Optical beam steering functionality of an InP/InGaAsP based optical waveguide

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An optical beam steering device capable of controlling the beam position across the facet of an InP/InGaAsP chip is proposed and experimentally demonstrated. The beam steering is implemented in a 14.5 µm wide waveguide by applying a negative voltage to one of two p-electrodes. An adiabatic taper is connected to the waveguide to minimize the number of spatial modes. The steering device has been co-integrated with a laser source at 1568 nm. The optical beam can be continuously moved in a total tuning range of 1 µm with a minimum applied voltage of -4V.

Introduction

Optical beam steering and optical beam switching may play an important role for Light Detection and Ranging (LIDAR) [1], printing [2], holographic memories [3] and communication [4]. Optical phase arrays (OPAs) have been extensively researched to control the radiation pattern of an optical source through interferometric beam forming [5]. While the radiation patterns are defined by the number of emitters, improvements in beam quality may be anticipated through high density integration [6], but the co-integration with laser sources remains a challenge.

The possibility to exploit the cavity of a laser to steer an optical beam has been demonstrated by injecting nonuniform current through the resonant cavity [7], but this requires high currents, complex control and the potential for PIC integration is limited.

The control of the refractive index profile of a waveguide cross section enables a decoupled beam steering solution. A digital form of beam steering has been demonstrated by selectively injecting current through a frustrated mode MMI coupler [8], and a smoother control has been achieved by tuning the current injected through two electrodes at the boundary of a slab based MMI concept [9]. A tuning range of 17 µm has been achieved by the latter solution with current injection up to few tens of mA.

In this work we propose a voltage driven beam steering device based on InP/InGaAsP technology. The device is capable of laterally moving an optical beam across the facet of the optical chip. The steering effect occurs in an individual optical waveguide electrically which is perturbed with reverse bias voltage. This offers the potential of a single mode operation with low power consumption. The device has been fabricated and integrated with an on-chip laser source on generic integration platform [10]. Experimental data in terms of voltage controlled beam displacement in the near field are shown.

Device and principle of operation

Fig. 1 shows the schematic 3D view of the proposed device. Two electrodes (Electrode 1 and Electrode 2) are placed on top of a 14.5 µm large waveguide. The electrodes are designed to be 500 µm. These electrodes are separated by a gap 7.5 µm wide and the p++ layer is removed in between to ensure electrical isolation between them. The n-side electrode is grounded. The optical beam can laterally move across the output facet of the steering section according to which p-electrode is negatively biased.

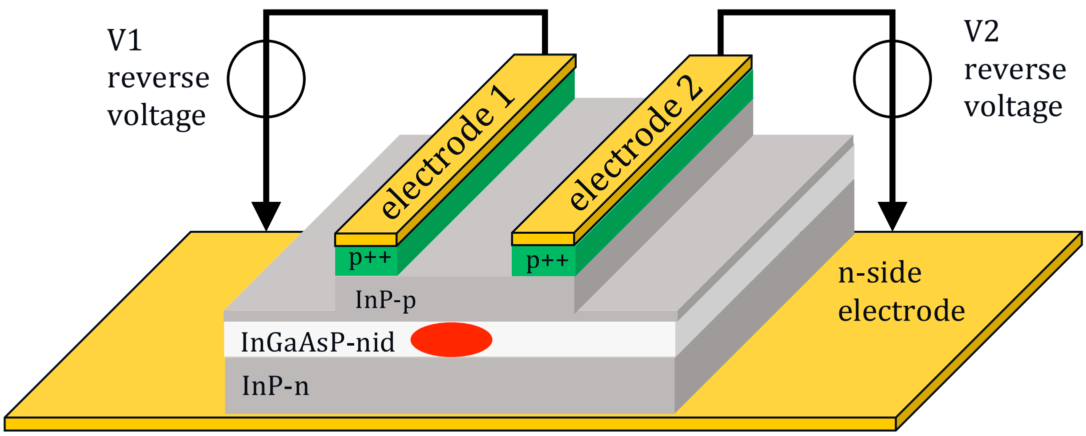

Fig. 1. Schematic 3D view of the proposed beam steering device.

The steering device has been fabricated in a JePPIX multiple project wafer run [11]. A single-frequency laser source [12], has been integrated on chip to demonstrate the suitability for generic photonic integration and simplify testing. A linear adiabatic taper 800 µm long connects the steering section to the on-chip laser source, minimizing the number of modes used for steering operation. After fabrication the chip is epoxy bonded on top of a water cooler mount, and the electrodes are wire bonded to the neighbor printed circuit board for laser ad beam steering control.

Experimental setup

Fig. 2 shows the scheme of the experimental setup. The laser oscillates at a wavelength of 1568 nm with a side mode suppression ratio of 38 dB. The near field of the chip is imaged by a 100X objective at a distance of 140 cm from the chip facet, with a magnification of 575.

