Improving the Efficiency of Fibre-chip Grating Couplers Near 1310 nm

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***Abstract*—We present our recent work on fibre-chip grating couplers operating around 1310 nm. For the first time, we demonstrated the combination of dual-etch and apodization design approaches which can offer state of the art performance. Initial tests from fabricated structures show a -2.2dB loss.**

***Keywords*—Grating couplers, Optical Waveguide, Silicon-on-insulator, Integrated Optics, Integration, Laser, CMOS,**

I. INTRODUCTION

Grating couplers are widely used for coupling between fibres and photonic waveguides in photonic circuits [1, 2]. As illustrated in Fig. 1, the fundamental optical mode from the photonic waveguide is first expanded laterally (y-direction) by an adiabatic taper to a waveguide with a width of approx. 10 μm, which matches the mode size of optical fibre. The light is then coupled by diffraction of shallow-etched gratings into the optical fibre. The period needed for out-of-plane coupling to the fibre is calculated by the phase matching condition. The fibre is slightly titled with an angle θ from perpendicular to the surface of the SOI wafer in the x-z plane as shown in Fig. 1. This is to avoid the large second-order Bragg reflection, which would reflect about half of the optical power back to light incoming direction.

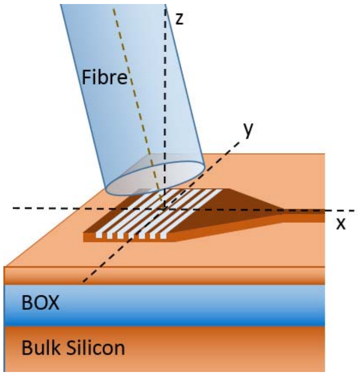

Fig. 1. Schematic illustration of fibre-chip grating couplers.

II. GRATING DESIGNS AND OPTIMIZATIONS

Two dimensional Finite-Difference Time-Domain (2D FDTD) simulations were used to simulate the grating diffraction [3]. The grating couplers presented in this paper were optimized for coupling with only the transverse-electric (TE) mode. The devices are based on Silicon-on-Insulator (SOI) wafers with 220 nm thick top silicon and 2 μm thick buried oxide (BOX). Fibres were aligned with a tilting angle θ = 10° when assuming index matching gel applied on top of grating couplers, or fibre block as is realistic in practical packaging scenarios. The fabrication was performed in the nanofabrication cleanrooms in the University of Southampton. In order to simplify the fabrication process, a 70 nm etching process and a 120 nm etching process are implemented for our designs. The 70 nm etching process is provided in most silicon photonics foundries, which is optimized for shallow-etch uniform grating couplers. The 120 nm etching process was primarily used to form the slab waveguides. A 1000 nm thick PECVD oxide cladding was deposited on top of the photonic devices.

As a reference point, single-etch uniform grating couplers were first optimized for coupling at 1310nm wavelength. For this design, we are using only uniform shallow-etched trenches to diffract light, as illustrated in Fig.1. According to our simulations, a 70 nm etched grating also give the best result. It has a coupling directionality of 0.7 (defined as the ratio of up-coupled power over total out-coupled power). We achieved a simulated peak efficiency of 59% at 1310nm. The grating period Λ is 510nm with a fill factor $f = 0.55$ (defined as the ratio of trench width over the period).

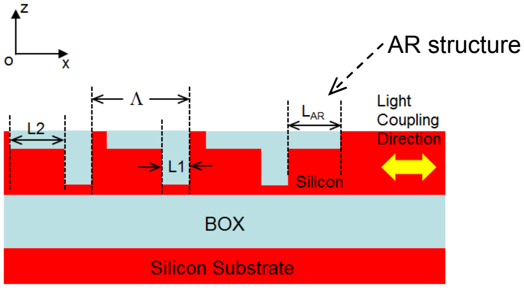

Fig. 2. Cross-section of dual-etch grating couplers (side-view).

