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Fabricating Nanophotonic Devices using Nanofabrication Techniques

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Fabricating Nanophotonic Devices using Nanofabrication techniques

Presenter: Scott Cummings

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Overview

Nanophotonics

- Harrison Lab @ Fowler School of Engineering.
- Design digital logic components using optical signals.
- Fiber optics already used but require translation into electrical signal.

Nanofabrication

- Primarily used for integrated circuit, standard technology for computer chips.
- Deposition
- Photolithography (Masks)
- E-beam Lithography (Lower resolution)
- Etching

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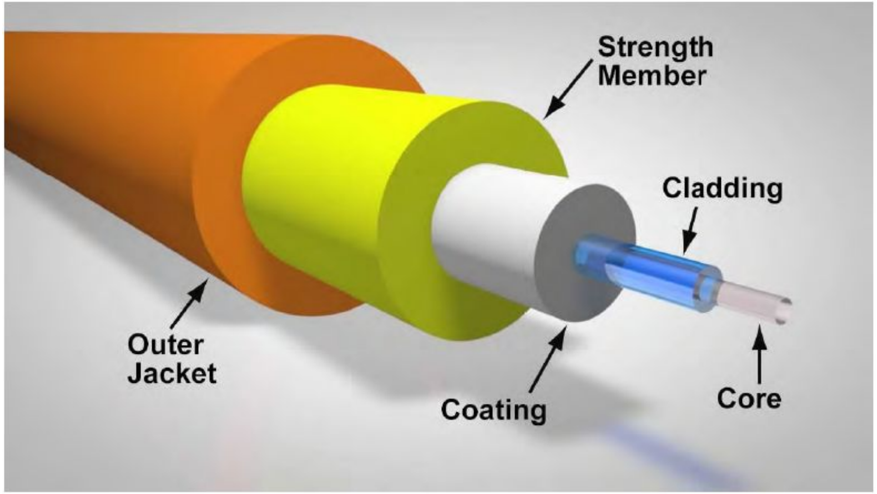
Waveguide Background

<u>Waveguides-</u> Analogous to wires in electrical circuits. A structure created to guide light through a series of photonic devices.

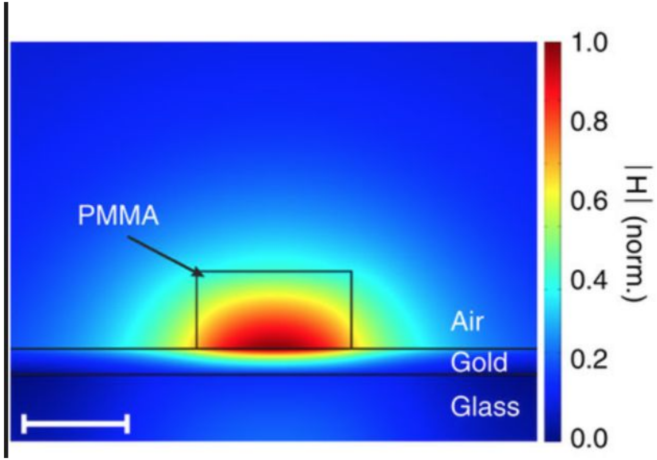
Most common form: Optical Fiber

For this project: DLSPP Single-Mode Waveguide



https://engineer-educators.com/topic/basic-structure-of-an-optical-fiber/

Waveguide Background



Bloch oscillations in plasmonic waveguide arrays - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Dielectric-loaded-surface-plasmon-polariton-waveguides-a-Schematic-view-of-an-array-of_fig2_262226798 [accessed 30 Nov, 2021]

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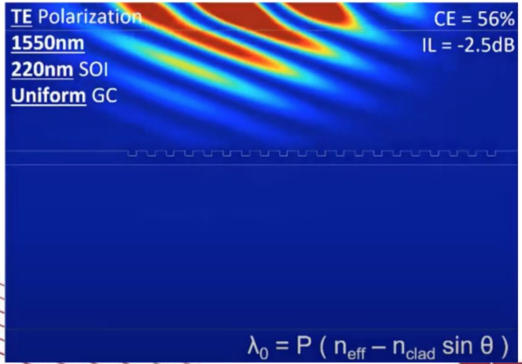
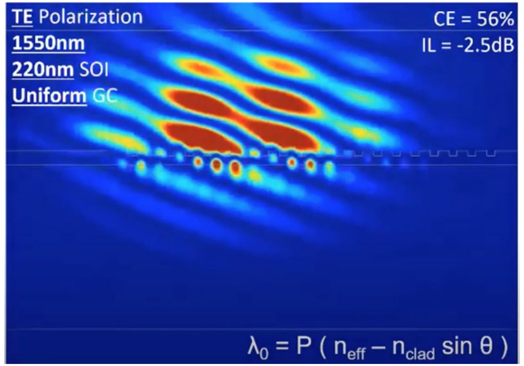
Grating Coupler Background

