coupler: 1x5











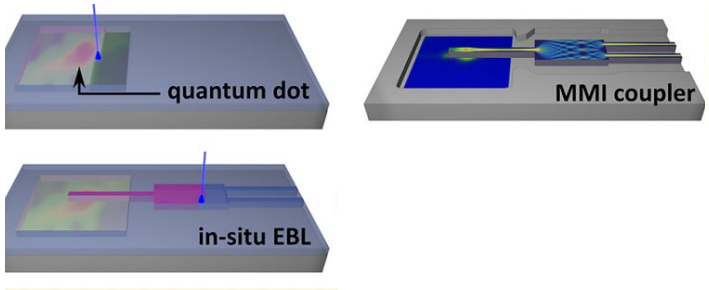
Substrate	PDMS
Material	Selenium (Se)
Coupler Length	212 μm
Wavelength	1550 nm
Coupler width	26.1 μm
Separation	10.4 μm
Taper length	10 μm
Taper width	0.7 μm
Waveguide width	0.49 μm
Coupler thickness	0.63 μm
Transmittance for length = 212 μm	0.186, 0.160, 0.152
Transmittance for wavelength=1.55 μm	0.186, 0.160, 0.153

Applications

- **Power splitters**

  Uniform Splitting

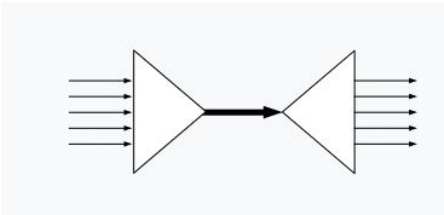
  Non-Uniform Splitting

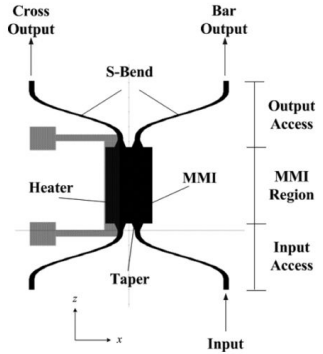


- **Switch-type devices**

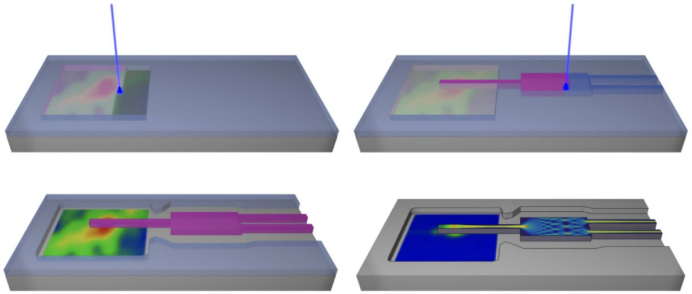
  Optical path switching

  Wavelength division multiplexing

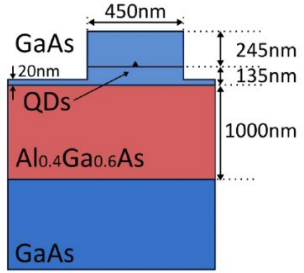




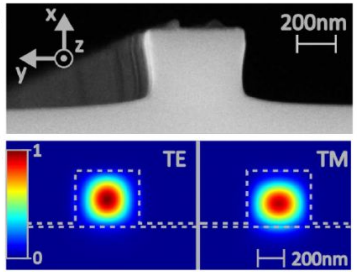
Deterministic Integration of Quantum Dots into on-Chip Multimode Interference Beamsplitters Using in Situ Electron Beam Lithography



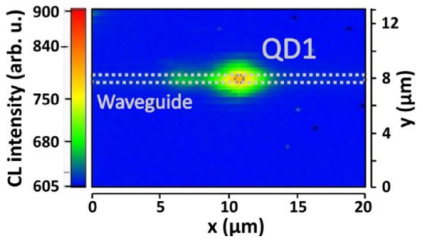
Schematic visualization of the in situ EBL device manufacturing process



Schematic view of the sample

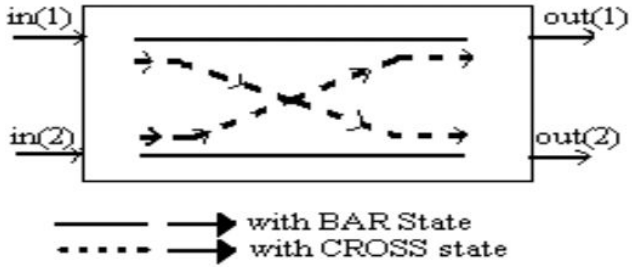


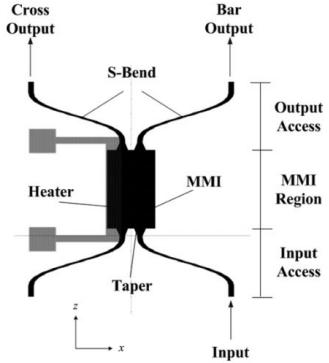
Simulated electric field intensity distribution of the fundamental WG modes of a 450 nm wide waveguide.

