Heterogeneous integration of III-V semiconductors and Silicon for optical systems-on-a-chip

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Abstract-In this paper we present the heterogeneous integration of III-V semiconductor optical components and Silicon optical components. By integrating these materials into one system a large increase in optical functionality is possible, combining the advantages of the different material systems. We present the realization of InP/InGaAsP photodetectors integrated on a Silicon-on-Insulator optical waveguide circuit.

Keywords: Heterogeneous integration, Silicon, III-V, integrated optics

I. INTRODUCTION

Integration of optical functionalities on a chip has the same advantages as the nowadays ultra large scale integration of electronic functionalities on a chip. Performance, economy of scale, compactness and reliability are increased by integrating more functions onto a single chip. In photonics there is an extra reason to integrate as many functions as possible on a chip: coupling light from one component to another typically requires accurate - and therefore expensive - alignment. When integrating functions this alignment is largely taken care of by means of lithography.

In the past, silicon – the workhorse of electronics- has not been of major importance for photonic functions. Discrete photonic components were generally made in the most suitable material and - with the exception of detection of visible and near-infrared light - this was generally not Silicon but rather other materials such as compound semiconductors, glasses, polymers, liquid crystals, … This is now changing rapidly. Given the call for more integration there are several reasons why Silicon comes into the picture. First of all many photonic functions need to be integrated with (Silicon) electronic circuitry and in a variety of cases it makes sense to build the photonic functions directly on top of the Silicon chip. To do so with high yield and low cost the processes involved should as much as possible be wafer-scale processes. Secondly the technologies used in Silicon microelectronics are much more mature than those used for most other material systems. Therefore if a particular function can be realised by means of the Silicon material, there is an advantage to do so, certainly if the process steps involved are essentially no different from those used for CMOS-processing.

Leaves the fact that, in spite of a lot of research, Silicon has never been – and may never become – a suitable material for particular photonic functions such as efficient and compact light emission, modulation or switching at high modulation rates. Therefore there is a need to develop technologies to heterogeneously integrate functions based upon other materials such as III-V semiconductors on Silicon which may contain electronic circuitry or passive photonic circuitry. This integration should, as much as possible, be done by wafer-scale technologies.

II. HETEROGENEOUS INTEGRATION: TECHNOLOGY

A. Choice of material systems to integrate

As Silicon is the material of interest, Silicon-on-Insulator (SOI) wafers are used to fabricate optical waveguides to guide near infra read wavelength light and to perform passive optical functionalities like splitting, wavelength selection and so on [1]. A typical example of a Silicon photonic waveguide (also called photonic wire) is shown in figure 1.

Figure 1 Scanning electron microscope (SEM) image of an SOI waveguide.

As III-V materials like InP and InGaAsP are the workhorse of telecom industry and yield very efficient devices operating at high speed both for detection, light emission, modulation and amplification at 1.3µm and 1.55µm, the integration of these materials on top of the SOI passive waveguide circuitry would lead to a large increase of functionality of the optical chip.

B. Heterogeneous integration by semiconductor wafer bonding

Although there are several means of integrating different material systems, the use of a wafer bonding approach is investigated in this work. The approach is outlined in figure 2. On a processed SOI wafer, containing the passive optical functionality chip a polymer layer is spin coated which will act as a bonding agent. In our work we focused on using two CMOS compatible polymers, namely benzocyclobutene (BCB) [2] and Spin-on-glass (SOG) [3].
In a second step, InP dies with unprocessed InP/InGaAsP epitaxial layers grown on them are bonded epi side down to the SOI waveguide circuits. It turned out that BCB is the best choice for our application as its planarization properties are better than for SOG, leaving no air voids at the interface between polymer and III-V material. After bonding, the polymer is cured to fix the III-V dies and the original InP substrate is removed by mechanical grinding and chemical etching, leaving only the thin III-V epilayer stack bonded to the SOI waveguide circuit. An example of these structures is shown in figure 3, both for BCB and SOG. In the SOG case, the air voids are visible.

Figure 3 Cross section of InP/InGaAsP epitaxial layers bonded to SOI waveguide circuits. Figure 3a is for BCB bonding, while figure 3b is for SOG bonding

III. HETEROGENEOUS INTEGRATION: DEVICES

To demonstrate the integration of III-V material onto an SOI waveguide circuit, we fabricated a first generation of InP/InGaAsP photodetectors on an SOI waveguide circuit. The device structure is shown in figure 4 and a fabricated structure (prior to top contact metallization) is shown in figure 5. Light in the SOI waveguide is diffracted upwards by means of a grating coupler and is absorbed and detected by the BCB bonded InP/InGaAsP photodetector on top of the grating. First measurement results show an efficiency of 0.02A/W. The integration of III-V laser diodes onto an SOI substrate is on the way.

Figure 4 Structure for coupling light into a photodetector circuit

Figure 5 Fabricated structures

IV. CONCLUSIONS

We presented for the first time the integration of III-V photodetectors and Silicon-On-Insulator optical waveguide circuits. The integration technology involved the bonding of InP dies to SOI substrates using benzocyclobutene as a bonding agent.

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REFERENCES