III-V/silicon photonic integrated circuits for communication applications

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Abstract – In this paper we outline our work in the field of heterogeneously integrated III-V on Si photonic integrated circuits. Photodetectors and laser sources integrated on a silicon waveguide circuit are demonstrated.

1. Introduction

Silicon photonics has become a well-accepted technology with a considerable potential for large-scale industrial adoption, due to the high refractive index contrast that can be achieved and its compatibility with CMOS fabrication technology. Photonic integrated circuits for communication applications however require the integration of light sources and photodetectors. Achieving these features is not straightforward, given the indirect bandgap of silicon and its transparency at telecommunication wavelengths. In this paper, we outline our recent results on the heterogeneous integration of III-V/Silicon light sources and photodetectors for telecom applications. The heterogeneous integration technology used to fabricate these III-V/silicon devices is briefly described.

2. Heterogeneous integration technology

In order to heterogeneously integrate III-V semiconductors on top of a silicon-on-insulator waveguide circuit, an adhesive die-to-wafer bonding process using DVS-BCB as the bonding agent is adopted. An adhesive bonding process is inherently more relaxed in terms of required wafer cleanliness compared to a molecular bonding approach. This improves the yield of the process and makes the process less dependent on the supplier of the III-V epitaxy. In our group we have developed both a die-to-wafer bonding process and a wafer-to-wafer bonding process, since, depending on the application, one of both approaches is more economic. Using this process, a separation between the III-V and Si of less than 100nm can be reproducibly achieved, which is sufficient for most applications [1]. It is important to state that in this process unpatterned III-V films are transferred to a patterned silicon waveguide circuit, which implies that there is a large alignment tolerance in the heterogeneous integration process. An example of a transferred III-V epitaxial layer and a cross-section of the layer stack is shown in figure 1.

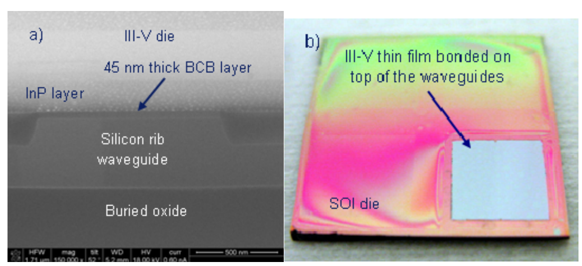


Fig. 1. Cross-section of a III-V on silicon layer stack and a top view image of a III-V epitaxial layer transferred to a silicon waveguide circuit

3. Heterogeneously integrated photodetectors

Based on this technology, heterogeneously integrated photodetectors were realized. While there is strong competition from Ge-based photodetectors integrated on silicon waveguide circuits, there are particular applications where III-V photodetectors outperform Ge. This is for example the case when realizing a transceiver array for point-to-point fiber-to-the-home transceivers, where, at the central office side, a 1310nm wavelength channel needs to be efficiently detected, in a polarization independent way, while a 1490nm/1550nm data signal needs to be sent to the users. To implement this functionality, we use the scheme depicted in figure 2, where the III-V epitaxial layer structure is designed to be transparent for the 1490nm/1550nm wavelength channel, while it is highly absorbing for 1310nm. Using this approach, a 1310nm responsivity of 0.4A/W was obtained, with a polarization dependent loss of less than 0.5dB over the 1260nm-1360nm wavelength range. The crosstalk from the 1490nm/1550nm channel was below -20dB [2].

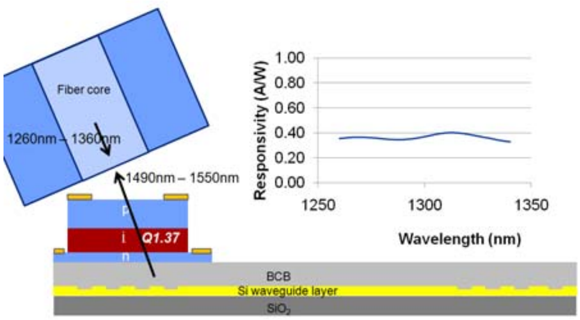
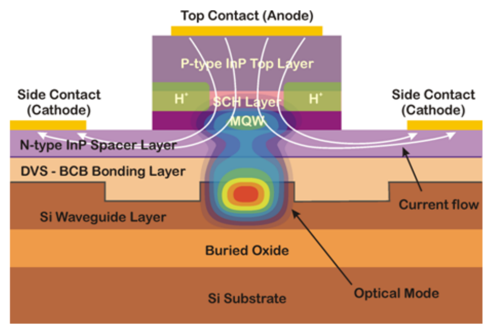


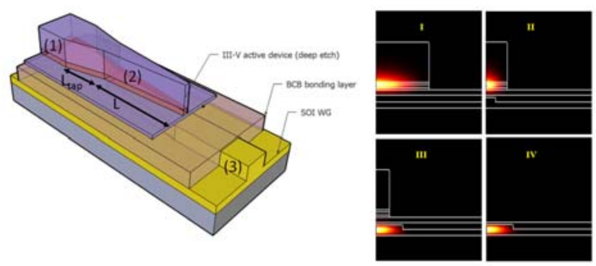
Fig. 2. Schematic cross-section of the realized photodetector for FTTH central office applications. In the inset, the experimentally obtained responsivity is plotted.

4. Heterogeneously integrated laser diodes

The largest merit for integrating III-V semiconductors on top of silicon waveguide circuits comes from the ability to realize heterogeneously integrated laser sources on a silicon waveguide circuit. Several laser architectures can be used to realize mW-level optical output power. A first approach relies on the adiabatic mode transformation from a III-V gain waveguide to the underlying silicon waveguide. This allows for maximum modal confinement in the III-V gain section, while a silicon waveguide filter can be used to provide wavelength selective feedback. First generation devices with cleaved silicon facets show continuous wave operation at 10°C, at 1560nm [3]. A second approach relies on the use of a hybrid optical mode, which is predominantly confined in the silicon waveguide circuit. This approach reduces the modal gain, but allows for an easy interfacing with the silicon passive waveguide circuit. In a first generation devices, continuous-wave Fabry-Perot lasers operating at 1310nm were demonstrated, with 2.9mW output power [4]. Both approaches are schematically outlined in figure 3. We will elaborate on our progress towards integrated DFB laser diodes during the conference. Also, the integration of III-V opto-electronic components on top of active silicon photonic integrated circuits, containing electro-optic modulators, will be discussed.



(a)



(b)

Fig. 3. Schematic cross-sections of the laser architectures

5. Conclusions

In this paper a subset of demonstrated components based on III-V/Si photonic integrated circuits is outlined. It is clear that the heterogeneous integration of III-V semiconductors on top of silicon is a promising technology for many applications, including, but not limited to, optical communication.

6. References

1 S. Stankovic et al., Electrochem. Soc. meeting, p. 411(2010)
2 D. Vermeulen et al., ECOC, p.Tu.5.C.2 (2010)
3 M. Lamponi et al., Group IV photonics, p.WB6 (2010)
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