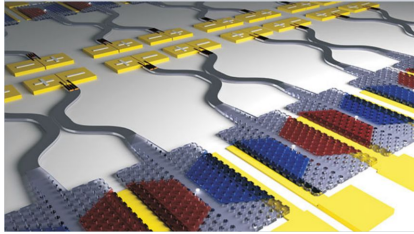


The emission of QD1 from inside the WG to the top

Optical Switch Based on Multimode Interference Coupler



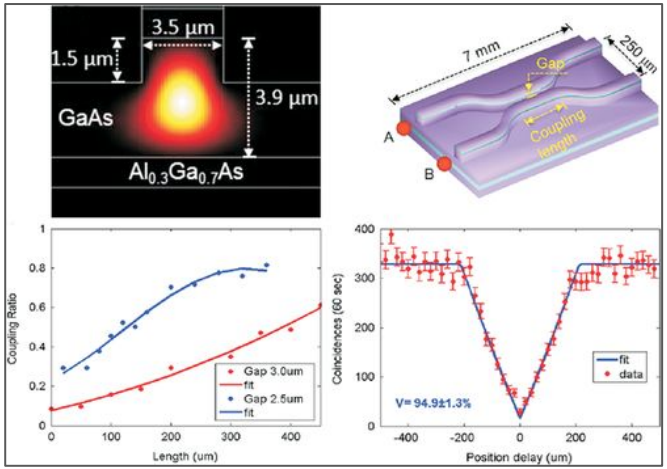




Future Scope

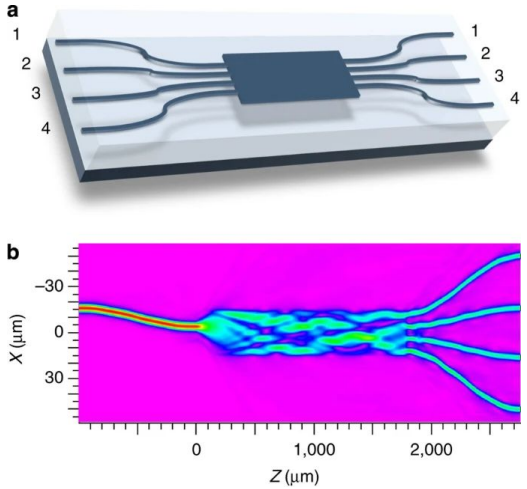
- Implementation of circuits for Quantum Computing

GaAs Quantum Integrated Photonic Circuits



Christof P. Dietrich , Andrea Fiore , Mark G. Thompson, Martin Kamp, and Sven Höfling

Quantum interference in multiport devices



Alberto Peruzzo, Anthony Laing, Alberto Politi, Terry Rudolph & Jeremy L. O'Brien

Bibliography

- “EM POSSIBLE LECTURES” Youtube Channel - EM POSSIBLE, BY DR. RAYMOND C RUMPF
- Plasmonic-multimode-interference-based logic circuit with simple phase adjustment” Masashi Ota, Asahi Sumimura, Masashi Fukuhara, Yuya Ishii & Mitsuo Fukuda
- Schnauber, Peter, et al. "Deterministic integration of quantum dots into on-chip multimode interference beamsplitters using in situ electron beam lithography." *Nano Letters* 18.4 (2018): 2336-2342.
- Wang, Fan, et al. "Optical switch based on multimode interference coupler." *IEEE Photonics Technology Letters* 18.2 (2006): 421-423.
- Dietrich, Christof P., et al. "GaAs integrated quantum photonics: Towards compact and multi‐functional quantum photonic integrated circuits." *Laser & Photonics Reviews* 10.6 (2016): 870-894.
- Peruzzo, Alberto, et al. "Multimode quantum interference of photons in multiport integrated devices." *Nature communications* 2.1 (2011): 1-6.

Thank you