Bottom Air-Cladding for Low Loss Polymer-Based InP Waveguide Optical Coupling

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We propose a coupling device concept for passive low-loss optical coupling, which is compatible with the "generic" InP multi-project-wafer platform. A low-to-high vertical refractive index contrast transition (RICT) InP waveguide is designed and tapered down to adiabatically couple light into a top polymer waveguide. Numerical analysis shows that coupling losses lower than 1.5 dB can be achieved for a TE-polarized light. The obtained results are promising and may open a route to large port count and cheap packaging of InP-based photonic integrated chips.

Introduction

While the rapid developments in integration technologies have led to a dramatic reduction of PIC (Photonic Integrated Circuit) design and manufacturing costs, those have not been followed by a similar trend in packaging and testing costs yet. The lack of a cheap and low loss method to couple in and out of optical InP (Indium Phosphide) inputs/outputs (I/Os) waveguides also impacts the chip performance [1]. The large mode size ratio (~1:9) and refractive index mismatch between these small core waveguides (n_{core} ~3.36) and the optical fiber cores (n~1.5) produce a large coupling loss that can be even higher than 3.0 dB for a position accuracy within ±0.25 μm [2]. When moving from a single to multiple fibers, other issues like fiber core eccentricity and fiber misalignment add up to the already strict per-fiber alignment tolerances.

A comprehensive analysis of the proposed implementations for fiber-to-chip passive light-coupling in silicon photonics [3] highlights how these solutions do not represent a viable approach for a lower vertical refractive index contrast material platforms such as the InP-based platform, because of light leaking into the bottom InP cladding layer.

In this paper we propose a new design concept for low-loss light coupling for InP I/O waveguides, based on the implementation of an on-chip integrated transition from low-to-high refractive index contrast waveguide, in combination with an on-chip embedded polymer I/O waveguide. The device concept is based on the adiabatic coupling of light from a standard InP waveguide into a wider polymer waveguide and, at the same time, the presence of a bottom air-cladding. A study of the modal content and light propagation in this transition waveguide is carried out for predicting coupling losses. Points for improvements are identified and strategies for further reducing coupling losses are proposed.

Device concept

The device concept, based on adiabatic coupling of light from a standard InP waveguide into a wider polymer waveguide and on the presence of a bottom air-cladding at the same time, is shown in Fig.1. The spot-size conversion is obtained by designing an inverted taper and by adding a layer of polymer (n ~1.67) on top of the existing InP cladding. The polymer transition waveguide provides a refractive index and a guiding cross- section which better matches the ones of the optical fiber. To avoid light leaking into the bottom InP cladding layer, an air-bottom cladding is provided to the structure for the creation of the low-to-high refractive index contrast transition (RICT) device.

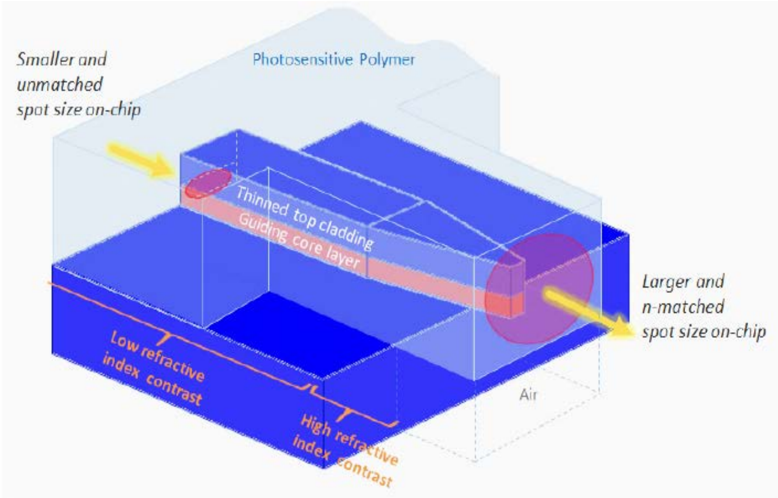

Fig. 1 Sketch of the polymer aided low-to-high refractive index contrast transition (RICT) waveguide.

