Progress in III-V/SOI photonic integrated circuits

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***Abstract*—In this paper we review our work in the field of III-V/SOI photonic integrated components for intra-chip optical interconnect applications. III-V/SOI microdisk light sources, modulators and switches, together with resonant III-V/SOI photodetectors will be discussed.**

I. Introduction

Due to the continued down-scaling of the transistor size in electronic integrated circuits, the (long-distance) on-chip electrical interconnects are becoming a bottleneck. One approach to tackle this problem is to use optical interconnects for long-distance communication on the chip. The silicon-on-insulator material platform is well suited for this optical interconnect application, due to the fact that its processing is compatible with the fabrication of the electronic integrated circuits. All basic functionalities for optical interconnects can be realized on the silicon platform, except for an electrically pumped light source. In order to realize this on an SOI platform, the heterogeneous integration of III-V semiconductors has been proposed. This III-V layer can however also be used for the active optical functionality such as optical modulators, photodetectors and switches. Thereby the function of the SOI photonic layer is purely that of a passive interconnect layer. The footprint of these active III-V devices should be as small as possible, while their power consumption and operation speed should be compatible with the envisioned application. In this paper, we will review our work in the field of compact III-V microdisk structures for on-chip light sources, modulators and switches; and we will elaborate on the realization of a resonant III-V photodetector for WDM intra-chip optical interconnects. In order to heterogeneously integrate the III-V material on top of the SOI waveguide circuit, an adhesive bonding technology is used, using the DVS-BCB polymer as the bonding agent. The advantage of this approach is the large flexibility in terms of bonding layer thickness that can be achieved and its robustness against the sometimes inferior quality of III-V semiconductor surfaces. The low thermal conductivity of the DVS-BCB can be countered by integrating a heat sink structure close to the active components, as will be shown later on in this paper. More details on the DVS-BCB adhesive bonding process can be found in [1].

II. III-V microdisk lasers

Figure 1 schematically illustrates the layout of the III-V microdisk lasers integrated on a silicon-on-insulator waveguide platform. The lasing mode is a whispering gallery mode of the microdisk, which evanescently couples to the SOI waveguide layer [2]. The main features of the microdisk structure are the use of a n++/p++ tunnel junction to reduce the optical loss experienced by the lasing whispering gallery mode due to highly doped and absorbing contact layers. For the same reason, the current injection is realized using a centered metal contact not covering the full microdisk surface and a lateral bottom contact. Omitted from the drawing is the use of the metal top contact as a heat sink by connecting the top metal contact through the bonding layer to the silicon substrate. Recently, the design and fabrication of these devices has been optimized in order to reduce the threshold current of the device and increase the output power levels [3]. Current devices show a threshold current of only 350μA and 120μW optical output power coupled to the SOI waveguide layer at a 3.5mA bias (7.5μm disk diameter). This is a tenfold improvement over previously demonstrated devices and is mainly related to the improvement of the microdisk etching process (lower surface roughness) and the reduction of the thermal impedance of the device by integrating the heat sink. Single wavelength lasing is obtained with a side mode suppression ratio of 35dB. Based on these single wavelength microdisk lasers, multi-wavelength light sources have been demonstrated, by cascading multiple microdisk lasers with slightly different cavity dimensions on a single bus waveguide [4].

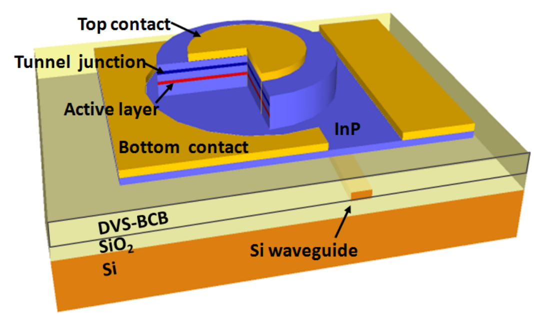

Fig. 1. Schematic representation of a heterogeneously integrated microdisk laser on SOI.

