One-Step Growth Optical Transceiver PIC in InP

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Abstract *The design and characterization of monolithically integrated optical transceiver PIC in InP is reported. The PIC is fabricated in one growth step and comprises a DFB laser / monitor in 1310nm, a PIN photodetector in 1490nm, a 1310nm – 1490nm wavelength splitter and a 1310nm / 1490nm spot-size converter.*

Introduction

Photonic integration in indium phosphide (InP) is considered to be an enabling component technology for new generation optical access, because of its potential for high cost efficiency and reliability in mass deployment[1]. To realize this potential, the InP-based monolithic photonic integrated circuits (PICs) at the core of such components have to be fabricated in volume with low cost per die and high yield per wafer. Since both are affected by the number of epitaxial growth steps, it is advantageous to use just one, original, growth and thereby decouple the epitaxial growth and wafer fabrication processes.

Here, we report a one-step growth optical transceiver PIC that implements this approach. It is based on a multi-guide vertical integration (MGVI) platform[2], which enables multiple functions to be monolithically integrated onto one substrate without re-growth or post-growth modification of the epitaxial material. The PIC is intended for applications in fiber to the home (FTTH) passive optical networks and includes transmit in 1310nm and receive in 1490nm functions, along with wavelength demultiplexing. Whereas PICs targeting similar applications have been reported earlier[3,4], ours is believed to be the first that is re-growth free and, with its on-chip spot-size converter (SSC) and back-side power monitor (BSPM), also the most comprehensive solution.

Design

The schematic functional diagram of the PIC is shown in Fig. 1 a). It comprises, right to left: (i) an optical port equipped with SSC that facilitates low-loss passive alignment to single-mode fiber; (ii) a wavelength splitter to spatially separate incoming and outgoing optical signals which share the common optical port; (iii) a 1310nm transmitter channel featuring a laterally-coupled DFB laser (DFBL) with BSPM; and (iv) a 1490nm receiver channel utilizing a PIN broadband photodetector (BPD), following a wavelength selective absorber (WSA) formed from laser layers. A top view of an actual PIC die, which has its front facet anti-reflection coated to reduce parasitic cavity effects, is shown in Fig. 1 b). The die is intended for automated flip-chip attachment to a silicon optical bench (incorporating a V-groove for fiber placement) and, therefore, is equipped with hard references and solder bonding pads (seen in Fig. 1 b).

All functional elements of the PIC are based on optical waveguides, which, in accordance with MGVI princples[2], are vertically stacked in an ascending order of their core layer bandgap wavelength, such that the SSC, DFBL/WSA and BPD are at the bottom, in the middle, and at the top of the epitaxial structure, respectively. The design challenge is to optimise the performance of each PIC function while maintaining mutual compatibility, and respecting the requirements of MGVI. This, inevitably, calls for new solutions, if and when the MGVI platform does not easily accommodate conventional device designs. E.g., the DFBL reported here is based on a well known laterally-coupled surface etched grating design in an effective ridge configuration[5], but is different from any of the previous art because it uses a top N and side P contacts (as shown in Fig. 3 c)) that is needed to

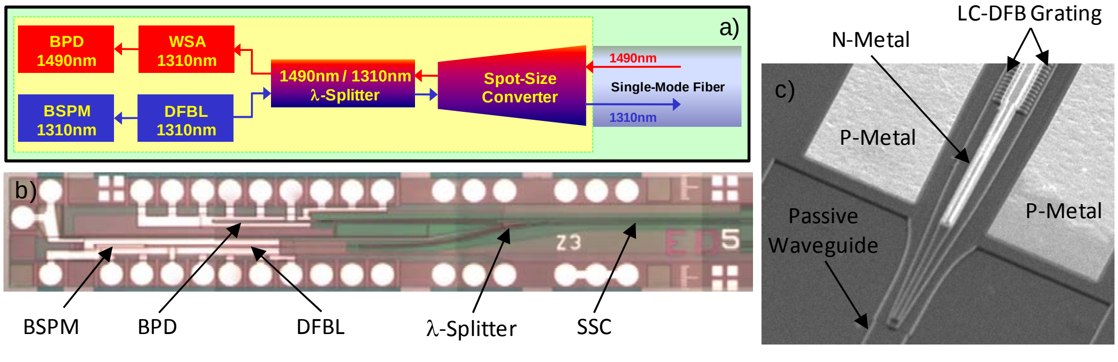

Fig. 1: An optical transceiver PIC. a) - schematics of the photonic circuit featuring a spot-size converter at common optical port, a wavelength splitter, a DFB laser with back-side power monitor in one wavelength and broadband photodetector with front-side wavelength selective absorber in the other; b) – top view of a fully processed PIC die; c) – SEM photograph of a front end of the integrated laterally-coupled DFB laser, coupled to passive waveguide.

978-3-8007-3173-2

make the design compatible with the passive waveguide circuitry underneath the laser layers[6]. Likewise, even though the wavelength splitter includes elements of both conventional twin-guide and Y-branch designs, it is different from either because the wavelength-selective, lateral taper assistant vertical transition between the twin passive waveguides precedes the lateral splitting of the shorter wavelength, thereby providing both vertical and lateral separation from the longer wavelength[2].

