Edge-coupling of O-band InP etched-facet lasers to polymer waveguides on SOI by micro-transfer-printing

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ABSTRACT

O-band InP etched facets lasers were heterogeneously integrated by micro-transfer-printing into a 1.54 µm deep recess created in the 3 µm thick oxide layer of a 220 nm SOI wafer. A 7×1.5 µm^2 cross-section, 2 mm long multimode polymer waveguide was aligned to the ridge post-integration by e-beam lithography with <1 µm lateral misalignment and incorporates a tapered silicon waveguide. A 170 nm thick metal layer positioned at the bottom of the recess adjusts the vertical alignment of the laser and serves as a thermal via to sink the heat to the Si substrate. This strategy shows a roadmap for active polymer-waveguides-based photonic integrated circuits.

Keywords: Heterogeneous integration, III-V semiconductors laser, silicon photonics, polymer waveguides.

1. INTRODUCTION

Silicon photonic integrated circuits for application in the telecommunications wavelength domain of 1300–1600 nm use InP-based materials as these provide the most mature structures for lighting, amplification, modulation and detection [1]. InP reflective semiconductor optical amplifier chips have been edge-coupled to silicon photonics in external cavity laser configuration [2]. The edge-coupling of InP-based etched-facet lasers to SOI by heterogeneous integration inside recesses defined on the SOI has been recently demonstrated through micro-transfer-printing (µTP) [3, 4]. In this case the devices are printed directly on the Si substrate and use an n-InP cladding layer of calibrated thickness for aligning the emitting waveguide to a trident mode size converter defined on the SOI. The recesses are etched at the ends of the SOI waveguide for reduced longitudinal misalignment. A similar approach can be applied for edge-coupling an InP laser to a polymer waveguide defined on the oxide layer of an SOI. This work reports the first O-band Fabry-Perot InP laser heterogeneously integrated into a recess on the SOI by µTP and edge-coupled to an SU8 polymer waveguide. The strategy allows us to engineer the alignment of the laser along the vertical axis through an intermediate metal layer deposited at the bottom of the recess.

2. EXPERIMENTAL METHODS

Pre-released etched-facet InP O-band lasers were heterogeneously integrated by µTP to recesses fabricated on a SOI wafer [Fig 1(a)]. This technique involves shearing the coupon to the sidewall while in light contact to the bottom of the recess and then bonding the coupon when matched. A metal layer pre-deposited at the bottom of the recess allows the tuning the height of the laser waveguide along the vertical axis and sinks the heat to the Si substrate. The alignment of the emitting facet along the two remaining spatial directions is ensured by the tolerances of µTP and by matching the device to one of the sidewalls. The use of a <3 nm thin vapour coated HDMS layer improved the yield of printed devices to >90 %. A straight polymer waveguide was defined post-integration on top of the SiO_2 cladding and edge coupled to the laser with <1 µm lateral misalignment [Fig 1(b)].

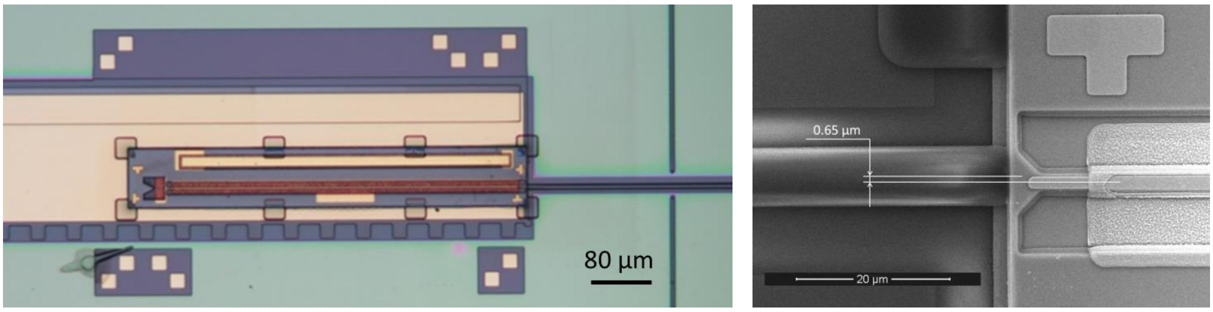

Figure 1.(a)Digital microscope image of the InP laser printed in a recess on the SOI and edge coupled to the polymer waveguide. (b) A scanning electron microscopy image of the waveguide aligned to the ridge of the laser shows <1µm lateral misalignment.

