Optimization and Characterization of a Photo Definable BCB for HV3S and HVHBT Technologies

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Abstract

A 7µm and 9µm thick photo definable BCB process has been introduced into a GaAs manufacturing line for the HV3S and HVHBT technologies. This paper reviews the initial characterization, the process introduction and process issues encountered during the installation which include peeling nitride, a “wrinkled” BCB surface and bubbles in the BCB.

INTRODUCTION

TriQuint Semiconductor offers a low dielectric constant coating process for GaAs MMICs consisting of B-stage bisbenzocyclobutene (BCB). During the process the BCB overcoat is applied on top of the existing SiN protective overcoat (PO) layer which is designed to encapsulate the MMIC surface and under fill the air bridges. BCB also provides a low-K dielectric spacer between the MMIC and any packaging encapsulate. The addition of BCB allows for increased die protection from scratches, mishandling, and underside mechanical support for air bridges.

PROCESS CHARACTERIZATION

The baseline 7µm BCB process uses DOW Chemical CYCLOTENE 4022-35 as the photo definable BCB. The basic process flow is as follows: 1) Spin application of an adhesion promoter AP-3000 (Dow Chemical). 2) Manual spin application of the BCB 4022-35 using an EFD syringe. 3) Hot plate soft bake. 4) Broadband exposure using a Karl Suss MPA-150 in contact mode. 5) Double puddle track developed with DS2100 (Dow Chemical). 6) Inline track hot plate post develop bake. 7) Descum using O2/CF4/SF6 chemistry removing approximately 2000Å of the BCB film. 8) Oven cured in a low O2 environment of <100ppm at above 250°C.

During the process, the BCB thickness is measured at multiple steps during processing to ensure a final minimum thickness and to monitor the stability of the process. The initial spun thickness on silicon monitors is targeted at 7.1µm. After develop the thickness is 6.7µm, after descum the thickness is 6.2µm, and after cure the final thickness is 5.7µm. The photoactive compound used in the BCB process can be closely monitored during storage. It degrades at room temperature and it must be stored at <-15°C until it is ready to be applied. Before the application, the BCB syringe is removed from the freezer and allowed to defrost for a minimum of 45 minutes. This short stability can be a challenge to maintain a stable process in a manufacturing environment and the major process parameters were characterized with the proposed process flow. The BCB stability was evaluated to correlate the final coating thickness vs. resist age (i.e. the number of days the BCB has been defrosted). From the data below in Fig 1.1, the material can be used safely within the 0 to 3 days of recommended shelf life without a significant increase in film thickness.

Figure 1.2 is an example of the non-linear behavior of BCB to the develop process film thickness loss and curing process film thickness loss as a function of resist age. Post develop film loss shows the most significant change as a function of resist age (slows). Descum etch film loss shows little change.

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Figure 1.2 BCB film loss vs. age of BCB resist.

Figure 1.3 shows the impact of BCB age on the film thickness and the amount of time it takes to clear a standard film thickness in develop.

Figure 1.3 BCB Thickness/Clear time vs. age of BCB resist.

The goal of the process was to provide sufficient protection for the packaging process and add additional support for the air bridge. Figure 2.0 shows that the end results were successful for HV3S technology 7um BCB process.

PROBLEMS ENCOUNTERED AND SOLUTIONS

Due to an overall topology difference in the final height of HV3S vs. the HVHBT device, two different processes with different viscosities of BCB were developed with the thickness targeted at 7µm and 9µm respectively. A higher viscosity BCB (DOW CYCLOTENE 4024-40) was used in order to achieve the 9µm thickness after the initial coat. As a result of the two different process thicknesses, we were able to optimize the process parameters to create a workable solution for both processes by simply scaling the exposure dose and develop time to compensate for the film thickness. The FIB was performed to verify that there is enough BCB~1.5µm on the top of the air bridges. (See Figure 3).

