3D Microfabrication of Waveguides using Two-Photon Polymerization

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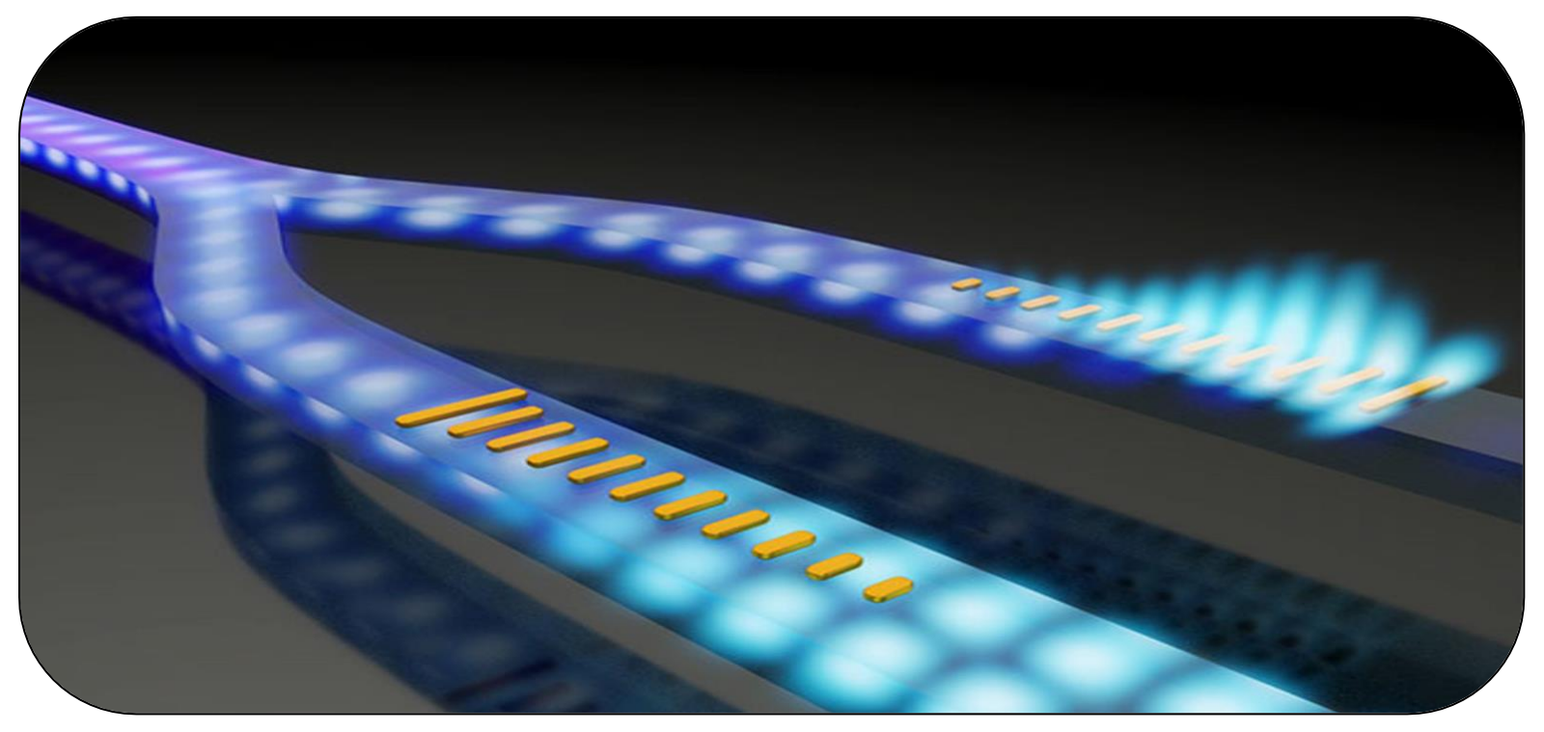
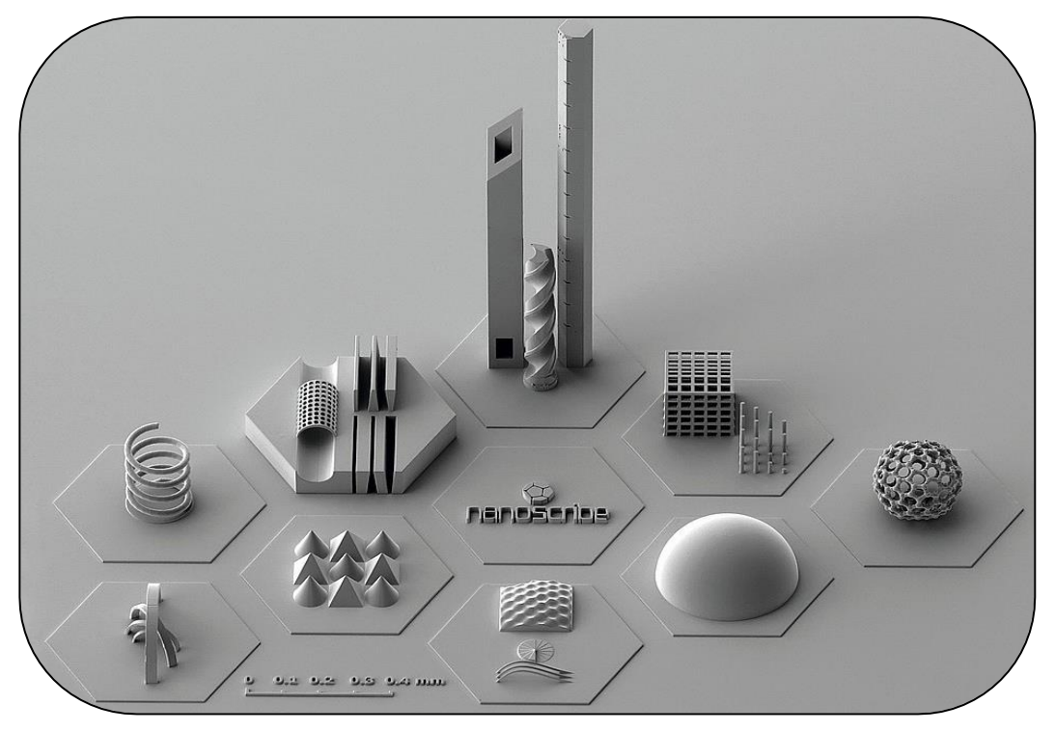
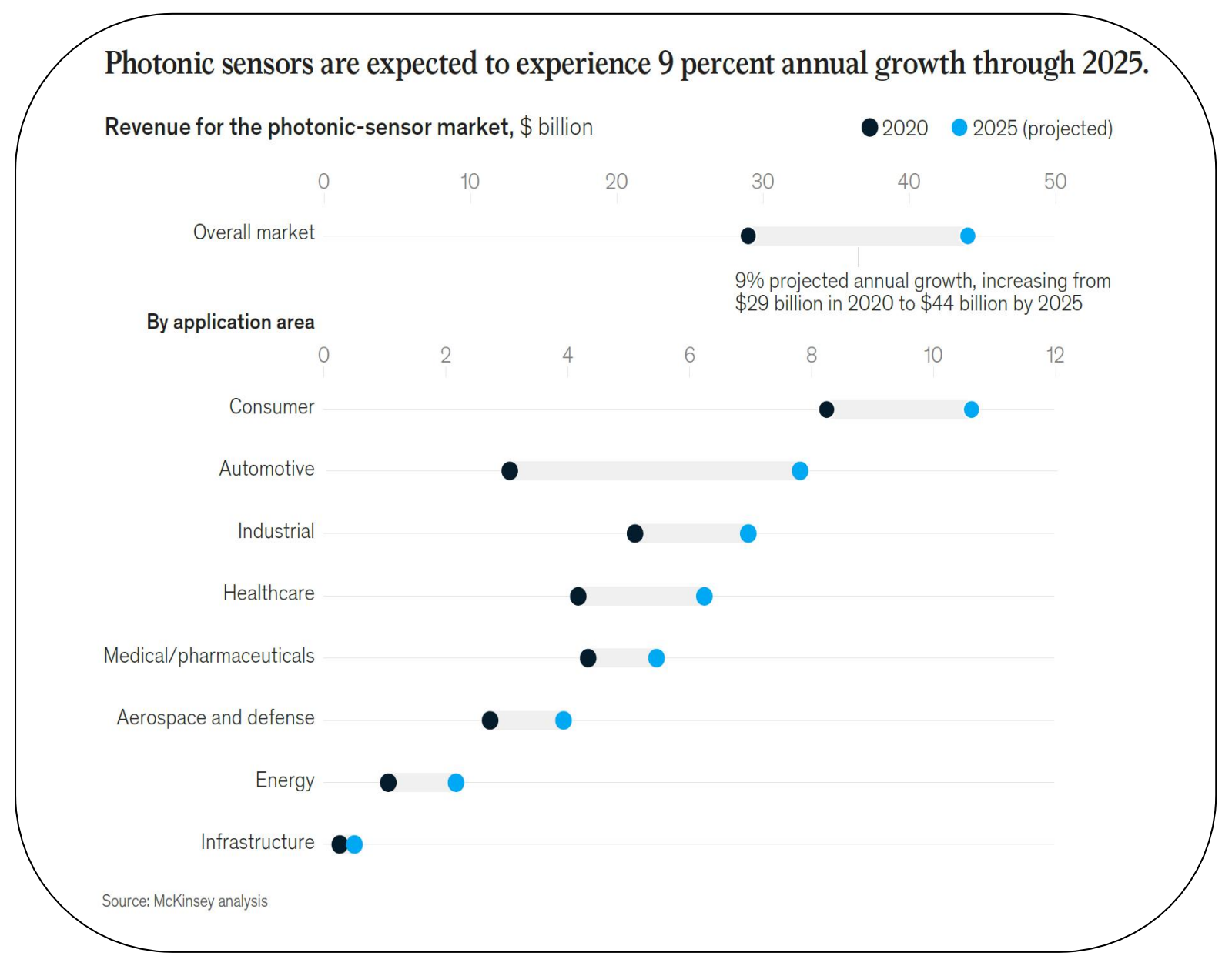
Abstract

