Design of a Broadband Adiabatic Coupler for Interfacing PICs to Optical Redistribution Layers

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Abstract

The design of a broadband adiabatic coupler for interfacing PICs to ORDLs is presented, enabling optical interconnections between PICs, or providing an interface towards an optical fiber connector. As first proof-of-concept, the coupling between a SiN waveguide and a polymer waveguide ORDL is investigated. A generic taper-layout model, implemented in Lumerical Mode, maximizes the SiN-to-ORDL coupling efficiency for various integration techniques. We obtain polarization-tolerant coupling losses smaller than 1 dB across the O-band, while maintaining the SiN taper length below the 1-mm footprint limit. The 1-dB SiN-to-ORDL lateral alignment tolerance is ±1.8 μm, within reach of our target integration/assembly tools.

Introduction

Efficient optical coupling between two Photonic Integrated Circuits (PICs) is crucial for the next generation of optoelectronic devices. Nowadays, the major challenges for the optical signals transfer are the stringent alignment tolerance between different waveguides, polarization sensitivity and wavelength dependency. Here we demonstrate that efficient coupling is possible between a SiN waveguide, located in a PIC, and a polymer Optical Redistribution Layer (ORDL), addressing the mentioned problems. Soon, we will experimentally demonstrate this concept based on Back-End-Of-Line (BEOL) compatible processes with low-loss SiN waveguides [1].

Adiabatic optical coupler

For optimal working conditions, the optical coupling between two waveguides needs to be adiabatic. This means there is very limited intensity loss due to reflection and/or radiation when coupling light from one waveguide to another. This calls for a dedicated taper design with small geometrical changes to minimize the energy transfer from any currently present (fundamental) modes to other (higher order) modes [2].

As shown in Figure 1, we consider a polymer ORDL waveguide that remains constant in geometry along the propagation direction, while a second SiN waveguide in optical proximity has a gradually decreasing width. A dedicated light signal, initially coming from the PIC, is launched into this latter, SiN tapered waveguide. Due to the varying geometric shape of the taper, the light beam gets less confined and is expanded in diameter while propagating through the taper. From the moment the Mode Field Diameter (MFD) is large enough to optically experience the presence of the ORDL waveguide, a part of the light and energy is coupled from the SiN waveguide to the ORDL waveguide. The highest energy transition between the 2 waveguides occurs at phase-matching condition, when the propagation constants β_1 and β_2 of the 2 isolated (uncoupled) waveguides are identical. To quantitatively monitor the evolving difference in effective index n_{eff} of the individual waveguides, we define $\delta = (\beta_2 - \beta_1)/2$, with $\beta_i =$

$2\pi n_{eff,i}/\lambda$ for each waveguide (i = 1 or 2). As we investigate the adiabatic coupler in the O-band, we use λ = 1310 nm as the central wavelength. Additionally, we also define $2S = 2(\delta^2 + \kappa^2)^{1/2} = \beta_e - \beta_o$ as the difference between the propagation constants for the even and odd supermode, with κ being the coupling coefficient between the SiN and ORDL waveguide in the case of the coupled waveguides setup.

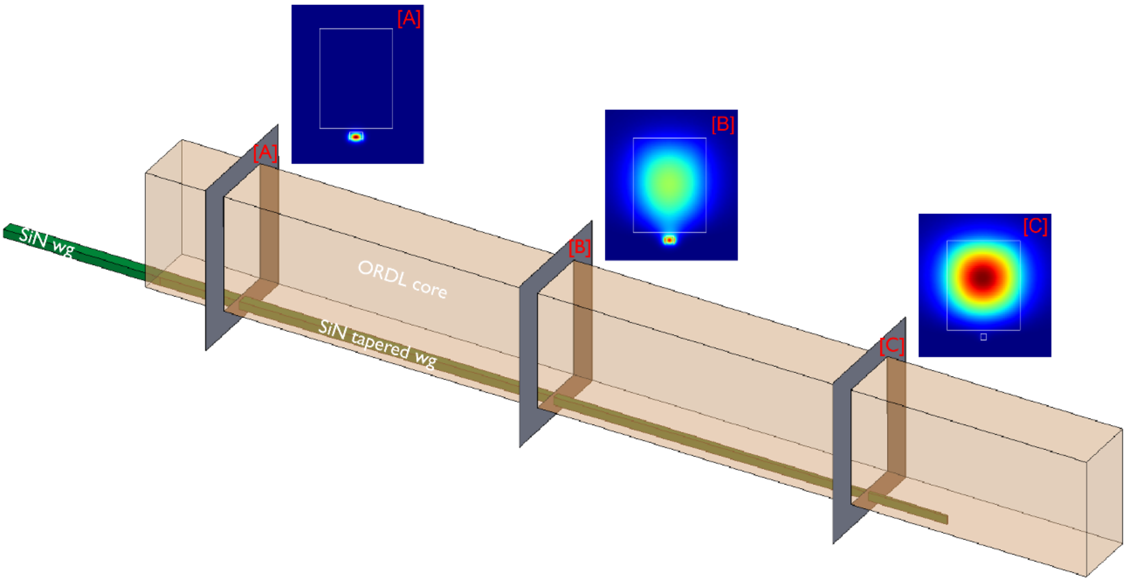

Figure 1: Illustration of the adiabatic coupling between a SiN (tapered) waveguide and an ORDL core. Light that is initially confined by the SiN waveguide, is gradually spreading out into both waveguides, forming the 2 fundamental supermodes. At the end of the adiabatic coupler, almost all light is confined by the ORDL waveguide. The inserted mode profiles are acquired by Lumerical Mode FDE simulations.