As with any new process introduction, marginalities during daily operation were uncovered. The following is a description of these issues and the solutions that were implemented for the 7µm thick BCB (DOW 4022-35) process. At the early stage of the process trials, a delimitation problem was discovered. Figure 4 shows poor adhesion of PO/BCB to the plated metal (M2) that was observed within specific pad designs.

The wafers that were impacted exhibited a failure rate of as high as 80% at demount. This failure rate was isolated to
an adhesion failure of PO to M2 when BCB was present and the PO was torn from M2. To improve the adhesion, two process changes were implemented: 1) Addition of a 500Å evaporated titanium layer over the top of MET2. 2) Replacement of the tensile-stress 2000Å SiN protective overcoat (PO) deposited at 250°C with a compressive stress PO deposited at 350°C.

The next challenge that was encountered was the wrinkled BCB issue—see Fig 5.1. Wrinkled BCB was an intermittent problem in the first two years that we were running the 7um BCB process. It typically impacted only one wafer out of multiple lots accounting for a less than 8% hit rate. However, recently the wrinkled BCB defect has become a more prevalent problem causing a temporary shutdown of the BCB process. In addition to the wrinkled BCB problem, a defect began appearing in the form of multiple bubbles or blisters at the edge of closely spaced metal lines. See Fig 5.2. The first hypothesis based on feedback from DOW Chemical for the sudden spikes in wrinkled and bubbles was that it could be due to a temperature increase in the developer. An increase of the developer temperature can make the developer more aggressive on the BCB and since there is no temperature control on the current track, a new developer track was evaluated with a temperature control system. The results show that a temperature adjustment of +/- 3ºC had minimal impact on the wrinkle defect.

After several DOE experiments were conducted, the main cause for wrinkled BCB was a combination of primarily underexposure and a secondary impact of overdevelopment. In underexposure the polymer was absorbing more solvent than it could tolerate for the crosslink density induced by the photo exposure. This caused wrinkles to occur on the surface of the BCB at the transition from the field area to the metal lines where the BCB film is the thickest. The exposure dose was not sufficient to crosslink the film thickness and it allowed more solvent retention during the develop step that was swelling the polymer causing it to rupture at the surface to accommodate the increased volume. The DOE showed that by increasing the exposure energy and reducing the develop puddle time the wrinkles disappeared.

The issue of bubbles forming in the metal line edges was thought to be the result of the out gassing of the adhesion promoter. During the post coating bake step the AP was pooling in the small metal line spaces and not totally evaporating during the spin dry process. The initial process for the adhesion promoter application was to use a spin dry after dispense with 3000 rpm for 10 seconds. A DOE was performed evaluating increased spin times and adding a post adhesion application hot plate bake to the process, but the bubble formation was not impacted. Another theory was the possibility of localized swelling of the BCB resulting from developer retention due to incomplete cross linked BCB. The bubble formation was evaluated against the exposure dose determining that an increase dose reduces the bubble formations. By doubling the dose the bubble formation was significantly minimized. See Figure 6 for examples of dose vs bubble formation.

An experimental mask was used to evaluate four design rules of the BCB opening size:
1. BCB coincident with PO on pads
2. BCB coincident with CAP on pads
3. BCB inside CAP metal for 2 um
4. BCB inside CAP metal for 4 um

The optimal opening was to place the BCB opening inside the CAP metal 4µm. Figure 6 shows the BCB encroachment onto the CAP metal when using the 4 different BCB opening sizes on the test mask.
CONCLUSION

A photo active BCB coating has been successfully added to GaAs manufacturing line for the HV3S and HVHBT technologies. The design rules have been established to ensure no BCB encroachment over the cap metal opening that prevent bonding integrity issues. The process integration has been improved to eliminate adhesion failures and process marginalities were stabilized to provide a robust solution for MMIC die protection during packaging.

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ACRONYMS

BCB: B-stage bisbenzocyclobutene
GaAs: Gallium Arsenide
MMIC: Monolithic Microwave Integrated Circuit
SiN: Silicon Nitride
PO: Protective Overcoat
HV3S: High Voltage S-Band
HVHBT: High Voltage Heterojunction Bipolar Transistor