Grating couplers under flood illumination as a low-cost readout mechanism for photonic sensors

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Grating couplers are a vital component for integrated photonics, as they provide an interface with the chip from anywhere on the surface. Conventionally, they are used with optical fibers, providing excellent power efficiency. The grating couplers are designed to match the size of the fiber mode. The alignment of the fiber to the chip requires high precision, rendering the couplers incompatible with applications where a low cost is crucial, like point-of-care biosensors. We present a reoptimization of grating couplers, for usage with a light source that illuminates an area much larger than the grating coupler, strongly reducing the required precision.

Introduction

Grating couplers are an integrated photonic structure, consisting of periodically etched waveguide. Through this sub-wavelength periodicity, light incident on the structure from inside the waveguide will be partly diffracted out of the waveguide and vice versa, providing an interface to and from the chip. The angle under which this happens for a given wavelength is given by the Bragg condition:

$$\frac{2\pi}{\lambda} n_{eff} = \frac{2\pi}{\lambda} \sin\theta + \frac{2\pi}{\Lambda}$$

Where λ is the wavelength, θ is the angle with respect to the normal of the chip surface, Λ is the pitch of the grating coupler. n_{eff} is the effective refractive index of the grating coupler waveguide [1].

Such devices are an essential building block for integrated photonic structures, as they provide an interface to and from the outside world from anywhere on the chip surface. Therefore, they have been developed for numerous material platforms as well as wavelength ranges [2,3]. The common usage is in combination with an optical fiber, which is typically brought within proximity of a few μm of the chip surface. The size and the extinction length of the grating coupler are adapted to match the mode of the optical fiber as much as possible to limit the losses. For basic design, these grating couplers of around 10 μm in length and width yield losses of around 5 dB when coupling to and from an optical fiber [1,2,3].

A drawback of this method of coupling light to and from the chip is the required precision of alignment, as a positional mismatch of a few μm of the fiber relative to the grating coupler already causes additional losses of several dBs [4]. This means that highly precise, typically expensive alignment equipment is required. For numerous potential applications, such as point-of-care diagnostics and environmental monitoring, low cost is essential and such expensive alignment mechanism becomes impossible.

We propose an alternative use of the same grating couplers, where the high alignment precision is no longer required. Rather than an optical fiber, we use a free space light source, where the light is collimated to a spot on the chip, typically a few 100 μm in size. This technique is commonly known as flood illumination. While greatly reducing the required alignment accuracy, such an approach also strongly reduces the amount of light coupled by the grating coupler, as only a small fraction will be incident on the grating coupler. To mitigate these losses, we reoptimize the design of grating couplers for this new coupling mechanism, without requiring additional processing steps. This will mainly involve changing the length of the grating coupler, as the etch depth for the given fabrication scheme was set at 0.5, but the latter will be investigated separately as well. The material parameters used in this work are those of silicon nitride waveguides on a silicon oxide cladding operating in the very near infrared [5], but the conclusions are qualitatively valid for any similar high-index-contrast material platform.

The figure of merit for such a grating coupler depends on the application, as in some cases only optimizing a specific wavelength will be of importance, while others require sufficient power within a certain interval. We will comment on both cases, with a focus on the latter, as these devices are developed with the intention of using them in a photonic sensor circuit requiring adequate power within a 20 nm interval [6].

Increasing the grating coupler length

To simulate these structures, FDTD techniques were used. To limit the scope and time of these simulations, infinitely wide grating couplers were used, so only the effect of changing the length was verified. The results are shown in figure 1, where both the transmitted power at peak wavelength and the full width at half maximum (FWHM) of the transmission spectrum are shown as a function of the number of periods used in the grating coupler. The standard grating coupler, used for coupling to and from an optical fiber, has 20 periods. For these simulations, a plane wave source was used, as the light hitting the grating coupler through flood illumination will locally be a plane wave as well. To simulate the effect of flood illumination, the light source was numerous times larger than the biggest grating coupler. The results for transmitted power are normalized with respect to the standard grating coupler. Like in the platform that will be used for fabrication, the etch depth is 50%. The fill factor is kept at 50% as well.

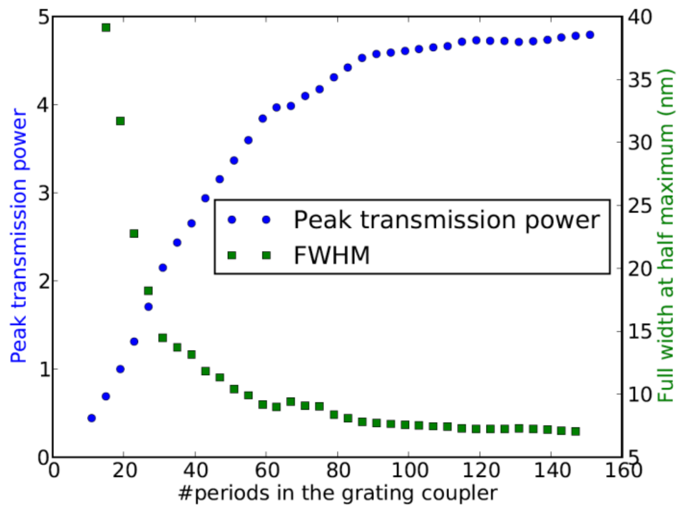

Figure 1: The peak transmission power and full width at half maximum of a grating coupler in function of number of periods. The former is normalized with respect to the grating coupler of 20 periods that is conventionally used for coupling light from optical fibers.