Low loss grating couplers are essential to improve the overall device performance, such as high-speed modulators. Dual-etch grating couplers as shown in Fig.2 were employed to further improve the coupling efficiency. Similar to the design presented in [4], the dual-etch grating couplers were formed by using two etch depths and can have a much higher directionality. To simplify fabrication, we used a 120nm depth for the second etch which is the same as the process step used to form the rib waveguides in our modulator fabrication process, Simulations show that, with the 70 nm deep and 120 nm deep trenches, grating couplers can reach around 0.85 directionality for optimum designs. A directionality of 0.95 was achieved by simulation when the 120 nm and 70 nm deep etch processes are overlapped to achieve 190 nm deep trenches for the grating couplers. Using this approach a simulated coupling efficiency of 70% was achieved. For this design, the period, $\Lambda = 576$ nm, the width of 190nm depth grooves L1 is 104nm (corresponding to a 0.18 fill factor), the width of the 70nm depth grooves L2 is 317nm (corresponding to a 0.55 fill factor). The drawback of this grating coupler design is a high value of back-reflection of 10.4%. High back reflection would not only reduce the coupling efficiency, but would also induce interference and instability to the photonics circuits in which they are used. We have therefore included a section etched to a depth of 70nm etch in front of the grating coupler to reduce the back reflection as shown in Fig.2. After optimization by simulations, the width of the anti-reflection part is set to be 325 nm ($L_{AR} = 325$ nm). The final design gives a coupling efficiency of 71% with 6% back reflection.

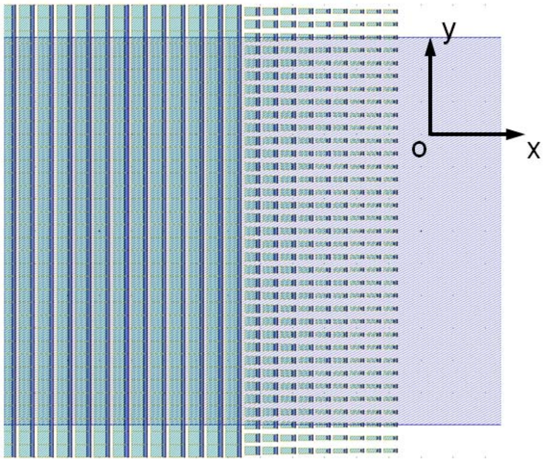

Fig. 3. Mask layout for the apodized subwavelength grating coupler

We can further improve the coupling efficiency by apodizing the dual-etch grating to improve the mode matching efficiency with optical fibres [3, 5]. In general, we want to keep all dimensions larger than 100 nm for the ease of fabrication and compatibility with DUV-193nm processing as it would typically be used in high volume production. Unlike some apodized design demonstrated previously, the fill factor in x-axis cannot be varied for an optimized directionality. We thus make use of subwavelength structures and change the lateral fill factor (in y-axis) to tune its coupling strength along light propagation direction [6]. The design was shown in Fig.3.

III. EXPERIMENTAL MEASUREMENT

All four types of grating couplers introduced in section II were fabricated and measured experimentally. E-beam lithography process was used for fabricating these gratings. Initial results were plotted in Fig.4. The single-etch uniform grating provides a peak efficiency of -4.1dB. The dual-etch samples show a slightly improved efficiency at about -3.8dB. About -2.2dB coupling efficiency was achieved with apodized subwavelength grating couplers. We can also observe that the dual-etch gratings have a very strong FP effect, caused by the strong back reflections. The AR structure has reduced the reflection at the front-end of the grating, as the FP effect with 0.1 nm pitch is reduced.

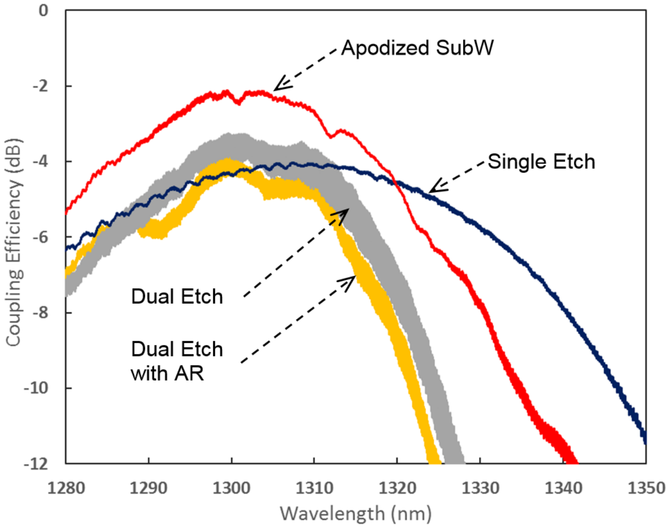

Fig. 4. Typical measured results for the four types of grating coupler presented in section II, including the single-etch uniform grating couplers, dual-etch grating couplers, dual-etch grating couplers with AR structure and apodized subwavelength grating couplers.

For the initial tests, no index matching gel was used. So we changed the fibre tilting angle ($\theta = 14.5^0$) to compensate the refraction on the top surface of oxide cladding. The air gap between fibre and chip will induce some additional loss. Our analysis suggests that there is also some overlay shift between those two etch steps because of inaccurate mask alignment. Further improvement is therefore under way to enhance the coupling efficiency.

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