Ultra-thin BenzoCycloButene (BCB) bonding of III-V dies onto an SOI substrate

G. Roelkens, D. Van Thourhout, R. Baets

Abstract: The bonding of InP/InGaAsP heterostructures dies onto an SOI substrate is reported. Bonding layer thicknesses down to 200nm were reproducibly achieved. Bonding was achieved both on unprocessed SOI substrates as on processed SOI substrates containing high index contrast waveguides.

Introduction: In recent years, there has been a lot of interest in using Silicon-on-Insulator substrates for optical waveguiding applications. Main advantages of this technology are the possible use of standard CMOS technology for the definition of the waveguides [1], which makes it mass manufacturable and the high index contrast between the Silicon core (n=3.45) and the oxide buffer layer (n=1.45), which makes ultracompact circuits possible and extends the degree of integration [2]. Although this is a very interesting technology for passive functions, up till now no highly efficient active opto-electronic devices fabricated in Silicon were reported despite significant research. If active functions need to be integrated with the passive Silicon components for telecom wavelengths, InP/InGaAsP heterostructure dies need to be bonded on top of the Silicon components and light needs to be coupled between both optical layers. As in these applications InP/InGaAsP active opto-electronic devices are bonded on top of the Silicon waveguides, the bonding layer has to be very thin for efficient heat sinking of the active component through the bonding layer [3]. Optical coupling through this layer in an efficient way also requires ultra thin bonding layers (~200nm) [4] due to the high index contrast between InP/InGaAsP, BCB (n=1.55) and Silicon. Direct bonding of two semiconductor substrates requires ultra flat surfaces [5]. Therefore, direct bonding of processed SOI substrates and InP/InGaAsP dies requires advanced chemical mechanical polishing (CMP) to obtain the needed surface quality. Moreover, the influence of edge effects (due to roughness of the die edge) becomes important when directly bonding small dies (few mm^2). Also Spin-on glass (SOG) can be used to obtain a thin bonding layer [6] when bonding two substrates. However, the required curing temperature is relatively high (400C) and to our knowledge bonding on processed substrates using SOG is not yet demonstrated.

Because of these drawbacks, benzocyclobutene (BCB), a spin-on polymer, was investigated as a bonding agent [7]. The planarizing properties of the polymer make a CMP process redundant and due to the physics of the bonding process edge effects are believed to be small. BCB bonding using layer thicknesses above 1μm is well known [7][8]. In this paper we demonstrate for the first time sub micron layer bonding layer thicknesses, thereby enabling good heat sinking and the possibility for optical coupling. Successful bonding with a layer thickness down to 200nm was obtained, even on substrates showing a surface topography of the same order of magnitude.

Bonding method: The bonding of InP/InGaAsP heterostructures on both processed and unprocessed SOI was investigated. The SOI wafers consist of a 750μm thick Silicon substrate, a 1μm thick buried SiO_2 buffer layer and a 220nm thick Silicon waveguide layer. Optical waveguides were processed using standard CMOS deep UV lithography and by etching through the Silicon waveguiding layer. The waveguides were defined using 4μm wide trenches and are 30μm separated. The waveguide width varied from 0.3μm to 10μm. Both SOI dies (few cm^2) and InP dies (0.25-1cm^2) were thoroughly cleaned using acetone, isopropylalcohol (IPA) and deionized water. Samples are dried at 150C on a hotplate. In a second step BCB is spun onto the SOI substrate. The achievable bonding layer thickness of commercially available BCB, supplied by Dow Chemicals, is limited to 1μm (Cyclotene 3022-35). As this is too thick for most applications of optical coupling, Cyclotene 3022-35 was diluted by adding mesitylene (C_9H_{12}). Measured bonding layer thickness as a function of added mesitylene is shown in Fig. 1. This figure shows that a BCB-mesitylene solution concentration of 2:3 spun at 5000rpm results in a 200nm bonding layer thickness. This is sufficiently thin to allow direct optical coupling between the Silicon and InP waveguide layer [4] and have efficient heat sinking of active opto-electronic devices. The thinned BCB needs to be ultrasonically agitated before application to allow reproducible bonding layer thicknesses. After the BCB is spun onto the substrate both samples are bonded at 150C to drive out any residual solvents and to allow a maximum bonding strength. Bonded samples are cured at 250C in nitrogen ambient for 1 hour. After curing the InP substrate is mechanically thinned down to 50μm. A final chemical etching step using HCl removes the rest of the substrate until an InGaAs etch stop layer is reached. The processing sequence is shown in Fig. 2.

