Colorless Grating Couplers Realized by Interleaving Dispersion Engineered Subwavelength Structures

Xiaochuan Xu[1,*], Harish Subbaraman[2], David Kwong[1], John Covey[1], Amir Hosseini[2], and Ray T. Chen[1]
[1]The University of Texas at Austin – 10100 Burnet Rd, PRC/MER 160, Austin, TX 78758 (USA)
[2]Omega Optics, Inc – 10306 Sausalito Dr, Austin, TX 78731 (USA)
Author e-mail address: (xiaochuane.xu@utexas.edu, raychen@uts.cc.utexas.edu)

Abstract: A wideband grating coupler based on interleaving dispersion engineered subwavelength structures has been proposed and experimentally demonstrated. The fabricated device shows a coupling efficiency of 5.1dB and a 1dB bandwidth of 70 nm.

OCIS codes: (050.2770) Gratings; (050.6624) Subwavelength structure; (350.4238) Nanophotonics and photonic crystals;

During the past decade, people have witnessed the rapid development of silicon photonics [1-4]. One of the foreseeable obstacles lying ahead is fiber-to-chip coupling [4]. Grating couplers have been considered as one of the potential methods to resolve this problem [5-9]. One significant feature that grating couplers possess is their inline testing capability, which increases the throughput, thus reducing the cost. Compared to its inverse taper counterpart, grating couplers also have competitive performance, except in bandwidth, which is intrinsically limited by waveguide dispersion, [8]. A widely exploited method to reduce waveguide dispersion is to reduce the average effective index of the grating [8]. When the effective index decreases, the light becomes loosely confined [8]; therefore, the waveguide boundary is less wavelength sensitive. The drawback of this approach is that the decrease of average effective index sacrifices the index contrast between the cladding material and the grating. Hence, there is a compromise between efficiency and bandwidth. In this paper, we show that the waveguide dispersion can be effectively controlled by reducing the period of a subwavelength structure Λ_G. A TE-polarized wideband grating coupler with 70 nm 1-dB bandwidth has been demonstrated based on this principle.

The dispersion curves of the fundamental modes of subwavelength structures with different filling factors W_{sub}/Λ_{sub} are shown in Fig. 1(a). The fundamental modes exhibit different dispersion characteristics for small and large frequencies. The inset of Fig. 1(a) shows that the effective index gradually evolves into a constant value as the wavevector K decreases. To better understand this phenomenon, the effective index versus wavelength relation for different subwavelength periods Λ_{sub} is plotted in Fig. 2(b) (red). When the filling factor W_{sub}/Λ_{sub} is fixed at 0.1, the dispersion can be reduced through reducing the subwavelength period Λ_{sub} .The blue curves in Fig. 1(b) are the corresponding waveguide dispersions. When Λ_{sub}=200nm, the waveguide dispersion is around -0.08/μm, which is about one third of the value (about -0.24/μm) when Λ_{sub}=400nm. This phenomenon can be interpreted by stating when Λ_{sub} is much smaller than the wavelength inside the waveguide, the light cannot "sense" the periodic structure [10]. Therefore, the effective index is no longer sensitive to wavelength. For design convenience, the effective index versus filling factor relation (at λ=1.55 μm) is extracted and plotted in Fig. 1(c). The corresponding waveguide dispersion is also plotted in the same figure.

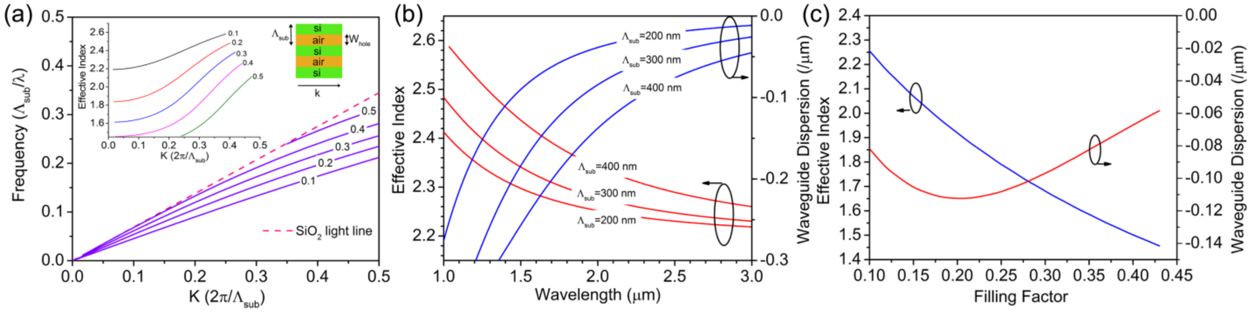

Fig. 1. (a) The dispersion curves of subwavelength structures with different filling factors 0.1~0.5 and the effective index versus wave vector (inset), (b) effective index versus wavelength for different subwavelength period Λ_{sub}(red), and the corresponding waveguide dispersion(blue).(c) The effective index versus filling factor relation when the wavelength is 1.55 μm (blue) and the corresponding waveguide dispersion (red).

