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# Experiment and Analysis of the Effect of BCB Sealing Ring Flatness on BCB Cap Transfer Packaging

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**Abstract**—This paper presents the effect of BCB sealing ring flatness on BCB bonding for wafer-scale BCB cap transfer packaging. BCB sealing ring has shown partial bonding or full bonding depending on its flatness. It is found that the principal cause of the partial bonding is due to non-flat BCB sealing ring caused by multilayer BCB coating process. As a solution, BCB dry etching has been proposed to improve the flatness of the BCB sealing ring for full BCB bonding. Besides, partial bonding of BCB ring has been analyzed through FEM modeling of BCB cap with a non-flat sealing ring. The FEM model consists of Si carrier wafer, BCB cap, and Si target substrate. Unique load is applying pressure on top of Si carrier wafer like wafer-scale bonding. The role of applying pressure is to get BCB sealing ring to be contacted and expand bondable area with target Si substrate. As BCB sealing ring is bonded through BCB polymerization by holding the pressure for 1 hour at 250 °C, mechanical properties of virgin BCB sealing ring has been changed during bonding. Thus, it has been chosen as variable for parametric analysis. Also, BCB cap dimension has been used as another parameter for the parametric analysis.

**Keywords**—Flatness, BCB sealing ring, packaging, polymer, FEM.

## I. INTRODUCTION

Polymer materials have been widely used as an intermediate layer or encapsulation caps in MEMS packaging [1, 2]. The polymer intermediate materials are used as sealing ring between packaging caps and device substrate since most of the packaging caps are glass or Si. They are bonded by means of thermocompression bonding or laser. Low temperature bonding capability of the polymer is particularly attractive as high process temperature in MEMS packaging could create thermal mechanical failure of MEMS devices. For usage, polymer material with high viscosity is dispensed in a cap wafer with a housing cavity for MEMS device. Due to the high topography of the MEMS packaging cap, wafer-scale coating of the polymer on MEMS cap wafer could create non-flat sealing ring on the rim of packaging cap [3]. Such a non-flat polymer ring can be a reason of low bonding strength of MEMS package [4]. Thus, novel fabrication methods have been reported to implement the flat polymer ring on MEMS packaging cap with housing cavities [4]. Recently, polymer cap encapsulation has been presented to take advantages of low-profile and low packaging loss for high frequency devices [5, 6]. The polymer cap packaging of MEMS devices has been

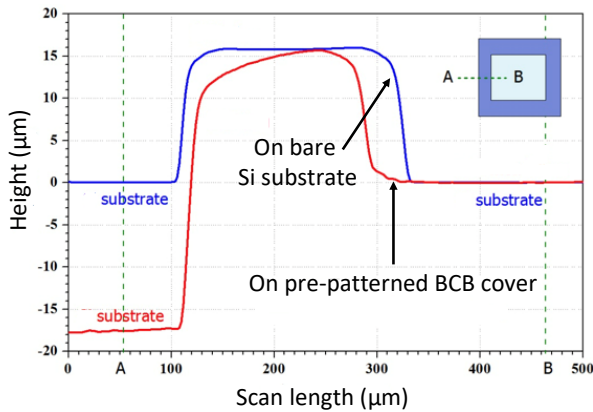
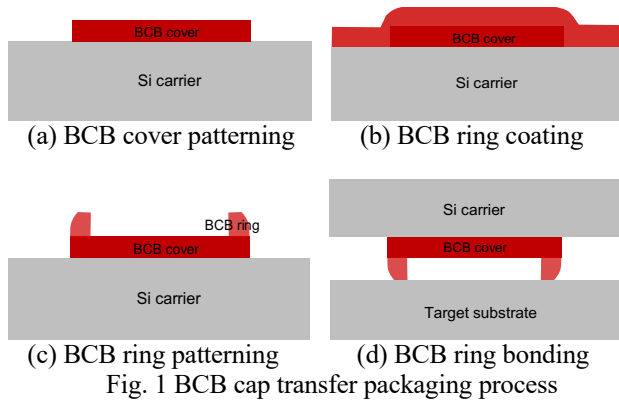
realized in two different ways; 1) release of packaging cap 2) transfer of packaging cap. Polymer cap release has been carried out by plasma etch of organic sacrificial layer through access holes or wet etch of the polymer cap partially cross-linked. Transfer packaging of polymer cap needs a temporary carrier wafer to literally transfer the fabricated packaging cap to a target device substrate. When the polymer packaging cap is prepared in a carrier wafer, we ought to use multilayer coating of the polymer to build packaging cover and the sealing ring of the packaging cap. When polymer sealing ring is coated on pre-patterned polymer cover, sealing ring layer shows certain non-flatness due to surface profile of the pre-patterned polymer cover layer. Moreover, polymer sealing ring is directly affected by the non-flatness since it should be built in the rim of polymer cover. It is thought that non-flat polymer sealing ring would not be significant because high applying bonding pressure can flatten it resulting in expansion of bonding area. Therefore, it is necessary to study the effect of non-flat polymer ring on polymer cap transfer packaging. FE (Finite Element) model is useful technique to evaluate mechanical stress and deformation of a MEMS package [7] and to investigate contact surface behavior when two different materials are jointed or contacted [8].

