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Two-way-fed silicon-on-insulator grating couplers with a broad bandwidth

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Abstract: A silicon-on-insulator grating coupler with a broad 1-dB bandwidth of 76nm and a coupling efficiency similar to that of a standard grating coupler is experimentally demonstrated. The design is based on a novel two-way-fed method.
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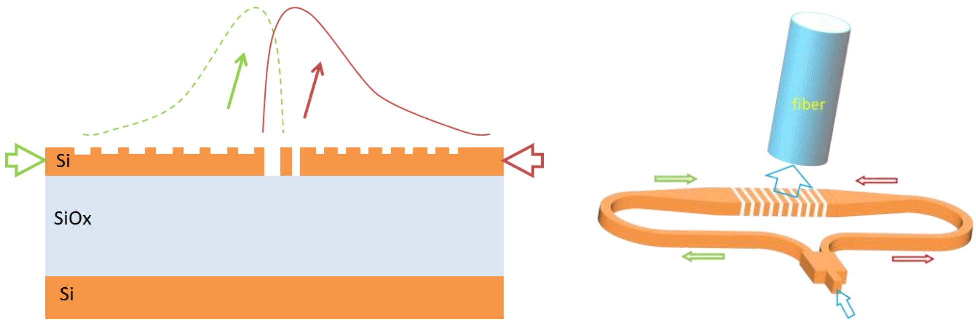
1. Introduction

Surface grating coupler structures are important optical interfaces between on-chip optical components and fiber-based/free-space optical devices. The possibility for a wafer-scale test makes the grating coupler a popular device in integrated photonics. A grating coupler has two important parameters: the peak coupling efficiency to a single-mode fiber and the transmission bandwidth. Many efforts have been made to increase the coupling efficiency of grating couplers, by either increasing the directionality or improving the mode-matching coefficient [1-3]. However, there is still no good method to effectively increase the bandwidth of grating couplers without penalty to its efficiency. The commonly used methods are either by making a different waveguide structure (in a horizontal slot waveguide [4]) or by using another waveguide material (e.g. nitride waveguide [5]). However, it is difficult to realize these methods in a standard silicon-on-insulator (SOI) platform.

In this paper, we demonstrate a different method to increase the grating coupler's bandwidth [6]. In order to couple light from a waveguide to a single mode fiber via this structure, we need to first split the light signal into two parts, and then send them to the grating from two sides. Hence, this coupler is called a two-way-fed grating coupler (TWF-GC). The reason why a TWF-GC has a broad bandwidth will be explained in the theory section.

2. Theory



(a) **(b)**

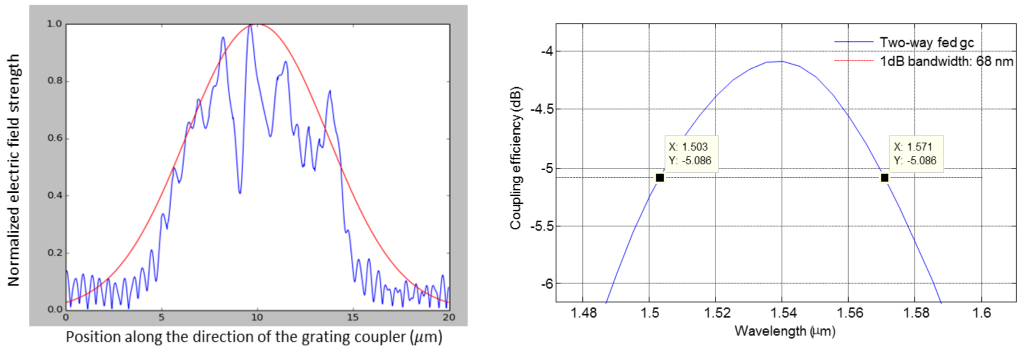
Figure 1. (a) Cross-section of a double grating. The green and red arrows show the directions of the input light beams from the waveguides and the light beam coupled to free space. The green and red curves on top of the grating region show the designed electric field profile of the output light beams. (b) 3D schematic show of the TWF-GC: including a double-grating and a 3dB coupler.

The bandwidth of a normal grating coupler is mainly limited by the diffraction effect of the grating and the effective length of the out-coupled electric field L_{eff}. For a normal grating coupler, when the fiber is at the best coupling angle, the phase profile of the out-coupled field is well aligned with that of the fiber mode. Once the wavelength changes, the phases of the out-coupled field at different locations will also change due to the diffraction effect of the grating. A shift of the coupling angle is the impact of this phase change. Since the phases are not totally in phase, the coupling efficiency becomes lower. At some locations the phase change may even reach 180°, which causes the unfavorable destructively interference. That explains why the coupling efficiency decreases as the wavelength deviates from the best value. The other factor L_{eff} determines the region where the phase matching condition is considered. Out of this region, the field strength is so small that its contribution to the total coupling can be ignored. The total phase mismatch due to grating diffraction has a negative correlation to L_{eff}. Therefore, one way to increase the bandwidth is to reduce L_{eff}. However, L_{eff} needs to be the same as the effective size of the fiber mode to ensure a good mode-matching condition. Reducing L_{eff} usually leads to a penalty to the coupling efficiency, which makes this method not practical.