<u>Grating Couplers-</u> Light from optical fibers are coupled into waveguides through these devices.

1) Light approaches grating coupler



2) Light hits Grating Coupler and coupling begins:



Europractice Services - S1 -E4 Grating Couplers Part 1 https://www.youtube.com/watch?v=XH3Mzelu0j0

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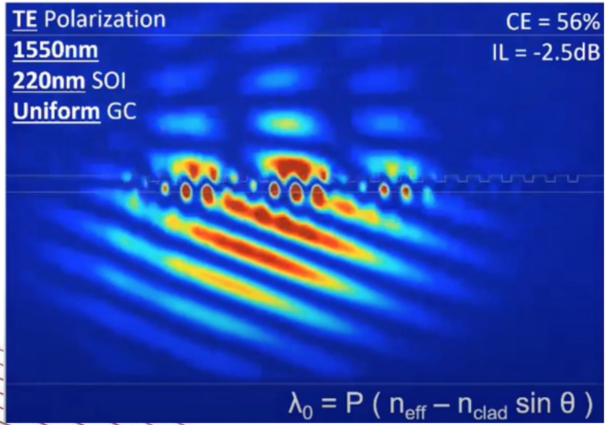
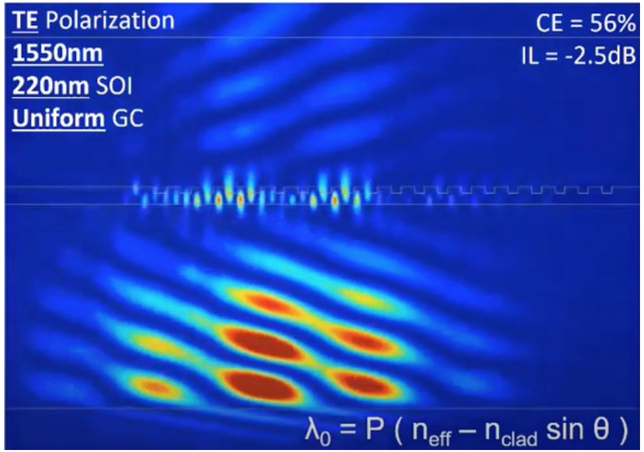
Grating Coupler Background

3) The majority of the wave has passed through the coupler:



4) The remnants of the wave move perpendicular to the vertically oriented fiber:



Europractice Services - S1 -E4 Grating Couplers Part 1 https://www.youtube.com/watch?v=XH3Mzelu0j0

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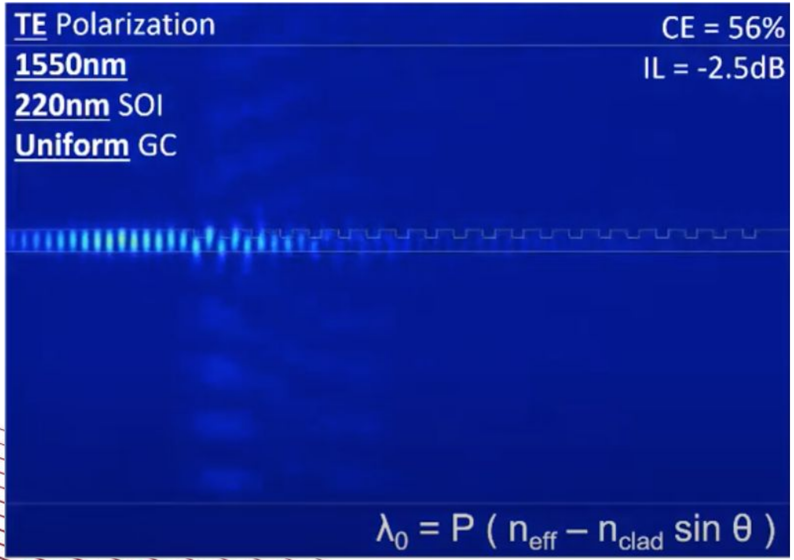
Grating Coupler Background