In this paper, experimental results effect of flatness of BCB sealing ring on BCB packaging cap bonding and corresponding FEM analysis have been presented. BCB cap transfer packaging and experimental results of BCB cap transfer packaging with two different BCB sealing ring flatness are presented in Section II. FEM modeling and simulation of BCB cap packaging with non-flat BCB ring explained in Section III. Finally, conclusion will be made in Section IV.

## II. BCB CAP TRANSFER PACKAGING AND BCB SEALING RING NONFLATNESS

Fig. 1 shows BCB cap transfer packaging process based on photosensitive BCB multilayer coating [9]. As shown in Fig. 1, BCB cap is prepared by using spin-coating of photosensitive BCB. BCB cap has one cover layer having thickness of 15-20  $\mu\text{m}$  and one sealing ring of 15-20  $\mu\text{m}$ . The BCB sealing ring can have non-flat shape as it is coated and patterned on the pre-defined BCB cover and thus it could cause partial bonding of the sealing ring to target Si substrate. Fig. 2 shows the profile measurement of BCB sealing ring built on bare silicon wafer and BCB sealing ring

on pre-defined BCB cover respectively. As clearly seen in this figure, flat BCB ring area is substantially reduced due to pre-patterned BCB cover.



As the non-flatness of BCB ring is caused by coating on a pre-defined BCB layer, dry etch-based BCB cap process has been presented as shown in Fig. 3. The difference with the previous one is that BCB cover layer is not patterned before BCB ring layer coating. BCB ring and BCB cover are defined by using BCB dry etch to achieve better BCB sealing ring flatness. BCB cap profile measurement, shown in Fig. 4, validated BCB ring flatness better than the previous one. Note that outer wall of the BCB sealing still has slightly inclined as it has been defined by wet etch of BCB after photolithography.

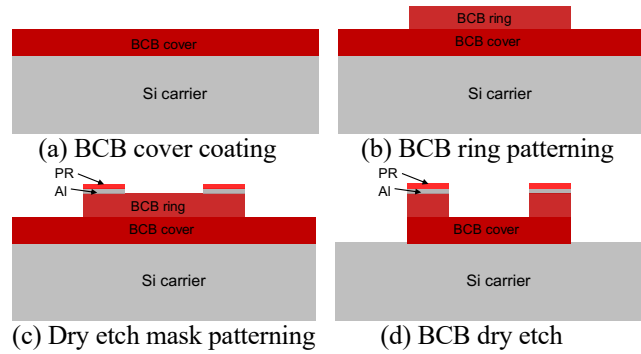
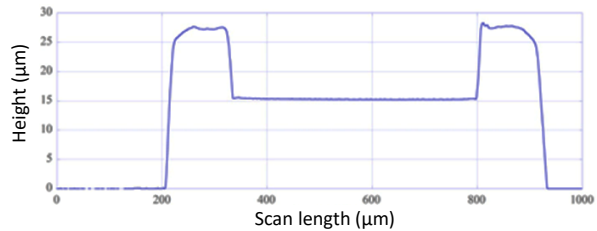


Fig. 3 Dry etch-based BCB cap process



Wet-etched BCB cap and dry-etched BCB cap are bonded with target substrates in same bonding conditions. The transferred BCB caps are shown in Fig. 5. Wet-etched BCB caps have frequently produced partial bonding due to the non-flat BCB sealing ring even if large applied pressure, while dry-etched BCB caps has achieved full bonding. It should be noted that dry-etching process needs high cost due to increased photomasks and process steps.

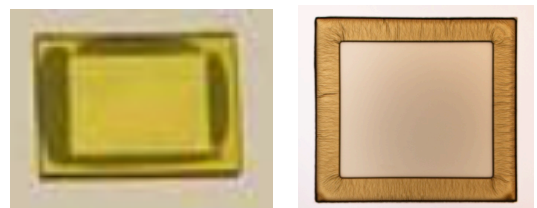
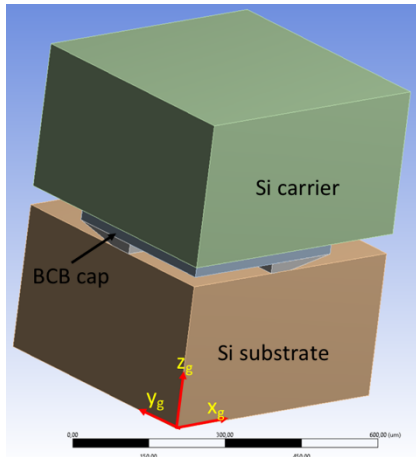


