Polarization Insensitive Grating Coupler Based on a Zero-Birefringence Corelet Waveguide

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Abstract: We propose a polarization insensitive grating coupler using a zero-birefringence corelet waveguide. Simulations show coupling of −5.4 dB for TE and −5.6 dB for TM at 1.3 μm wavelength and a 61 nm polarization insensitive 3 dB bandwidth.

Integrated photonic grating couplers vertically emit light from a planar photonic circuit and enable important applications ranging from fiber-to-chip optical coupling [1] to beam forming for ion trapping [2] and optical phased arrays [3, 4]. One of the major challenges in using grating couplers is that the standard single input waveguide implementation is highly polarization sensitive. This is because a standard grating coupler has large birefringence, which causes transverse-electric (TE) and transverse-magnetic (TM) polarized light to emit at very different angles and with different radiation profiles. Fiber to grating coupler coupling efficiency is highly dependent on both radiation angle and profile, thus the standard grating coupler can efficiently couple to TE or TM polarization, but not both simultaneously. To solve this problem, previous work has mainly focused on polarization beam splitting (PBS) gratings with two input waveguides [5]. While PBS gratings have been claimed with insertion loss as low as 2.7 dB [5], they are rather complicated to design (e.g. designed by supercomputer optimization) due to the large parameter space and symmetry constraints. Instead, a simpler, single input waveguide polarization insensitive grating coupler can be designed by removing birefringence from the grating coupler. The angle of diffraction is dependent (to first order approximation) on the grating coupler waveguide's effective index as given by $\theta = sin^{-1}\left(\frac{n_{\text{eff}}k_0 - \frac{2\pi}{\Lambda}}{n_{\text{clad}}k_0}\right)$, where n_{eff} is the waveguide mode's effective index, Λ is the grating pitch, k_0 is the free space propagation constant, and n_{clad} is the cladding material index. When both polarizations share the same n_{eff} and similar field profiles, then the diffracted beams will radiate to the same output angle with similar radiation profiles, enabling efficient and polarization independent coupling. This has been initially demonstrated by [6], however, the design uses alternating regions of opposite birefringence which complicates the design strategy.

In this work, we propose a new polarization insensitive grating coupler design which uses alternating regions of zero-birefringence material systems - low index homogeneous SiO_2 and a high index zero-birefringence 'corelet' waveguide - to construct a grating coupler with low birefringence. The key to the design is the zero-birefringence corelet waveguide, which is designed by considering mode evolution from a wider-than-tall to a taller-than-wide waveguide. A standard 1-D grating coupler uses a wider-than-tall waveguide, where the fundamental TE (TE_{11}) polarized mode's n_{eff} is larger than that of the fundamental TM (TM_{11}) mode. For a rectangular waveguide, the amount of birefringence depends on the aspect ratio of the waveguide's width and height. Because a grating coupler is typically much wider than it is tall (13 μm wide to 220 nm thick in this proposed device to couple to an SMF-28 fiber), TE_{11} has much higher n_{eff} than TM_{11}. In contrast, a taller-than-wide waveguide's TM_{11} mode will have larger n_{eff} than TE_{11}. The key design concept is to use a transitional geometry between a taller-than-wide and a wider-than-tall waveguide such that the TE_{11} and TM_{11} modes have equal n_{eff}, while retaining a 13 μm total width. The geometry transition to consider is to start with a small, taller-than-wide waveguide 'corelet', and construct a wide waveguide using a transverse array of these corelets, as shown in Fig. 1(a-c). A 5 μm wide waveguide is shown for ease of visualization, however the same design strategy extends to any total waveguide width. A 200 nm wide and 220 nm tall corelet is used, however, any corelet that is taller-than-wide will suffice. Since the corelet's aspect ratio is taller-than-wide, an individual corelet's TM_{11} mode has the higher n_{eff}. When the spacing between corelets in the array is large, as shown in Fig. 1(a), the corelets can be approximated as individual taller-than-wide waveguides which do not perturb each other. Because the individual corelet fields are not strongly perturbed, the "supermode" effective indices are closer to that of the individual corelets, resulting in the TM_{11} "supermode" having the higher n_{eff}. As the corelets are brought closer together, they will eventually merge into a solid-core, wider-than-tall waveguide where the TE_{11} mode has the higher effective index, as shown in Fig. 1(c). The result is that there will exist a transverse separation where the TE_{11} and TM_{11} effective indices intersect, satisfying the condition for zero birefringence. For the considered corelet geometry, zero birefringence occurs at 100 nm separation. The geometry and field profiles for the zero-birefringence corelet waveguide is shown in Fig. 1(b), and n_{eff} as a function of corelet separation is shown in Fig. 1(d).

