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

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Abstract

We present the design and optimization strategy of shallow-angle grating couplers for vertical emission from InP devices. When a long period (pitch: 10 um) grating is written on an InGaAsP waveguide mounted on a Si substrate, downward emission at an angle of 15 degrees inside the InP substrate occurs. This beam is reflected at the vertical cleaved facet, and the emission angle becomes 55 degrees from the facet normal. With proper grating design, the near-circular beam can be focused on a Si grating coupler, and the coupling efficiency becomes larger than 50%, with 1 dB bandwidth of 35 nm, expected through simulation. In this paper, we focus on the detailed grating design and the optimization strategy. Specifically, we use 2D finite difference time domain (FDTD) simulations and machine learning for the initial optimization. Sub-gratings are shown to decrease higher-order diffraction, resulting in higher coupling efficiency into a Si grating. We then use cascaded 3D FDTD simulations for the further optimization of the elliptic grating designs. The cascaded 3D simulations can give accurate result without using huge amount of resources. Because the beam size can be as large as 10 um, there is a possibility of passive alignment. Also, there is no need for special processing at the back side of the InP chip. Therefore, this work may pave the way for a new technology for low-cost InP-Si hybrid integration.

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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



- 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



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





Grating pitch $8-12 \ \mu\text{m}$, 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)



With typically available materials can achieve almost zero reflection for $\sim 15^{\circ}$ with downward emitting light.

This corresponds to \sim 55° from the facet. If the angle is larger, then reflection suddenly increases.







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





2D FDTD Simulation



Sub-grating suppresses higher-order diffraction

2D FDTD Simulation

MITSUBISHI Changes for the Better Grating structure used in the experiment

InGaAsP ($\Lambda g = 1.30 \ \mu m$) Thickness: 0.35 μm Grating depth = 0.15 μm Grating pitch = 10.59 μm at the start (-0.1 μm 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 52% peak coupling 0.35 0.45

InP cladding layer

• 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).

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

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.

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

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

Beam width (1/e²) at 50 μm

Δy (1/μm)	Sim. (μm)	Exp. (μm)
-0.6x10 ²	17.4	20.4
-1.2x10 ²	16.5	20.2
-1.8x10 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.

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.