BCB bonding of high topology 3 inch InP and BiCMOS wafers for integrated optical transceivers

M. Spiegelberg[1], J.P. van Engelen[1], T. de Vries[1], K.A. Williams[1] and J.J.G.M van der Tol[1]

[1] University of Technology Eindhoven, De Rondom 70, 5612 AP Eindhoven, The Netherlands

In this publication the challenges of bonding InP and BiCMOS wafers with high topology are described. A possible process is discussed. Planarization with thick BCB is motivated and the challenges of wafer alignment are explained.

Introduction

Optical transceivers consist of optical elements and related electrical circuits. Telecom and Datacom applications require continuously increasing bandwidth of the transceiver. A main limitation of the bandwidth is given by the excessive parasitics of the interconnects. The European project WIPE [1] aims at a reduction of these parasitics by using wafer bonding. The photonic integrated circuit is fabricated within Indium-Phosphide (InP) technology and the electronic integrated circuit is realized in a BiCMOS process. Bonding both wafers to each other enables short interconnects and therefore leads to reduced parasitics [2]. Adhesive wafer bonding is studied and used for many applications [3, 4]. Here the focus lies on bonding two wafers with high topology on both of them. The proposed bonding process is described and first results on alignment are presented.

Bonding process

In figure 1 the starting point of the bonding process is presented. The two wafers are fully processed and include key features for the following process steps. The topology on the photonic wafer shows height differences in the order of 6 µm, the BiCMOS wafer has 3 µm of topology. The bonding is performed by using Benzocyclobutene (BCB) as an intermediate layer. Depending on the type of BCB and the used method of coating, different layer thickness can be achieved.

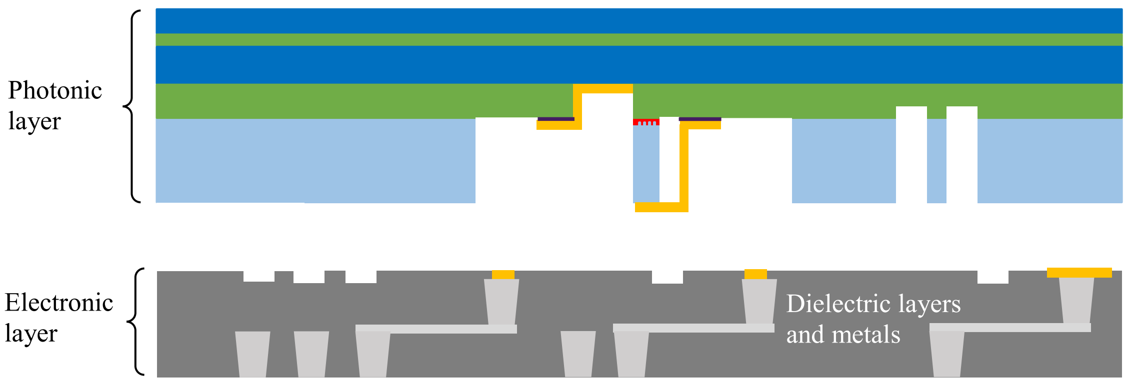

Figure 1: Schematic cross section of the photonic (top) and electronic (bottom) wafer

The following results were realized with spin coating. The first step is to create an adhesive surface whereby a strong chemical bond between BCB and wafer surface can be achieved. The supplier of the polymer recommends the adhesion promoter AP3000 which creates an oxidation. To improve that mechanism a SiO_2 layer is deposed

beforehand on each of the two wafer surfaces. Before applying the AP3000 it is necessary to extract gaseous chemical products which are formed in SiO_2.
If the outgassing is not performed gas inclusions can be created during the bond which disables further processing steps that include vacuum. The outgassing is performed in a nitrogen atmosphere for 1 hour at 240 ºC. After spin coating the AP3000 the BCB can be applied. For the best bond result it is necessary to planarize the two bonding surfaces. BCB itself has a planarization factor of 90 % which refers to the reduction of the height of the remaining bump relatively to the initial height of the topology. The BCB layer thickness has to have at least double the thickness of the target height of the topology [5]. This means that a 12 µm thick BCB layer has to be used to planarize the 6 µm topology of the InP wafer while the remaining bumps will reach values of up to 600 nm.

