Integrated Grating Coupler/Power Splitter for On-chip Optical Power Distribution

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***Abstract*—We present a novel fiber grating coupler structure with integrated 16-way power splitter. The device has a total coupling efficiency of -3.23dB (2.48dB better than a single grating coupler) and a nonuniformity of 1.1dB.**

I. Introduction

Submicron silicon photonics waveguides offer the potential of large-scale integration. However, the current lack of efficient on-chip light sources requires efficient coupling of an off-chip optical light source as an optical power supply for the rest of the chip. Given the cost of the external laser integration, it can be advantageous when a small number of such lasers can be used, combined with an on-chip splitter tree distribution network [1]. Because one laser needs to feed many parts of the optical circuit, the initial coupled power should be quite high. However, in silicon, the optical power that can be efficiently guided in a submicron wire waveguide is limited by nonlinear processes: two-photon absorption and subsequently free carrier absorption. These effects kick in at powers as low as 10 mW in a 450 nm wide silicon strip waveguide, and at 50 mW the additional propagation loss due to nonlinear processes is already 3 dB/cm. This limits the maximum on-chip power of an external laser, and therefore the number of on-chip subcircuits that it can power.

We propose a coupling scheme where the external optical power is never confined in full into a single waveguide core. Rather, the coupler distributes the power immediately over N waveguides (N=16 in our case). For this, we use a variation on the grating coupler which is commonly used in silicon photonics [2]. The principle is shown in Figure 1: a curved grating diffracts the external light into the silicon slab, but unlike a traditional curved grating coupler, the light is not focused into a single waveguide [3], but rather defocused towards a set of apertures, similar to star couplers used for arrayed waveguide gratings (AWG) [4]. The individual apertures are tailored to capture an equal amount of power diffracted from the grating and then taper towards a single-mode waveguide. This way, the optical power is never confined in a single waveguide, but immediately distributed, reducing the highest local power density with two orders of magnitude.

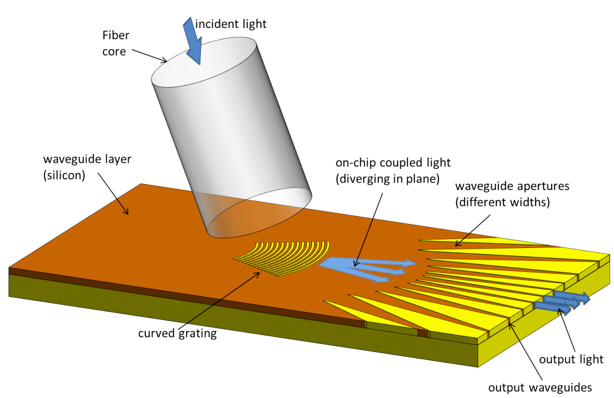

Fig. 1. Grating Coupler + Power splitter. The grating distributes the external light over the N output waveguides.

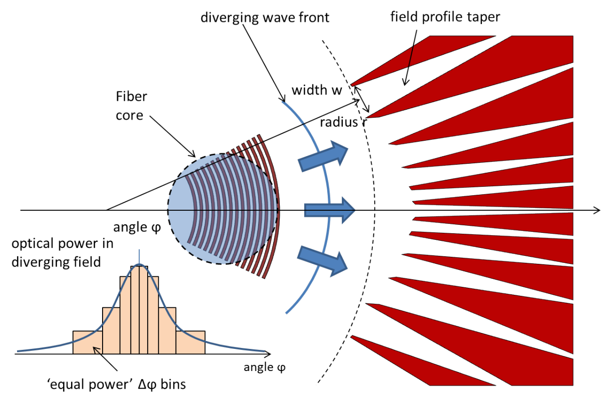

Fig. 2. Design of the star coupler. The angular spread of the diverging light is distributed over equal power bins.

II. Design

The design consists of two parts: the grating and the star coupler. The grating is designed similarly as a focusing grating coupler by periodic confocal elliptical lines [3]. But the fiber is not oriented towards the focal point, but rather away from it. The grating period is calculated for a 10 degree fiber angle at 1550nm wavelength. We use a poly-silicon overlay to improve the coupling efficiency [5].