This project set a foundation for future related projects at the new photonics laboratory at WPI. Integrated photonics is a rapidly growing industry with applications in communications, sensing, medicine, defense, computing, and beyond. To illustrate the capabilities of the new laboratory, two waveguides, one straight and one with an S-bend were developed and tested. The design was simulated using the finite element method and fabricated using two-photon polymerization based direct laser writing. For characterization, we measured the insertion loss of the waveguides and inspected the quality of the prints. As a recommendation for future potential projects, applications that could build upon this project without significant challenges were proposed. Lastly, after analyzing the roadblocks and difficulties encountered by the project, several process recommendations were made.

Background






Photonic sensors are expected to experience 9 percent annual growth through 2025.

Source: McKinsey analysis

The photonics industry is expected to experience strong growth. For example, photonic sensors are expected to grow 9% annually through 2025. Waveguides are one of the basic building blocks of a photonic integrated circuit, the photonic counterpart to an electrical connection. Two-photon polymerization allows for maskless rapid prototyping of nano and micro-structures.

Project Strategy

Goal

The goal of this project was to showcase the capabilities of the new photonics laboratory at WPI and set a foundation for similar future projects at the laboratory. To accomplish this goal, the following objectives were developed:

Objective 1

Develop basic waveguides using two-photon polymerization

Objective 2

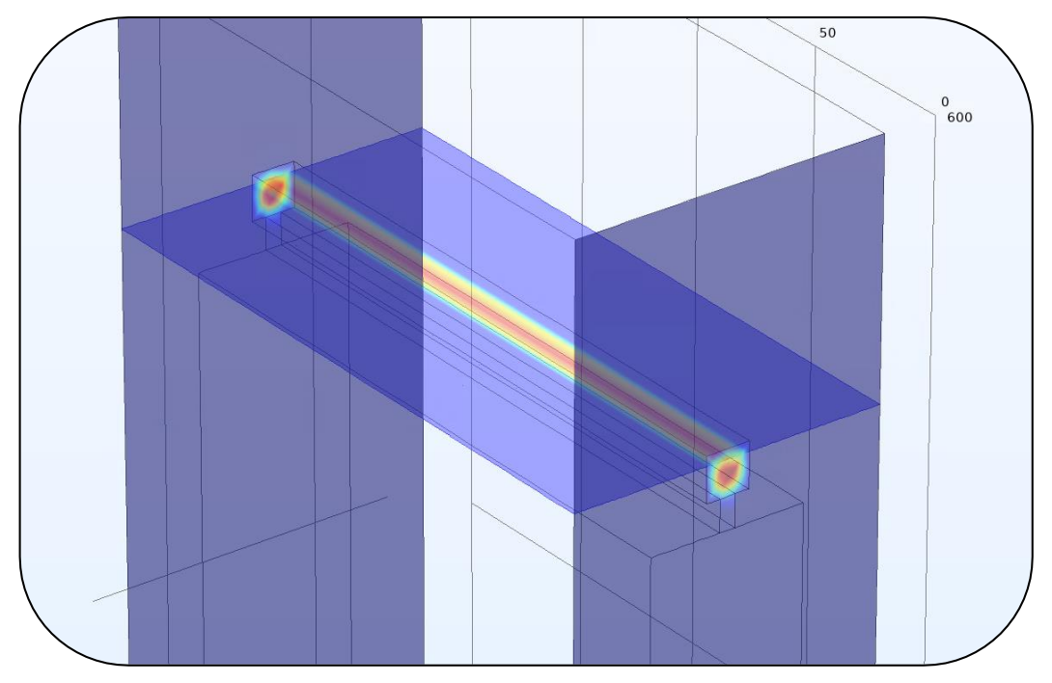
Provide recommendations for similar future projects at WPI