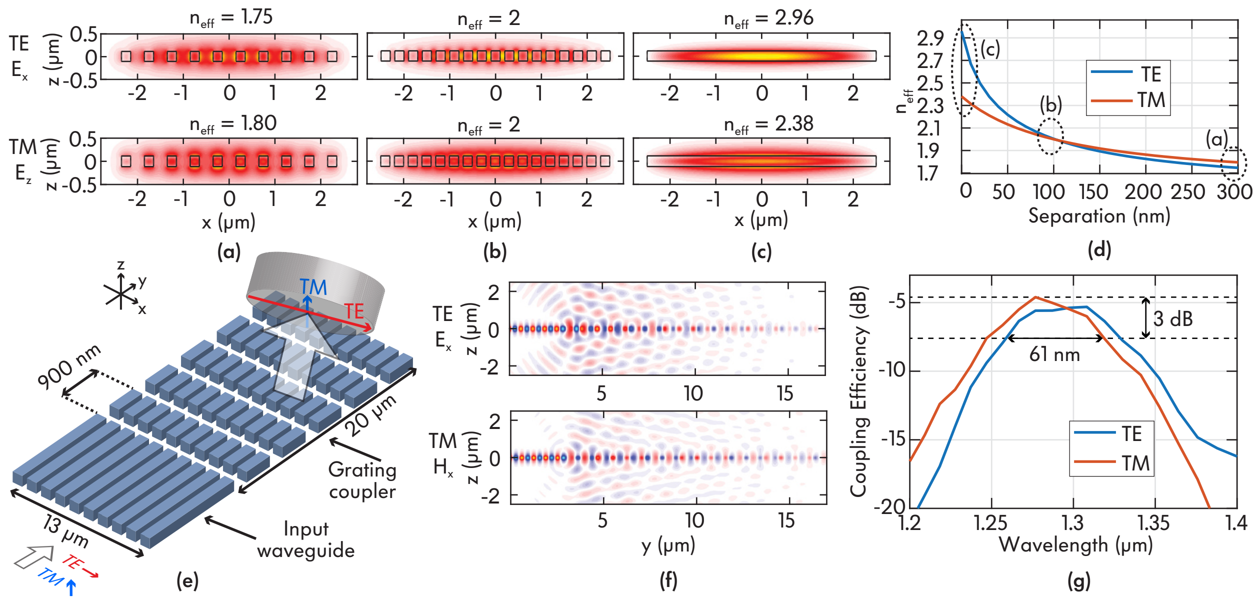

Fig. 1: E_x and E_z components of TE_{11} and TM_{11} modes, respectively, at 1.3 μm wavelength for (a) a 5 μm wide silicon-on-insulator (SOI) corelet waveguide with 300 nm separations, (b) zero-birefringence corelet waveguide with 100 nm separations, (c) a solid-core 5 μm wide SOI waveguide. (d) Effective index versus corelet separation. Labels indicate plotted geometries in Fig. 1(a-c). (e) Graphical illustration of polarization insensitive grating coupler (not to scale). (f) 3D FDTD simulation results. E_x and H_x field components are shown for TE and TM sources, respectively. (g) Coupling efficiency versus wavelength to fiber angled at 12° off normal.

Using the zero-birefringence waveguide, we design a polarization independent grating coupler. The grating coupler consists of alternating regions of corelet waveguide and SiO_2 with uniform pitch and duty cycle, as illustrated in Fig. 1(e). We design for coupling to an SMF-28 fiber (mode field diameter of 9.2 μm at 1.3 μm wavelength), angled at 12° off normal. A total waveguide width of 13 μm, longitudinal pitch of 900 nm, and longitudinal duty cycle of 65% is chosen for this design. The simulated E_x and H_x field components for TE and TM waveguide sources, respectively, are shown in Fig. 1(f) (simulated by 3D FDTD). By observation, it is clear that the radiated fields have similar profiles. Figure 1(g) shows the coupling efficiency (overlap of radiated and fiber mode, multiplied by upwards power transmission), when the fiber is angled at 12° off normal and positioned for best TE coupling at wavelength of 1.3 μm. At wavelength of 1.3 μm, the coupling efficiency is -5.4 dB for TE polarization and -5.6 dB for TM. There is a 61 nm bandwidth where both polarizations' coupling efficiencies is greater than 3 dB below the peak TM coupling efficiency, which we define as the polarization independent 3 dB bandwidth. We observe that while the grating coupler can operate at both TE and TM at the center wavelength, the overall TM coupling efficiency spectrum is slightly blue-shifted from the TE spectrum by approximately 10 nm. This is due to the fact that a small amount of birefringence is re-introduced from the longitudinal grating patterning. The most likely cause of the additional birefringence is the large amount of longitudinal (E_y) field in the TM mode, which is discontinuous at the longitudinal gap boundaries and thus causes the TM grating Bloch mode to have slightly lower effective index compared to the TE Bloch mode. This shift can be compensated for by either slightly increasing the transverse corelet spacing or narrowing the corelet width such that the corelet waveguide's TM_{11} mode has slightly higher effective index.

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