Progress in heterogeneously integrated silicon-InP laser diodes for on-chip all-optical networks and signal processing

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Abstract: We describe progress in the design and fabrication of laser diodes based on InP-membranes heterogeneously integrated onto silicon-on-insulator wire waveguides. Applications in optical interconnect and all-optical logic are discussed.
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1. Introduction

Using the silicon-on-insulator material platform with its high refractive index contrast, it is possible to make very compact passive optical waveguide circuits. In addition, by heterogeneously integrating Indium Phosphide membranes, it is possible to implement high speed, low-power and compact active devices such as microdisk laser diodes and resonators [1]. Recently, we have demonstrated compact, electrically pumped microdisk lasers with diameters as small as 5 μm using the III-V/SOI heterogeneous integration [2]. Several of such microdisk lasers with slightly different diameters have been integrated to form a multiwavelength transmitter for WDM on-chip interconnect [3]. Using optimized microdisk lasers, we also demonstrated the first electrically pumped all-optical flip-flops (AOFF) on the SOI platform [4]. Other functionalities such as gating and wavelength conversion have also been demonstrated [5-6]. The variety of functionalities that can be obtained using these microdisk lasers and the fact that they can easily be coupled to compact passive SOI optical circuits, makes them very suitable as basic building block to implement more elaborate photonic integrated circuits implementing more complex optical logic.

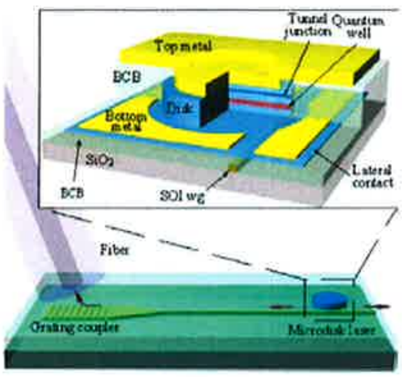
2. Fabrication and device concepts

The InP microdisk lasers are heterogeneously integrated onto SOI using adhesive die-to-wafer bonding with the divinylsiloxane-benzocyclobutene (DVS-BCB) polymer [3]. The SOI circuit, with a 220nm top silicon layer and a 2 μm buried oxide, is fabricated with 193nm DUV lithography through the ePIXfab silicon photonic platform. The III-V membrane has a total thickness of 583nm and includes 3 compressively strained quantum wells that provide the TE mode gain and a tunnel junction for a low loss p-contact. Figure 1(a) shows schematic drawings of the entire circuit and the bonded microdisk lasers. The light from the lasers is coupled to straight SOI waveguides, which are then coupled to single mode fiber using grating couplers.

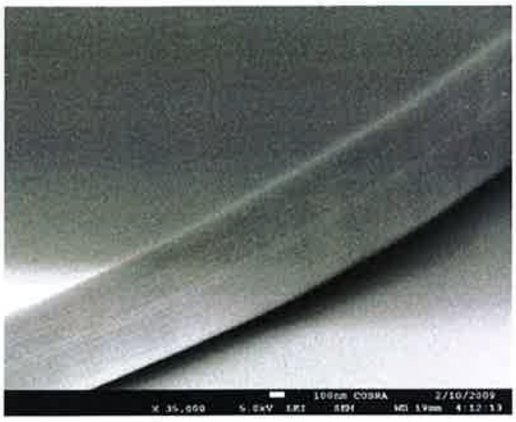
For a good operation of the devices it is imperative that losses are reduced to a minimum. In addition to the use of a tunnel junction, the alignment of the top contact is very important. So far this top contact has been defined using optical lithography, which doesn't allow good accuracy. We are currently developing the use of e-beam lithography for the top contact definition and the first devices have been fabricated. In parallel, we have also been testing other epi-layer stacks. Characterisation results from the new microdisk lasers will be presented at the conference.

For optical interconnect, where it is important to have most power coupled out on one side, the microdisk lasers can be made to lase in a predefined direction by adding gratings on one side of the silicon waveguide.

