InP Grating Coupler Design for Vertical Coupling of InP and Silicon Chips

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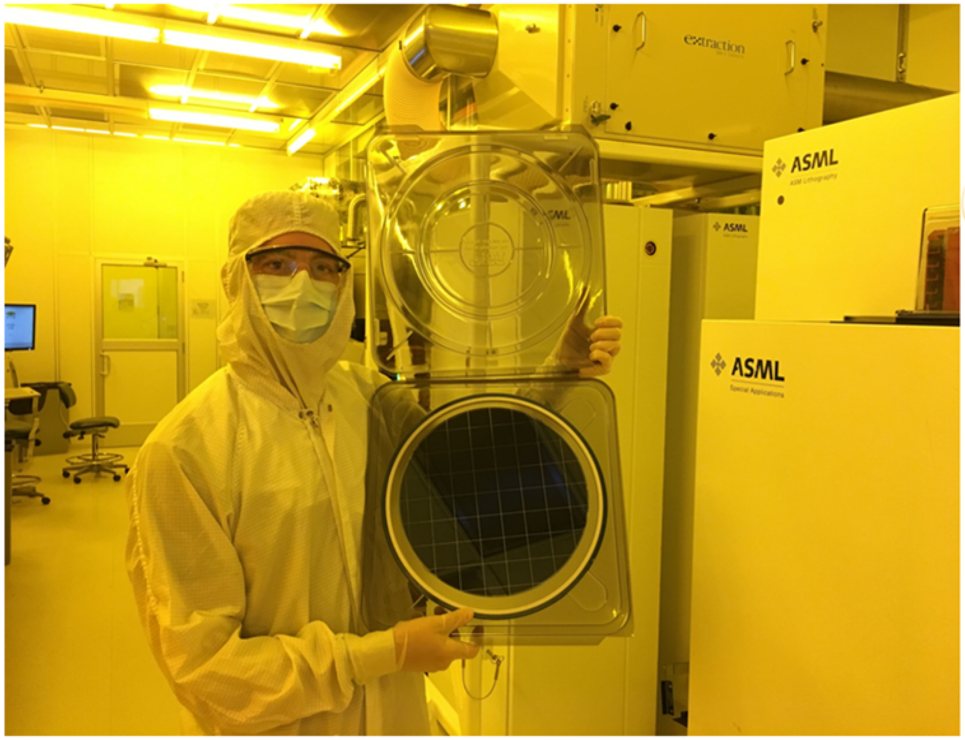
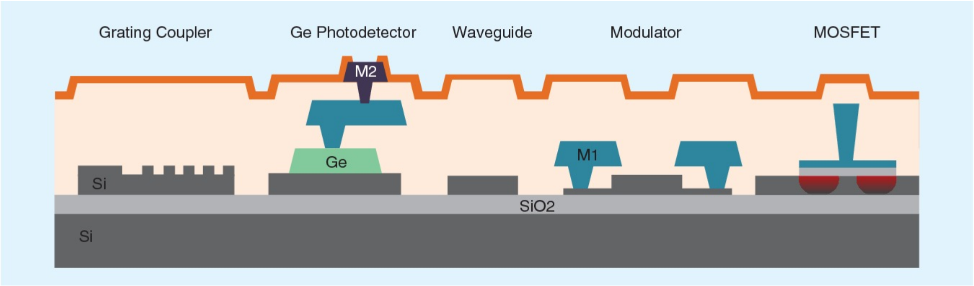
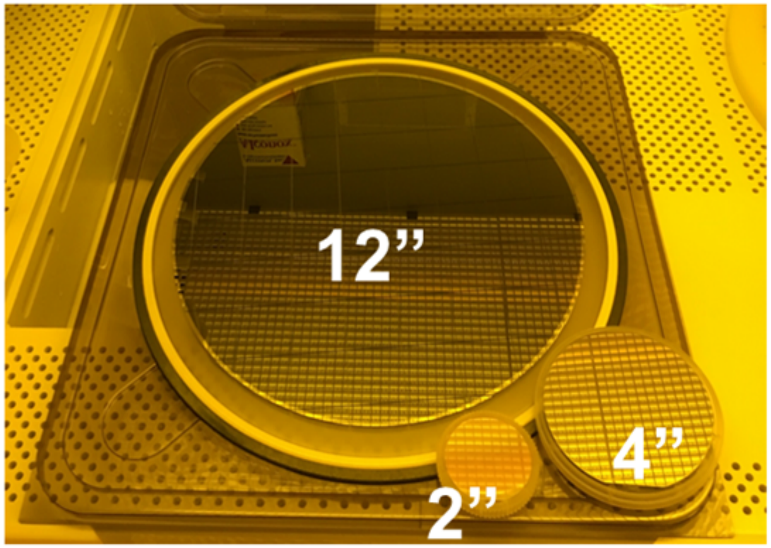
Outline

- Background and motivation
- Novel grating-based vertically emitting device for hybrid integration
- 2D Simulation
- 3D Simulation
- Device fabrication and results
- Machine learning
- Summary

