Bandwidth-Enhancement of Silicon Grating Couplers Using Dispersive Coatings

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***Abstract*—The design of a highly efficient fiber-to-chip link using a silicon grating coupler with an enhanced optical bandwidth in a 250 nm silicon-on-insulator platform is presented. Consisting of a standard grating coupler with backside mirror and a special dispersive coating, this link offers a simple design and an enhanced 1-dB-bandwidth. Special attention is paid to the influence of the coating-dispersion on bandwidth. Optical simulations demonstrate the performance of the fiber-to-chip links at a wavelength of about 1550 nm and for the transverse electric waveguide mode.**

I. Introduction

The demand for highly efficient, stable and ultra-broadband optical fiber-to-chip links in the fields of communications, medicine and biotechnology encourages the development of advanced silicon photonic grating couplers. Meanwhile, the achieved coupling efficiency for a single polarization is about -0.6 dB at a wavelength of 1550 nm with 1-dB-bandwidths of 40 nm [1-2]. This high efficiency in the grating designs is realized with the help of aperiodic silicon grooves and bars to match the Gaussian fiber mode more accurately, and with the help of reflectors to enhance the coupling directionality, e.g. with a metal layer adapted on the backside of the chip. In designing a suitable grating coupler for a specific application there is always a tradeoff between the achievable bandwidth and the maximum efficiency, which is clarified with the help of a few benchmarks of published grating coupler efficiencies with their corresponding bandwidths in Table I. Although these gratings are well suited for stable fiber-to-chip links with packaging processes as described in [5-6], the usable optical spectrum is limited. A change of the fiber-coupling angle or the active controlling of the grating coupler with thermal heaters [7] shifts the usable wavelength range but do not extend the optical bandwidth. For receivers using several wavelength channels in a wavelength division multiplexing (WDM) system or for the coupling of spectrally broad signals in a lab-on-a-chip a broadband fiber link an extended optical bandwidth and a flat top characteristic is desirable. A first design with an additional complex optic layer on top of a silicon grating to enhance the usable bandwidth is described in [8] with a simulated bandwidth of 126 nm. In this work, we present alternative simple grating add-ons, which include only dispersive claddings and are adapted to a high efficient grating in the INT/IMS CHIPS silicon-on-insulator (SOI) technology [2]. Fig. 1 depicts the schematic view of the proposed fiber links including the dispersive claddings on top of the grating. In this work, the optical influence of the cladding is investigated and the ideal properties for a high bandwidth and a high coupling efficiency are examined with the help of simulations.

TABLE I
A Comparison Of Coupling Efficiencies (η) And 1-dB-Bandwidths (bw)

Other publications[1]			This work	
η (dB)	bw (nm)	Ref.	η (dB)	bw (nm)
-0.58	38	[1]	-0.65	83
-0.6	40	[2]	-3.3	116
-5.1	70	[3]	-3.73	118
-4.7	100	[4]		

[1] Measured in the C-band and SOI-based.

The optical simulations are based on the eigenmode expansion method (EME) of the full-vectorial Maxwell solver in the cavity modelling framework (CAMFR) [9].

II. Influence Of The Cladding-Dispersion

Starting with an analysis of the existing grating design, the coupling efficiency depends on the coupling angle and fiber placement. Following the simulations and measurements in [2], high coupling efficiencies for 1500 nm, 1550 nm and 1600 nm can be achieved by a coupling angle of 13°, 9° and 5°, respectively. In simulations, a change of the refractive index of the cladding results in a spectral shift of the transmission maximum for a fixed angle, while the maximum efficiency is more-or-less unchanged. This behavior implies that adapting the cladding index has a similar influence on the transmission spectrum as adapting the fiber angle. Taking this consideration into account, a pure passive approach with a refractive index matching for different wavelengths is promising. For that matter the SiO_2 cladding is replaced with an artificial dispersive material (see Fig. 1(a)).

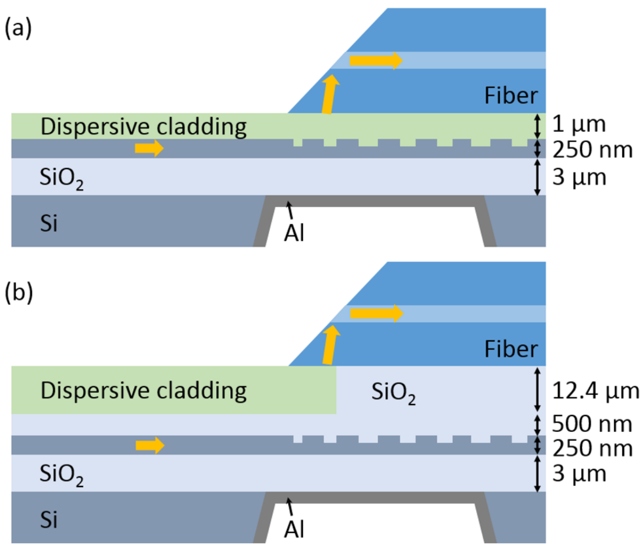

Fig. 1. The schematic views of the presented fiber-to-chip links are shown. The silicon grating couplers with a suitable dispersive cladding (a) and a structured dispersive cladding (b) offer an enhanced bandwidth.

