Designs and simulations of low-loss shallow-to-deep waveguide transitions on an InP membrane on Silicon platform

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In the InP membrane on Silicon (IMOS) platform, shallow and deep etch waveguides are implemented into various devices, like arrayed waveguide gratings (AWGs) and planar concave gratings (PCGs), in order to achieve different functions. Thus, a transition taper is needed to connect the two waveguides with different dimensions. In this paper, two different taper designs for shallow-to-deep waveguide transitions, a bi-level taper and a butt-jointed taper, are proposed in the IMOS platform. In Eigen mode expansion (EME) solver, the dimensions of the two designs are optimized. Over 0.99 transmission is simulated for both fundamental TE and TM mode input of the two designs. Pros and cons of the two different taper designs are discussed. The fabrication process and measurement methods are also considered.

Introduction

In the InP membrane on Silicon (IMOS) platform, a sub-micro layer of InP membrane is adhesively bonded to a Silicon wafer using benzocyclobutene (BCB) polymer [1]. The high refractive index contrast between InP and BCB and the sub-micro dimension of the IMOS waveguide create a high optical confinement. Plenty of compact passive and active devices have been demonstrated in the IMOS platform [2,3]. Among these devices, both shallow and deep etch waveguides are implemented to realize different functions. Thus, a transition taper is needed to connect the two waveguides with different dimensions. For instance, planar concave gratings (PCGs) could enable wavelength multiplexing and demultiplexing. An 0.25 mm^2 eight-channel PCG demultiplexer, with -18 dB cross-talk and 2.9 dB insertion loss, has been demonstrated in the IMOS platform [4]. Because of the existence of the unetched free propagation region (FPR) in the PCG, a shallow-to-deep waveguide transition is needed to couple light from the input/output waveguides to the FPR. A properly designed shallow-to-deep waveguide transition could provide an efficient coupling and reduce the insertion loss .

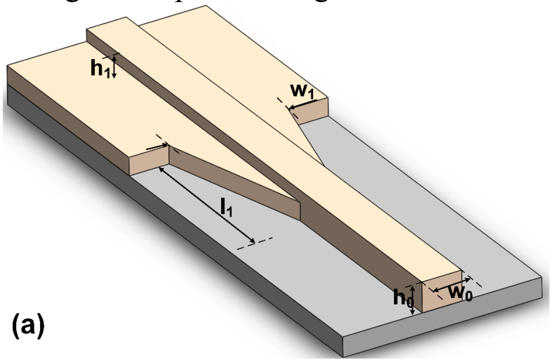
In the past decades, different designs of shallow-to-deep waveguide transitions have been proposed both on SOI [5,6] and III-V platform [7]. These taper designs are optimized in simulation to reach high transmission (>99%) and low mode conversion (<1%). However, these designs might not be suitable to the IMOS platform because the change of waveguide dimensions and layerstacks. A design of shallow-to-deep waveguide transition is proposed by Gargallo et al [8], based on the IMOS platform. Over 99% transmission for TE mode light is obtained with a taper length of 24 μm and an interface length of 2.1 μm. However, the shallow and deep widths are fixed to 2 μm and 0.8 μm in the design, which does not match with the waveguide widths in this paper. Additionally, the transmission for TM mode light is not investigated.

In this paper, two different taper designs for shallow-to-deep waveguide transitions, a bi-level taper and a butt-jointed taper, are proposed and simulated in the IMOS platform.

Device design

Fig. 1(a) shows the schematic of the bi-level taper. The deep-etched waveguide section is 400 nm in width (w_0) and 300 nm in height (h_0), which is the standard dimensions of the passive waveguide section in IMOS platform. Only fundamental TE and TM modes can exist. The shallow-etched waveguide section is 400 nm in width (w_0) and 120 nm in height (h_1).

The shallow waveguide etch depth is chosen to be the same as the etch depth of the grating couplers in the IMOS platform. It is very beneficial since it simplifies the processing. The taper will maintain a smooth transition for the propagating light. Fig. 1(b) shows the cross-section of the taper section. Once the dimension of the taper is optimized, the fundamental TE and TM mode in the shallow-etched waveguide section could propagate through the taper with high transmission and low mode conversion.