Silicon Photonics

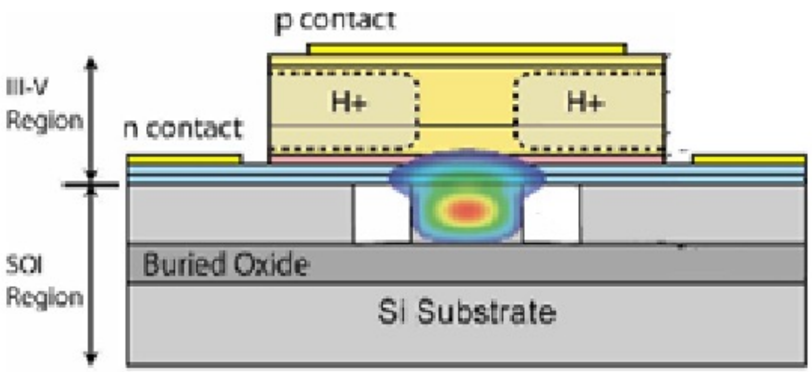




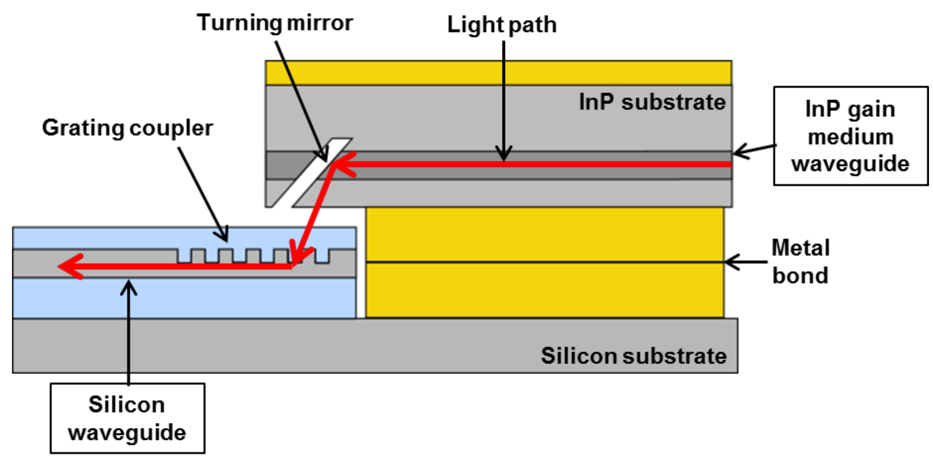


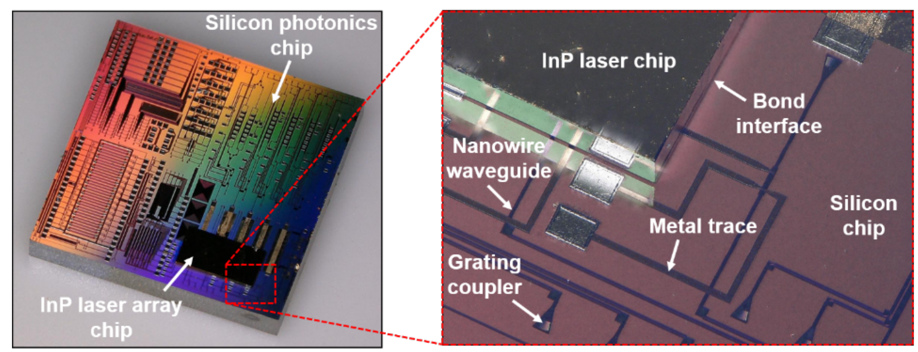
- Significant investments have been made in large-scale silicon photonics manufacturing
- Laser integration remains a challenge
  - Monolithic approaches promising but early stage
  - Hybrid and heterogeneous techniques being commercialized

Hybrid and Heterogeneous Integration



A. Fang et al., 2006

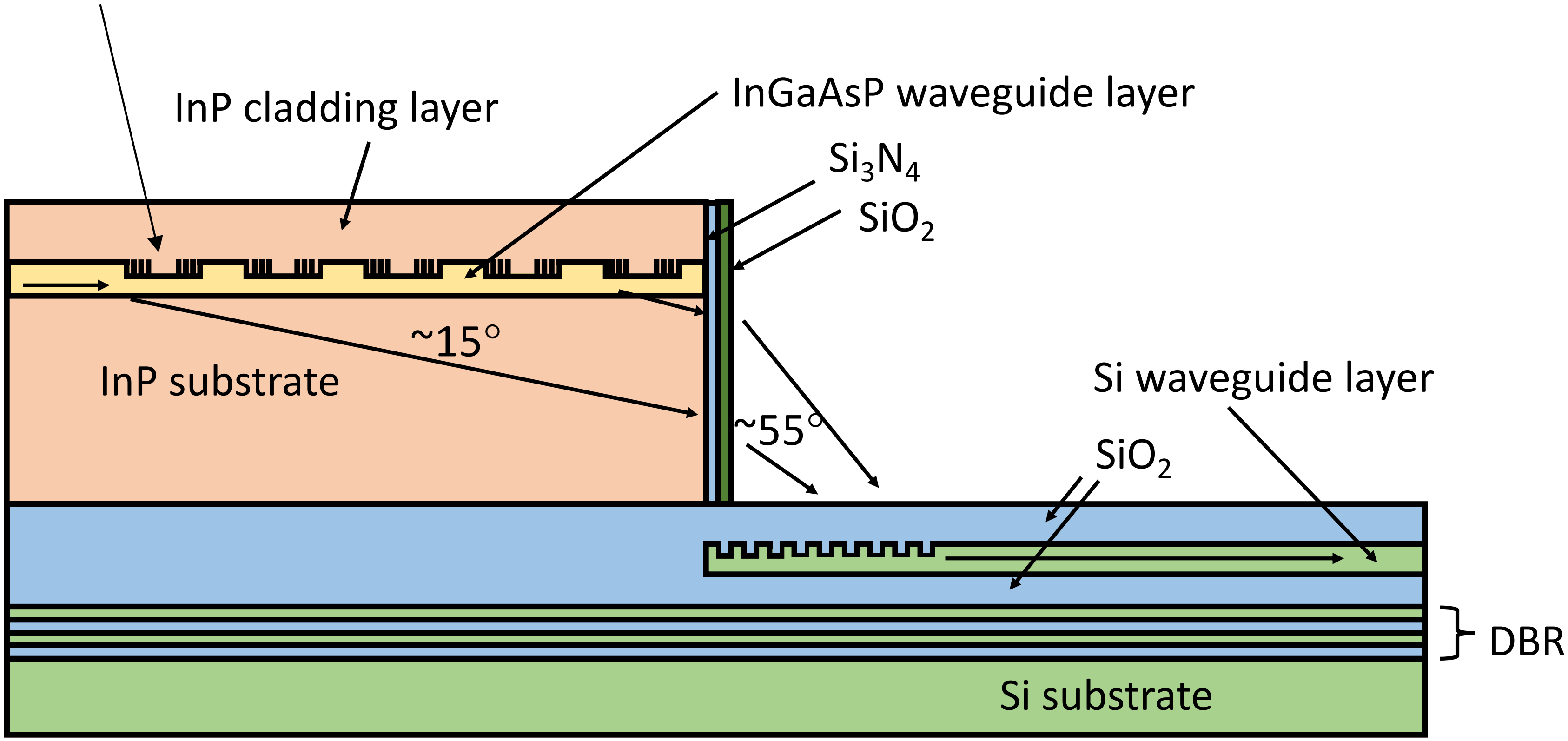




B. Song, et al., Optics Express, 2016

Novel Grating-based Vertical Emitter

Grating pitch 8-12 µm, depending on the waveguide effective refractive index

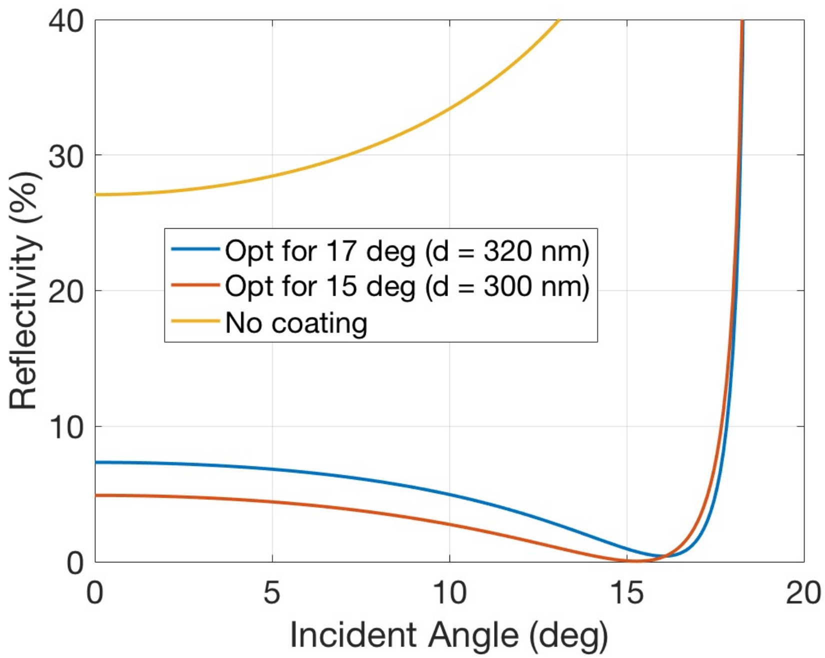


Internal angle should be 15° or more, otherwise incident angle to Si grating is too shallow

