

Optimized focusing sub-wavelength TM grating couplers in IMOS platform

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We demonstrate a deep-etched TM grating coupler for the InP membrane on silicon (IMOS) platform. Simulation and experimental results show these gratings feature low insertion loss, good coupling efficiency, low reflection and small footprint, which allows to couple light in and out of the chip efficiently.

Introduction

It is highly demanded to use photonic integrated circuits (PICs) in high capacity, low power and high speed communication. PICs enable reduced size, power consumption and increased data rate. InP-based PICs are playing an important role because they can integrate all the active and passive components in a single chip [1]. However due to the relatively low optical confinement, the integration density in the chip is limited. In this regard, InP membrane on silicon substrate (IMOS) is a promising idea to combine both passive and active components in one optical membrane layer. The IMOS platform has a high refractive index contrast which leads to better mode confinement and decreased dimensions of the components, compared to traditional substrate-based InP PICs. Additionally, this platform has the potential to integrate both electronics and photonics together. Electronics can be realized on the Si substrate and the photonic counterpart on the InP membrane layer [2].

Reduction of dimensions of the on-chip components has made coupling between these components and optical fibers difficult, due to significant mode mismatch. An elegant solution for this problem is using grating couplers to couple light in and out of the chip with good coupling efficiency. The simple linear grating coupler [2] works very well for TE polarized light. However, for TM polarized light, it is very difficult to use a traditional grating design with a linear taper. It is because at a certain width of the taper, the fundamental TM mode will be converted to the first-order TE mode, leading to a complete power loss. Therefore, a new design of the grating, which is called focusing grating, has been introduced [3]. A focusing grating eliminates the need for long tapering and has a very compact footprint. Furthermore, introduction of subwavelength sections makes it possible to use the same deep etching to manufacture the gratings as for the waveguides. This makes the fabrication quite simple in comparison to shallow etched gratings. [4, 5]. Here TM focusing gratings are designed and fabricated according to the optimized parameters obtained with simulations. Moreover, different parameters' effects on the grating's performance have been tested experimentally. The results will be reported.

Subwavelength grating design

The grating out couplers are simulated with a two-dimensional finite-difference time-domain (FDTD) method. There are three different design parameters which dominate the performance of the grating. These design parameters are shown in Fig. 1: grating period (Λ), filling factor (ff) and subwavelength width (sub). An optimization has been performed in order to obtain low insertion loss and reflection, as well as high coupling

efficiency to a single-mode optical fiber. A particle swarm method was used for this optimization. The TM fundamental mode at 1550 nm wavelength was launched within the waveguide and then diffracted upwards by the grating. The incident angle of the fiber is determined by the diffraction angle of the grating. This angle is defined as the angle between the normal of the membrane and the propagation direction of the light waves. This incident angle is predefined to be 10 degrees, and all the simulations are based on this condition.

