CMOS Compatible Subwavelength Grating Couplers for Silicon Integrated Photonics

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***Abstract*—We demonstrate a through etched subwavelength grating coupler, which can be patterned together with other photonic components. It achieves a very high coupling efficiency of 59% with a 3dB bandwidth of 60 nm.**

Keywords - gratings; subwavelength structure; nanophotonics and photonic crystals

I. Introduction

Silicon-on-insulator (SOI) enables high density integration of photonic devices due to the high index contrast between silicon (3.476) and its cladding (air-1, silicon dioxide-1.445). However, coupling of light between the conventional single mode fiber and a small single mode waveguide is very challenging because of the large mode mismatch. The grating coupler (GC) has been considered as one possible solution [1-9]. However, as indicated in Table 1, the experimentally demonstrated GC usually involves either complex fabrication processes such as timed etching [1], epitaxial silicon overlay [3] or uncontrollable processes like lag effect [6]. Despite these steps, the coupling efficiency leaves room for improvement.

Table 1 Comparison between SOI based grating couplers.

	Coupling Efficiency	Peak Wavelength	Polarization	Process Steps
Aug-06 [1]	37%	1550 nm	TE	4 a
Jul-07 [2]	34%	1550 nm	TE	5 b
Mar-08 [3]	55%	1525 nm	TE	8 c
Aug-08 [4]	32%	1550 nm	TE	4 a
Sep-09 [5]	34%	1480 nm	TE	2 d
Mar-10 [6]	64%	1520 nm	TE	4 e
Feb-10 [7]	42%	1550 nm	TE	2 f
Oct-10 [8]	43%	1530 nm	TM	2 d
Feb-11 [9]	35%	1550 nm	TE	2 g
Our work	59%	1550 nm	TE	2d

a-70 nm timed etch b-metal grating c-epitaxial silicon overlay d-subwavelength structure e-reactive ion etching lag effect f- photonic crystal g-index matching oil

Ideally, a GC would be patterned and etched in the same step as photonic circuits, while yielding a comparable coupling efficiency. However, through etched air trenches makes the index contrast of the grating very strong. As a result, the reflection is prohibitively high, and the efficiency is very limited. An intuitive solution is to fill the air trenches with higher index material, but such a solution may not always be available. In this letter, we use subwavelength nanostructure (SWN) to replace air trenches and form a subwavelength grating coupler (SWG), as shown in Fig. 1a. The effective index of the SWN can be tuned between the index of the cladding material and silicon. For our designed coupler, a coupling efficiency of 59% at 1551.6 nm is demonstrated for TE polarization with a 3 dB bandwidth of 60 nm. Thus, an SWG proves its viability, and the fabrication requires only one etching step, which can be performed along with the patterning of other photonic components (e.g. photonic crystals).

II. Design and Simulation

The proposed SWG is based on SOI with a 250 nm top silicon layer and a 1μm buried oxide (BOX) layer. The BOX thickness is chosen to form constructive upwards interference [7,9]. Via simulation, the SWG is simplified into designing an equivalent conventional grating coupler with a uniform material of refractive index n_{sub}, as shown in Fig. 1b. After optimizing the grating period Λ_G and n_{sub}, a SWN of n_{sub} is designed to replace the uniform material, as shown in Fig. 1c. An open source simulation package CAMFR, which is based on the eigenmode expansion technique [9], is

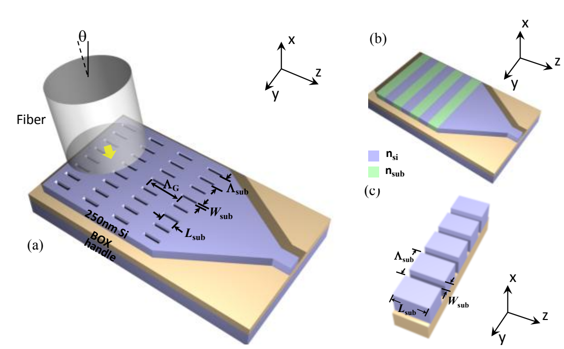

Fig. 1 (a)Schematic of the proposed SWG. (b)The equivalent conventional grating. The trenches are filled with artificial material of refractive index n_{sub}. (c)Schematic of the SWN

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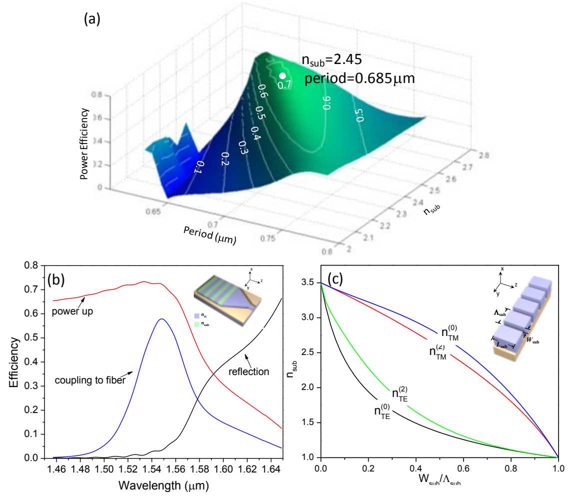