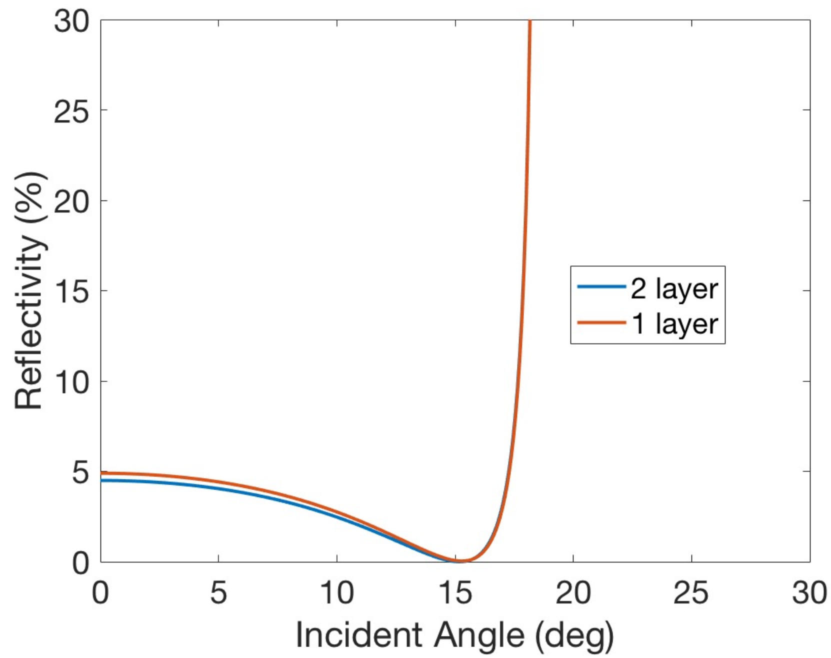
Novel grating-based devices that avoids angled-etched facet for vertical emission (Kojima et al., IPR 19)

Facet Reflectivity and Incident Angle

Single layer Si_3N_4



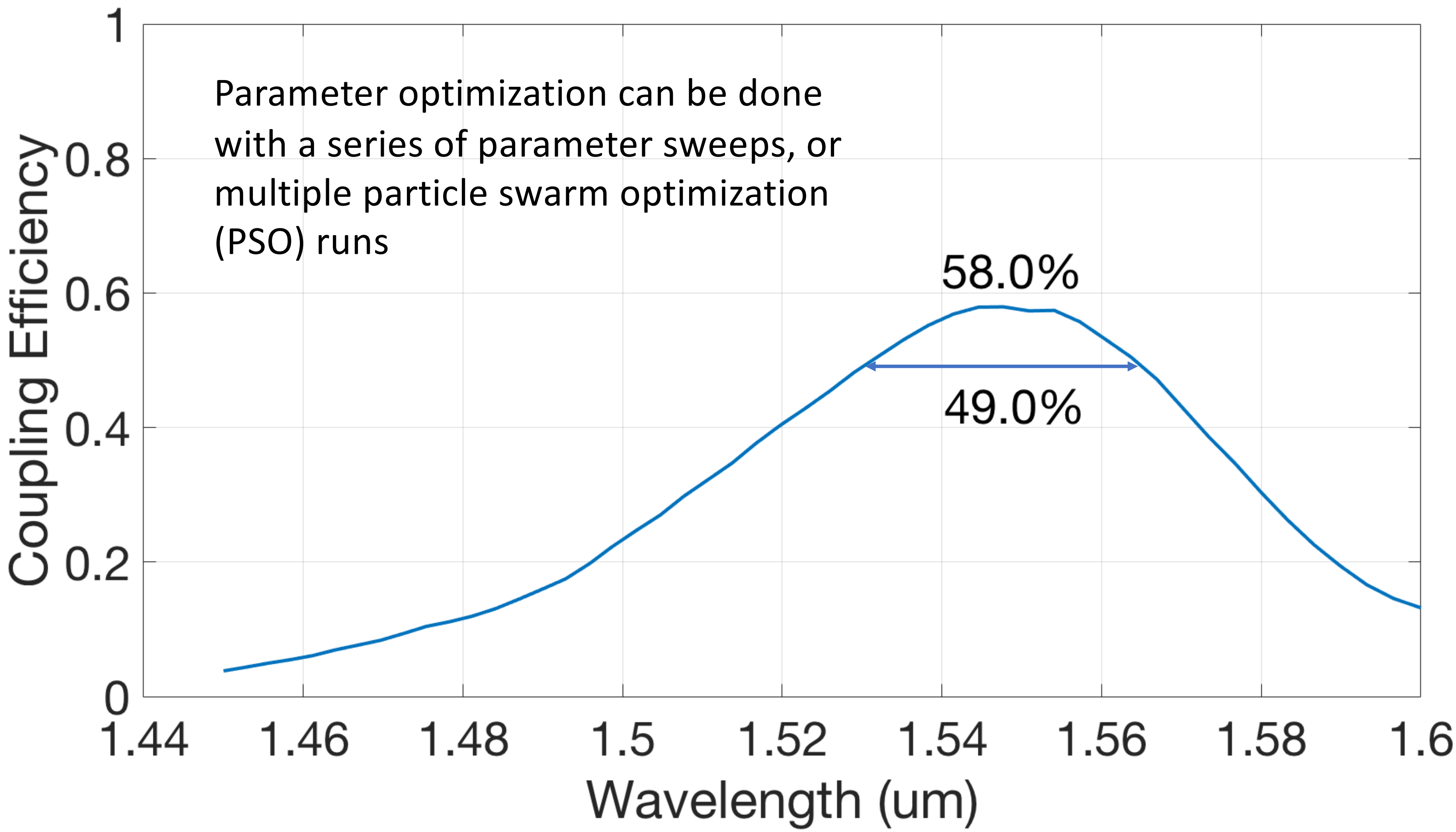
Single Layer vs. Double Layer Coating (Si_3N_4/SiO2)



S-polarization for a TE mode

With typically available materials can achieve almost zero reflection for ~15° with downward emitting light.
This corresponds to ~55° from the facet. If the angle is larger, then reflection suddenly increases.

