Broadband Sub-wavelength Grating Coupler for O-Band Application

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***Abstract*—We demonstrate a broadband sub-wavelength grating coupler for the O-band application, which has a simulated coupling efficiency of -3.3 dB with 3-dB bandwidth of 78 nm and a measured coupling efficiency of -4.5 dB with a 3-dB bandwidth of 65 nm for fundamental TE mode.**

I. Introduction

Silicon photonics, based on the silicon-on-insulator (SOI) platform, provides an unprecedented opportunity to make highly integrated photonic circuits with sub-micron silicon-wire waveguides. However, the small feature sizes of the waveguides raise the problem of large mode mismatch when coupling light from optical fibers to the sub-micron silicon waveguide cores. Edge coupling and surface coupling are two popular approaches to address the mode mismatch issue. Surface coupling using grating couplers provides the flexibility to put the grating couplers anywhere on the chip, which enables better architectural design. Grating couplers also enable wafer-scale automated measurement, without the need to dice the wafer. However, the disadvantages of using grating couplers is that they are in general polarization dependent and sensitive to wavelength, which results in narrow operating bandwidth. Most of the grating couplers that have been demonstrated so far are operating at C-band (around $1.55\,\mu\mathrm{m}$) [1], [2], with only a few attempts for the O-band operation [3]. However, the short-reach data communications are often operating at O-band (around $1.31\,\mu\mathrm{m}$) to benefit from the zero-dispersion feature of standard single-mode optical fibers. Therefore, high efficiency and broadband O-band grating couplers are required. Sub-wavelength gratings (SWGs) has been used to improve the performance of grating couplers [4]. However, it is more challenging to design grating couplers, especially sub-wavelength grating couplers (SWGC), for O-band applications because smaller feature sizes are required if a scaling approach is used [3]. Significant effort has been devoted to improve the coupling efficiency of grating couplers [1], [2], [3]. while only a few attempts have been made to improve the bandwidths [5].

In this paper, we demonstrate a broadband SWGC operating at O-band. Our SWGC is designed for SOI wafers with a $220\,\mathrm{nm}$ silicon layer and a $3\,\mu\mathrm{m}$ buried oxide layer. The fabrication of our SWGC only requires a single etching step, which provides an efficient and economical solution for rapid prototyping.

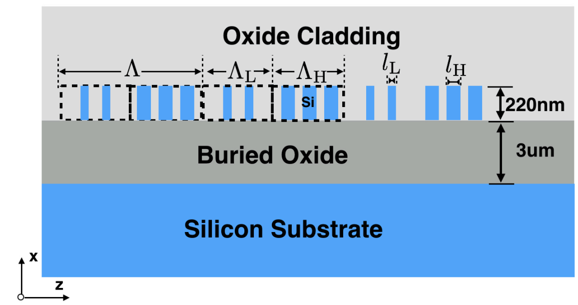

Fig. 1. Schematic of the cross-section of the O-band broadband SWGC.

II. Design and Simulation

The schematic of our SWGC is shown in Fig. 1. Each grating period, Λ, consists of a high index region with a length denoted by Λ_{H} and a low index region with length denoted by Λ_{L}. The lengths of the SWG teeth in the high and the low index regions are denoted by l_{H} and l_{L}, respectively. The fill factor, ff, of the grating coupler, is defined as the ratio of Λ_{H} to Λ. The numbers of gratings in each high and low index region are N_{H} and N_{L}, respectively. The fill factors of the high and low index regions, denoted by ff_{H} and ff_{L}, are defined as $N_{\mathrm{H}} * l_{\mathrm{H}}/\Lambda_{\mathrm{H}}$ and $N_{\mathrm{L}} * l_{\mathrm{L}}/\Lambda_{\mathrm{L}}$, respectively.

The bandwidth of a grating coupler can be expressed as [5]:

$$\Delta\lambda_{3\mathrm{dB}} = \Delta\theta_{3\mathrm{dB}} \cdot 2\left|\frac{-\,n_{\mathrm{c}} \cdot cos(\theta) \cdot \lambda}{n_{\mathrm{g}} - n_{\mathrm{c}} \cdot sin(\theta)}\right| \tag{1}$$

where λ is the operating wavelength, n_c is the refractive index of the cladding, n_g is the group index of the grating, and θ is the incident angle. $\Delta\theta_{3\mathrm{dB}}$ is a constant that depends solely on the fiber parameters. The factor of 2 accounts for the 3-dB bandwidth including the wavelength range both above and below the central operating wavelength.