Fig.2 (a)Scanning the Λ_G and the n_{sub} assuming the subwavelength structure is a uniform material. (b) Coupling efficiency from designed coupler (the simplified model is shown in the inset). (c) The zero and second order approximation of the n_{sub}.

utilized to search for an optimal combination of grating period Λ_G and n_{sub} in order to achieve the highest grating to free space efficiency. As indicated in Fig. 2a, 72% power efficiency can be obtained when Λ_G=0.685 μm and n_{sub}=2.45. The filling factor of the grating is 50%, and the grating consists of 25 periods. The grating to free space efficiency, coupling efficiency, and the back reflection are shown in Fig. 2b. The refractive index of the SWN is engineered based on effective material theory (EMT) [5, 8]. Fig. 2c shows the correlation of n_{sub} with the filling factor L_{sub}/Λ_{sub} of the SWN. The calculated W_{sub} and Λ_{sub} are 80 nm and 387.5 nm, respectively.

III. Fabrication and Testing

The designed GC is fabricated using electron beam lithography and reactive ion etching. The scanning electron microscope (SEM) image of the fabricated grating is shown in Fig. 3. The GC is characterized by measuring the fiber-waveguide-fiber insertion loss coupled via a pair of grating couplers connected by an 8 mm long, 2.5 μm wide waveguide. A pair of linear tapers, each with a length of 500 μm, is used to bridge the 10 μm wide grating region to the waveguide. The coupling efficiency, as shown in Fig. 4a, is

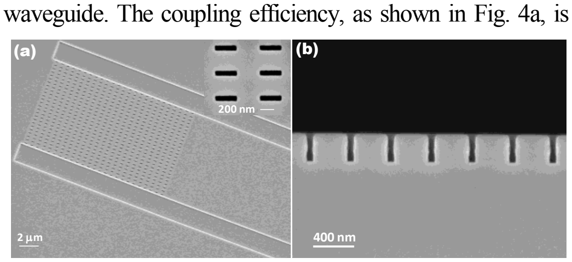

Fig.3 (a) SEM images of the fabricated GC. Inset: the magnified view of the air holes. (b) the cross section of the rectangular air holes

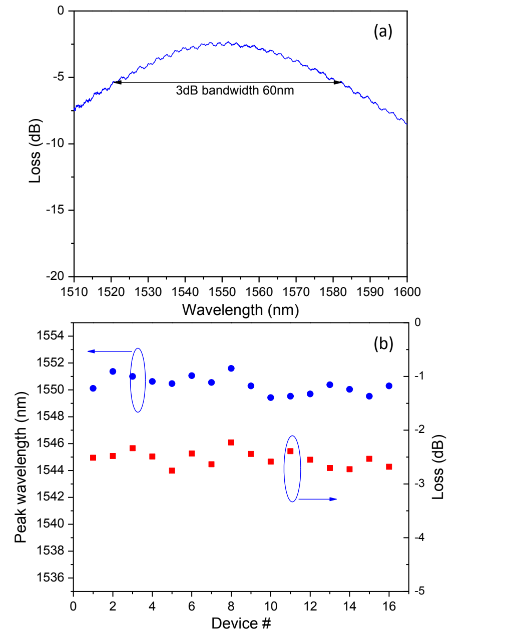

Fig. 4 The experimental results of the GC fabricated on an SOI of 1μm BOX. (b)The peak wavelength (blue dot) and the coupling loss (red square) of the fabricated 16 grating pairs

extracted by assuming equal coupling efficiency for both gratings. The loss of the waveguide is considered negligible. Both input and output fibers are tilted by 10° from the vertical direction. The peak efficiency is 59% (-2.29 dB). The peak wavelength is shifted to 1551.6 nm due to fabrication error. The 1 dB and 3 dB bandwidths are 32 nm and 60 nm, respectively. The Fabry-Perot ripples near the peak wavelength are ~0.3 dB, indicating very low reflection. 16 input/output-grating pairs fabricated on two chips were tested, and the results are shown in Fig. 4b, showing good repeatability in performance.

IV. Conclusion

In conclusion, we designed and demonstrated a through etched SWG which can be patterned together with other photonic components without any extra fabrication steps. It achieves a peak coupling efficiency of 59% and a 3 dB bandwidth of 60 nm. The performance is very competitive to gratings requiring complicated fabrication processes.

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