Coupling Efficiency and Bandwidth

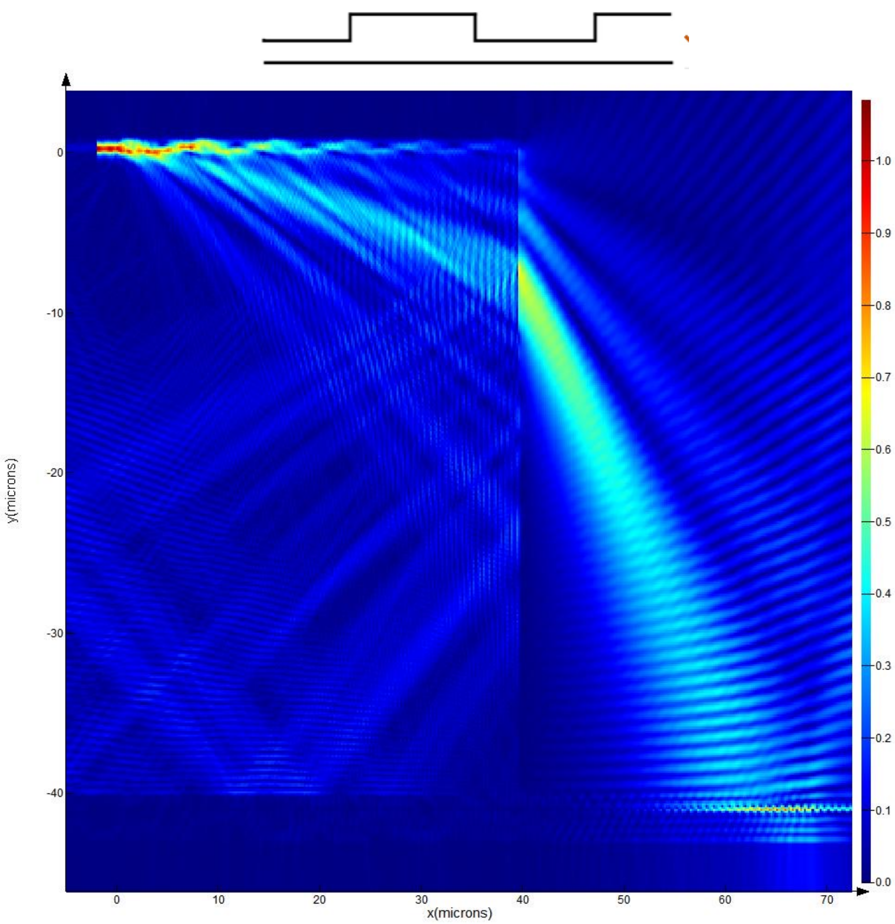


For 1530 – 1565 nm, TE mode coupling efficiency of 49% is expected

Effect of InP Sub-Grating

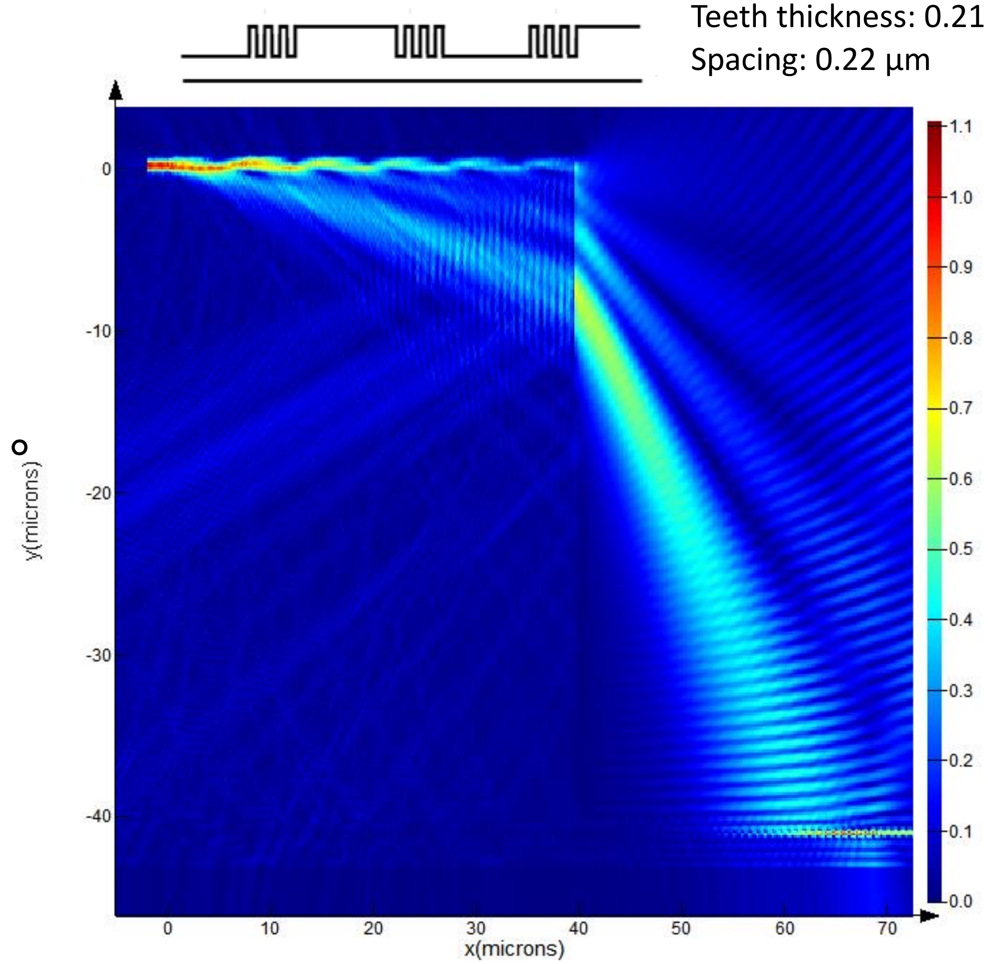
2D FDTD Simulation

Without sub-grating



With sub-grating

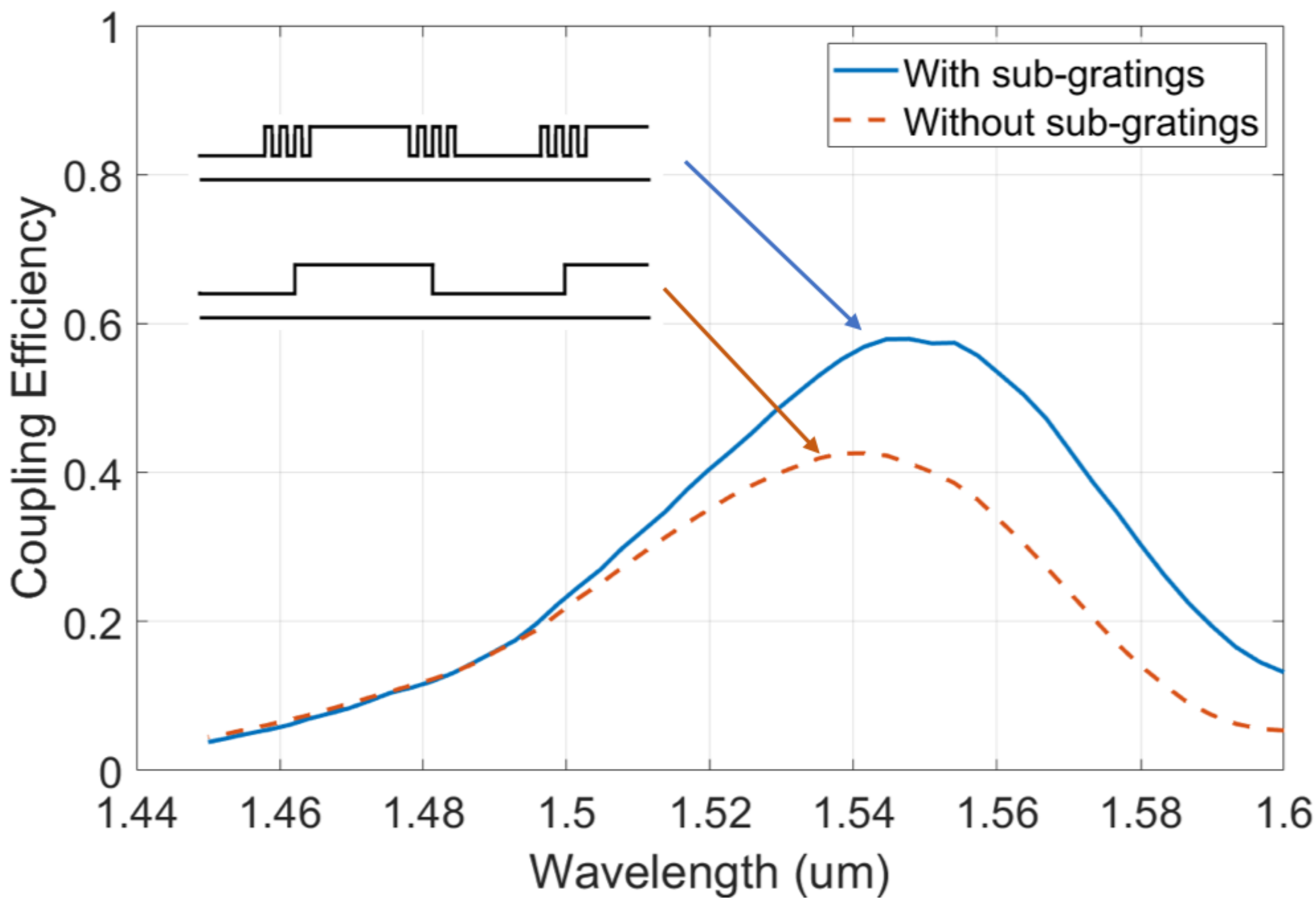
Teeth thickness: 0.21 μm
Spacing: 0.22 μm



Sub-grating suppresses higher-order diffraction

Coupling Efficiency with Sub-Grating