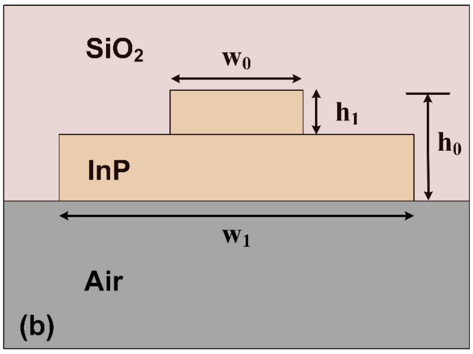
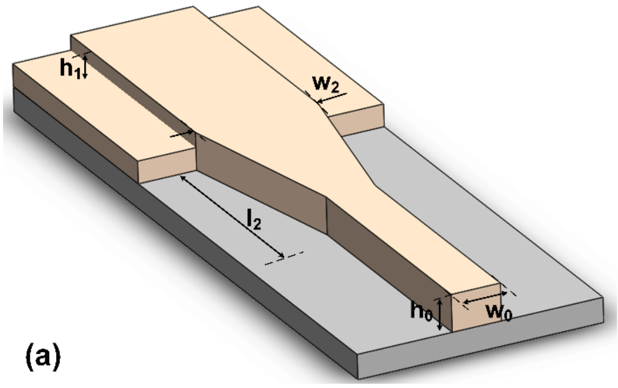


Fig. 1 The bi-level taper (a) the schematic (b) the cross-section in the taper section

Fig. 2(a) shows the schematic of the butt-jointed taper. Compared to the bi-level taper, this taper design is expected to be more tolerant to the fabrication misalignment because the transition taper is defined together with the deep-etched waveguide. The performance of the taper is mainly determined by the width w_2 and length l_2 of the taper. Fig. 2(b) shows the cross-section of the transition taper.



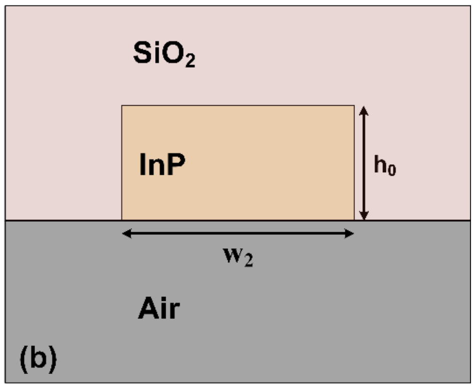


Fig. 2 The butt-jointed taper (a) the schematic (b) the cross-section in the taper section

Simulations

The performance of the two taper designs is analyzed using the Eigen-Mode Expansion (EME) method. For the bi-level taper, the width and height of the shallow/deep-etched waveguides are fixed. The width of the taper w_1 is swept from 0.6 μm to 1.0 μm, in steps of 0.1 μm. The length of the taper l_1 is swept from 0 to 500 μm. Fig. 3(a) shows the transmission of the bi-level taper for TM_0 mode input at 1550 nm. When the width of w_1

is 1.0 μm, the transition for TM_0 mode input is the lowest among all the five different widths. Fig 3.(b) shows the transmission of TM_0 and TE_1 mode for TM_0 mode input when w_1 is 1.0 μm. About 22% mode conversion can be observed between TM_0 and TE_1 mode when the length of the taper is 250 μm. It is because the angle of the taper is too large according to the ray model proposed by Milton et al in 1977 [9] to describe the mode propagation. For a shallow-to-deep etch transition taper, the mode conversion should be avoided. As shown in Fig 3.(a), When w_1 is 0.9 μm and l_1 is over 250 μm, the transmission for TM_0 mode is over 0.99. For TE_0 mode input, a transmission of over 0.99 is also obtained when w_1 is 0.9 μm and l_1 is over 250 μm in simulation.

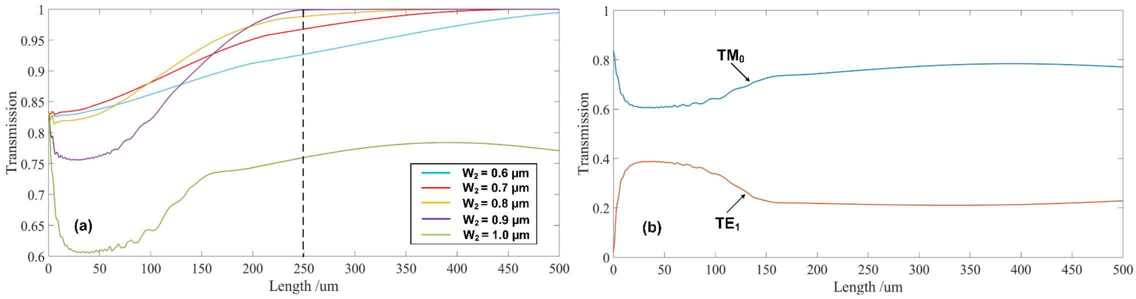


Fig. 3 Simulation results of the bi-level taper (a) transmission of TM0 mode (b) transmission of TM0 mode and TE1 mode when w1 is 1.0 μm