However, in our new design, the coupling efficiency penalty can be reduced or even avoided. Our method is to put two grating couplers with small L_{eff} side by side. One grating is designed for coupling light to 10° angle, while the other one is for -10°. To excite this coupler, light needs to be sent to both sides of the grating coupler simultaneously (shown in **figure 1(a)**). The out-coupled fields corresponding to these two sources can be sent into the same single-mode fiber and combined into one mode if the phase relation of the two sources ensures a constructive interference. In order to couple light from a single mode waveguide to this double-grating, a 3-dB coupler is needed to first split the light into two parts. The two parts are then sent to the double-grating from both sides (**figure 1(b)**). The two optical paths from the 3-dB splitter to both sides of the double-grating should be equivalent to avoid an interferometer effect. Since this structure consists of two small gratings with small L_{eff} values, the average grating-induced phase change in the out-coupled field of this design is smaller than that of the standard grating coupler. This means that the coupler based on this double-grating structure has a broader bandwidth than the standard grating couplers.

The double-grating structure is designed according to the following rules: the period of the left-side grating is derived from the designs used for coupling 1550nm light to 10° angle, while the period of the right-side gratings is the same as the designs for -10° angle coupling. To ensure a good mode matching between the output field and the fiber mode, the gratings in the middle part are designed differently: 1. these trenches are deeply etched to increase the scattering strength; 2. the widths and separations of these trenches are adjusted to ensure the desired phase distribution.

This double-grating design is simulated using the eigenmode expansion method. The simulated field profile on top of the grating and the transmission band are shown in **figure 2**. It is seen that we can actually make a good mode matching between the output field and the fiber mode with our method. A bandwidth of 68 nm and a peak coupling efficiency of around 39% (-4.1 dB) are obtained in the simulation.



(a) **(b)**

Figure 2. (a) Simulated electric field profile of the out-coupled field on top of the TWF-GC (blue line) and the mode profile of the single mode fiber (red line). (b) Simulated coupling spectrum of the TWF-GC to a single mode fiber, where the 1dB bandwidth is around 68 nm.

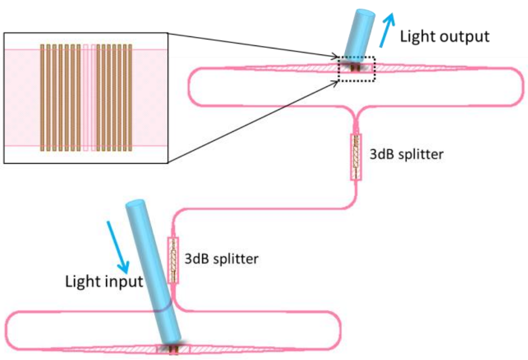


Figure 3. The test structure for the two-way-fed grating couplers.

3. Design and measurements results

In the test structure, one double-grating is connected to a multimode-interferometer-based 3dB coupler with two single-mode waveguides at both sides to form a TWF-GC. We connect two identical TWF-GCs with another single-mode waveguide to make a transmission test structure. The test structure is shown in **figure 3**.

This test structure was fabricated by using the 193 nm deep ultraviolet lithography in imec via europractice IC-service [7]. In the measurements, the light signal from a supercontinuum LED source is sent to the left TWF-GC via a single mode fiber. Another single mode fiber is aligned to the other TWF-GC to collect the transmitted signal. The measurement results show that the 1-dB bandwidth of the TWF-GC is to 76 nm, which is considerably larger than the 1-dB bandwidth of the standard grating coupler (around 40 nm). It is also shown that a maximal transmission peak of the TWF-GC is -5.5 dB at 1520 nm (**figure 4.**). This peak transmission is only 1dB less than that of the standard grating coupler. The transmission spectrum of the standard grating coupler is also measured and shown in figure 4 for a comparison.

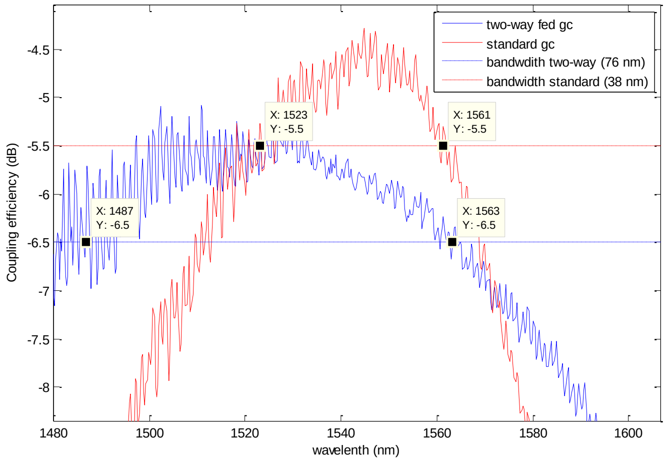


Figure 4. The measured transmission spectra of the fabricated two-way fed grating coupler (blue) and the standard grating coupler (red).

The major problem of the current TWF-GC design is the shift of the transmission band. Besides, the best coupling angle is also not 10°, but 12°. These problems are probably caused by unexpected trench width deviations induced by fabrication. We also need to further increase the coupling efficiency. Most methods used for boosting the efficiency of normal grating couplers, e.g. placing a backside mirror or silicon overlays, can also be applied to the TWF-GC.

4. Discussion and conclusions

In this paper, we experimentally demonstrate a grating coupler with a broad transmission bandwidth (76 nm) using the two-way fed method. The peak transmission efficiency is around -5.5 dB. The next step is to shift the transmission peak to 1550 nm and improve the peak coupling efficiency.

5. References

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