The PIC structure is MOCVD grown on 100-mm semi-insulating Fe:InP substrate and comprises a large number (~50) of layers to form the vertically stacked passive and active waveguides. All the passive waveguides are based on lattice-matched bulk InGaAsP materials, whereas the 1310nm DFBL uses a strained quantum-well and lattice-matched bulk AlGaInAs material (details are provided in Ref. 6) and the 1490nm detector utilizes bulk GaInAs. The wafers are processed by using standard fabrication techniques, e.g. dry and wet etching, passivation and planarization, with all the lateral features, including DFBL grating, being patterned by I-line optical stepper lithography.

Characterization

The fabricated devices were comprehensively characterized on a temperature controlled stage. Some of the continous-wave testing results are presented in Fig. 2, which illustrates typical integrated transmitter (Fig. 2 a)), receiver (Fig. 2 b)) and SSC-equipped optical port (Fig. 2 c)) performance.

It is seen, that the on-chip laterally-coupled DFBL operates at a reasonable threshold current (~25mA at room temperature) and generates a significant optical power even though it has a 3rd order grating (pitch ~600nm), which suffers from radiation loss[7], and top N / side P contacts, which negatively affects intracavity loss. Also, being in essence a complex-coupling DFBL because of the higher-order grating[6], this laser source has no longitudinal mode degeneracy and demonstrates a superior side-mode suppression ratio (~55dB). As to the on-chip BPD, once properly reverse biased (~2V and higher), this shows no saturation over any applicable optical power range, while demonstrating high fiber-coupled responsivity (~0.7A/W) with little polarization and wavelength (over intended 1480nm – 1500nm range) sensitivity. Both the transmitter and receiver channels are optically connected to the single-mode fiber through a SSC-equipped common optical port, which, as it is seen from Figs. 2 c-d), has a superior tolerance ~4μm / ~5μm and ~5μm / ~6μm for vertical / lateral displacement at 1310nm and 1490nm, respectively (all at 1dB loss penalty). This is sufficient for a passive alignment to the single-mode fiber by using commercially available pick-and-place machine.

Dynamic properties of the PIC (not shown here) also are promising: on-chip laser and detector both have 3-dB bandwidth greater than 3GHz and are well suited for applications with a speed up to 2.5Gb/s.

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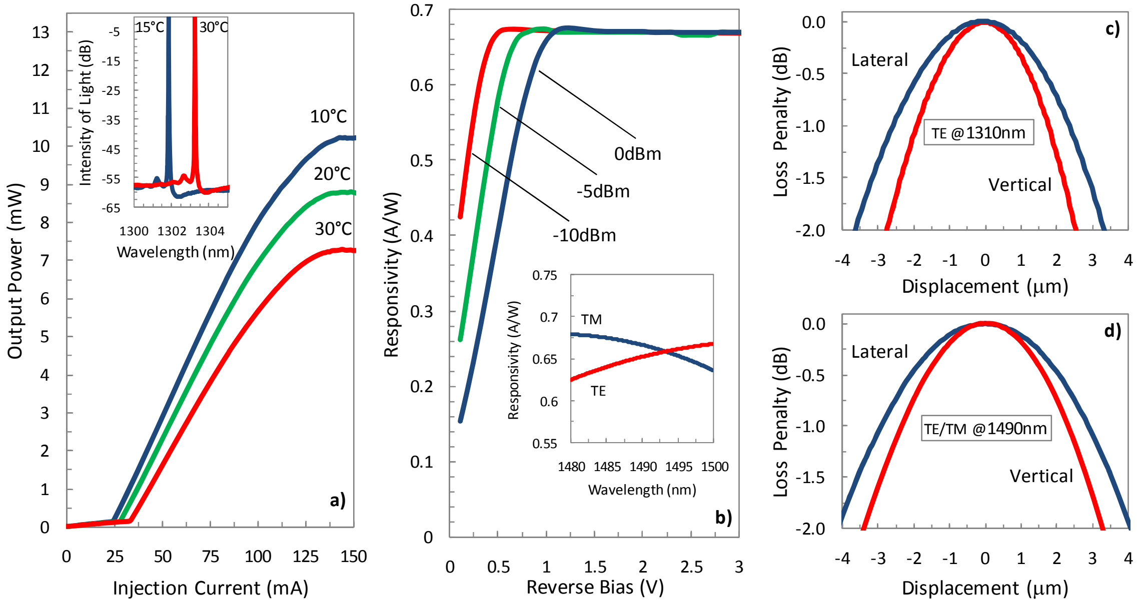

Fig. 2: Characterization of an optical transceiver PIC. a) - light-current characteristics of an on-chip laser source, featuring 350μm DFB cavity (inset – single-frequency spectra at 60mA bias current); b) – responsivity vs. voltage in an on-chip photodetector (inset – wavelength dependence at -2V, -5dBm); c), d) – displacement tolerance of the PIC's only optical port.

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