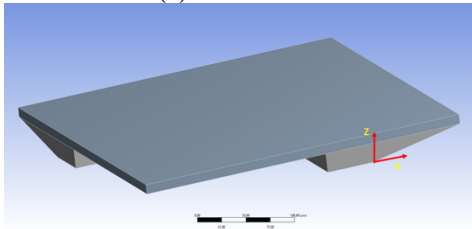
Fig. 5 BCB cap transfer packaging results

### III. FEM MODELING AND SIMULATION

As mentioned in previous section, non-flat BCB sealing have caused partial bonding even if the applied larger bonding pressure. Thus, it is required to study the effect of applying pressure on non-flat BCB ring at wafer-level bonding. A FEM model of the BCB cap transfer packaging with non-flat BCB sealing ring has been built as shown in Fig. 6. It consists of Si carrier, BCB cap and target Si substrate as is in the packaging process. Note that it is a quarter model of a single package to reduce element number as well as simulation time. By consequence, boundary conditions are applied as follow;  $U_x = 0$  at  $x_g = 0$ ,  $U_y = 0$  at  $y_g = 0$ . Bottom surface of Si substrate is fixed. Si carrier wafer movement are constrained to be in z-axis when bonding pressure is applied on top of Si carrier. Applied force is 1500 N as is in the experiment [10]. Dimension of each component and material properties are summarized in Table 1 and Table 2 respectively.



(a) Total model



(b) BCB cap

Fig. 6 FEM model of BCB cap transfer packaging with non-flat BCB sealing ring

Table 1. Dimension of the model

	Length ( $\mu\text{m}$ )	Width ( $\mu\text{m}$ )	Thickness ( $\mu\text{m}$ )
Si carrier	500	500	300
BCB cap			
BCB cover	350	350	20
BCB ring	350	150	20
Si substrate	500	500	300

Table 2. Material properties

	Young's Modulus	Poisson ratio
Silicon	190 GPa	0.21
BCB	3 GPa	0.34

To reflect the non-flat BCB ring, it is modelled as two different parts as depicted in Fig. 7; bonded and non-bonded. As non-flat BCB ring has been bonded from inner part of the ring to outer side, it is modelled to have bonded contact and frictional (non-bonded) contact. The bonded contact of the BCB cap means BCB cap has good bonding, while the frictional one is used to monitor the behavior of BCB cap deformation due to applied bonding pressure. The bonded contact has 50  $\mu\text{m}$  width and the remained area of the BCB sealing ring are defined as frictionless one. As the BCB ring has 150  $\mu\text{m}$ , the unbonded ring width is 100  $\mu\text{m}$ .

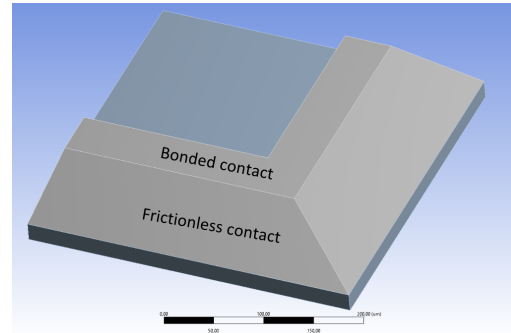
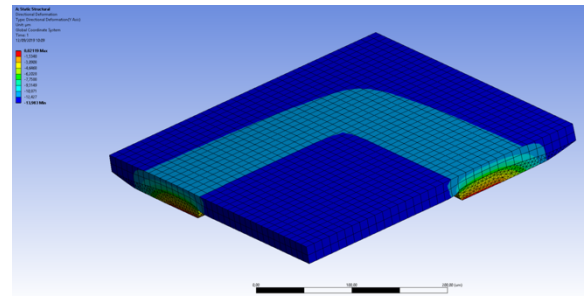
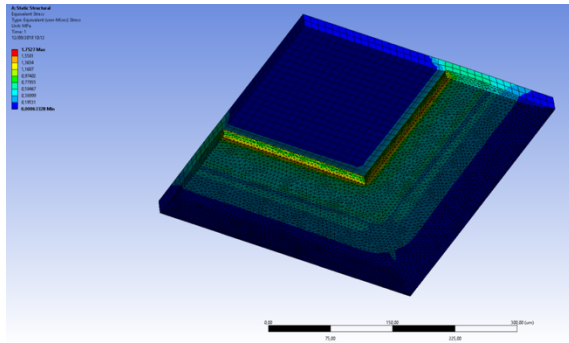