Results: Different solution concentrations up to BCB-mesitylene 2:3 were successfully used to bond onto both processed and unprocessed SOI. SEM pictures of the interface of bonded samples are shown in Fig. 3. Fig. 3a and fig. 3b show the bonding of an InP-die onto respectively an unprocessed and a processed SOI substrate, in both cases using a 200nm thin bonding layer. Due to the excellent planarizing properties of BCB, these thin bonding layers can be applied on a substrate with 220nm topography height without introducing voids.

Conclusions: InP/InGaAsP thin films were bonded to processed and unprocessed SOI substrates. Bonding layer thickness is sufficiently thin to allow direct optical coupling through the bonding layer and allow sufficient heat sinking of active opto-electronic components. This enables the integration of III-V sources, modulators, amplifiers, detectors and ultracompact SOI passive waveguide structures to fabricate complex photonic circuits.

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Figure captions:

Fig.1 Bonding layer thickness (spun at 5000rpm) as a function of added fraction of mesitylene

Fig.2 Bonding processing sequence

Fig.3 InP film bonded to an unprocessed SOI substrate (a) and to a processed SOI substrate (b) using a 200nm thick bonding layer. The SOI substrate consisted of a 220nm Si layer on top of 1μm thick SiO_2 buffer layer. The Si substrate was 750μm thick.

Figure 1

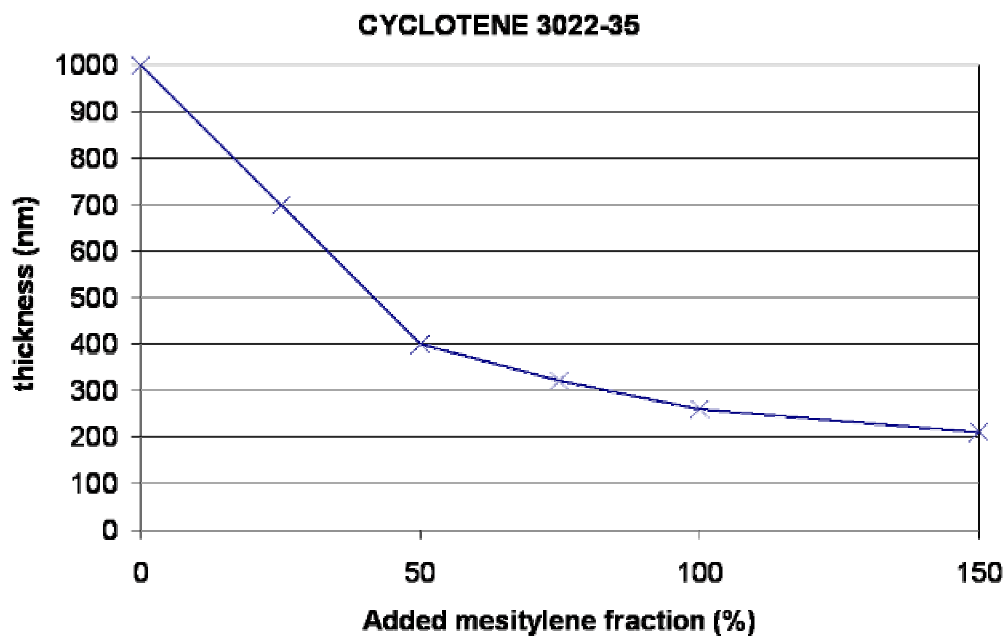
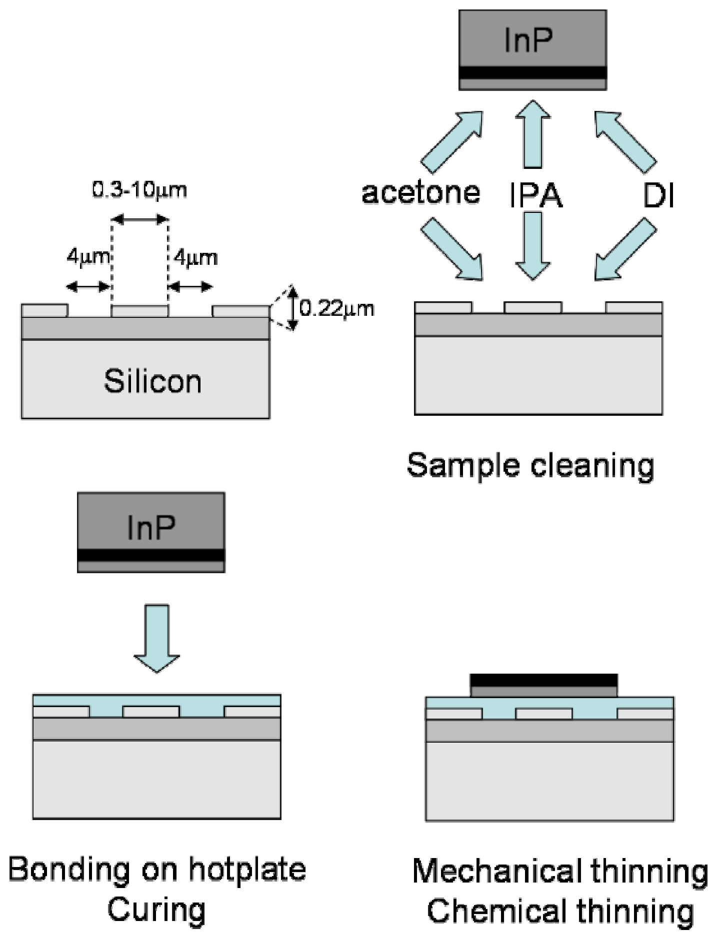