2.1 Laser devices

The lasers were pre-fabricated on the source InP wafer as dense arrays (about 1,000 devices per cm^2) of 550 µm long and 60 µm or 80 µm wide micro-transfer-printable coupons. A 500 µm long Fabry-Perot cavity was defined by two dry etched facets and passivated by an optically neutral SiO_2 layer and the back facet was then coated with a reflective metal layer. A 2 µm wide ridge etched just above the active region provides the lateral confinement of the light for single mode output. Accessible P- and N-type metal contacts were defined for testing the devices before and after transfer. The fabrication of the lasers included the steps for preparing the coupons to the undercut and the µTP as shown in previous work [5, 6]. The coupons were released from their native substrate by selectively etching a 500 nm thick InAlAs sacrificial layer arranged at the bottom of the N-InP cladding in $FeCl_3$:H_2O (1:2) kept at 1.0±0.1 °C for maximum selectivity to InP. The resulting suspended devices were then picked up and transfer-printed epitaxial-side-up to pre-fabricated recesses on the SOI.

2.2 SOI

A 220 nm SOI layer on a 3 µm thick buried oxide cladding was patterned to create 1.54 µm deep rectangular recesses suitable for edge coupling to waveguides [Fig 2]. Electron-beam (e-beam) lithography and a dry etch opened the SOI layer on the recesses area and defined some 0.6 µm wide tapered waveguides. A second etch formed the recesses on the SiO_2 without reaching the substrate. A third dry-etch opened part of the recesses, close to the printing area of the device, in order to access the Si substrate. A low rate flat evaporation of a Ti:Au (10:110) nm and a following low rate 360° angled Ti:Au (10:40) nm evaporation defined a smooth flat metal layer suitable for adhesive-less printing at the bottom of the recess. A flat and smooth metal layer is vital for achieving direct printing as imperfections and debris present on the metal surfaces require thick adhesive layers that would affect the alignment and the thermal performance [7]. High flatness and smoothness of the underlying SiO_2 surface is vital to prevent defect formation on the metal layer. The resulting surface of the metal shows flatness of <0.03 nm/µm and nominal roughness of <1 nm. The metal layer was connected to the substrate creating a thermal via for the heat sink. The metal layer thickness can be tuned with ±10 nm accuracy and allows alignment of the active region of the device to the polymer waveguide along the vertical axis. This recess design is suitable for the edge-coupling of laser coupons with different n-cladding thickness to polymer and SOI waveguides.

2.3 Polymer waveguide

A SU8 polymer layer of 1.5 µm thickness was spun on the SOI after printing the devices in the pre-fabricated recesses. The calibration of the thickness targeted a 1 µm thick layer with the difference between expected and actual thickness due to the topography present on the SOI. An etch-back of the polymer waveguide will bring the height of the waveguide back to 1 µm. An e-beam lithography defined a 7.5 µm wide and 2 mm long waveguide edge coupled to the ridge of the laser with <1 µm misalignment. The polymer waveguide incorporated a parallel SOI waveguide positioned at 4.75 µm distance far from the edge of the trench. This strategy allows etching the recesses without impacting the 140 nm wide tip of the taper. The other end of the waveguide lands in another recess which is in line to the first. Some polymer pads were defined around the coupon for locking the device in place as further processing on the sample could affect the adhesion [Fig. 1(a)].