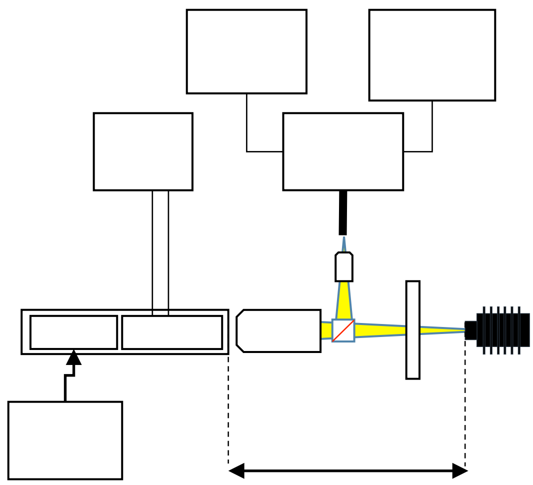

Fig. 2 Measurement setup.

A 50:50 beam splitter is placed immediately after the 100X objective: half the power travels toward the camera and half the power is collected into a single mode fiber by means of a 40X objective. The optical power collected into the optical fiber is divided by a 3dB splitter for optical power and optical spectrum monitoring. The near field image is acquired by means of an IR camera, with 320x256 pixel sensor with a pitch of 30 µm. A 20dB optical attenuator has been placed between the beam splitter and the camera to avoid pixel saturation. The optical setup has been optimized to remove any evidence of reflections. The voltage applied to Electrode 2 (Fig. 1) is swept from 0 V to -4 V and back to 0 V with a step of 0.1 V, while the voltage applied to Electrode 1 is initially fixed at 0 V. Afterwards the opposite electrical configuration is applied to Electrode 1 and 2 and the voltage sweep is repeated. Measurement of the near field, the optical spectrum and the integrated optical power is performed for every applied voltage configuration. One array of pixels is recorded at the peak point of the near field intensity profile. An unintended leakage current path between the p-electrodes limits the applied negative voltage to -4V. The maximum leakage current is 40mA.

Experimental results

For analysis purposes, the acquired optical beam profiles have been fitted with polynomials to remove the effect of the non-uniform pixel response. The peak position and beam waist are estimated from the interpolated data. The lateral beam peak displacement of the fitted acquired profiles and the full width half maximum (FWHM) are shown in Fig. 3a and Fig. 3b respectively. Fig. 3a shows that the optical beam can be moved up to 0.8µm to the right and 0.2µm to the left, indicating a total beam steering of 1µm. A difference in efficiency between the two electrodes is evident. Fig. 3b shows that the FWHM of the near field broadens from 6 µm to 6.7 µm and narrows from 6 µm to 5.5 µm for the left and the right electrode steering respectively. The asymmetry of the beam steering and the FWHM indicates the presence of higher order mode excitation. The quantization of both the curves is attributable to the finite pixel size. The integrated power of the acquired intensity profiles varies by less than 0.3dB over the applied voltage range.

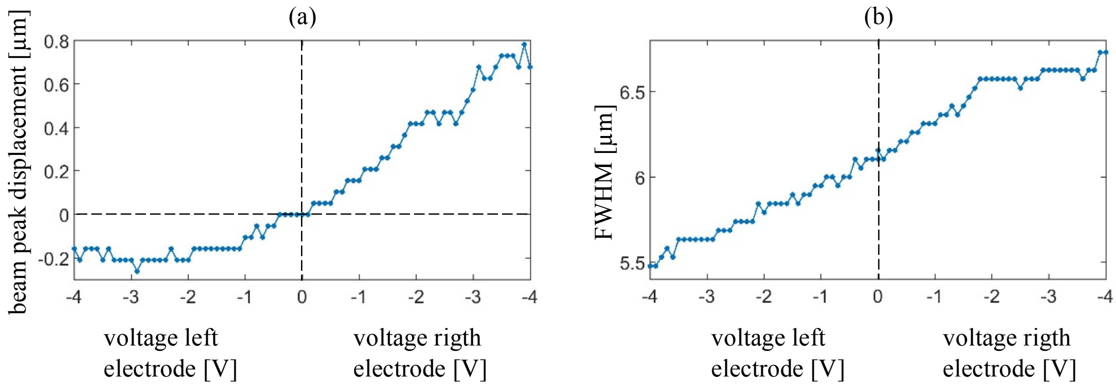

Fig. 3. a) Lateral displacement of the optical beam peak ; b) Full Width Half Maximum of the steered optical beam.

Conclusions

We have introduced a novel beam steering concept based on depletion effects in an InP/InGaAsP based waveguide. A prototype device has been integrated with a laser source, fabricated and characterized in terms of voltage-tuned near field displacement. The device is capable of moving the optical beam across the facet of the optical chip in the lateral direction, with a total tuning range of 1 μm. The beam can be moved continuously with a gradient of up to 0.2 μm/V.

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