This corresponds to designing a multiple stage multiple layer taper for enabling a low loss adiabatic coupling. The top view and the different cross-sections of the RICT device are depicted in Fig. 2b and 2c, respectively. The waveguide taper is constituted of four different device cross-sections with four different lengths. These parameters are optimized after modal content and back reflection analysis at each section. In the specific, the input cross-section (Fig. 2b, 1) shows the the guiding InGaAsP core layer sandwiched between two InP cladding layers. This is slowly tapered down and a polymer waveguide is co-embedded on top of the InP-based waveguide (Fig. 2b, 2). Along the transition, the bottom InP substrate is removed to be replaced with an air (n=1) cladding which pushes light inside the guiding core, reducing light leakage into the bottom cladding (Fig. 2b, 3). The placement of the bottom air cladding is critical and studied in this paper. While adiabatically narrowing the InP waveguide width, the light is forced to couple to the polymer waveguide, which eventually becomes the waveguide at the chip facet (Fig. 2b, 4), providing lower coupling losses to the optical fiber and easy alignment.

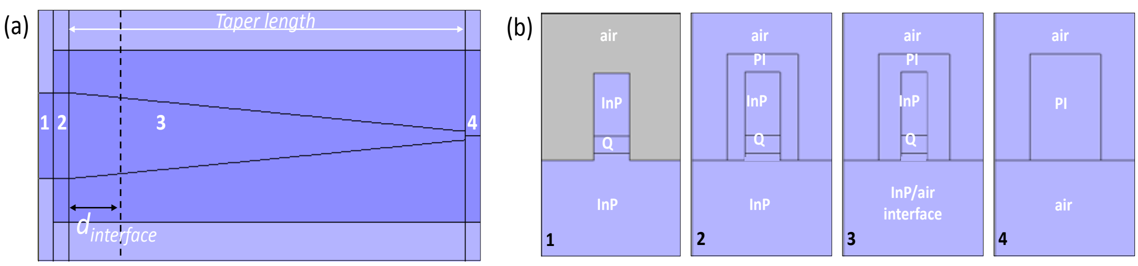

Fig. 2 Top view of the taper design (a), including the four different waveguide cross-sections (b).

The losses within the coupler include radiation losses, due to power converted into higher order modes, reflected light at the RICT point and also at the final InP tip point.

The modal content of the waveguide at different sections is analised and calculated through FIMMWAVE (PhotonDesign simulation software) using the film mode matching (FMM) mode solver algorithm, a fully vectorial waveguide solver. Two parameters are used to inspect if a mode is guided or radiated: The effective refractive index and the confinement factor. If the effective refractive index is larger than the refractive index of the cladding, the mode is confined and therefore guided. The confinement factor can be useful when studying single mode conditions as the transition from guided to radiative mode appears very clearly with a sharp drop in the confinement factor. Both these two parameters can be used to determine the radiation loss and the cut-off point to determine single mode (fundamental TE and TM) operation. After the modal content analysis, the design of the entire RICT device is made and optimized by investigating the light propagation and transmitted optical power through FIMMPROP (Photon Design beam propagation tool).

Results

To ensure single mode operation within the tapered device, the cut-off width is determined for both the TE and TM fundamental modes. For the input cross-section (Fig. 2b, 1) of the waveguide, the cut-off point occurs when the waveguide width is reduced down to 0.92 µm for the fundamental TE mode and 1.02 µm for the fundamental TM mode, respectively. These results are also validated using the confinement factor parameter: Around the width there is a steep drop when inspecting this parameter. These results are still valid also in correspondence of the 2nd cross-section, where a polymer waveguide of 3.0 × 3.0 µm² cross-section size is added (Fig. 2b, 2): the refractive index of the polymer waveguide (n ~ 1.67) has negligible effect on the modal content of the waveguide.

The waveguide width narrowing, when getting close to the cut-off condition, causes light leakage into the substrate. Therefore, in correspondence of the 3rd cross-section (Fig. 2b, 3), the substrate is replaced with air, which drastically changes the vertical effective refractive index contrast. Moreover, while propagating towards the polymer waveguide, the light encounters the top InP layer, which produces additional reflections and pushes modes down too. Therefore, although single-mode operation is desirable, the top InP layer (thickness = 1.8 µm) is maintained at this design stage.

