Heterogeneous integration of III-V membrane devices and ultracompact SOI waveguides

G. Roelkens[1], *Student Member IEEE*, D. Vanthourhout, *Member IEEE*, R.Baets, *Senior Member IEEE*
Department of Information Technology (INTEC) - Ghent University - Sint-Pietersnieuwstraat 41, B-9000 Gent
[1] e-mail: gunther.roelkens@intec.ugent.be

I. INTRODUCTION

In future technology nodes metal interconnection layers are no longer expected to satisfy the bandwidth needs, especially for the global interconnection layer where interconnection distances are the largest. A promising approach is the use of a photonic interconnection layer on top of CMOS [1]. This approach requires the integration of passive optical waveguides and active opto-electronic components, compatible with standard CMOS processing technology. Photonic wires and photonic crystals allow very large scale integration of optical waveguides. Remarkable results are obtained for Silicon-On-Insulator (SOI) high index contrast nanophotonic waveguide structures defined by Deep UV lithography, the workhorse of CMOS technology, and wafer scale processes [2]. In this paper we focus on the heterogeneous integration of III-V opto-electronic devices and ultracompact SOI waveguides.

II. HETEROGENEOUS INTEGRATION

As we need to couple light between the opto-electronics and the SOI waveguides an optically transparant bonding layer is needed. As our intention is to couple active devices to nanophotonic waveguide structures, alignment can only be achieved by lithography. Therefore, unprocessed InP dies are bonded to the SOI waveguide substrate, epi-layers down and the InP substrate is removed. This leaves an active membrane that can be processed subsequently, lithographically aligned to the SOI structures. The processing sequence is shown in Fig. 1.

III. COUPLING III-V AND SOI

In the following subsections two coupling schemes based on adiabatic tapers will be presented. The use of adiabatic tapers as mode transformers makes an efficient coupling with large optical bandwidth possible and allows a trade-off between fabrication tolerance and design compactness. The first design is based on a thin film spin-on glass (SOG) adhesive bonding layer. Bonding layer thickness below 0.5µm have been shown in [3]. The second design is based on a thick film benzocyclobutene bonding (BCB). Bonding layer thickness above 1µm is readily achievable [4].

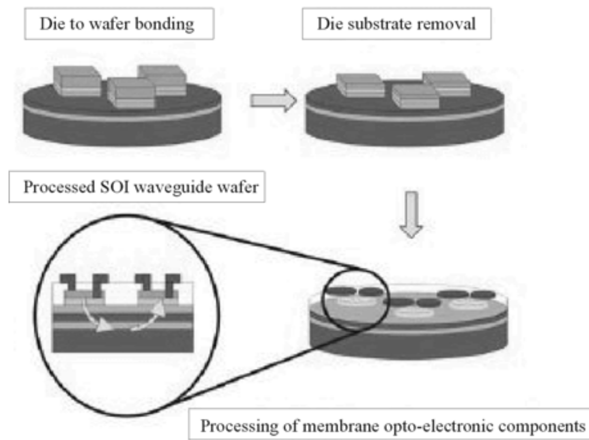

Fig. 1. Processing sequence for heterogeneous integration of III-V components and SOI waveguides

A. SOG bonding coupling scheme

The proposed SOG bonding coupling scheme is presented in Fig. 2. It consists of a double adiabatic taper structure to transform the fundamental waveguide modes. The first taper transforms the active waveguide mode to the fundamental mode of a passive InP membrane waveguide. The SOI adiabatic taper coupler is based on phase matching the fundamental modes of the SOI waveguide and the InP membrane. Simulations show less than 1dB coupling loss over the 1500nm-1600nm wavelength range. The critical dependence of the minimum adiabatic taper angle of the SOI taper on the waveguide separation is shown in Fig. 3. Although