5) The wave continues into the PIC:



Europractice Services - S1 -E4
Grating Couplers Part 1
https://www.youtube.com/watch?v=XH3Mzelu0j0

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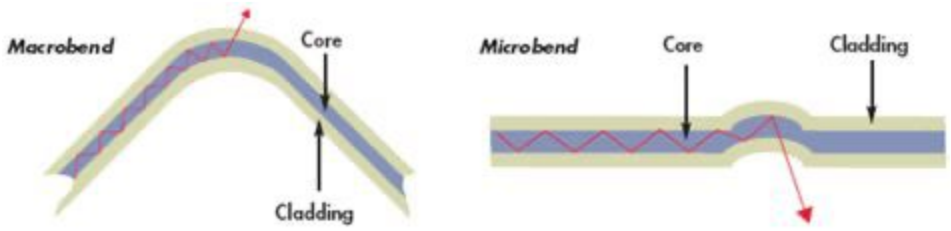
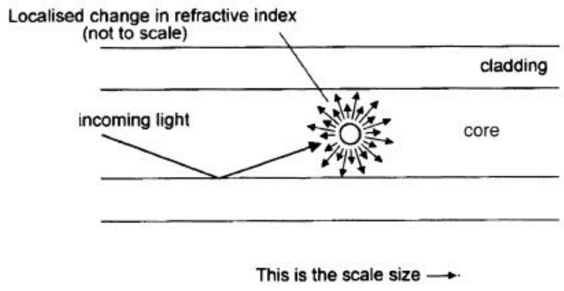
Optical Loss Background

Bending Loss:



Scattering Loss:

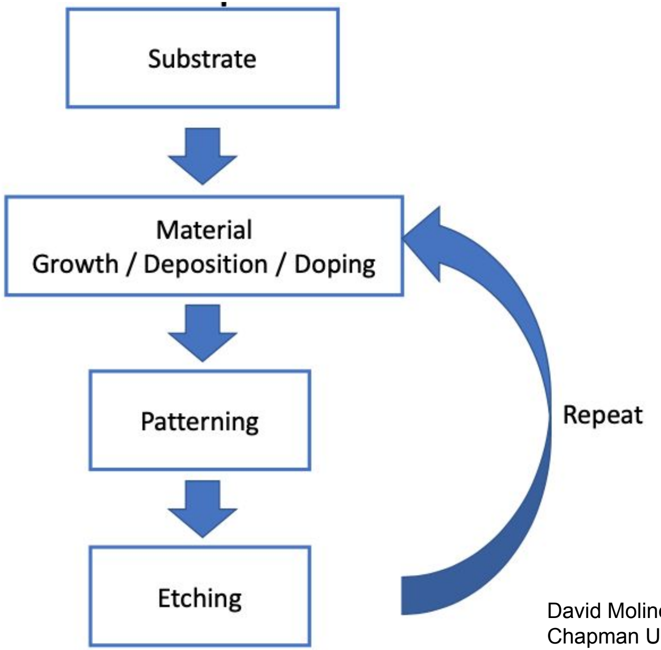


Absorption Loss (Most common):

Photons absorbed as wave passes through.

Fabrication Background

1) Deposition: Metal is deposited in layers as the device requires (structure and other properties). Photoresist is deposited so some pieces can be cut away.
2) Lithography: Pattern is written onto layers through photoresist exposure to light (Photolithography) or electrons (E-beam Lithography)
3) Etching: Written material is etched away either with chemicals (wet) or with ions (Reactive-Ion/Dry)
4) Repeat!: This process may need to be repeated many times for complex designs.