III. III-V microdisk modulators

Another option for optical interconnect applications is to keep the (continuous wave) light source off the chip and

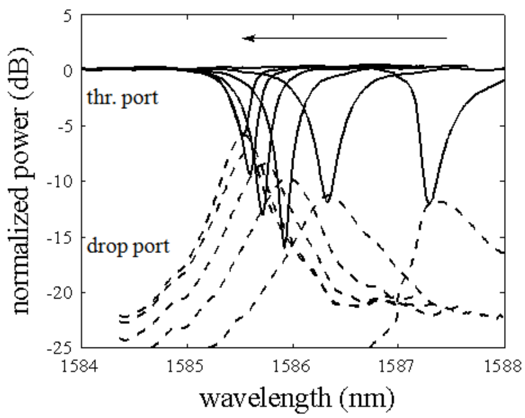

Fig. 2. Microdisk through port and drop port characteristics

imprint the data on the supplied continuous wave light using an integrated modulator. This modulator structure can also be realized using a III-V microdisk structure integrated on top of the SOI waveguide circuit. The use of a resonant structure allows to reduce the power consumption of the device and is directly compatible with WDM based intra-chip optical interconnects. The modulation mechanism is based on the modulation of the loss in the active layer by carrier injection [5]. If no current is injected in the device, the loss in the microdisk structure is high and hence no resonance can be observed when looking at the transmission spectrum of the notch microdisk filter. By injecting current in the III-V layer structure, the active layers can be brought to transparency and hence a high Q-cavity can be obtained, critically coupling the CW light in the microdisk cavity. In these devices this required a 400μA injection current. 6dB extinction ratio and a modulation speed of 2.75Gbps were obtained (without the use of pre-emphasis techniques).

IV. III-V MICRODISK SWITCHES

Besides wavelength routed networks on chip, also circuit switched networks can be considered. This requires the integration of a low power consumption 2 by 2 switch, which can also be realized using a III-V microdisk cavity, coupled to two microdisk bus waveguides. In this case the device operation is based on the plasma dispersion effect by injecting current in the active layer. Since we are operating close to the active layer bandgap wavelength, the plasma dispersion effect is large and allows for a substantial shift of the resonance frequency. This shift is shown in figure 2 for an injection current from 0mA to 0.5mA with a step of 0.1mA. The 3dB bandwidth of the resonance is about 50GHz. For an injection current of 0.2mA (1.1V), an extinction at the through port of 16dB is obtained. The loss at the drop port is about -9.5dB, which is related to the unbalanced coupling of the microdisk to the silicon bus waveguides in this first device batch. Switching of a 10Gbps signal was realized using these structures, with a switching time of 1ns.

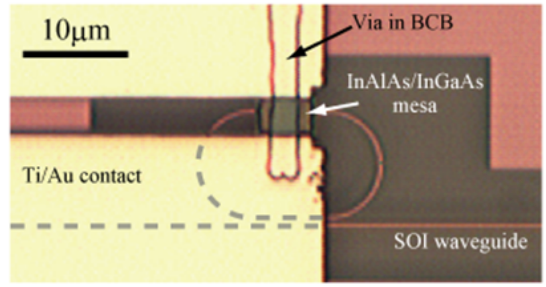

Fig. 3. Microscope image of resonant photodetector structure

V. III-V/SOI RESONANT PHOTODETECTORS

Also photodetection can be realized on the III-V waveguide platform. We demonstrated MSM photodetectors operating over a broad wavelength range (>100nm). A peak responsivity of 1A/W was obtained. while the dark current was about 5nA. In wavelength routed optical networks wavelength selective receivers are required. While this can be achieved by cascading a passive SOI waveguide filter and a broadband photodetector, a more compact implementation is shown in figure 3, where a resonant photodetector is realized by integrating a short absorbing III-V section inside the SOI resonator cavity. This allows to further scale down the receiver size and reduce the dark current of the detector. At resonance, again 1A/W responsivity is obtained, while the dark current is reduced to 0.5nA. The bandwidth of the resonances is about 2nm [6].

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