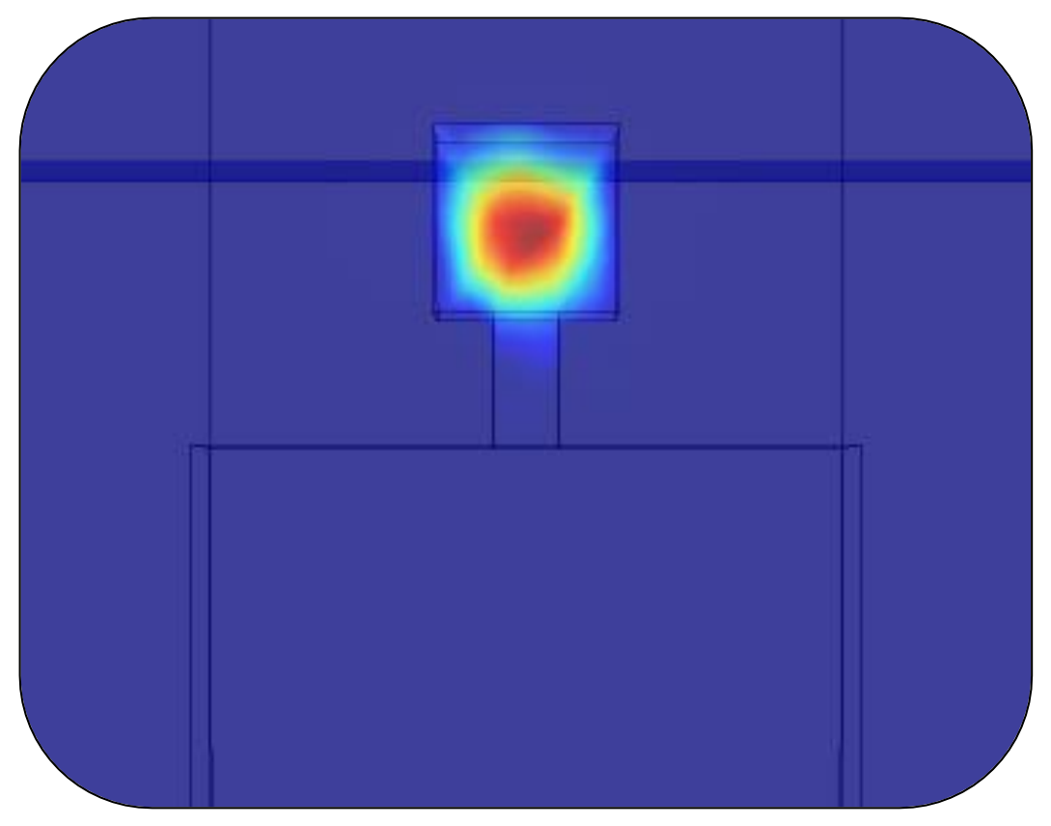
Implementation

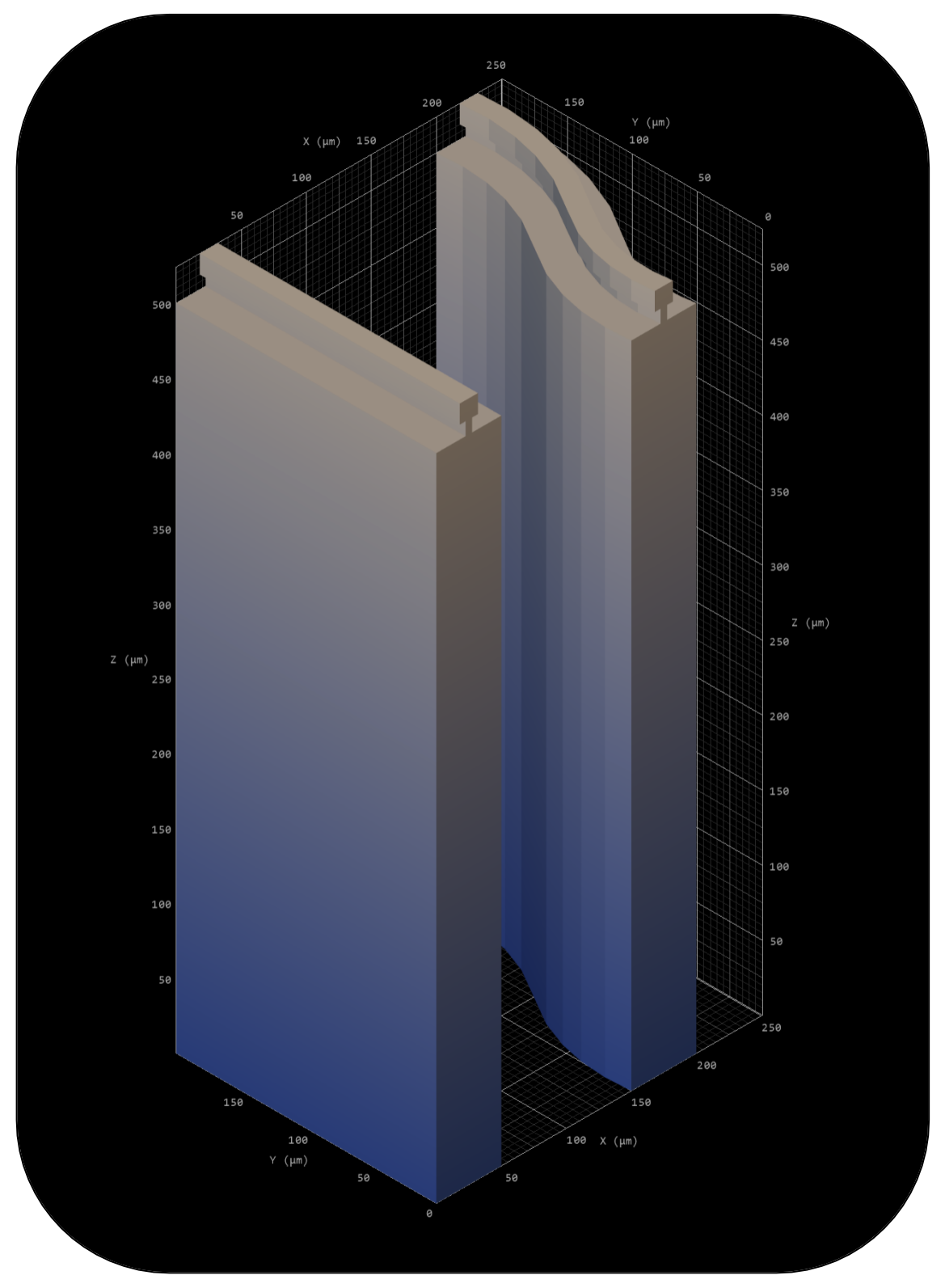
1. Research existing design rules
2. Design and simulate waveguides
3. 3D printing
4. Testing and characterization

1. Determine potential future projects of similar topic
2. Assess the roadblocks and difficulties encountered by this project

Design, Simulation, & Print





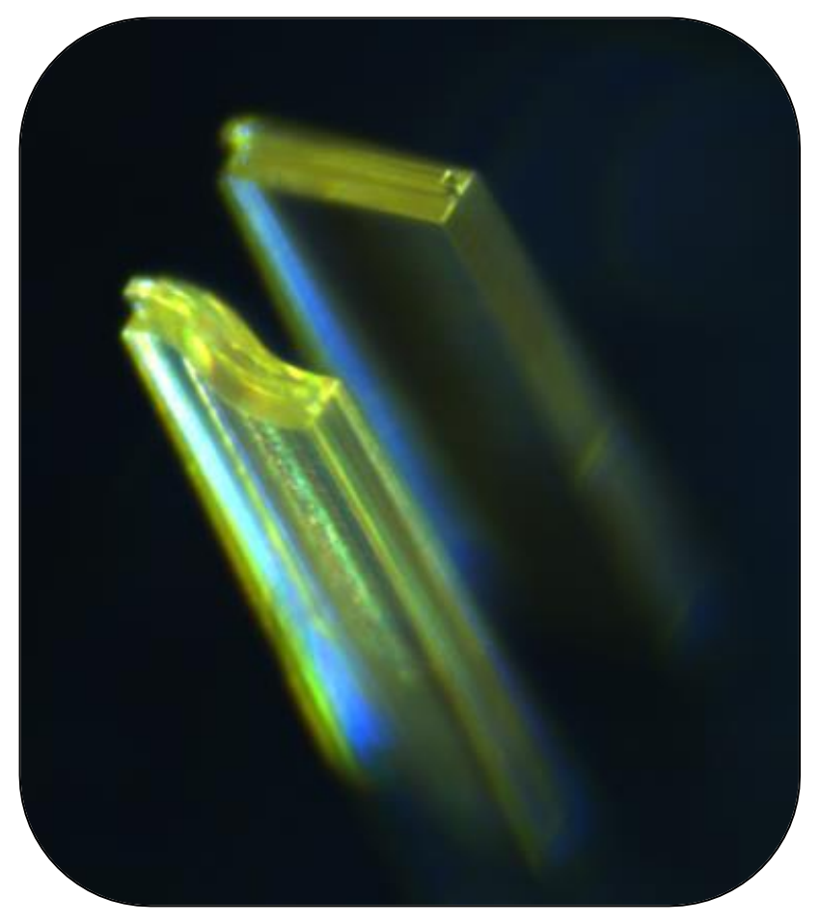


The COMSOL simulation shows that the electric field is confined in the waveguide. The pedestal was created to provide clearance for a much larger optical fiber and the ridge reduces the amount of coupling into the support pedestal. The design file was imported to a print job development software to be processed and loaded onto the printer.

