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*Integrated Photonics Research, Silicon and Nano Photonics (IPR)*

# Shallow Angle Grating Coupler


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**Abstract:** We propose to use long period grating waveguide to re-direct the incoming mode to 15◦ downward angle targeting hybrid integration with silicon waveguides. After parameter optimization, the end-to-end coupling efficiency up to 58% is obtained through simulations.


**OCIS codes:** (250.5300) Photonic integrated circuits; (230.1950) Diffraction gratings; (050.6624) Subwavelength structures;


## 1. Introduction

There have been many studies on hybrid integration of InP devices and silicon photonics [1, 2]. Bonding of a InP die onto a silicon wafer [3], epitaxial growth of quantum dot lasers onto a silicon substrate [4], and flip-chip bonding of an InP laser with an angle-etched mirror onto a silicon grating [5] have been investigated.

Grating couplers have also been extensively studied, however, significant portion of the diffracted light goes upwards to air through surface grating [6]. Zhang et al. [7] demonstrated an inclined emitted laser with 55◦ angle, using gratings within an InP-based laser cavity. This can lead to easy integration of light source on silicon photonics, since it potentially eliminates the need for active alignment. The structure uses the grating both as a laser cavity and as an grating output coupler, leading to some compromise in design parameters. In addition, surface grating can lead to scattering into the upward direction. An alternative approach is fabricating buried gratings on a passive waveguide. Gratings diffract light almost equally upward and downward. Therefore, it is important to fully utilize both components efficiently. Here, we propose to use buried long-period grating such that the the upward diffracted light is effectively reflected downward and the overall coupling efficiency is enhanced. We conduct two-dimensional FDTD numerical simulations to predict the ultimate performance of the combined system of shallow-angle grating coupler and silicon grating coupler.

## 2. Proposed structure

Fig.1 shows the schematic of the shallow angle grating coupler system configuration, where InP and silicon waveguide gratings are used to couple the optical power from the InP waveguide to the silicon waveguide.

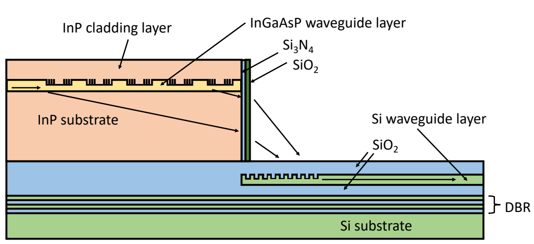


Fig.1: Schematic of the proposed structure

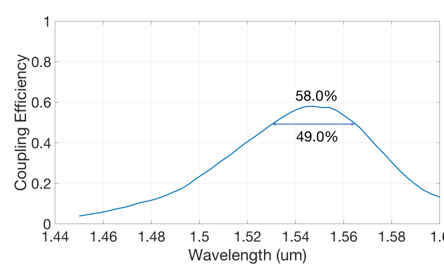


Fig.2: Simulated coupling efficiency

The cross-section of the InP device consists of 80 μm-thick InP substrate, 0.5 μm-thick InGaAsP (bandgap: 1.30 μm), 0.3 μm-deep etched grating, 0.47 μm-thick InP upper cladding layer, and 20 nm-thick SiO2 passivation layer. The length of the InP grating section is 200 μm. To achieve shallow diffraction angle (15.0◦ within InP and 55.1◦ in the air) and also to achieve focusing effect onto limited part of silicon waveguide grating, we use a long period grating (starting pitch: 8.5 μm) with linear chirp (pitch reduction: 0.1 μm per period). The grating has main teeth (28% of the pitch) and 3 periods of sub-gratings with 210 nm thickness and 220 nm spacing on each side of the main teeth. The grating is also apodized [8] in that the width of the etched part is linearly shrunk for each period. The facet has a pair of SiN and $SiO_2$ coating. In the silicon photonic device, we use two pairs ($Si/SiO_2$) of distributed Bragg reflectors (DBR) under the silicon waveguide. The 0.22 μm-thick silicon waveguide is sandwiched between a 2.1 μm-thick $SiO_2$ lower cladding layer and a 1.04 μm-thick $SiO_2$ upper cladding layer. The silicon grating depth is 87.5 nm. The length of the silicon grating section, starting from the end of the InP chip, is 32 μm. The silicon grating is apodized but does not have chirp.

## 3. Simulation results

We use Lumerical FDTD for 2D simulations, and scripts for efficiently generating series of simulation files with mul- tiple parameter sweep, and a PC cluster for running multiple simulations simultaneously. Refractive index parameters include proper wavelength dependences.

The simulated coupling coefficient as a function of wavelength is shown in Fig. 2. The structural parameters are optimized such that the minimum coupling coefficient for the wavelength range of 1530 − 1565 nm is maximized. The simulated coupling coefficient is 58.0 % (-2.4 dB) at the peak, and > 49% for the wavelength range of 1530 − 1565 nm. The 1 dB bandwidth is 41 nm, which is similar to the 1 dB bandwidth of typical silicon grating couplers when coupled to an optical fiber. As the wavelength becomes shorter than the optimal value, the propagation angle becomes shallower, causing the beam to focus at a farther point. On the other hand, when the wavelength becomes longer than optimal, the beam focuses much closer than the end of the silicon grating, causing some coupled light re-diffracted from the grating. This effect determines the ultimate bandwidth. On the other hand, both InP and silicon gratings have wavelength dependence of the same direction, partially cancelling out each other.

In order to quantify the benefit of the sub-gratings, we compared two structures: (a) with 3 periods of sub-gratings described before, and (b) without the sub-gratings but with optimized duty cycle. Fig. 3 shows the results. The effect of sub-gratings is 1.34 dB (36% increase). This can be interpreted as the reduction of higher order Fourier components, leading to reduced diffraction in undesirable angles.

Another important factor in achieving the high coupling efficiency is to use the top surface reflection between the InP cladding layer and the air (the existence of the dielectric layer is not critical from reflection point of view, as long as it is thin enough.) If the surface is corrugated, significant part of the diffracted light leaks upward into the air.

In the above discussion, we treated the grating as one dimensional (1D). For focusing beam also in the lateral direction, using elliptical grating lines is proposed. It is impossible to simulate the beam propagation in the large 3D space (~232 μm × 85 μm × 40 μm) using 3D FDTD, but a way to design 2D focusing grating will be presented.

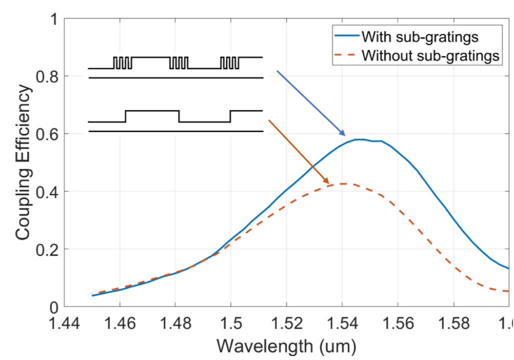


Fig. 3: Coupling efficiency with or without sub-gratings around the InP grating main teeth

## 4. Conclusions

In this paper, we propose the use of a long period InP grating for efficiently coupling optical power through the facet and to a silicon waveguide grating.

The estimated coupling efficiency is 58 % at the peak, and >49% for the wavelength range of 1530 − 1565 nm through 2D FDTD simulations. Since it does not require sub-micron level alignment and flip-chip bonding, this method can potentially lead to low-cost packaging for hybrid integration of InP PICs and silicon waveguide chips.

## 3. References


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