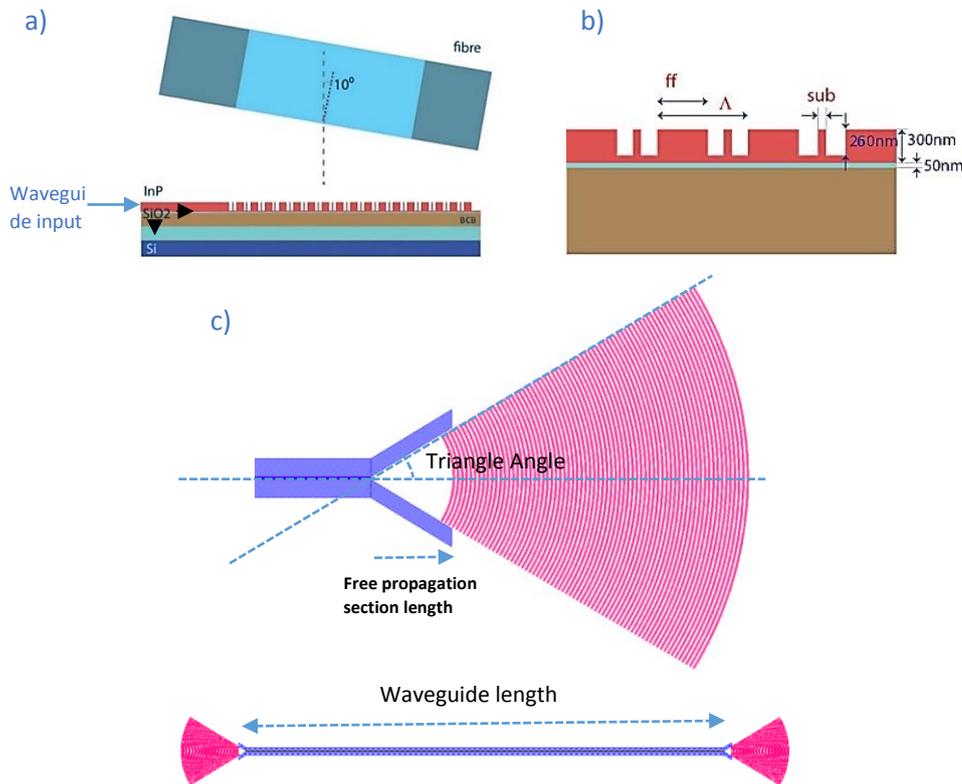


Figure 1. (a) Schematic illustration of the position of the grating with respect to the optical fiber, (b) simulation parameters for optimization. (c) Schematic illustration of the design and related parameters.

The optimized values of the optimization and the ones achieved via fabrication are listed in Table 1 for the TM grating coupler.

	Filling Factor (Duty Cycle)	Subwavelength width (nm)	Period (nm)
Optimized parameters	0.63	132	870
Achieved via fabrication	0.6	130	880

Table 1. Optimized parameters obtained from 2D simulation and the corresponding ones achieved via fabrication.

The simulation result for the transmission spectrum is shown in Fig. 2. The center wavelength has been set at 1553 nm. The minimum insertion loss corresponding to this wavelength is 2.74 dB, with a 1-dB bandwidth of 41 nm. The 2D optimization was based on uniform focusing gratings; further investigation could be performed by apodizing the grating period in order to acquire higher mode overlap of the grating and the optical fiber.

Focusing Layout Design

The focusing is obtained by curving the grating lines. The grating lines become sections of ellipses with a common focal point, which coincides with the position of the input/output of the waveguide.

Unfortunately a 2D simulation cannot predict the effect of the triangle angle and free propagation section length (FPSL) on the grating coupler's performance. In Fig.1(c), these two parameters have been schematically illustrated.

The triangle angle does have an influence on the mode matching of the grating and fiber and thus on the total coupling efficiency. On the other hand, the FPSL of the grating has influence on the back reflection of the light. For the triangle angle of the grating four different values (20, 30, 40, and 50 degrees), and for FPSL three different values (8.25, 12.6 and 16.95 μm) have been chosen to be fabricated.

Fabrication

The grating couplers are fabricated by using electron beam lithography. These gratings include an input and an output grating coupler connected with a waveguide in three different lengths (400, 600 and 800 μm , see Fig. 1c). The fabrication was done on an InP membrane bonded to a silicon substrate (IMOS) with BCB polymer [2]. The thickness of the membrane is 300 nm. Different exposure doses have been tested to find the correct dimensions according to the optimized design parameters. Although the exact dimensions

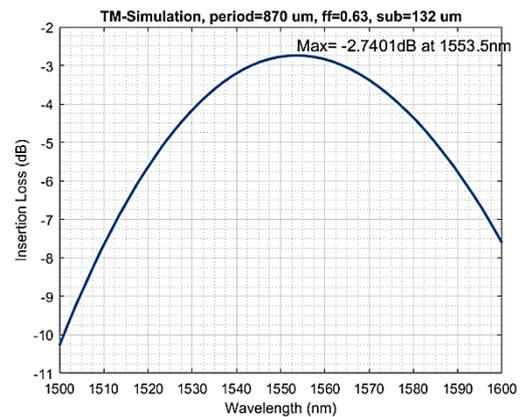


Figure 2. Simulation results for focusing subwavelength TM grating coupler.

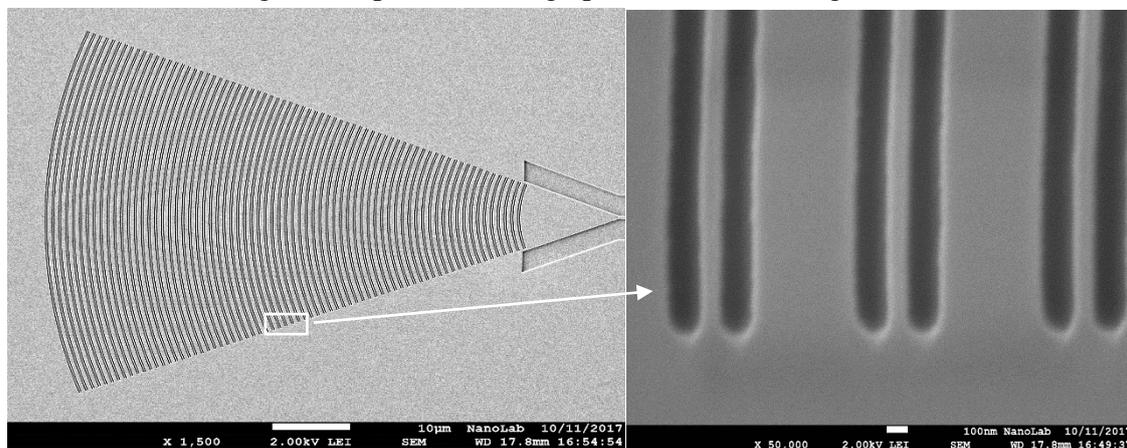


Figure 3. (a) SEM image of the fabricated grating coupler, (b) magnified inset of the grating lines.