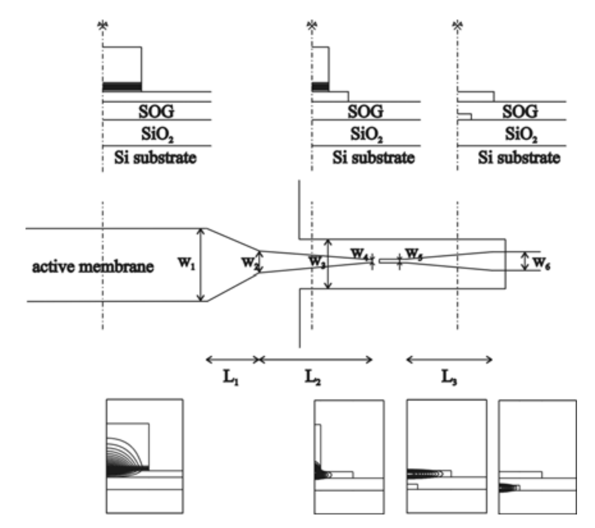

Fig. 2. SOG bonding coupling scheme – layout and mode transformation

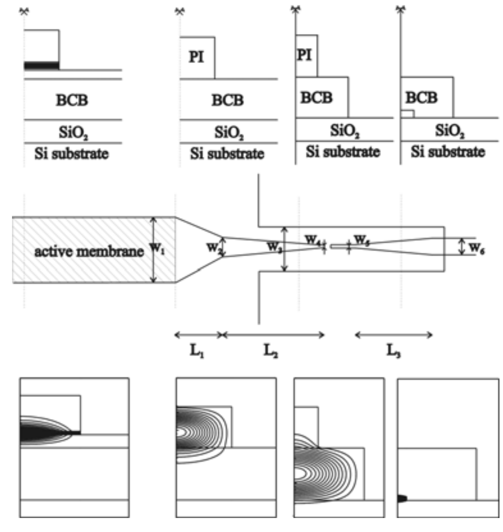

Fig. 4. BCB bonding coupling scheme - layout and mode transformation

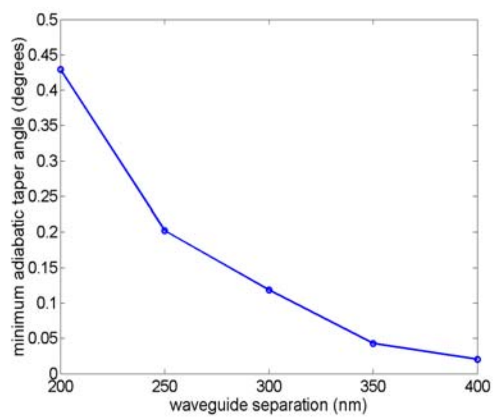

Fig. 3. Minimum adiabatic taper angle versus waveguide separation for SOG bonding coupling scheme

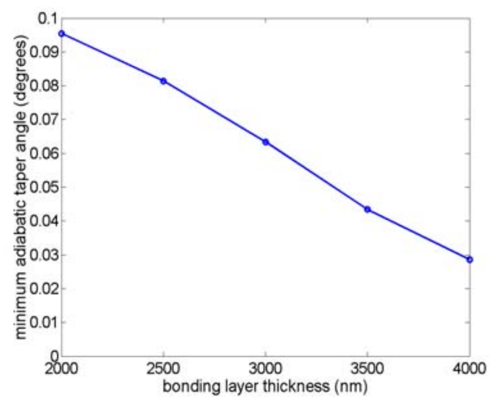

Fig. 5. Minimum adiabatic taper angle versus bonding layer thickness for BCB bonding coupling scheme

the adiabatic taper can inherently be made tolerant to bonding layer thickness variations this dramatically decreases the taper angle and thereby increases the taper length. Therefore, accurate control over bonding layer thickness is necessary.

B. BCB bonding coupling scheme

Because of the critical dependence on the bonding layer thickness in the SOG bonding coupling scheme, an alternative coupling scheme based on thick film BCB bonding is presented in Fig. 4 that reduces this dependence. The coupling mechanism is conceptually equivalent to the first and transforms the waveguide mode using a double adiabatic taper structure. The first adiabatic taper is implemented in a polymer waveguide layer however, that is butt-coupled to the active ridge waveguide. This implies an intrinsic reflection at the semiconductor/polymer interface and a reduced efficiency due to butt-coupling loss. Fig. 5 shows the dependence of the minimum adiabatic taper angle of the SOI waveguide as a function of bonding layer thickness. Compared to Fig. 3 this dependence is drastically reduced. The transmission loss of the double adiabatic taper structure is simulated to be below 0.5dB over the 1500nm-1600nm wavelength range. The intrinsic reflection at the semiconductor-polymer interface enables the heterogeneous integration of edge emitting lasers and passive nanophotonics.

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