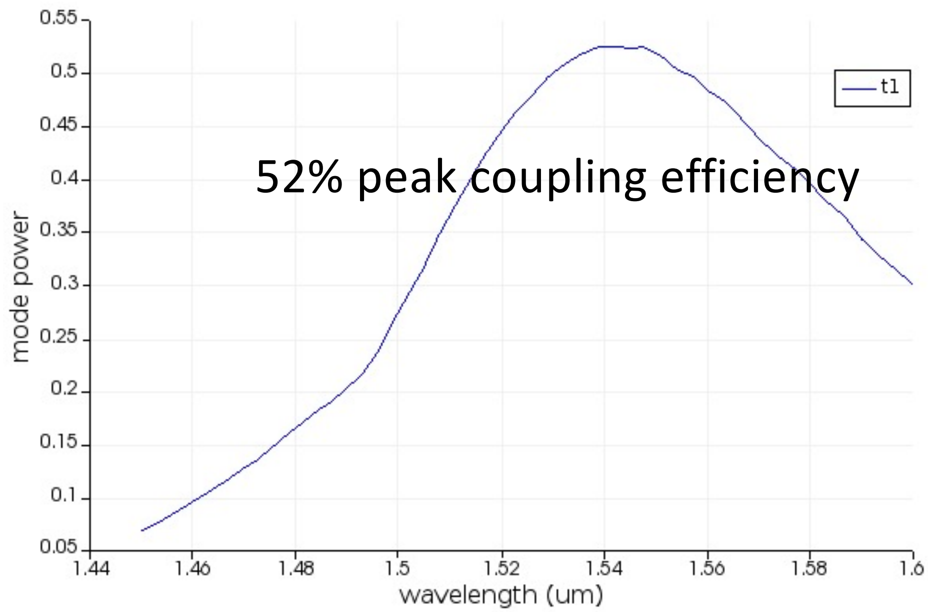
2D FDTD Simulation

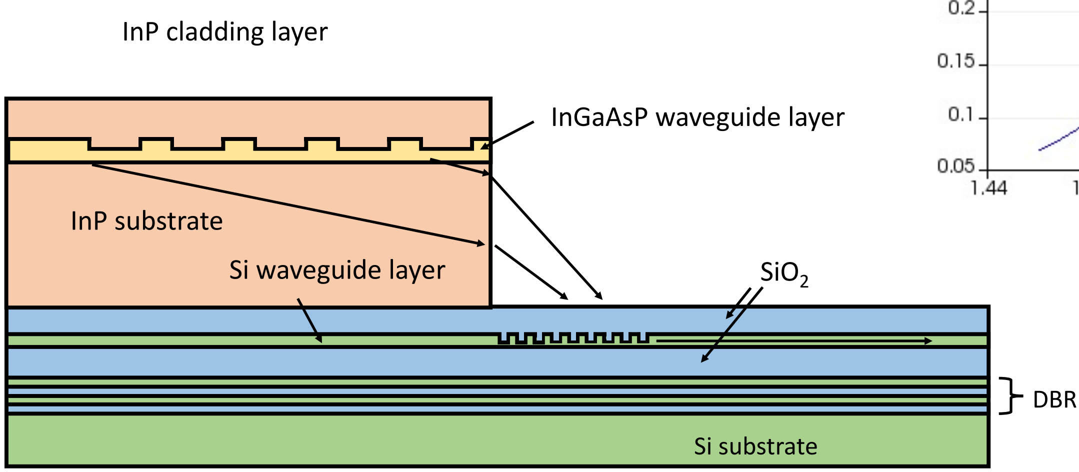


Grating structure used in the experiment

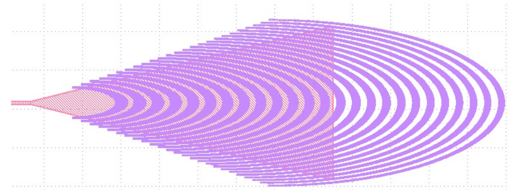
InGaAsP (Λg = 1.30 μm)
Thickness: 0.35 μm
Grating depth = 0.15 μm
Grating pitch = 10.59 μm at the start (-0.1μm chirp per pitch)
Target substrate thickness: 40 μm
- 120 μm does not change the peak CE, but 1dB bandwidth smaller