Dimensions

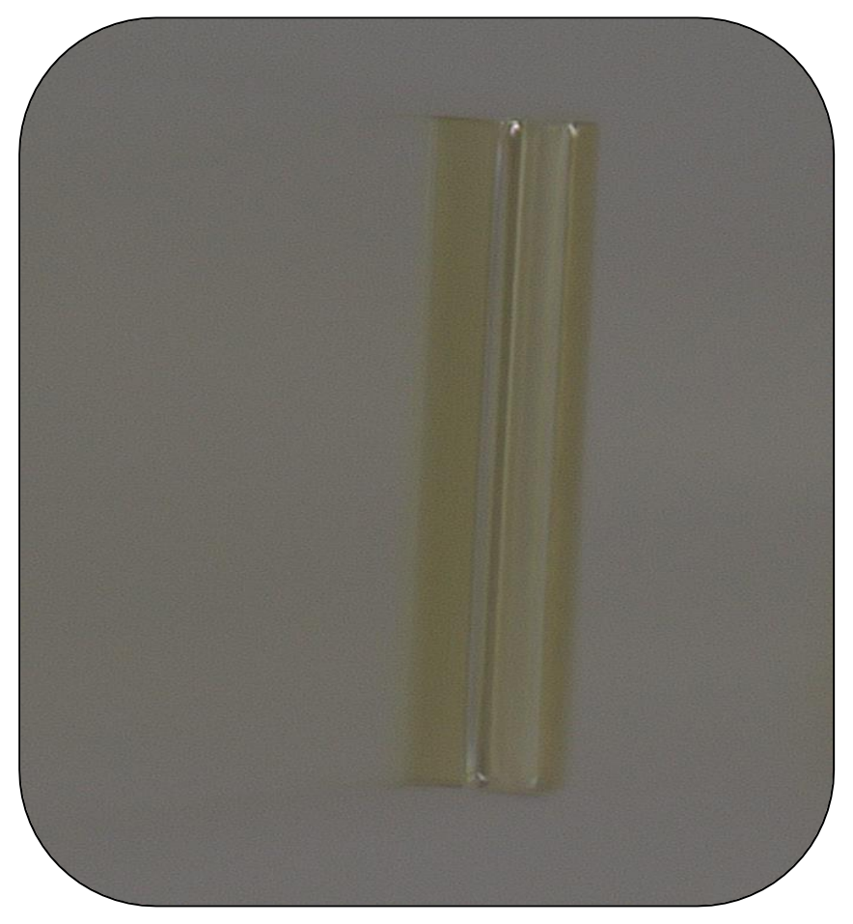
- Waveguide = 14 x 14 μm^2
- Ridge = 5 x 10 μm^2
- Support = 50 x 500 μm^2
- Length = 200 μm
- S-bend Offset = 50μm