We used the same methodology demonstrated in [5] to design our O-band SWGC, which follows a four-step process. Based on Eq. 1, we first determine the θ for our SWGC, which is 30° in our case. Secondly, Λ and ff are optimized using two-dimensional finite-difference time-domain (FDTD) method with the particle swarm algorithm (PSA). The optimized values for Λ and ff are $924\,\mathrm{nm}$ and 0.5, respectively. In the third step, ff_{H} and ff_{L} are first calculated using zeroth-order effective medium theory (EMT) [6], and then optimized using the PSA. The optimized values for ff_{H} and ff_{L} in our case are 0.46 and 0.17, respectively. The dimensions of the SWGs have both a lower limit, which comes from the fabrication limitations, and an upper limit, which is determined by EMT. Finally, we optimize N_{H} and N_{L} based on the optimized values of ff_{H} and ff_{L}, and the optimized values are 3 and 2, respectively. The simulated coupling efficiency as a function of wavelength for our O-band SWGC is shown in Fig. 2. For comparison purposes, we also designed a regular SWGC based on the methodology shown in [5]. Our broadband SWGC has a simulated peak coupling efficiency of $-3.3\,\mathrm{dB}$ with a 3-dB bandwidth of $78\,\mathrm{nm}$, which is twice as large as that of the regular SWGC.

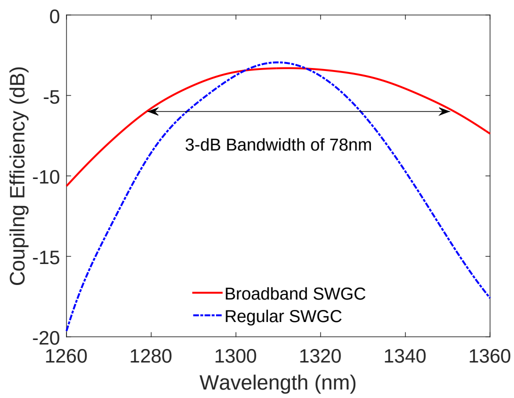

Fig. 2. Comparison of the simulated coupling efficiencies as a function of wavelength for the broadband SWGC and the regular SWGC .

III. Measurement results

Test structures, consisting of an input SWGC and an output SWGC with a spacing of $127\,\mathrm{\mu m}$, connected by a strip waveguide, were fabricated using electron beam lithography at Applied Nanotools Inc. Scanning electron microscope (SEM) image of a fabricated SWGC is shown in Fig. 3. Focusing gratings have been used to achieve compact design shape, and the dimensions of our broadband SWGC are $45\,\mathrm{\mu m} \times 24\,\mathrm{\mu m}$.

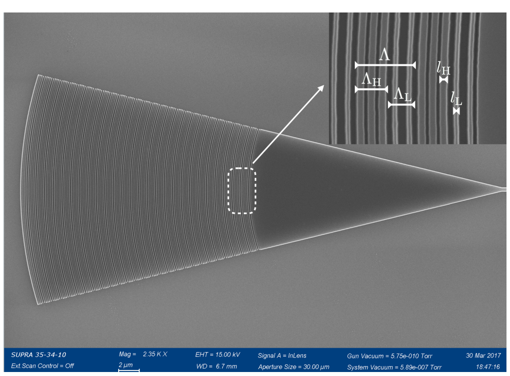

Fig. 3. SEM images of a fabricated broadband SWGC.

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 $1260\,\mathrm{nm}$ to $1360\,\mathrm{nm}$ in $10\,\mathrm{pm}$ steps. The measured coupling efficiencies as a function of wavelengths for a fabricated broadband SWGC and a regular SWGC is shown in Fig. 4. The measured broadband SWGC has a peak coupling efficiency of $-4.5\,\mathrm{dB}$ at $1310\,\mathrm{nm}$ with a $\Delta\lambda_{3\mathrm{dB}}$ of $65\,\mathrm{nm}$, which is almost twice as large as that of the regular SWGC. The insertion losses from the laser, the CT-400, the polarization controller, and the single mode fibers connecting them have been calibrated out from the measurement data, while the insertion loss from the fiber array is included in the results shown in Fig. 4. We can see that the broadband SWGC has a peak coupling efficiency about $0.5\,\mathrm{dB}$ lower than the regular SWGC, but with a $\Delta\lambda_{3\mathrm{dB}}$ almost twice as large as the regular SWGC. Due to the fact the back reflection from the broadband SWGC increases as the wavelength is approaching $1260\,\mathrm{nm}$, stronger oscillation ripples are observed in the shorter wavelength regions of the measured spectrum. The measured coupling efficiency of our SWGCs agrees well with the simulation while the the measured $\Delta\lambda_{3\mathrm{dB}}$ is about $10\,\mathrm{nm}$ smaller than the simulated value, which we think is due to the fact that the fabricated l_{H} and l_{L} are larger than the designed values.

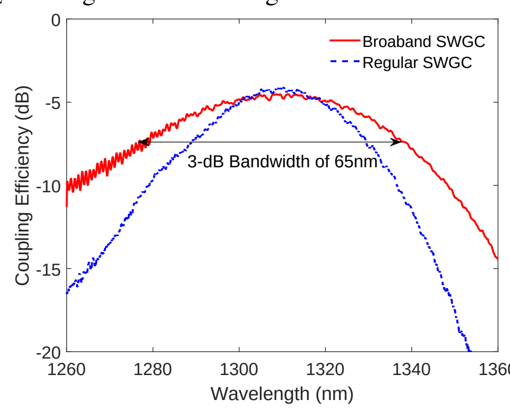

Fig. 4. Comparison of the measured coupling efficiencies as a function of wavelength for a broadband SWGC and a regular SWGC.

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