O-Band Sub-Wavelength Grating Coupler

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***Abstract*—We demonstrate a compact, single-etched sub-wavelength grating coupler for the O-band application, which has a measured coupling efficiency of -4 dB, a 3-dB bandwidth of 39 nm, back reflections below -20 dB, and a design footprint of 20um $\times$ 40um.**

I. Introduction

To meet the explosive growth of data traffic, major Internet content providers are building hyper-scale data centers operating at O-band (around $1.31\,\mu m$) to benefit from the zero-dispersion feature of standard single-mode optical fibers. Silicon photonics, based on the silicon-on-insulator (SOI) platform, provides a cost effective solution to meet the bandwidth requirement of the datacom interconnects, which are also power efficient and scalable. Grating couplers have been used as the input/output (I/O) devices to couple light into and out of the SOI based photonic integrated circuits, with the advantages of low cost, easy-alignment, small footprint, etc. Sub-wavelength gratings, with the flexibility to engineer both the index profiles and the dispersion properties [1], have been used to improve the coupling efficiency and bandwidth of grating couplers [2-5]. However, all the grating couplers mentioned above are designed for the C-band applications with a central wavelength near $1.55\,\mu m$. It is more challenging to design grating couplers for O-band applications because smaller feature sizes are required if a scaling approach is used [6]. One dimensional sub-wavelength gratings [3], [5] have been demonstrated to make both high-efficiency and broadband C-band sub-wavelength grating couplers (SWGCs), with the advantages of compact design footprint, lower fabrication cost, higher fabrication accuracy and repeatability, design simplicity, etc. In this paper, we demonstrate a compact, high-efficiency SWGC for O-band applications using the one-dimensional SWGs. The SWGC is designed for the fundamental transverse electric, TE_{00}, mode with the central operating wavelength at $1310\,nm$. Our SWGC is designed for SOI wafers with a $220\,nm$ silicon layer and a $3\,\mu m$ buried oxide layer, which are the same as those provided by Multi Project Wafer (MPW) foundry services such as imec and IME. The fabrication of our SWGC only requires a single etching step, which provides an efficient and economical solution for rapid prototyping.

II. Design and Simulation

The schematic of the cross-section of our SWGC is shown in Fig. 1, which consists of alternating high and low index regions with widths of Λ_H and Λ_L, respectively. The fill factor, ff, of our SWGC is defined as the ratio of Λ_H to the grating period, Λ. The width of the SWG "teeth" in the low index regions is denoted by l_{sub}. As shown in Fig. 1, the high index regions are silicon, and the low index regions are formed using SWGs with the cladding material, which is silicon oxide in our case. The SWGs are small enough so that each low index region can be treated as a homogenous material.

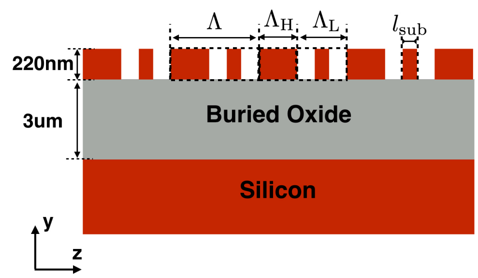

Fig. 1. Schematic of the cross-section of an SWGC.

In a grating coupler, the grating diffraction is governed by the phase matching condition, from which Λ can be derived as:

$$\Lambda = \frac{\lambda}{n_{\text{eff}} - n_c \cdot sin(\theta)} \tag{1}$$

where λ is the operating wavelength, n_{eff} is the effective index of the grating, n_c is the refractive index of the cladding, and θ is the incident angle, which is defined as the angle between the normal of the grating and the diffraction direction of the light wave. From Eq. 1, we can find that for a given λ, Λ will increase as θ increases. Therefore, the minimum feature size of our SWGC can be increased by using a large θ.

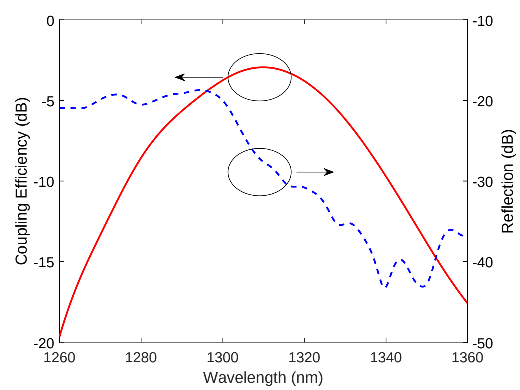

Fig. 2. Simulated coupling efficiency and back reflection of the SWGC.