At phase-matching condition, δ = 0 and so $\kappa = (\beta_e - \beta_o)/2$. Finally, with ε the fraction of unwanted power coupling to other modes, the minimally required coupler length can be derived as $L = \frac{1}{\kappa\sqrt{\varepsilon}}$. This length L allows the initially launched mode to adiabatically transfer from the SiN to the ORDL waveguide [3].

Cross-section configurations and taper shape

To support the theoretical concept of adiabatic coupling, we consider 3 implementation approaches (shown in Figure 2) for establishing the SiN-to-ORDL adiabatic coupling.

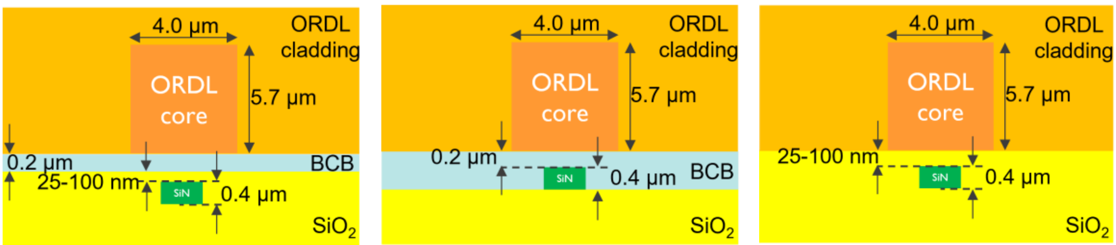

Figure 2: Schematic illustrating the cross-section for the 3 main setups in our simulations. Additionally, some dimensions are changed to overcome potential challenges on the PIC manufacturing.

For setup #1, the PIC part consists of a SiN tapered waveguide with constant height = 0.4 µm, with variable width starting from 710 nm in the straight waveguide section. The SiN taper is surrounded by SiO_2 acting as cladding material to ensure mode confinement. The polymer ORDL consists of core/cladding made from EpoCore/EpoClad material [4]. The ORDL dimensions are chosen to obtain a circular Gaussian beam profile. At λ = 1310 nm, EpoCore has a refractive index of 1.579, while EpoClad's refractive index is 1.571. To achieve optical coupling, both parts need to be brought in very close proximity to each other. In this case we assume the PIC and ORDL are bonded by using benzocyclobutene (BCB), acting as glue between both parts.

As shown in the middle graph of Figure 2, setup #2 is slightly different as the SiN taper is located on top of SiO_2 and additionally surrounded by BCB. As will be shown later, the higher refractive index of BCB (with respect to SiO_2) has a beneficial influence on the coupling strength between SiN and ORDL.

In order to include multiple bonding techniques, we add a third cross-section to our analysis, to allow lithography as integration technique instead of adhesive bonding [5].

Each cross-section has its own specific coupling strength κ and required coupler length $L = \frac{1}{\kappa\sqrt{\varepsilon}}$. Depending on the value for ε that we allow to occur, the SiN taper length is fixed. The exact taper layout (as illustrated in Figure 3 for setup #2) is defined based on a semi-analytical method, by ensuring a large overlap (linked with ε) between consecutive sections in the taper. In the following section, we show the Lumerical EME simulation result for each setup, based on the best-matching taper layout in each situation. By sweeping the dedicated taper length, it is determined how resistant the coupling efficiency can be to fluctuations in taper length.

Coupling efficiency and wavelength dependency

The right figure of Figure 3 displays the coupler loss behavior as a function of taper length at the central wavelength λ = 1310 nm. Note that, except for 1 analyzed setup, the coupler loss is lower than 1 dB for a taper length around 750 µm. Comparing the different graphs, setup #2 can be considered the most suitable cross-section since it shows the least coupler loss for both TE and TM polarization. For this reason, we stick to this setup for further analysis in the current publication.