Fig. 4(a) and Fig. 4(b) show the transmission of the butt-jointed for both fundamental TM and TE mode at 1550 nm. For TM_0 mode input, over 0.99 transmission can be obtained when w_2 is around 1.1 μm and l_2 is over 90 μm. For TE_0 mode input, w_2 is not critical compared to TM_0 mode input. Over 0.99 transmission can be found when w_2 is over 0.9 μm and l_2 is over 70 μm. For the butt-jointed taper design, the transmission for both fundamental TM and TE mode changes within 0.06 when w_2 is swept from 0.8 μm to 1.2 μm, which could be more tolerant to fabrication errors in terms of width variation, compared to the bi-level design.

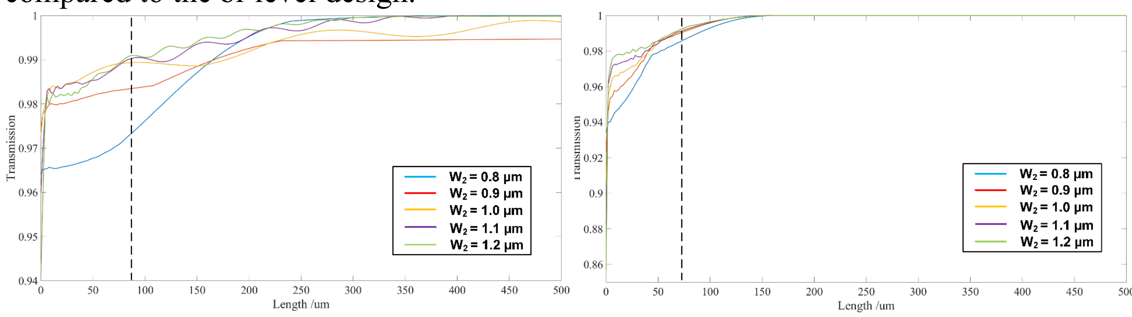


Fig. 4 Simulation results of the bi-level taper
(a) transmission of TM_0 mode (b) transmission of TE_0 mode

Fabrication and Measurement methods

The two proposed structures are compatible with the IMOS platform. Since the shallow waveguide etch depth is chosen to be the same as the etch depth of the grating couplers, no additional process step is needed. Compared to the bi-level design, the butt-jointed taper design is more tolerant to fabrication errors in terms of width variation according to the simulation results.

The performance of the two tapers can be determined by the four-port structure, as shown in Fig. 5. Four TE/TM gratings are put on both sides of the cascaded tapers. Two independent measurements of the transmission and two independent measurements of the reflection can be obtained. First, the insertion loss of the taper should be determined.

Different numbers of cascaded tapers will be added into the structure. The insertion loss can be obtained by comparing the transmission spectra of the structure from port 2 to port 3. Then, he losses may be de-embedded from the grating couplers and MMIs by measuring the transmission spectra from different port combinations. Thus, the actual transmission and reflection can be obtained.

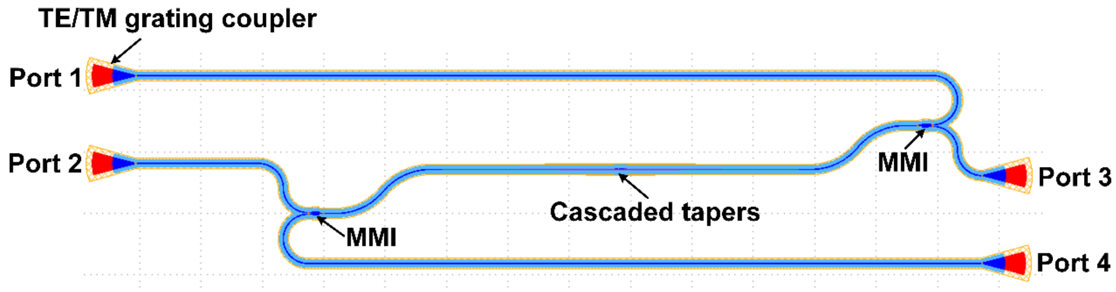


Fig. 5. Schematic of the four-port measurement structure

Conclusion

In this paper, two taper designs for shallow-to-deep waveguide transitions in IMOS platform are proposed. The dimensions of the two designs are optimized in the EME solver. Over 0.99 transmission is obtained from deep to shallow waveguides for both fundamental TE and TM mode input for both taper designs. Compared to the bi-level tape, the butt-jointed taper shows more tolerant in terms of taper with variation in simulation. The fabrication process is comparable with the existing process flow, and precision measurements are compatible with an optical four-port measurement.

References

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