No sub-grating due to lithography limitations





2D Focusing Grating Design



- The standard grating curve equation for the collimating beam is given below. (note that the light propagates in x-direction, and gradually spreads in the y direction).

$$q\lambda = xn_c \cos\phi_c \; - n_{eff}(x^2 + y^2)^{\frac{1}{2}}, \;\; \mathrm{q} = 1, 2 \; \ldots$$

This term gives tilt in x direction

Beam spreading in the grating plane

- The terms $\Delta_x x^2$ and $\Delta_y y^2$ give the focusing effect in x and y directions, respectively.

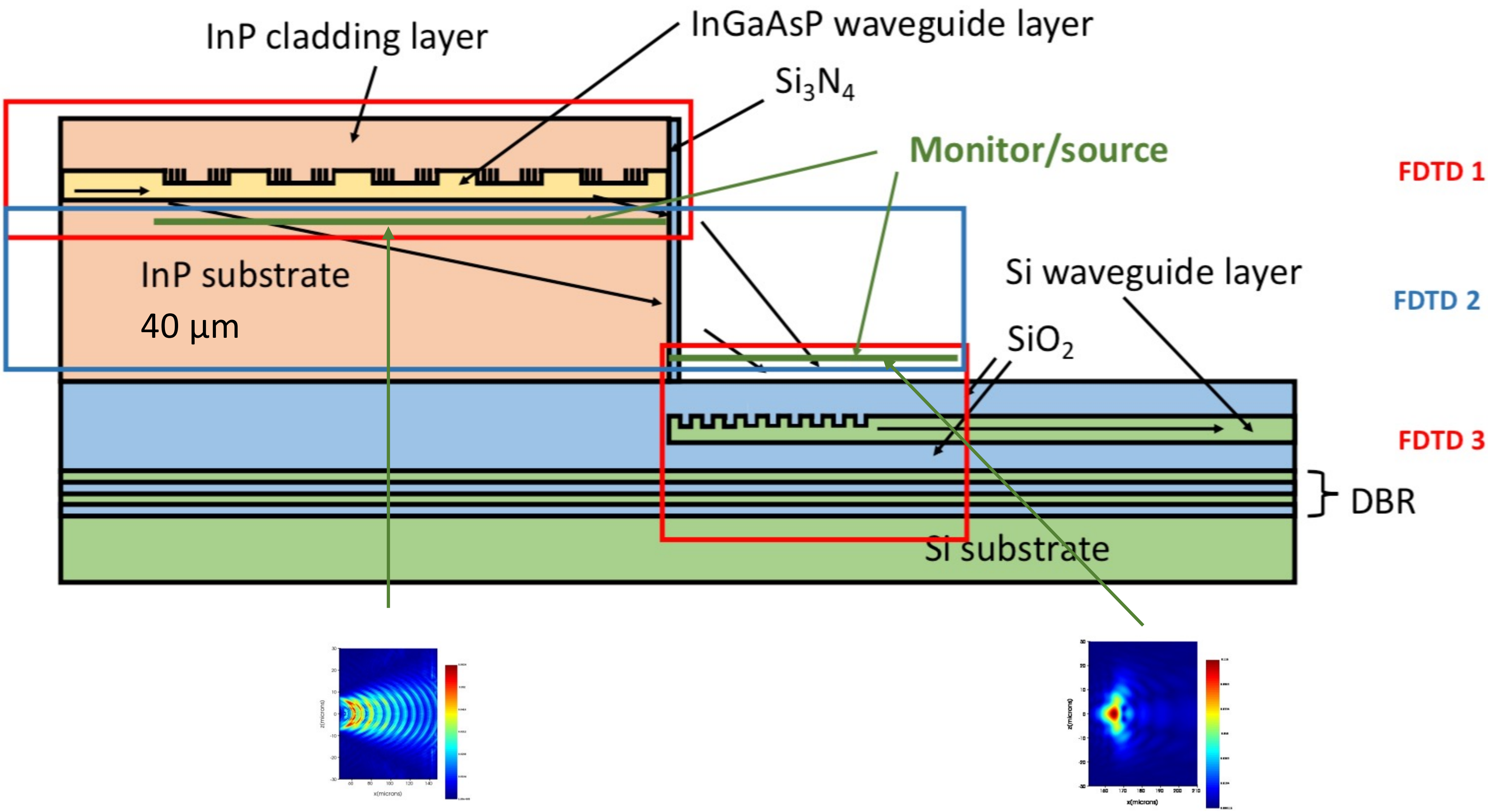
$$q\lambda = xn_c \cos\phi_c \; - n_{eff}(x^2 + y^2)^{\frac{1}{2}} + \Delta_x x^2 + \; \Delta_y y^2$$

- The term $\Delta_x x^2$ is already obtained in the 1D grating optimization process. We just need to find a factor Δ_y.

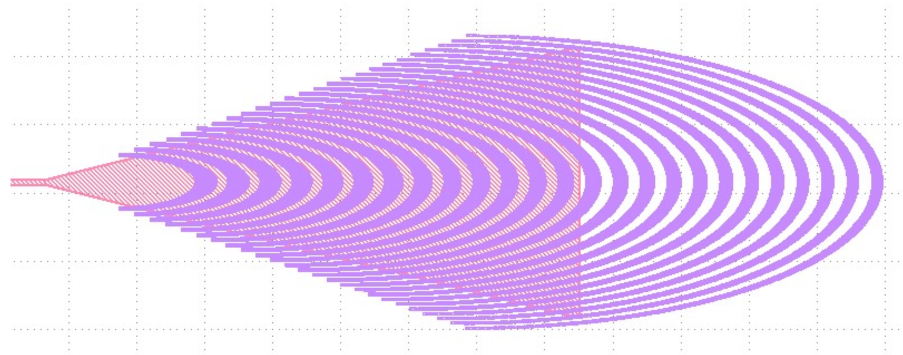
- Note that Δ_x and Δ_y are negative values.

3D FDTD Simulation Procedure

Full 3D FDTD simulation requires huge memory and astronomical computational time. So we split the simulations.