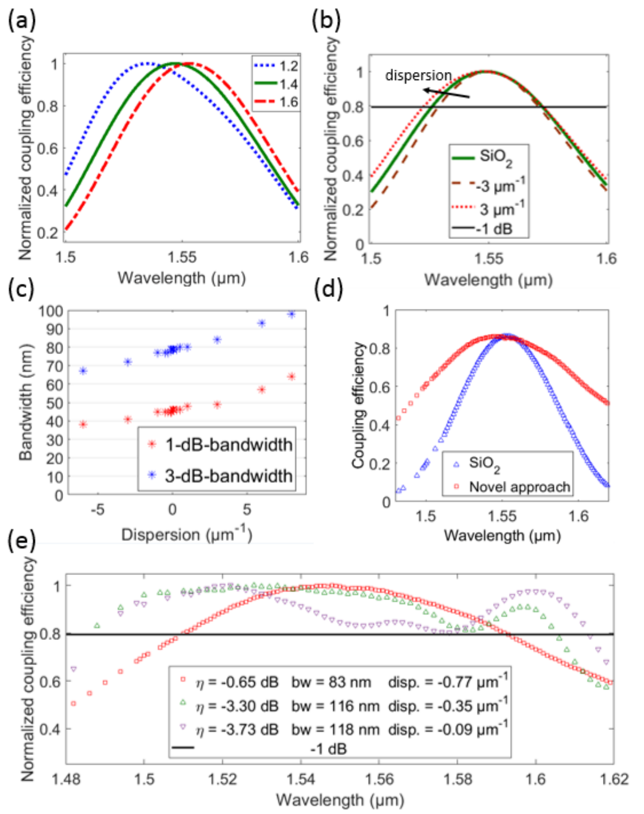

Fig. 2. Changing the claddings refractive index from 1.2 to 1.6 results in a spectral shift of the coupling efficiency maximum (a). A positive dispersion of the claddings refractive index has a positiv influence on the bandwidth (b). Taking different dispersion into account shows the trend between cladding-dispersion and bandwidths (c). An structured dispersive cladding results in 83 nm 1-dB-bandwidth with a dispersion value of -0.77 μm^{-1}. The corresponding coupling effiency versus wavelength is depicted in (d). Using a structured dispersive cladding and other aperiodic grating designs enhances the 1-dB-bandwidth (bw) further. The coupling efficiency (η) for such combinations is shown in (e).

To show the influence of the cladding, Fig. 2(a) depicts the simulated dependency of the transmission spectra for different refractive indices of an ideal non-dispersive cladding. For the introduced dispersive cladding regions in Fig. 1, the refractive index is fixed to 1.444 at 1550 nm and the shown cladding-dispersion influences the index values at e.g. 1500 nm and 1600 nm. Different dispersion values of the claddings refractive index are used in the simulations and the influence on the optical bandwidth is investigated (see Fig. 2(b)). With a suitable dispersion, the bandwidth increases without a degradation of the maximum coupling efficiency. A linear approximation with the data in Fig. 2(c) results in 1.8 nm/μm^{-1} and 2.2 nm/μm^{-1} for the dispersion-dependent enhancement of the 1-dB-bandwidth and 3-dB-bandwidth, respectively. Consequently, using a dispersive layer (e.g. adhesive) between Si grating and fiber can enhance the optical bandwidth of the gratings. If the refractive index of a dispersive cladding is not exactly 1.444 at 1550 nm, a change of the fiber angle can compensate this issue in a certain range. In the next step, a structured dispersive cladding layer is investigated (see Fig. 1(b)). The transition of the dispersive cladding to SiO_2 on top of the grating enhances the coupling angle optimization inside the fiber link at specific wavelengths. Fig. 2(d) shows the improvement of the bandwidth with a dispersion value of -0.77 μm^{-1} of the left cladding region. Combining this approach with other aperiodic grating designs (see Fig. 2(e)) in the same technology results in 1-dB-bandwidths of about 118 nm. Other cladding geometries may further enhance the bandwidth, but this study is focused on simple systems that are easy to fabricate and serious candidates for a down-market product.

III. Conclusion and Outlook

Design considerations and simulation results of a state-of-the-art Si grating coupler in combination with dispersive coatings are presented. A suitable dispersive coating (e.g. adhesive for packaging purposes) on top of the adapted silicon grating enhances the achievable bandwidth without a decrease in coupling efficiency at a wavelength of 1550 nm. The simulated bandwidth-improvements are approximately 1.8 nm/μm^{-1} and 2.2 nm/μm^{-1} for the 1-dB-bandwidth and 3-dB-bandwidth, respectively. Using structured dispersive claddings can enhance the bandwidth further. Simulations with optimized geometrical parameters show 1-dB-bandwidths of more than 100 nm with a cladding-dispersion of 0.09 μm^{-1}. While this work is focused on grating add-ons in combination with silicon grating designs in a 250 nm SOI platform, the dispersive coatings can be adapted for other designs.

Acknowledgment

The authors would like to thank Dr. W. Sfar Zaoui and A. Kunze for the adapted aperiodic grating design with backside mirror. Further, we thank C. Raichle for supporting the simulations regarding the bandwidth-enhancement.

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