could not be achieved, fabricated dimensions are close enough to proceed with the measurements. According to the SEM images, which are shown in Fig. 3, the final gratings after etching are very smooth with only minor sidewall roughness. The single etch depth was 260 nm for all the features, including waveguides and gratings.

Measurement

Gratings fabricated with different doses have been measured. The best grating coupler has a 3.83 dB insertion loss at 1525 nm wavelength. Waveguide propagation loss is 7.25

dB/cm, and the 1-dB bandwidth of this grating is 44 nm. In Fig. 4, the transmission spectrum for this grating is reported. Furthermore, we investigated the influence of the different parameters on the transmitted power.

Effect of triangle angle

In the Fig. 5, the effect of the triangle angle is reported. For the FPSL equal to 8.25 μm the highest transmitted power, belongs to 30 degrees. However, for the FPSL equal to 12.6 and 16.95 μm the highest transmitted power belongs to the grating with triangle angle equal to 20 degrees. This trend is the same for all the fabricated gratings. The trend roots in the different contributions of the two influencing factors, the back reflection and the mode matching, in each case.

Effect of free propagation section length

The best performing grating, providing the highest transmitted power for each FPSL, is selected to be compared. From Fig. 6 it can be inferred that the FPSL equal to 16.95 μm is the best case.

Conclusion

Different parameters have been investigated to realize the best performing TM grating in the IMOS platform. Results showed that a triangle angle of 20 degrees and a free propagation section length equal to 16.95 μm gives the best combination for the TM focusing subwavelength grating. This results in 3.83 dB insertion loss at 1525 nm wavelength. Further improvement can be done via apodizing and using a metallic back reflector.

References

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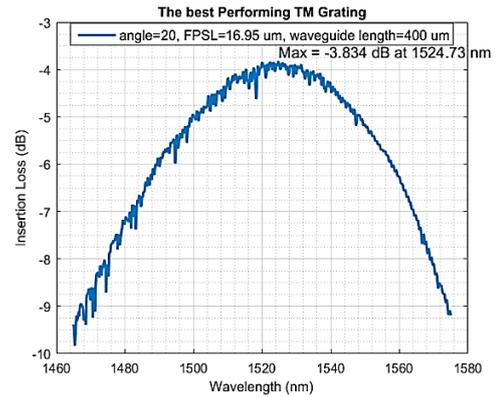


Figure 4. The best performing grating coupler.

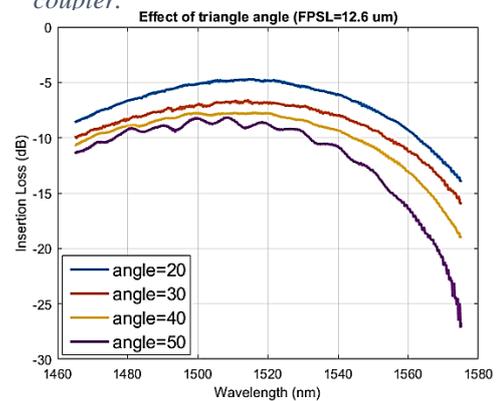


Figure 5. Effect of triangle angle on the transmitted power of the grating couplers, FPSL=12.6 μm .

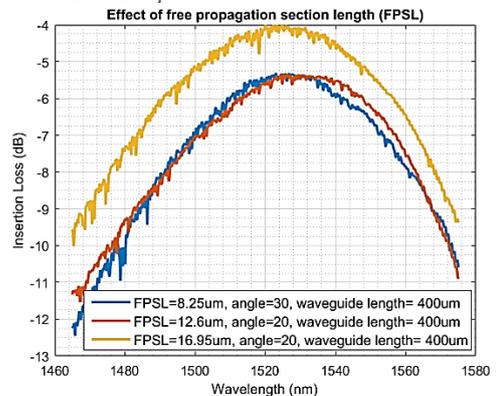


Figure 6. Effect of free propagation section length, comparison between highest transmitted powers for each FPSL.