David Molinero, PhD
Chapman University

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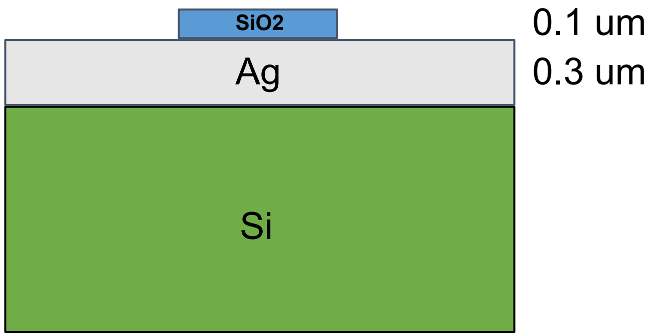
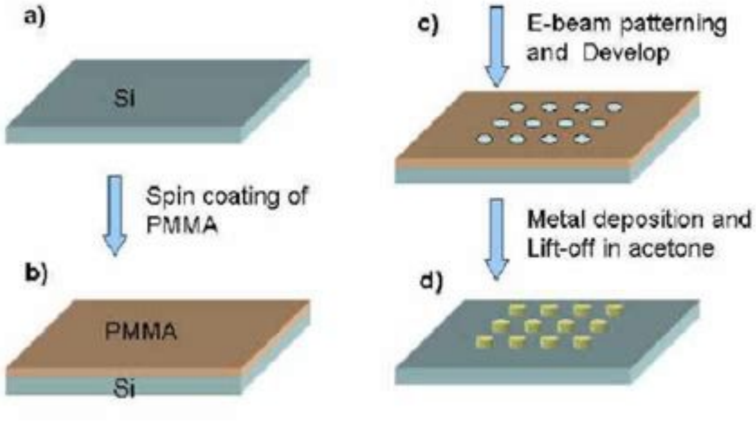
Silver and SiO2 deposition on Silicon

- Surface resolution < 30 nm -> E-beam writer
- 0.5 um silver layer lays flat against silicon bed.
- 0.1 um SiO_2 layer is cladded by air, sits on top of Ag layer



E-beam Lithography

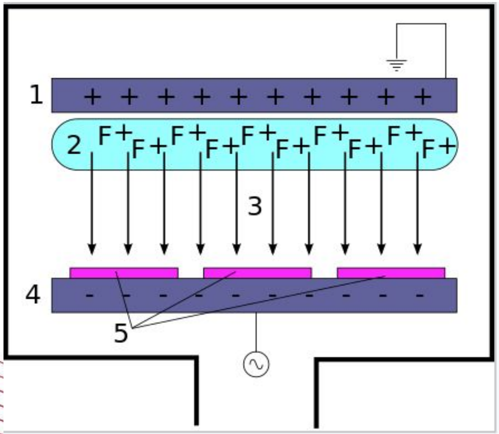
- Resist is added to the surface of the layered wafer.
- A pattern is drawn in the resist that marks the design required.
- An etchant is applied to the wafer to only leave the necessary material.
- In contrast to mask photolithography, possible to acquire 30 nm resolution.

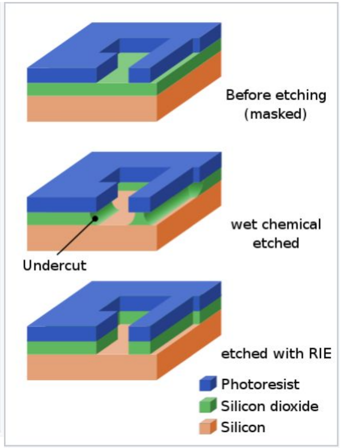


https://www.researchgate.net/figure/E-beam-Lithography-Process-Flow-for-growth-of-ZnO-Nanowires-Wang-et-al-Ref-10_fig4_221912059

RIE (dry etch)

- Reactive-Ion Etching
- Wet etching often causes undercutting in the SiO2 layer, RIE etching removes that problem
- Electric field used to accelerate ions towards photoresist surface evenly.





https://en.wikipedia.org/wiki/Reactive-ion_etching

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Waveguide Design

- Photonic component meant for guiding light of a certain mode.
- Analogous to copper wire in electrical circuits.