It can be clearly seen from figure 1 that the peak power increases width increasing length, by up to a factor 5. The added grating teeth add surface area to the grating coupler, increasing the total incident power. Because of the extinction of the grating coupler, the teeth at the end will contribute considerably less, and over 100 periods the effect of additional periods gradually becomes negligible and saturation occurs.

The FWHM on the other hand, decreases for increasing grating coupler length. This can be understood as follows: By adding periods, we are better approaching the transmission spectrum of a perfect, infinitely long grating coupler which is infinitely narrow. Similar to the peak power increase, this decrease in bandwidth is initially very strong, but saturates for high number of periods.
The combination of the increase in peak power and the reduction of bandwidth imply that the power in a given bandwidth will saturate as well. This is illustrated in figure 2, where the power in an interval of 20 nm around the peak wavelength is shown, the figure of merit for the given application. Here we see a steep increase at first, until the increase saturates at a factor 2.5 around 60 periods, even faster than the peak intensity, due to the added effect of the reduced bandwidth. This implies that additional periods beyond this point are useless and potentially even harmful for the given application.

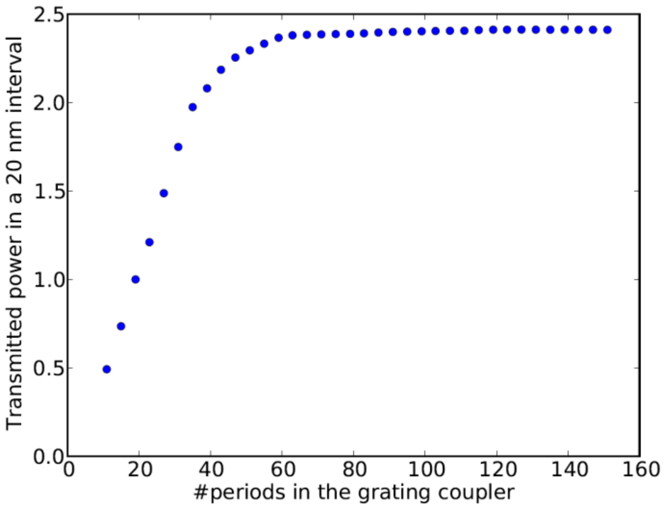

Figure 2: The total transmitted power in a 20 nm interval around the peak wavelength in function of the number of periods in the grating coupler, normalized with respect to the grating coupler of 20 periods.

Etch depth

While the previous paragraph focuses on an etch depth of 50%, as will be the case in the fabricated devices, a lower etch depth is potentially interesting for flood illumination, as it increases the extinction length of the grating coupler and thusly improves the added contribution of the additional periods. On the other hand, an etch depth that is too shallow will reduce the diffraction of the incident light, so a compromise has to be made. To verify the optimal position of this compromise, the simulation of figure 2 was repeated for numerous etch depths, displayed in Figure 3. As expected, a lower etch depth results in a slower saturation of the increase in transmission. The saturation power level in turn also depends on the etch depth, a very deep etch will have a comparatively low saturation level, as only the light incident on the very beginning of the grating coupler contributes significantly. For very shallow etches on the other hand, the saturation value is not even reached within the extensive scope of the simulation. The optimal value is an intermediate one, 64 nm, as expected this is significantly lower than the 50% etch commonly employed for fiber coupling.

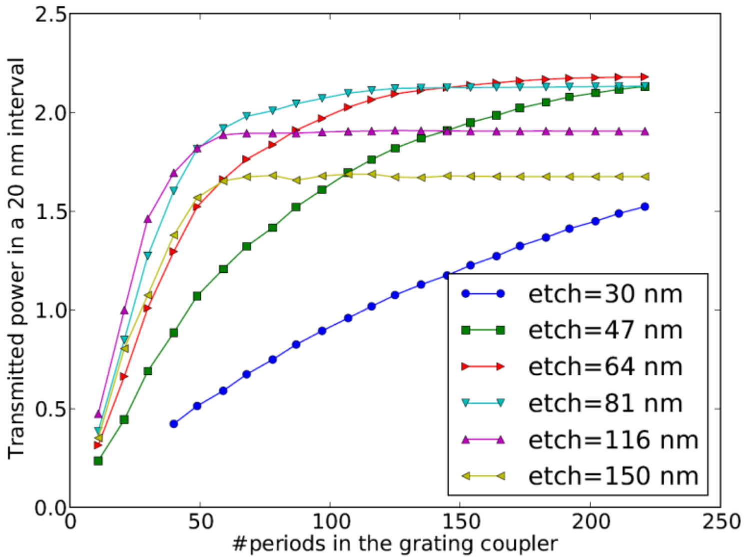

Figure 3: The total transmitted power in a 20 nm interval around the peak wavelength in function of the number of periods in the grating coupler for different etch depths. Normalized with respect to the grating coupler with an etch depth of 116 nm and 20 periods.

Conclusion

An alternative approach to couple light to and from a chip with grating couplers was proposed, using flood illumination instead of optical fibers. This reduces the required alignment precision severely, and thusly eliminates an important hurdle for point-of-care applications. Through adapting the grating coupler length to this technique, the peak and broadband transmissions were improved by a factor 5 and 2.5 respectively.

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