The AOFF operation is based on the switching between clockwise (cw) and counter clockwise (ccw) whispering gallery modes. To obtain unidirectional operation (cw or ccw), the coupling between the cw and ccw modes must be very small and the internal power density must be sufficiently high. In our microdisks, large internal power density results from the good mode confinement of the InP membrane due to the high index contrast. We also avoided degradation due to heating at higher currents, by making the Au layer of the top contact thick (600nm) and using it as heat sink. The coupling between cw and ccw modes was minimized by reducing the surface sidewall roughness using an optimized lithography and etching process. Figure 1(b) shows a SEM picture of the surface sidewall roughness.



(a)



(b)

Fig. 1. (a) Schematic structure of the InP microdisk laser coupled to an SOI waveguide and detail of the microdisk laser (inset) and (b) SEM picture illustrating the sidewall surface roughness. (From [3])

3. Switching using microdisk lasers

In addition to their operation as all-optical set-reset flip-flop [4], microdisk lasers (or resonators) can be used for other switching applications such as gating and wavelength conversion. Recenty, we published on the 10Gbps gating and wavelength conversion of NRZ signals using unbiased microdisks [5].

Using a combination of S-R flip-flops, gates and wavelength converters and passive SOI components, PICs for more advanced switching functions (e.g. shift registers, NAND gates,...) can be fabricated. This often requires that the resonance wavelengths (and thus dimensions) of the different microdisks are tuned to each other. Disk definition using e-beam or deep-UV lithography is required, but it has to be combined with thermal tuning of individual disks.

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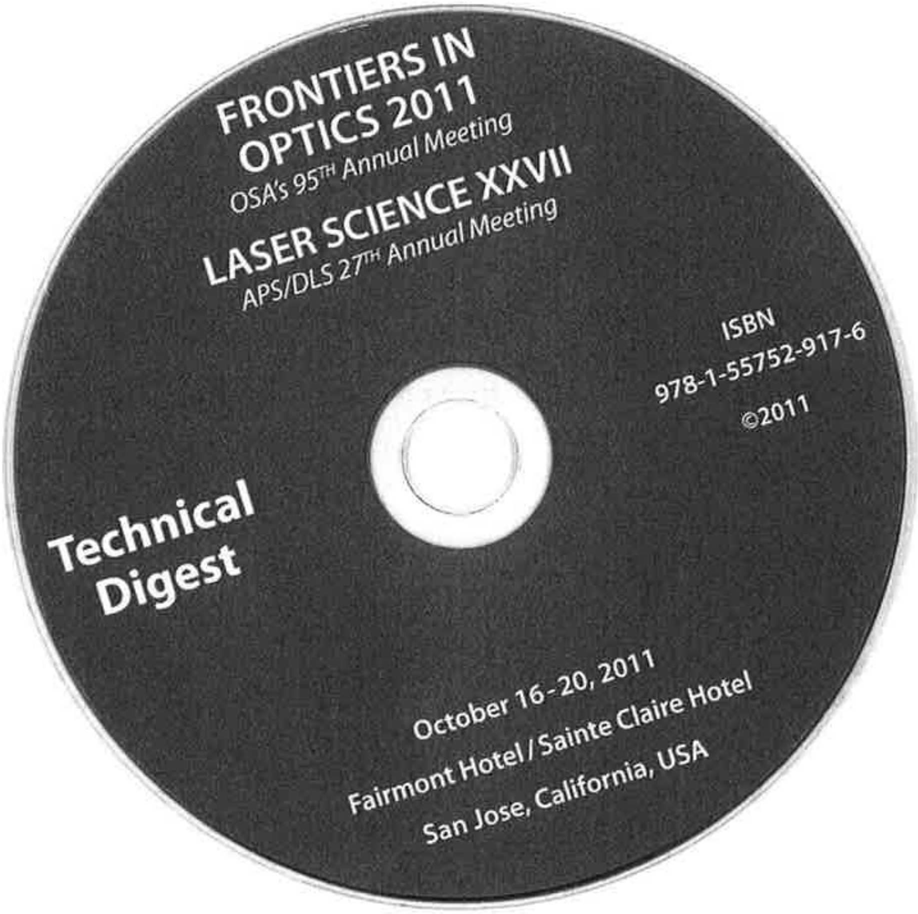
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