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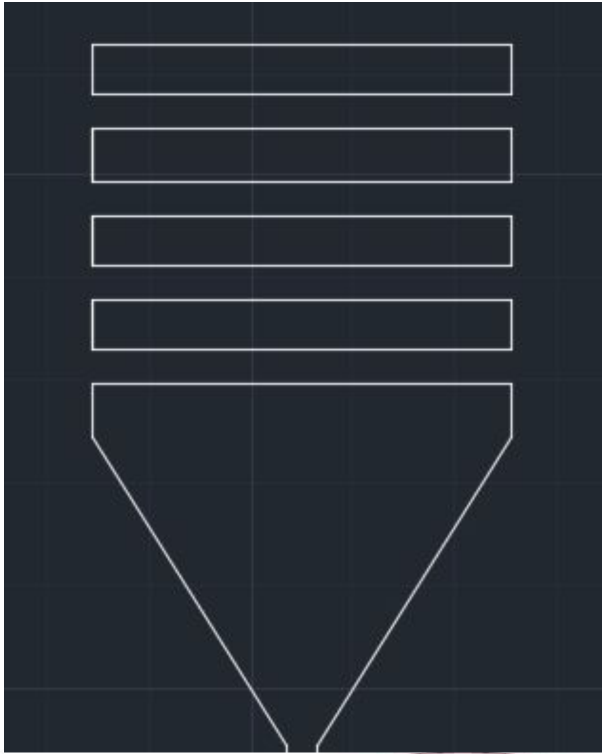
Grating Coupler Design

- Two widths of either 6400 nm or 3000 nm
  - These widths were used to accommodate for optical fiber spot size.
- Composed of series of teeth which lead into a taper and then the waveguide.
- Period: 1.3 um
- Duty Cycle: 60% (780:1300)



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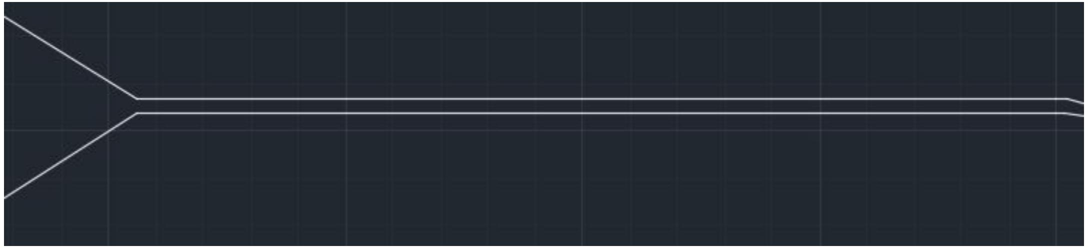
Waveguide Design

- Straight segment of various lengths.
- Longer lengths result in greater optical loss
- Made of same material as grating coupler and bend. Etched SiO_2 onto Ag & Silicon.
- SiO_2 is cladded by Silver and Air

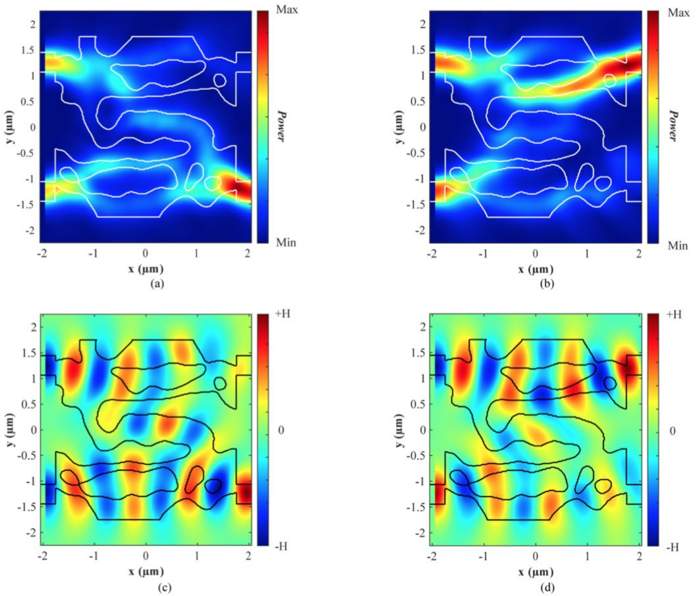


Logic Gate Design

“Implementing commercial inverse design tools for compact, phase-encoded, plasmonic digital logic devices” - Krishna Narayan and Mark C. Harrison

- Xor gate logic achieved through phase-shift keying.
- Lines indicate edges of geometry.
- 0->0, π -> 1