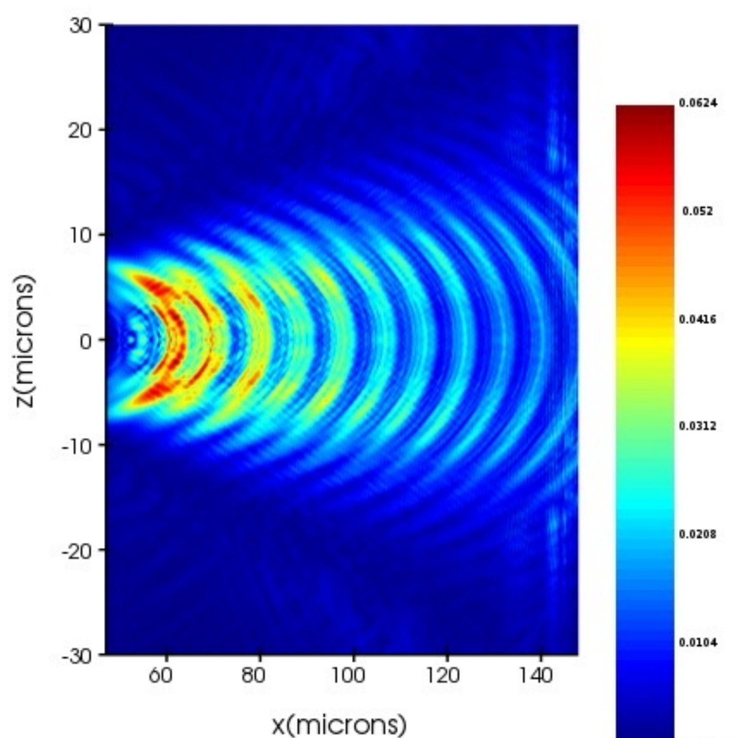


3D FDTD Simulation Results

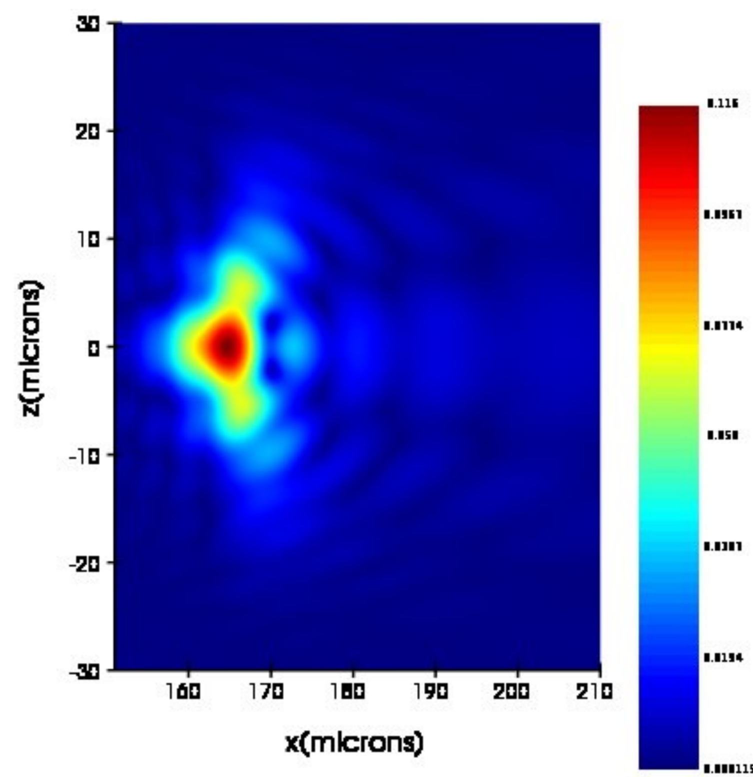


Emitted beam pattern at 2 µm
Below the InP grating

Projected beam onto a Si grating
40 µm below the InP grating, through the facet

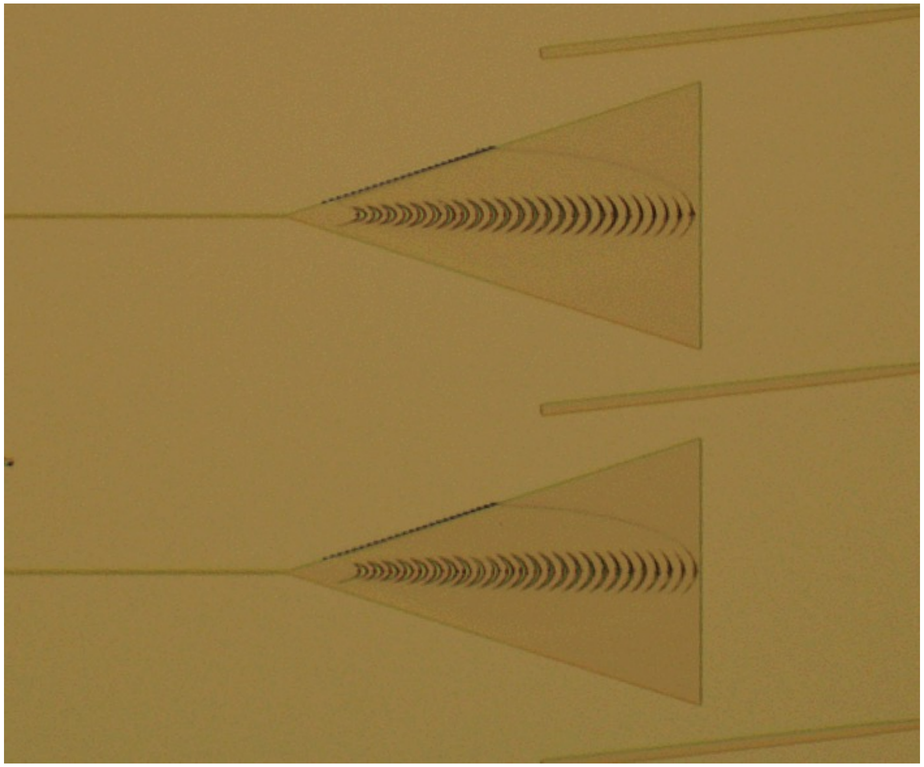


~4 hours in a cluster



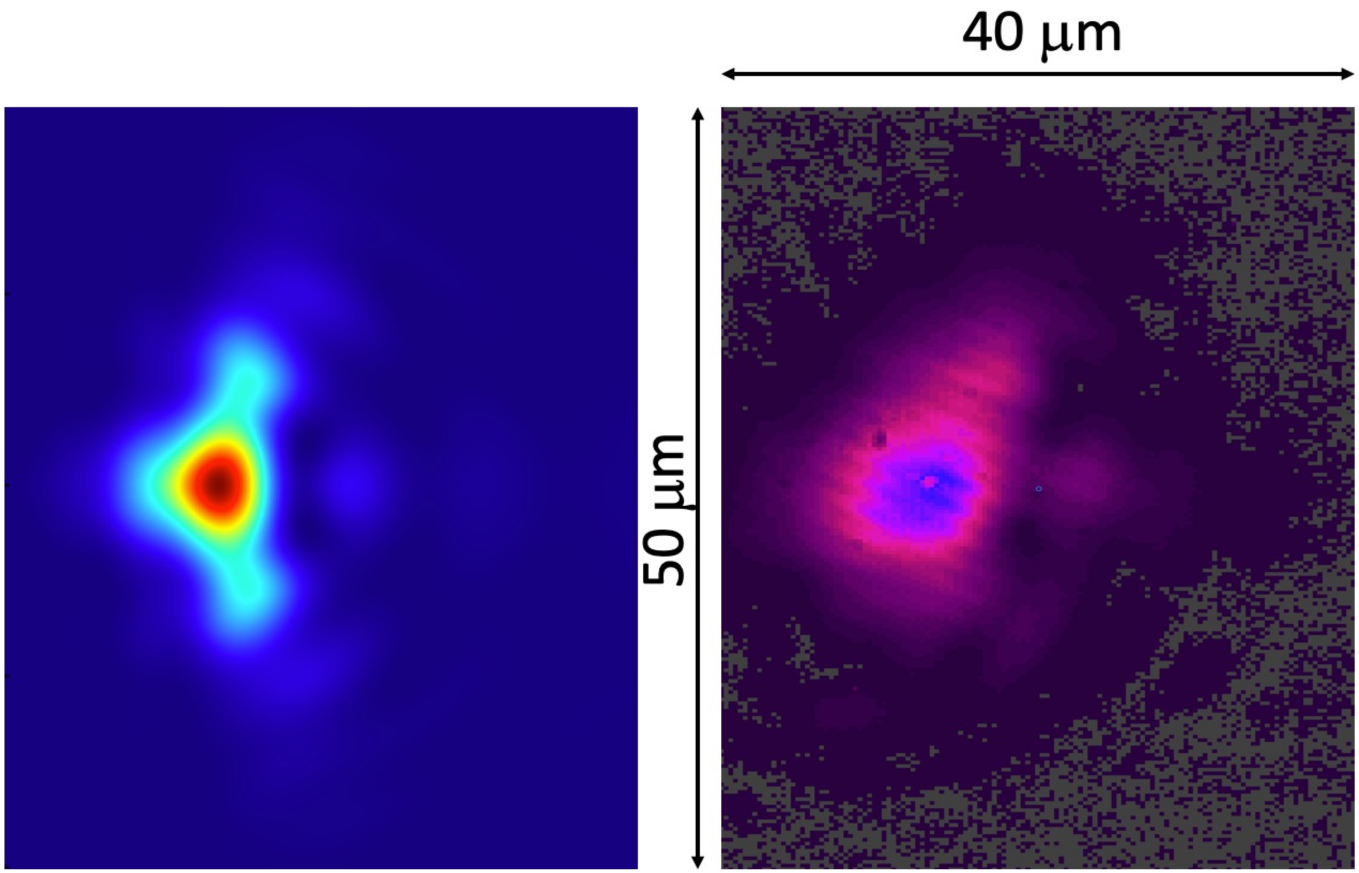
10-20 hours in a cluster

Microscope Image of First Prototype



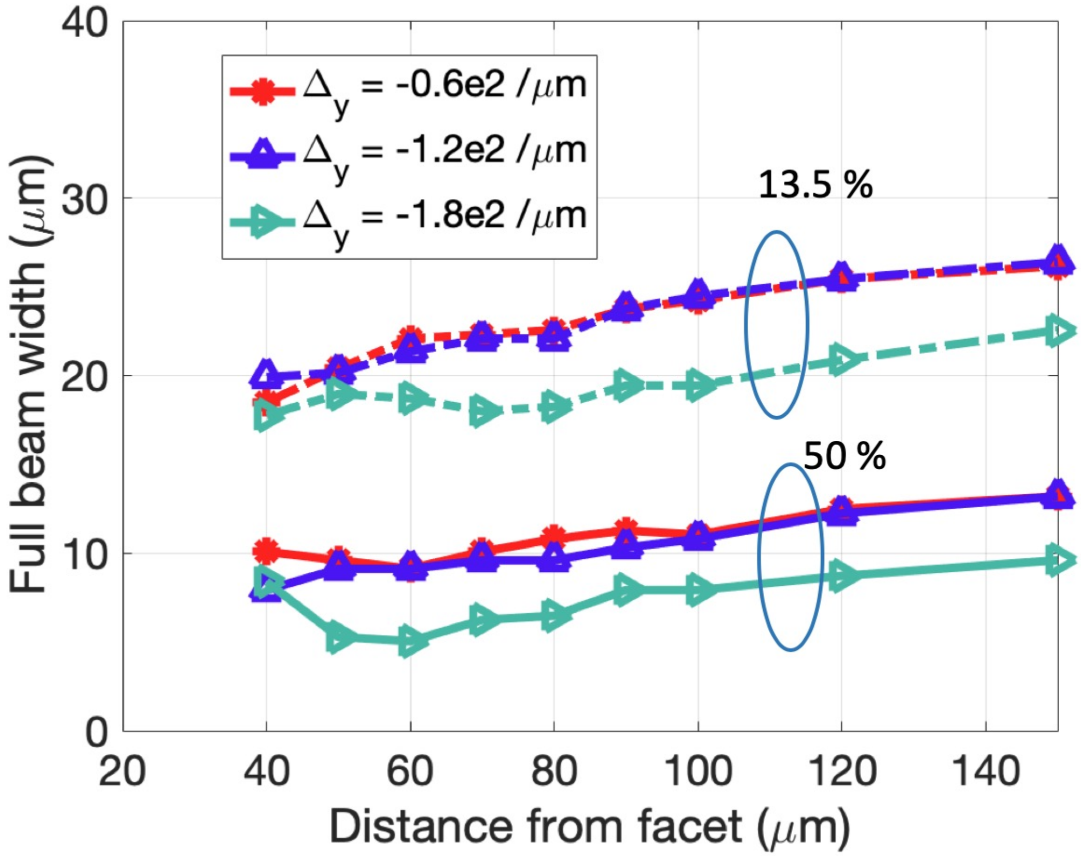
200 μm

Beam Pattern



(a) Simulated (b) Measured

Beam width in y-direction



Beam width ($1/e^2$) at 50 μm

Δy (1/μm)	Sim. (μm)	Exp. (μm)
-0.6×10^2	17.4	20.4
-1.2×10^2	16.5	20.2
-1.8×10^2	15.4	19.0

As shown in the figure, by increasing the chirp in y-direction, we were able to observe the beam narrowing effect. The simulations and the measurements agree qualitatively.

Summary

Proposed concept for a shallow angle grating for vertical emission from InP devices for coupling to Si grating devices

2D FDTD simulation predicts > 50% coupling efficiency into a silicon grating coupler.

3D FDTD simulation predicts nearly circular beam main lobe and some side lobes.

We prototyped InP grating couplers, and the measured beam profile agrees with the 3D FDTD simulation results.

This technology has the potential for simple hybrid integration and passive alignment.