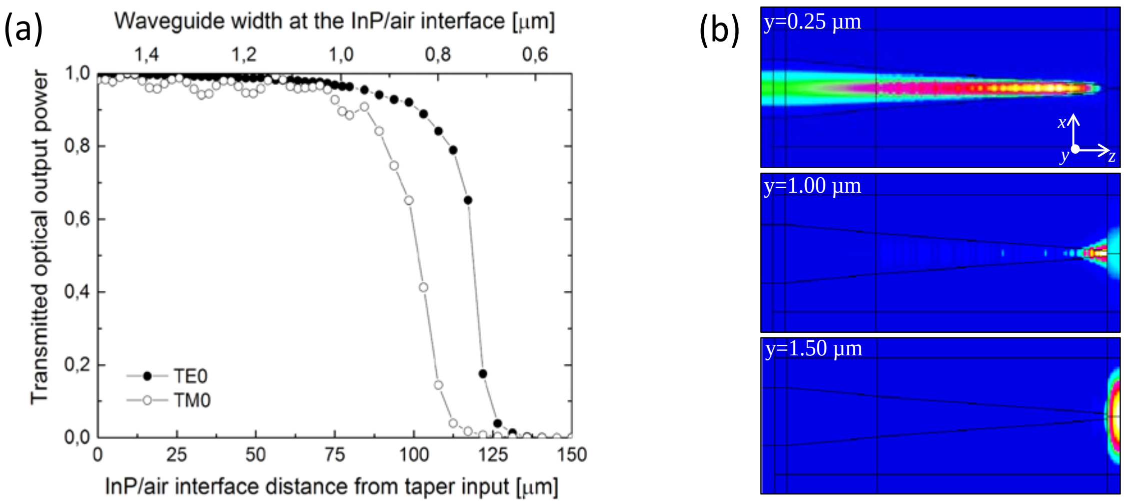

Fig. 3 InP/air bottom cladding interface placement scanning for optimized

trasmissionminimized reflections (a). The top views of the xz intensity profile for different heights are shown (b).

Along the taper design, the bottom cladding InP/air interface placement is scanned to optimize the optical transmitted power and therefore minimize the reflections at the RICT. The transmitted net optical power is calculated at the taper output and displayed in Fig.3a. The placement of the interface at 70 μm distance from the input taper (at a correspondent width of 1.05 μm) incurs into about 9% losses, which allows to keep the optical losses within the 1 dB level.
Finally the device parameters for the entire device design in Fig. 2a are set as: 250 μm total taper length, InP/air interface placed 70 μm far from the taper input, 150 nm output taper width, with an InP top cladding thickness fixed at 1.8 μm. In Figure 3b, the top views of the xz intensity profiles for a TE fundamental mode input are taken at different depths to show how the light couples into the polymer waveguide. This is reported for the TE mode only since generic InP circuits are generally designed for working with TE-polarized light. According to the Power Diagnostics function of FIMMPROP optical losses first occur where the substrate is removed (9%). The loss goes up to a total 29% at the interface between the InP tip and the polymer. While we managed to control the losses at the InP/air bottom cladding interface, more investigation is needed for keeping single mode operation in the waveguide before and while moving into the polymer waveguide. However, a calculated total coupling loss lower than 1.5 dB for a TE-polarized light shows that this technique is very promising.

Conclusions

We have demonstrated preliminary results of a novel I/O waveguide design with the intention to equip the InP generic platform with a low coupling loss polymer-aided low-to-high refractive index contrast transition (RICT) device. Initial investigations are carried out to demonstrate a total power coupling loss of less than 1.5 dB for a TE-polarized light. The performance are mainly limited by the difficulty to control single-mode operation after removal of the bottom InP cladding. The use of parallel design strategies, like the use of multiple polymer layers for facilitated adiabatic coupling, or the exploitation of selective wet etching solutions for a gradual transition from low-to-high refractive index contrast waveguide are foreseen to reduce reflections and improve further the optical transmission power. The InP RICT waveguide is foreseen to make a leap forward into low-coupling losses of multiple I/O InP based chips to multiple optical fibers.

References

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