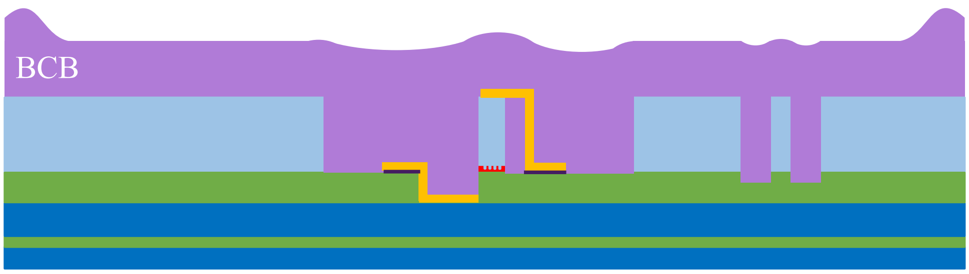

Figure 2: Schematic cross section of the InP wafer with the applied BCB including edge beads and remaining topology

Spin coating thick layers of BCB requires low rotation speeds and a BCB with a high viscosity. This leads to significant edge beads which are a few times higher than the remaining topology. In figure 2 a schematic cross section of the InP wafer with spin coated BCB is shown. The high viscosity is unprofitable for filling small structures, under edges or air bridges. Especially the air bridges create a risk of air inclusion if not filled completely. To avoid air inclusions a multilayer spin coating is used where first low viscosity BCB is used to fill the air bridges followed by the high viscosity BCB to achieve the needed planarization.
Bonding two wafers with topology to each other requires the planarization of both wafers, therefore it is needed to spin coat BCB on both surfaces. After spinning a soft bake is required to remove the remaining redundant solvents from the BCB. That reduces outgassing during the bonding and stabilizes the surfaces. Afterwards the BCB is still uncured, while the viscosity is increased. To fix the spin coated layer a soft curing could be used. Literature [3, 6] suggests a curing percentage of 40 %. In figure 3 the curing percentage of BCB is shown dependent on the used temperature and applied time. A soft cure of 40 % could be achieved by applying 175 ºC for 1 hour. This curing process should be performed within a nitrogen atmosphere or vacuum to avoid oxidization of the BCB layer. Such oxidization of BCB occurs for temperatures above 140 ºC and reduces the bonding quality. A negative aspect of the soft cure is the hardening of the edge bead. Due to its high topology the bond will be incomplete or unsuccessful, unless another layer of BCB is used to compensate for it or a chemical-

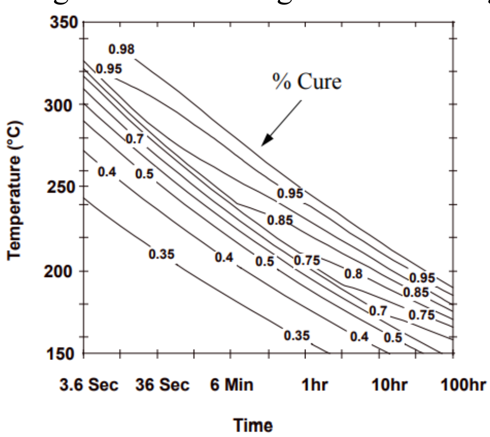

Figure 3: BCB curing function depending on time and temperature [7]

mechanical polishing step is used. An alternative is removing the edge bead before the soft cure or leaving the BCB uncured until the bond, when the edge bead will be squeezed out and helps with evacuation of the interface. We used the second option.

