A Metamaterial Converter Centered at 1490nm for Interfacing Standard Fibers to Nanophotonic Waveguides

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Abstract: We present data with both manual probing and self-aligned 12-fiber automated assembly. We find a peak transmission efficiency of -1.6 dB and a Fabry-Perot oscillation on one polarization induced by a mask layout misstep.

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1. Introduction

Low-cost and scalable optical inputs and outputs are a notable challenge for large-scale deployment of silicon photonics. A typical approach combines vertical grating couplers with active alignment [1]. However, diffractive couplers suffer from inherently limited spectral bandwidth and a notable performance penalty at two-polarization operation. In addition, active alignment requires manual assembly or custom assembly tools. This raises the cost of assembly and limits the scalability in fiber count and manufacturing volume.

For an essential leap forward in assembly cost and scalability, we have recently proposed leveraging standard high-throughput microelectronic pick-and-place tools for photonic assembly [2]. Our parallelized fiber assembly scheme is shown in Fig. 1. A short MT ferrule with a cleaved standard fiber array is assembled to a photonic die with the help of a polymer lid [3]. A V-groove array integrated on chip warrants the self-alignment of fibers to on-chip couplers.

We use in-plane coupling to enable the large spectral bandwidths required by the increasingly popular coarse wavelength division multiplexing schemes used in transceiver applications. We have previously reported on the first O-band metamaterial converter interfacing standard cleaved fibers to nanophotonic waveguides [4]. Data was acquired by manually inserting fibers in V-grooves. Here, we report on the first metamaterial converter between a standard cleaved fiber and a nanophotonic waveguide with design centered in the S-band. Data is acquired with both manual probing and automated self-aligned 12-fiber assembly.

2. Design, results and discussion

The metamaterial converter is shown in Fig. 2. It is formed of a single silicon layer embedded in a suspended oxide membrane. To enable mode expansion beyond the typical 2-3 um buried oxide thickness of silicon on insulator wafers, we undercut the silicon handle under the mode converter to allow sufficient mode expansion for efficient mode matching to a 10 um fiber mode without power leakage to the substrate. This undercut is filled with low-index adhesive

Fig. 1. Parallelized fiber assembly in standard high-throughput microelectronic pick and place tools. Concept in exploded view (a), assembled view (b) and top-down photo of assembled package (c).
at assembly. Our metamaterial converter is similar to a subwavelength grating [5]. We prefer the metamaterial terminology as it correctly infers index homogenization without diffraction while subwavelength gratings technically include mainstream diffractive devices such as Bragg gratings. The fiber coupler is formed of tightly spaced silicon dots in an oxide cladding. The period is sufficiently small to prevent diffraction and the wave propagates as if guided by a homogeneous medium with engineered optical properties. The mode is first converted by adiabatic non-linear tapering of the periodic structure. A butt-coupling junction is then used to traverse into a hybrid waveguide, which is adiabatically transformed into a standard silicon nanophotonic waveguide. The metamaterial to hybrid waveguide junction was optimized in design for mode matching on both polarizations. The result is a substantially different metamaterial component on both sides of the junction, which differs from the unchanged metamaterial component across the metamaterial to hybrid waveguide junction reported in [5].

A measured response of a loopback structure with manual placement of fibers in V-grooves is shown in Fig. 3(a). A large Fabry-Perot oscillation is seen on the TE polarization. Accurate replication of the metamaterial to hybrid waveguide transition can be a challenge in 193 nm lithography despite the use of optical proximity correction and advanced photomasks. It was associated with a modest spectral ripple on the TE polarization in [4] originating from reflection at the metamaterial to hybrid waveguide junction due to dimensional offsets on the front-end of the hybrid waveguide. As shown in Fig. 3(b), the hybrid waveguide is significantly rounded compared to design, which can create some mode-mismatch-induced reflection, but the dimensions are not sufficiently off here to warrant the amplitude of the TE ripple. Looking closely at the mask data we found that a layout misstep was responsible for the effective Fabry-Perot mirrors forming the polarization dependent ripple in our loopback test structures. The period of

Fig. 2. Metamaterial converter centered at 1490 nm wavelength. (a) Top-view optical micrograph. (b) - (e) Scanning electron micrographs at key stages of mode conversion. (f) - (g) Cross-sectional diagrams at positions defined in (a).

Fig. 3. Optical performance with manual assembly of fibers to V-grooves. (a) Transmission spectrum of a loopback structure. Data post-processed to remove Fabry-Perot fringes is shown in addition to raw data. (b) Dimensional control at the metamaterial to hybrid taper junction. (c) The TE spectral oscillations originate from a layout misstep making the metamaterial sides of the hybrid waveguide act as a Bragg grating near the end of the hybrid taper.
the metamaterial structure needs to be reduced in the hybrid waveguide section for the metamaterial to stay at a distance from the diffraction limit while the effective index is increased. A layout issue reused the period of the fiber coupler in the hybrid taper resulting in the metamaterial component of the hybrid waveguide behaving for TE as a short Bragg grating near the end of the hybrid taper. The lower effective index of the TM polarization prevents this effect as illustrated in Fig. 3(c) and any leftover TM ripple is attributed to issues with input light polarization control.

Results of an automated self-aligned 12-fiber assembly to a site with varied taper length are shown in Fig. 4. The required converter length to match a 10 um fiber mode can easily be an order of magnitude longer than one to match a 3 um mode as the adiabatic conversion needs to be significantly slowed down with decreasing confinement. Here, however, we find the needed conversion length to be even longer than expected from computations. This and a larger than expected TM roll-off on long wavelengths indicate lower than expected confinement. It is mainly attributed to slight index vertical asymmetry in the oxide cladding to which a highly de-confined mode is substantially sensitive. The TM polarization at the long wavelength edge of the spectrum experiences the highest penalty from this effect.

The transmission efficiency shown in Fig. 4 includes the MT interface of Fig. 1, which is not present in manual probing (Fig. 3). As a standard grade MT ferrule was used in this work, an additional connection loss under 0.75dB is expected and is part of the loss of Fig. 4. The MT loss can be contained to a typical value of ~0.1 dB with higher grade MT ferrules. We find a peak transmission of -1.6 dB with manual probing (Fig. 3(a)) and -1.7 dB with automated assembly (813 um taper at 1.47 μm wavelength with MT loss). Looking past the Fabry-Perot ripple by removing it in post-processing, we find the spectral penalty to be limited by TM roll-off with 1.1 dB penalty over a 100 nm bandwidth at a taper length of 542 um and 0.6 dB penalty over a 100 nm bandwidth at a taper length of 1084 um (Fig. 4(c)).

3. Conclusion

We have presented the first optical demonstration of a 1490 nm metamaterial converter interfacing standard cleaved fibers to nanophotonic waveguides. A peak coupling efficiency of -1.6 dB with wide spectral bandwidth was shown.

4. Acknowledgments

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5. References