To fully exploit the benefits of dispersion engineered subwavelength structures, a grating coupler with interleaved subwavelength structures is designed, as shown in Fig.2a. The grating period, effective indices of high and low index regions, and the filling factor are scanned through the open source software CAMFR while treating the subwavelength structure as a uniform material based on the effective medium theory(EMT). A detailed description on the simulation procedure can be found in Ref. [5]. The optimized period is 1.24 μm, and the filling factor is 0.5. The refractive index of the high index region is 2.55 (effective index 2.02) and low index region 1.75 (effective index 1.46). The corresponding filling factor is 0.43 (86 nm) and 0.20 (40 nm), respectively, which are calculated by using the spline fitting of the effective index versus filling factor curve in Fig. 1c.

The grating is fabricated on silicon-on-insulator (SOITEC, 250nm silicon/3μm buried oxide/650 μm silicon handle) with electron beam lithography and reactive ion etching (HBr/Cl_2). To achieve 40 nm line widths, a fabrication recipe with diluted resist and hardmask has been developed. The scanning electron microscopy photograph of the fabricated grating is provided in Fig. 2b. The grating is 13 μm wide and 17 μm long. To test the grating performance, two identical gratings are connected by a 2.5 μm wide waveguide. The gratings and the waveguide are connected by 500 μm long linear tapers. The grating test setup described in Ref. [5] is used to characterize the grating performance. Index matching oil is used to reduce reflections and to shift the emitting angle θ to ~16° . The transmission spectrum is shown in Fig. 2c. The 1 dB bandwidth of the grating coupler is ~70 nm, and the peak efficiency is ~5.1 dB. Limited by the spectrum range of our broadband source, only the transmission between 1510nm and 1610nm can be examined. The Fabry-Perot fringes are ~0.4 dB, indicating low reflection.

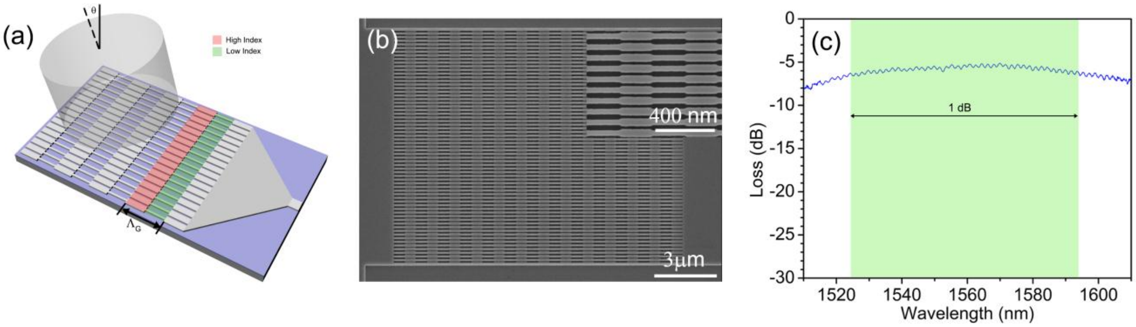

Fig. 2. (a) Schematic of the wideband grating coupler. (b) Scanning electron microscope of the fabricated grating coupler. A magnified view of the grating coupler, showing the interleaved subwavelength structures.(d) The transmission of the grating coupler. 1-dB bandwidth is ~70 nm, which is marked with a light green background.

In conclusion, we proposed and experimentally demonstrated a colorless grating coupler based on interleaving dispersion engineered subwavelength structures. The grating demonstrates a coupling efficiency of 5.1dB and a 1 dB bandwidth of 70 nm.

References

1. M. Asghari et al, "Silicon photonics: Energy-efficient communication," Nat Photon **5** (5), 268 (2011)
2. A. Hosseini et al, "Large optical spectral range dispersion engineered silicon-based photonic crystal waveguide modulator," Opt. Express 20, 12318-12325 (2012)
3. X. Xu et al. "Stamp printing of silicon-nanomembrane-based photonic devices onto flexible substrates with a suspended configuration". Opt. Lett. 37, 1020-1022 (2012)
4. M. Lipson et al "Guiding, modulating, and emitting light on silicon-challenges and opportunities," J. Lightwave Technol. **23** (12), 4222 (2005).
5. X. Xu et al. "Complementary metal–oxide–semiconductor compatible high efficiency subwavelengthgrating couplers for silicon integrated photonics," Appl. Phys. Lett. 101, 031109 (2012)
6. L. Liu et al., "High-efficiency, large-bandwidth silicon-on-insulator grating coupler based on a fully-etched photonic crystal structure," Appl Phys Lett 96 (5), 051126 (2010)
7. H. Subbaraman et al. Efficient light coupling into in-plane semiconductor nanomembrane photonic devices utilizing a sub-wavelength grating coupler," Optics Express. 20, 20659-20665 (2012)
8. X. Xia. et al. "Wideband subwavelength gratings for coupling between silicon-on-insulator waveguides and optical fibers,"Opt. Lett. 37, 3483-3485 (2012)
9. Y. Tang, Z. Wang, L. Wosinski, U. Westergren, and S. He, "Highly efficient nonuniform grating coupler for silicon-on-insulator nanophotonic circuits," Opt. Lett. 35 (8), 1290 (2010)
10. John D. Joannopoulos, "Photonic crystals: Molding the flow of light"

Acknowledgements

This research was funded by Air Force Office of Scientific Research (Dr. GernotPomrenke,Program Manager) under Contract number: FA9550-11-C-0014.