Input A	Input B	Output
0	0	0
0	1/π	1
1/π	0	1
1/π	1/π	0



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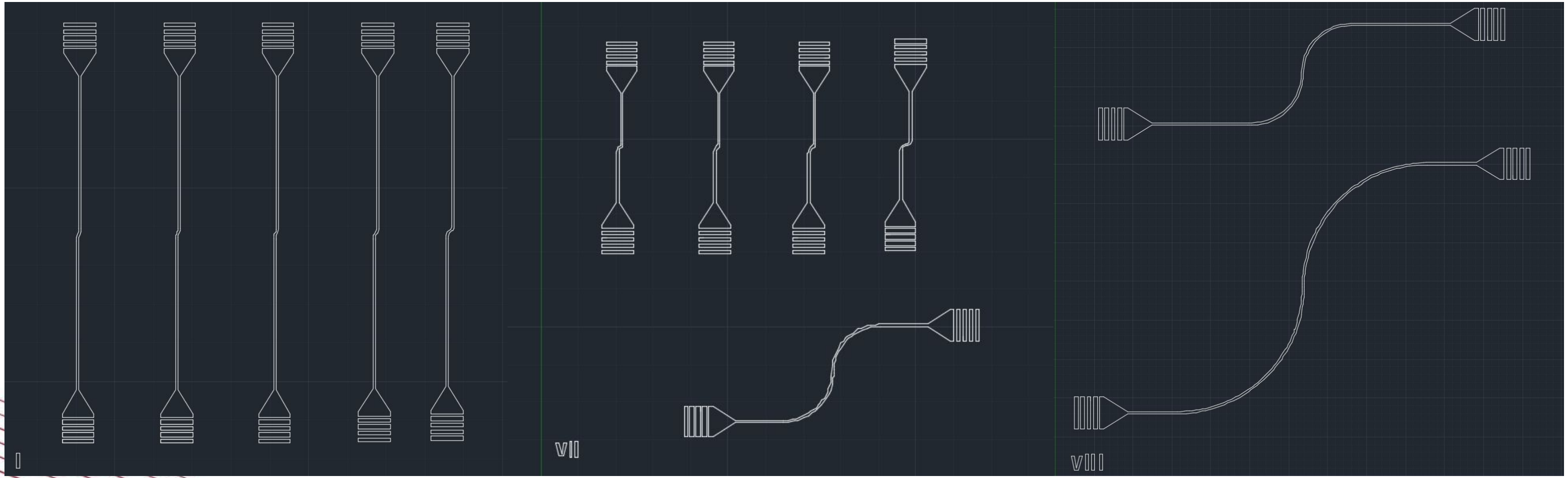
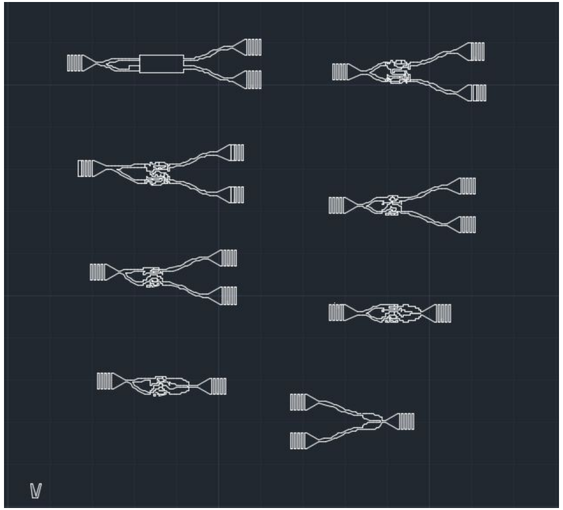
Waveguide Designs

- Variable length and bend to experimentally show propagation and bending loss



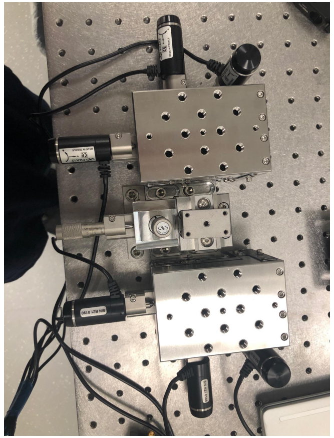
Inverse Designs

- Several components that can be compared to simulations in Lumerical, an optical simulation tool.



Complications with UCI Nanofab

- Power outages at UCI harmed RIE system and pressure systems.
- Resulted in delayed fabrication.
- Cannot confirm with experimentation...yet
- Optical table set up with actuators for lining up optical fibers



Alignment stages and cameras at Harrison Lab

Purpose

- Teaching students basics of waveguides, optical loss, and experimentally verify inverse designs.
- Develop pipeline with UCI to continue fabricating photonic components.
- Validate testing setup.

Questions?