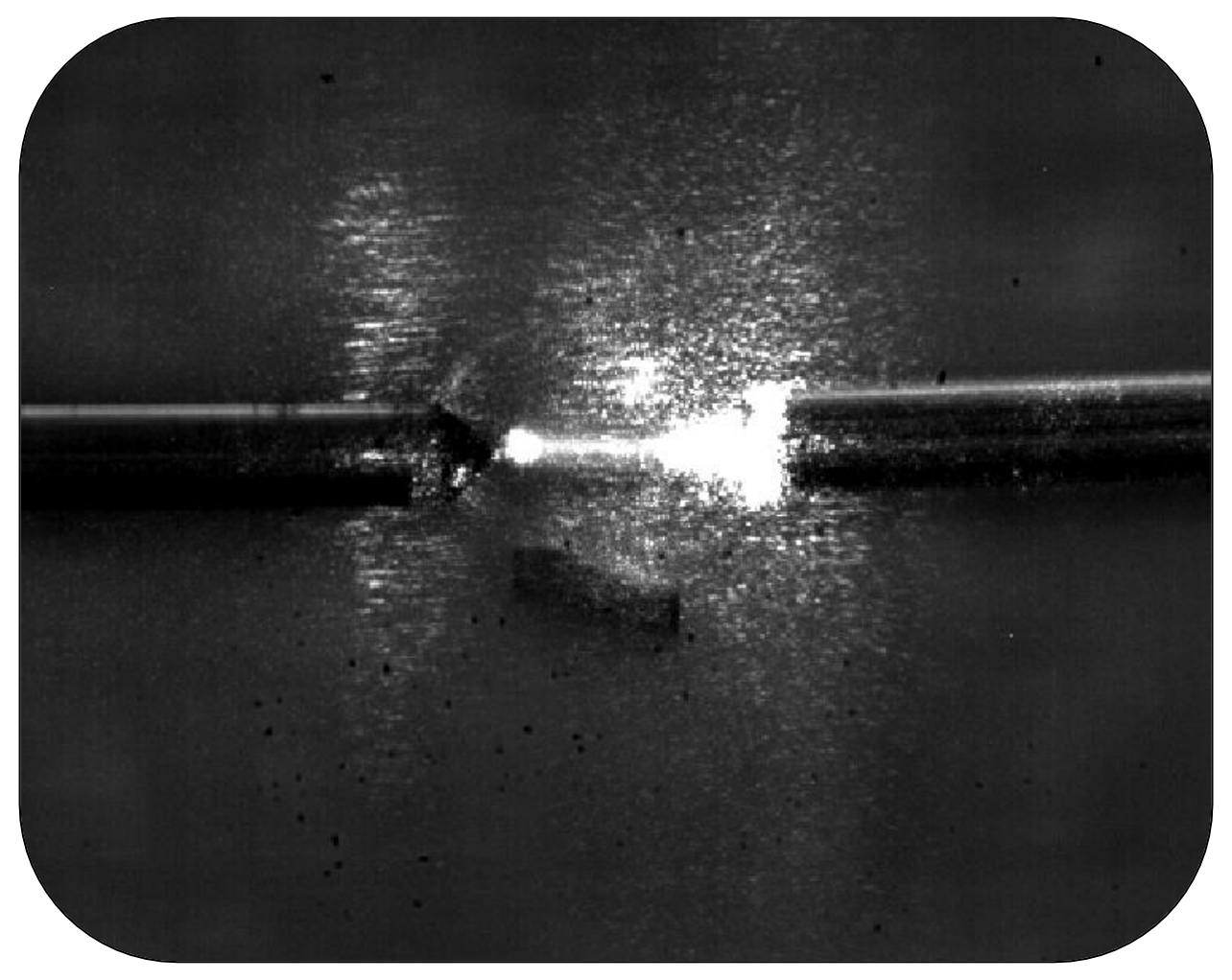
Results & Analysis

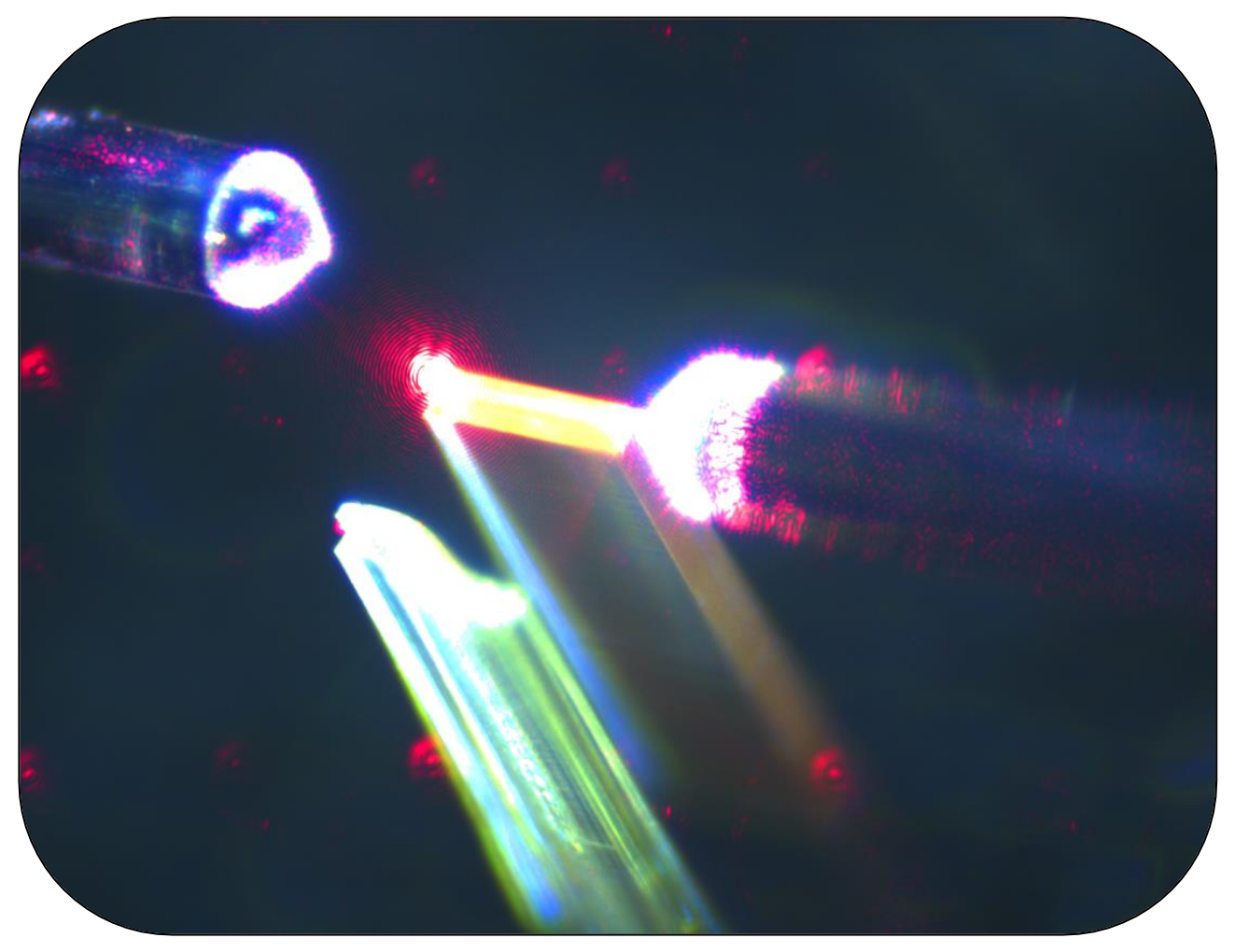


Print Time: 28 m 54 s
IP-S 25x ITO Solid Recipe

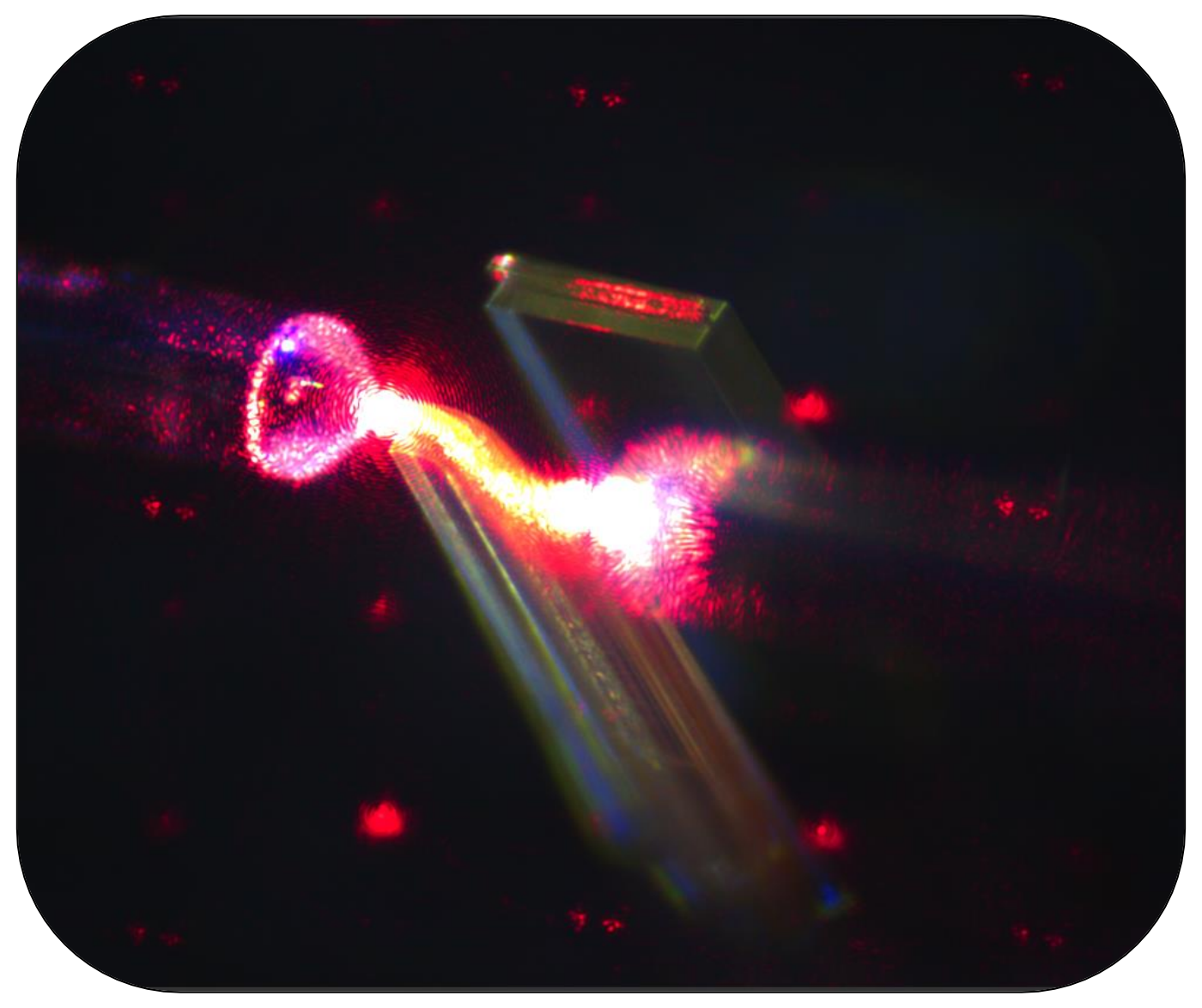
- Objective: 25x NA 0.8
- Resin: IP-S
- Substrate: ITO-coated

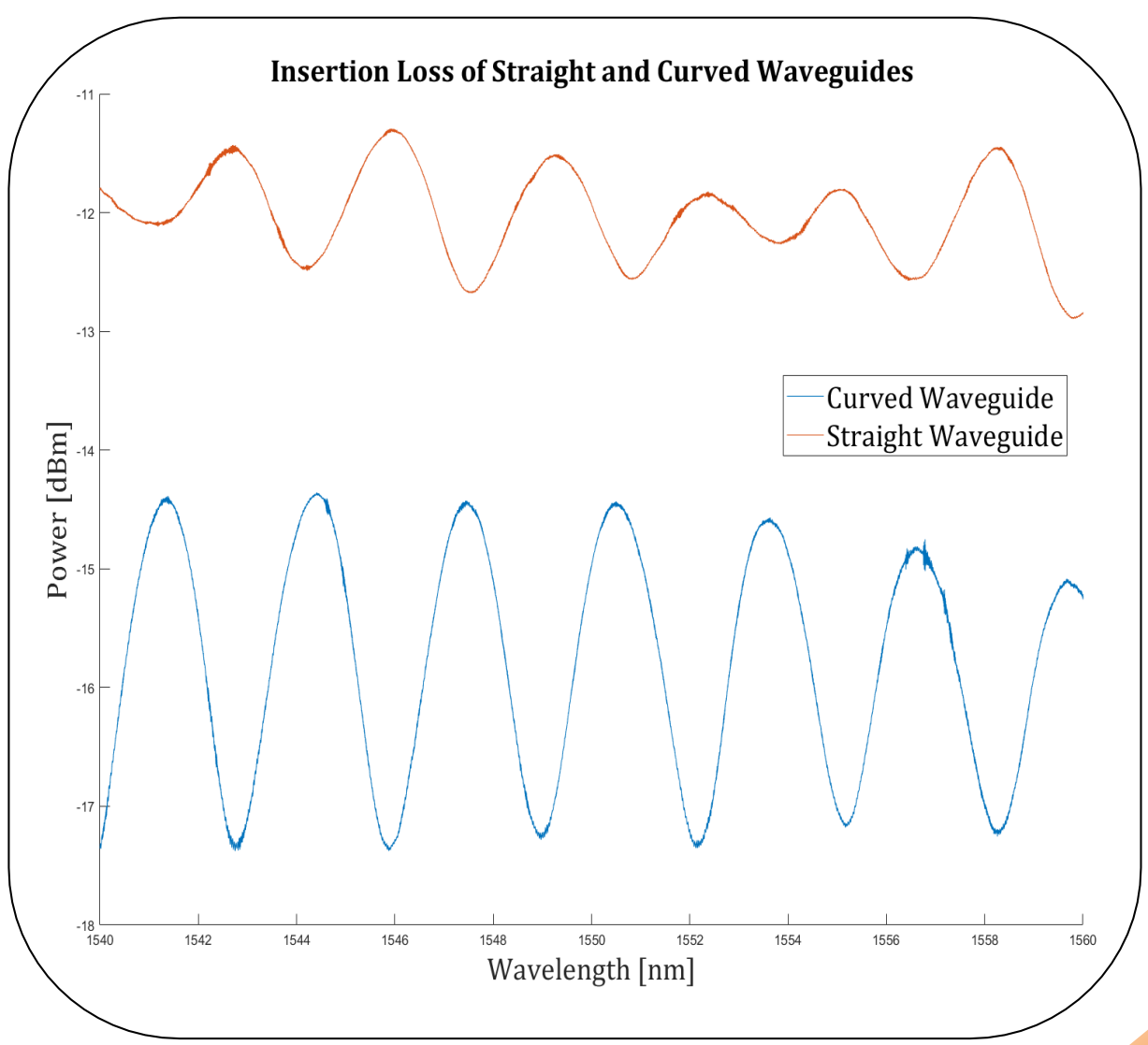






Fiber alignment was carried out using the probe station and visual fault detector. After alignment was established, transmission measurements were carried out by using a laser to sweep through the wavelengths 1540 – 1560 nm in 0.0003 nm increments. To reduce scattering, the power output on the laser was set to 0.1 dBm.