CYCLOTENE 3022-35
thickness (nm)
1000
900
800
700
600
500
400
300
200
100
0
0
50
100
150
Added mesitylene fraction (%)

Figure 2



InP
acetone
IPA
DI
0.3-10μm
4μm
4μm
0.22μm
Silicon
Sample cleaning
InP
Bonding on hotplate
Curing
Mechanical thinning
Chemical thinning

Figure 3a

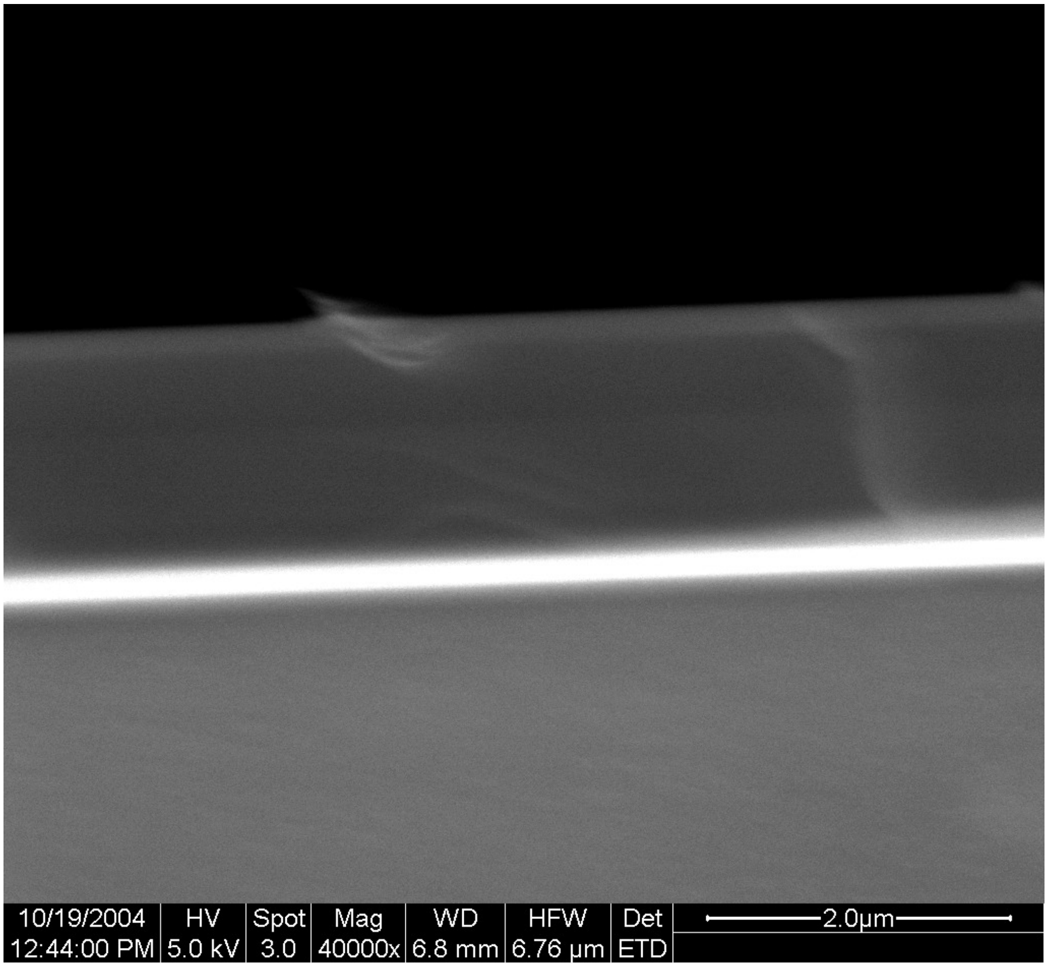

10/19/2004
12:44:00 PM
HV
5.0 kV
Spot
3.0
Mag
40000x
WD
6.8 mm
HFW
6.76 µm
Det
ETD
2.0µm

Figure 3b