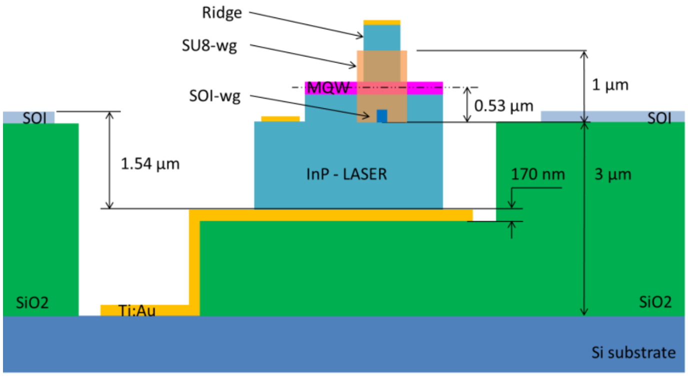

Figure 2. Diagram of the cross section of a laser printed in a 1.54 µm deep recess formed on the SOI, the 170 nm thick metal layer allows tuning the height of the active region (MQW) to 0.53 µm above the oxide layer, the 1 µm thick SU8 waveguide is aligned to the ridge.

3. EXPERIMENTAL RESULTS

The light-current characteristics of the devices show a threshold current of ~17 mA before and after µTP to the SOI that rises to ~23 mA after coupling the light to the SU8 waveguide due to reduced reflectivity on the front mirror. The laser operating at 20°C emits light at ~1340 nm wavelength. The light coupling to the polymer waveguide was detected with an infrared (IR) camera that shows the light coming out at the end of the 2 mm long waveguide [Fig. 3b].

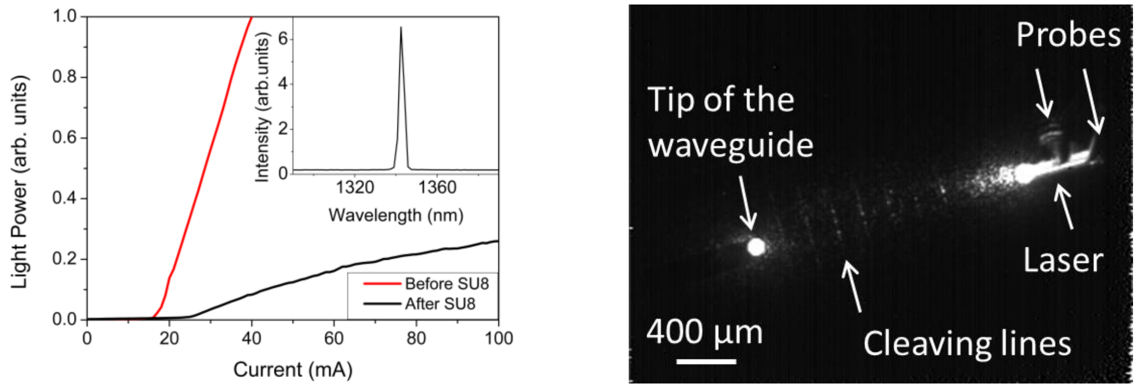

Figure 3. (a) LI characteristics for the laser printed in the recess before and after coupling the light to the SU8 waveguide. The inset shows the emission wavelength of ~1340 nm with the laser operating at 20°C before transfer. (b)IR camera imaging of the laser operating on the SOI and coupled to the 2 mm long polymer waveguide, the light comes out at the free end of the waveguide. Some transverse traces (cleaving lines) are due by recesses formed on the SOI to allow cleaving the chip.

4. CONCLUSIONS

Our approach allows the heterogeneous integration of generic thickness InP transfer printable devices in a desired location and on the desired layer of the SOI. Accurate vertical alignment of the emitting facet to the SOI is achieved through an intermediate metal layer pre-deposited at the bottom of the recess. This strategy enables use of micro-transfer-printing for the creation of PICs based on pre-fabricated devices connected by polymer waveguides or hybrid polymer-SOI waveguides. The efficiency of the light coupling can be improved by using alignment markers and pattern recognition at the transfer printer and by optimization of the polymer waveguide to make it single mode matched to the laser output. The measurement of the thermal impedance will provide a characterization of the thermal performance of the proposed laser.

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