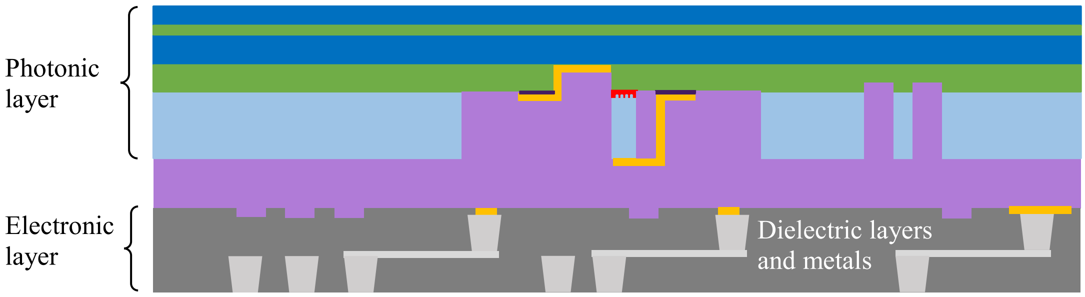

Figure 4: Schematic cross section of the bonded wafer stack

Before placing the wafers into the bonding tool they are aligned to each other and clamped to fix the alignment for the transport into the bond chamber. Due to the topology and the non-uniformity air is captured between the two wafers. The wafers are in contact, while precisely the edge beads are touching. By applying a vacuum in the bond chamber the air in the interface can be removed through openings in the non-uniform edge bead. The bond recipe consist of 6 main steps: evacuation of the chamber, heating the wafers, applying force, releasing force, curing and cooling. The used force for the 3 inch wafer is 700 N. The curing is done at 240 °C for 10 hours.

Alignment

A requirement to enable interconnects between the InP photonic wafer and the BiCMOS electronic wafer is an accurate alignment. In [3] the different techniques are described and possible alignment accuracies are given. In our work the back-side-alignment method is used. Thereby the topside of the BiCMOS wafer is aligned to the backside of the InP wafer. To enable this it is necessary to first create structures on the backside of the InP wafer, matching the key features on the topside of the BiCMOS wafer. This can be achieved with a transfer lithography (backside alignment) with an alignment accuracy of 1 µm. After etching the backside alignment features, the actual wafer alignment can be performed which adds another 1 µm to the total alignment accuracy. Thus the theoretically achievable alignment accuracy is 2 µm.

The different thermal expansion coefficients of the two wafer materials add a complication to the alignment process. InP is thermally expanding more than the BiCMOS wafer, with is mainly Si-based. The issue is that at the elevated temperature where the BCB solidifies the two wafers are strongly linked, so that they can no longer expand independently. Therefore the structures on the InP wafer have to be designed on corrected positions with respect to the referring structures on the BiCMOS wafer, while the alignment features have to be matching each other at room temperature.

In figure 5 the thermal expansion for a glass to Si bond is visible. Both markers have the coordinates [0, -32.5] mm, where the point of origin refers to the center of the wafer. After bonding there is a horizontal shift of 15.4 µm.

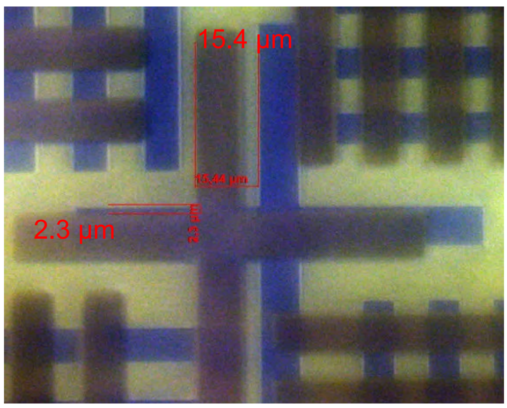

Figure 5: Alignment after bonding glass to Si, horizontal offset is due to thermal expansion

The horizontal thermal expansion mismatch for the position is estimated out of several measurements to be 18 µm. The difference between the thermal expansion and the measured horizontal shift, 2.6 µm, is explained by the alignment accuracy, which corresponds with the vertical alignment accuracy of 2.3 µm, where no thermal expansion occurs.
A dependency of the alignment accuracy on the BCB thickness could not be observed. The verification is done by bonding flat wafers to each other (glass, Si) with 1.4 µm, 6 µm and 18 µm of BCB thicknesses as an intermediate layer. A reproducible alignment accuracy of better than 4 µm was achieved. It was noticed that there is a reduced contrast of the optical marker, covered by thick BCB, during the alignment. This effect will limit the alignment accuracy for even thicker BCB layers. A positive effect of the thick BCB layers is the capability to tolerate dust particles which might be present on the surface during processing.

Summary

In this publication we propose a bonding process for bonding a 3 inch InP wafer to a 3 inch BiCMOS wafer by using BCB as the adhesion layer. The separate process steps are described and optimized solutions are explained. We show that an alignment accuracy of 2 µm is in theory achievable by using the backside alignment technique. In an experimental realization, where a bond of two flat wafers (glass, Si) was performed, using the proposed process an accuracy of better than 4 µm was achieved reproducibly for different BCB thicknesses. A planarization with thick BCB layers was motivated and will be further investigated.

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