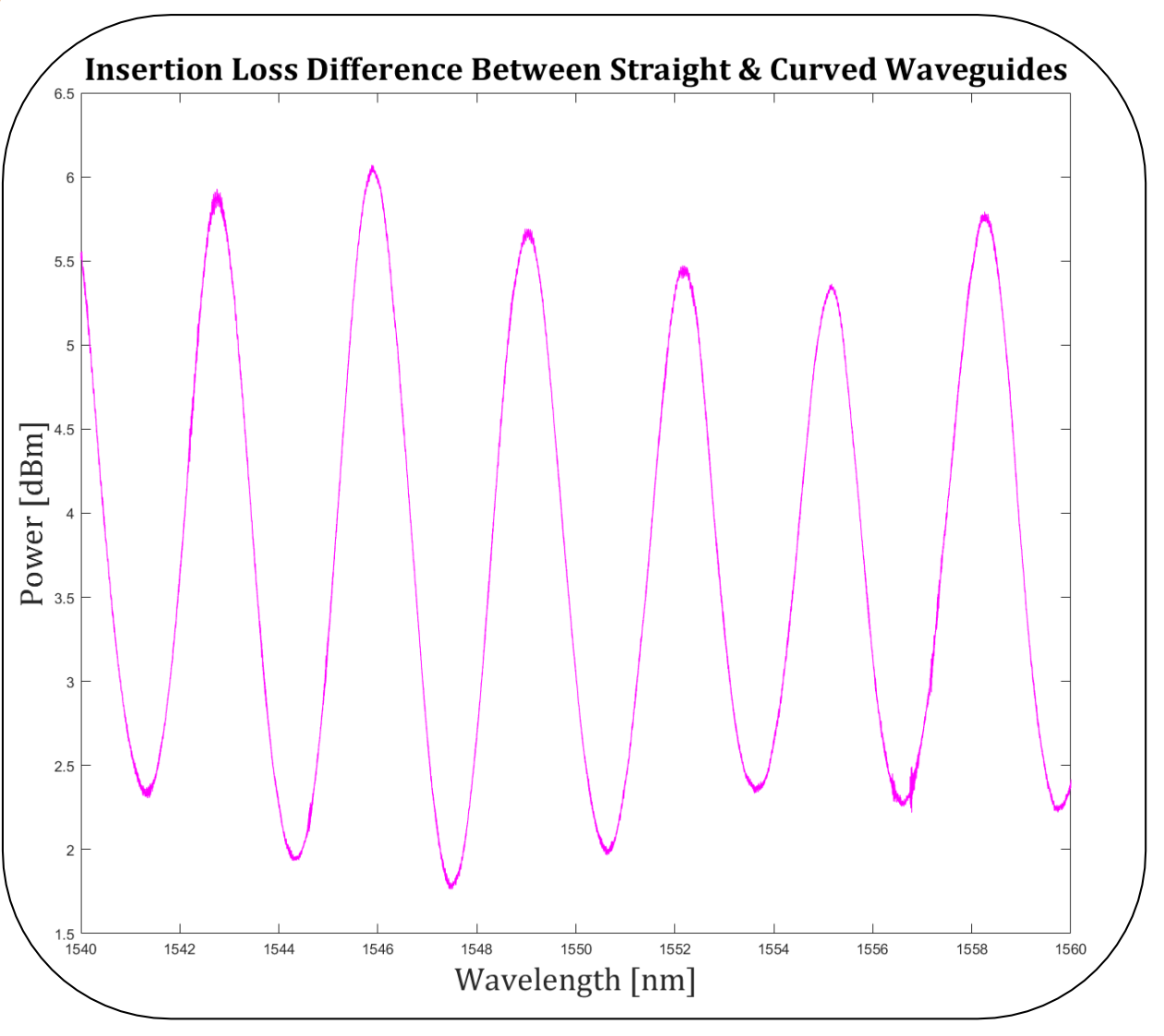

Insertion Loss of Straight and Curved Waveguides

Three trials were carried out for each measurement and were averaged together. The insertion loss of the waveguides were calculated by considering the insertion loss of the measuring optical fibers and adjusting the data accordingly. The straight waveguide showed lower loss than the curved waveguide as expected.

The oscillations in the loss spectra is a phenomenon that occurs when a multimode waveguide is placed in between two single-mode waveguides (optical fibers) and produces multimode interference.

Straight
- -12.90 dBm to -11.29 dBm
- -11.93 dBm at 1550 nm

Curved
- -17.38 dBm to -14.36 dBm
- -14.98 dBm at 1550 nm


Insertion Loss Difference Between Straight & Curved Waveguides

Recommendations

Potential Future Projects

- Single-Mode Waveguide
- Surface-Relief Bragg Grating Waveguide
- Micro-Ring Resonator

Recommendations for Process

Focus on understanding constraints
1. Develop an effective and repeatable coupling method
2. Be aware of the complex options and limitations of the Nanoscribe printer

Improve design simulations
1. Create a comprehensive set of simulations for each design
2. Research the potential benefits of using different simulation software

Measure more characteristics
1. Refractive index
2. Polarization effects
3. Scattering loss

Acknowledgements

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References

- www.ieee.org
- www.nanoscribe.com
- www.comsol.com
- www.mckinsey.com
- See full list in the final report