For the star coupler we start from the focal point of the grating coupler, from which the phase fronts diverge. We assume a Gaussian distribution of the optical power, corresponding to a fiber mode. A uniform star coupler will then give the same Gaussian distribution over the outputs. However, in a power distribution network, a homogeneous power distribution

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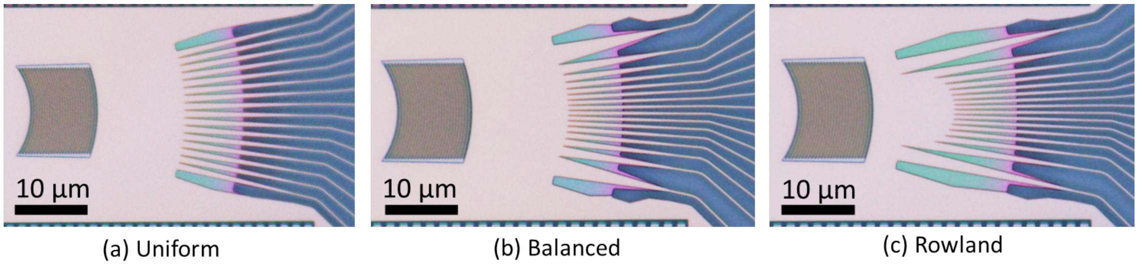

Fig. 3. Microscope images of fabricated power splitters with a defocusing grating coupler and a uniform (a), balanced (b) and Rowland (c) star coupler design.

is needed. Therefore we adapted the star coupler such that all apertures capture the same power. To homogenize the power distribution, we considered the radially diverging phase front and split it up into equal power bins along the in-plane angle ϕ. The different angular coverages can then be realized by changing the widths and radial positions of the individual apertures. This is illustrated in Figure 2. The radius and width give us a remaining degree of freedom. We used different schemes, ranging from a fixed radius to a fixed width, but found that the best results are achieved when using a more balanced approach, such as mounting the apertures on a Rowland circle and then modifying the widths accordingly. The design and simulation of the device was done using the IPKISS parametric design framework, and a Fresnel diffraction engine for the star coupler [4].

III. Fabrication and Characterization

A. Fabrication

The devices were fabricated in *imec*'s advanced passives silicon photonics platform on an SOI wafer with 220nm silicon on a $2\mu m$ buried oxide [5]. The fabricated devices are shown in Figure 3. We fabricated the star coupler power splitters both for different trade-offs between aperture width and radius. As a reference, we also included a design with a uniform star coupler (all radii and aperture widths identical) which is expected to have a Gaussian-like power distribution.

B. Characterization method

We characterized the devices using an automated twin-fiber probe station. Both fibers can be automatically positioned based on the design data. For the grating couplers in the center of the splitter, the position of the input fiber is optimized with the output fiber located on one of the center outputs. The input fiber is then kept in place while measuring the transmission on all the outputs. The result is normalized against the efficiency of a single-port grating coupler, which was -5.71dB.

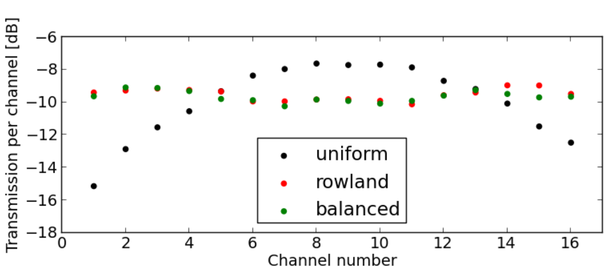

Fig. 4. Output power in each channel for different designs of defocusing grating coupler enabled power splitters.

IV. Experimental Results

Figure 4 shows the normalized transmission for each of the 16 channels of the power splitter. It is clear that for a uniform star coupler we indeed get a Gaussian distribution over the output channels. In case of a ”balanced” or a ”Rowland” configuration however, a more uniform power distribution is obtained in both cases. The ”balanced” configuration yields a maximum power imbalance of only 1.11 dB. Furthermore, it is found that the total coupling efficiency is 2.48dB higher than that of a normal focusing grating coupler, at -3.23dB. This is possible because the power is collected over a larger area in case of the defocusing grating coupler, making it more tolerant to imperfections in e.g. the grating teeth. A slightly higher total efficiency, but with a somewhat larger imbalance, was found for the ”Rowland” configuration.

V. Conclusion

We have demonstrated an integrated grating coupler and 16-way power splitter. A power uniformity over 16 channels better than 1.11 dB has been achieved and the devices are more tolerant compared to standard focusing grating couplers, which becomes apparent from the lower insertion loss compared to a single-channel grating coupler.

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References

[1] L. Vivien, S. Lardenois, D. Pascal *et al.*, *Appl. Phys. Lett.*, vol. 85, no. 5, pp. 701–703, Aug 2004.

[2] D. Taillaert, F. Van Laere, M. Ayre *et al.*, *Jpn. J. Appl. Phys.*, vol. 45, no. 8A, pp. 6071–6077, 2006.

[3] F. Van Laere, T. Claes, J. Schrauwen *et al.*, *Photon. Technol. Lett.*, vol. 19, no. 23, pp. 1919–1921, 2007.

[4] S. Pathak, M. Vanslembrouck, P. Dumon *et al.*, *J. Lightwave Technol.*, vol. 31, no. 1, pp. 87–93, 2013.

[5] D. Vermeulen, S. Selvaraja, P. Verheyen *et al.*, *Opt. Express*, vol. 18, no. 17, pp. 18 278–18 283, 2010.