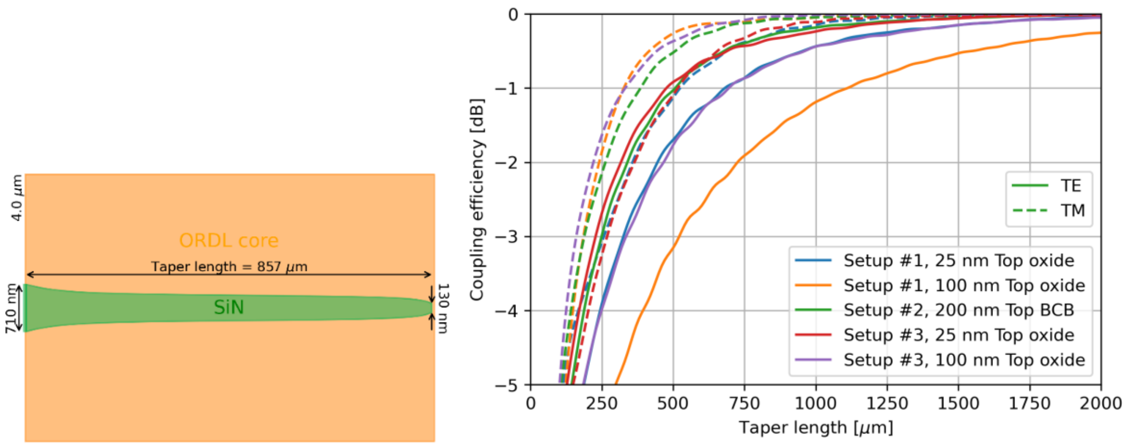

Figure 3: [Left] Exemplary taper layout, specifically designed for setup #2. Note that the taper's width decreases fast at both ends, and slowly in the middle at round the phase-matching condition. [Right] Comparison between the 3 setups in terms of coupler loss for λ = 1310 nm. The graphs are the result of Lumerical Mode EME simulations making use of the dedicated taper layout for each setup.

Looking at the wavelength dependency in Figure 4, we can state that it is feasible to obtain an optical coupler length below 1 mm, while maintaining a coupler loss below 1 dB over the entire O-band spectrum. Besides this, the difference in coupling efficiency between both polarizations for a suitable coupler length value is always lower than 1 dB. Finally, when investigating the tolerance for aligning the ORDL with respect to the PIC, we find the results depicted in Figure 5. When maintaining the same 1-dB threshold for additional coupler loss, the lateral alignment tolerance is ±1.8 µm.

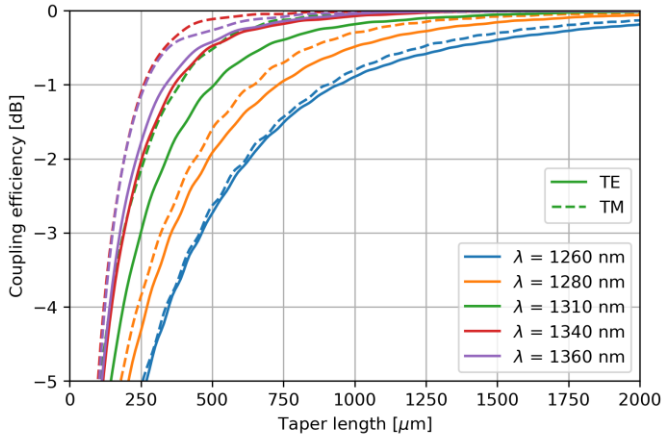

Figure 4: Broadband behavior of the coupler, for setup #2.

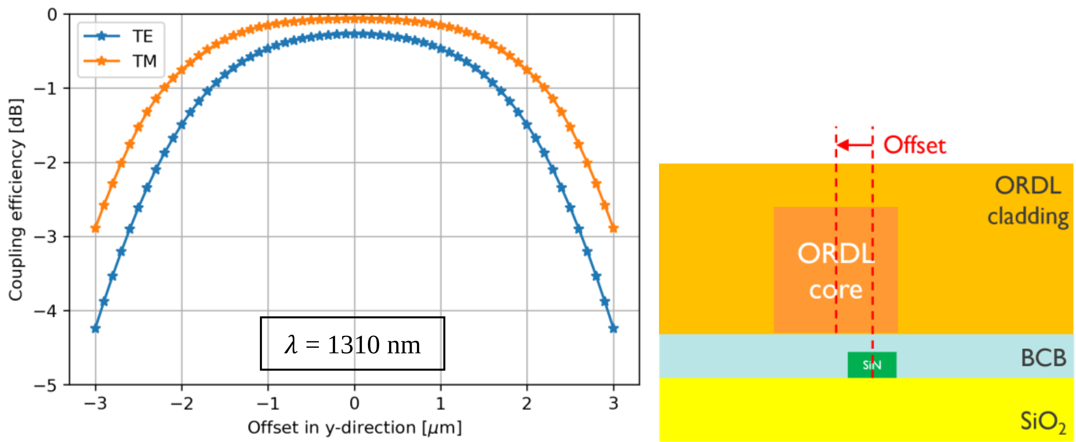

Figure 5: Alignment tolerance of ORDL with respect to the SiN (tapered) waveguide, for setup #2.

Conclusion

It is demonstrated that an adiabatic coupling, with less than 1 dB coupler loss, can be achieved between a polymer ORDL and SiN tapered waveguide of shorter than 1 mm. Due to the broadband behavior, low polarization dependence and alignment tolerance, we show a compact device footprint on the PIC.

Acknowledgement

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References

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