Due to the fact that one-dimensional SWGs are used to form our SWGC, two-dimensional finite-difference time-domain (FDTD) method can be used to optimize the design parameters of our SWGC, which significantly reduces the simulation time. Three design parameters, i.e., Λ, ff, and l_{sub} are optimized to achieve the highest coupling efficiency, η, using the particle swarm algorithm in FDTD Solutions, an FDTD-method Maxwell equation solver from Lumerical Solutions, Inc. The design parameters, η, θ, and the 3-dB bandwidth, $\Delta\lambda_{3\text{dB}}$, of the optimized SWGC are listed in Table I. The simulated coupling efficiency and back reflection of the optimized SWGC are shown in Fig. 2. The optimized SWGC has a peak coupling efficiency of $-3.1\,\text{dB}$ at $1310\,\text{nm}$ with a 3-dB bandwidth of $38\,\text{nm}$. The back reflections of our SWGC is defined as the optical power coupling backward into the waveguide, which is calculated using a mode expansion monitor. As it shown in Fig. 2, the simulated back reflection of our SWGC is below $-20\,\text{dB}$ over the wavelength range from $1260\,\text{nm}$ to $1360\,\text{nm}$, which means that the back reflections are well suppressed by using SWGs. For grating couplers with straight grating lines, the gratings are linearly extended in the lateral (X) direction as shown in Fig. 1, where long adiabatic tapers are required to coupler the mode from the grating into the sub-micron waveguide, with typical length on the order of a few hundred microns. In order to improve the space efficiency of our SWGC, focusing grating lines have been used, which results in a compact design shape with a footprint of $20\,\mu\text{m} \times 40\,\mu\text{m}$.

TABLE I
Design parameters, η and $\Delta\lambda_{3\text{dB}}$, for the optimized SWGC.

Pl.	Λ	ff	l_{sub}	θ	η	$\Delta\lambda_{3\text{dB}}$
TE_{00}	$630\,\text{nm}$	0.65	$79\,\text{nm}$	$34°$	$-3.1\,\text{dB}$	$38\,\text{nm}$

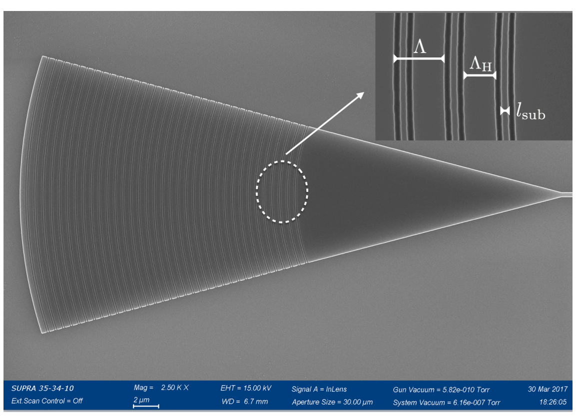

Fig. 3. SEM images of a fabricated O-band SWGC.

III. Fabrication and Measruement

Test structures, consisting of an input SWGC and an output SWGC with a spacing of $127\,\mu\text{m}$, connected by a strip waveguide, were fabricated using electron beam lithography at Applied Nanotools Inc. Scanning electron microscope (SEM) image of an as-fabricated SWGC is shown in Fig. 3. A custom-built test setup with a Yenista TUNICS T100S-HP O-band tunable laser and a CT400 passive optical component tester are used to characterize the fabricated devices. The wavelength was swept from $1260\,\text{nm}$ to $1360\,\text{nm}$ in $10\,\text{pm}$ steps. The measured transmission spectra of a fabricated SWGC is shown in Fig. 4. The measured SWGC has a peak coupling efficiency of $-4\,\text{dB}$ at $1315\,\text{nm}$ with a $\Delta\lambda_{3\text{dB}}$ of $39\,\text{nm}$. Slight oscillation ripples were observed in the measured spectra, which were due to the back reflections from the SWGCs. The wavelength dependent back reflections of the fabricated SWGC can be calculated from the extinction ratios of the ripples shown in the measured transmission spectrum, which is below $-20\,\text{dB}$ in our case. The coupling efficiency and bandwidth of the fabricated SWGC agrees well with the simulation results. There is a small central wavelength shift of $5\,\text{nm}$ exists between the simulation and measurement results, which may come from the fabrication inaccuracy or the misaligned fiber array angle during our measurement.

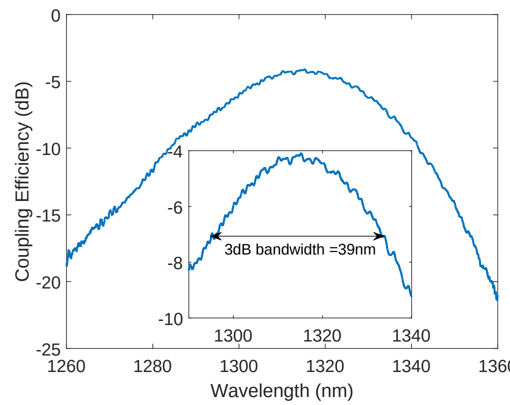

Fig. 4. Measured spectrum of the fabricated O-band SWGC.

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