Fig. 7 Contact surfaces of BCB cap

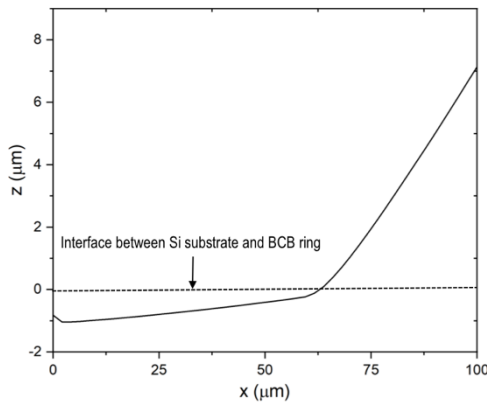
Displacement in z-axis direction and corresponding stress are shown in Fig. 8. BCB cap associated with bonded BCB ring has slightly smaller displacement than other parts of the BCB cap and thus maximum stress is found inner side of BCB ring. The maximal stress of BCB cap is much lower than yield stress of BCB polymer of  $87 \pm 9$  MPa [9]. Fig. 8 (c) shows deformed BCB ring along the slope of the unbonded BCB ring referring to x and z axes as indicated in Fig. 6. Point crossing with interface between Si substrate and BCB ring is upper limit of bonded sealing ring. In this case, the bonded zone is up to 62.5  $\mu\text{m}$  among initial unbonded zone of 100  $\mu\text{m}$ . Applying force of 1500 N makes total bonded area to be increased by 62.5 % of the unbonded BCB area.



(a) Displacement in Z-axis



(b) BCB cap stress



(c)

Fig. 8 FEM simulation results

BCB ring is assumed to be fully cured in the previous simulation, but it should be partially cured or virgin BCB ring to achieve good bonding with target Si substrate. During bonding process, force is applied to wafer stack through 3 mm-thick glass pressure diffuser from 150 °C as seen in Fig. 9. After 10 minutes, temperature goes up to 250 °C and stays for 1 hour to get the BCB ring fully-cured. Therefore, a parametric study depending on BCB ring material properties such as Young's modulus ( $E$ ) and poisson ratio is required.

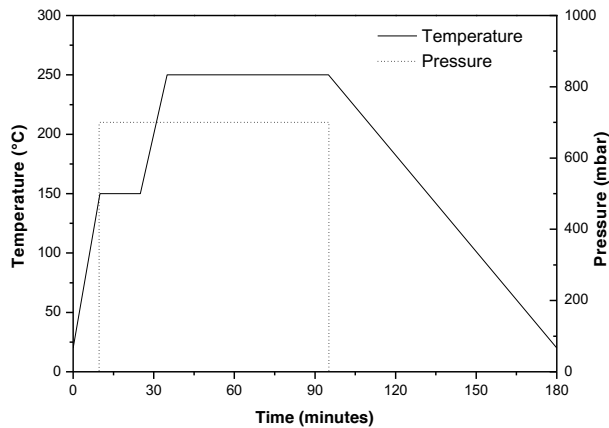
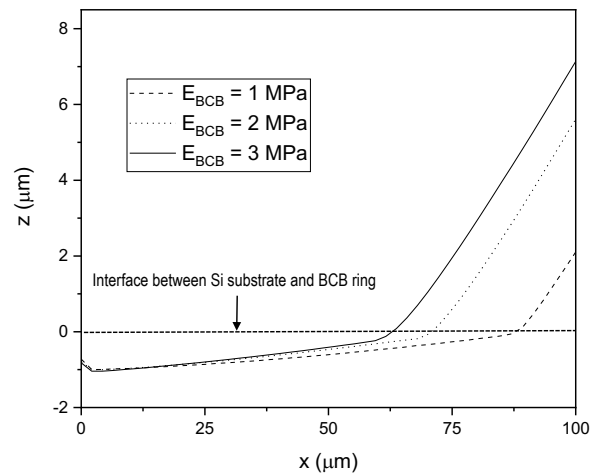
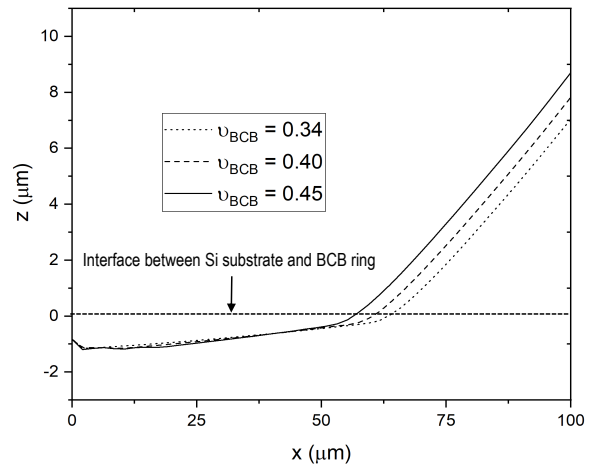


Fig. 9 BCB cap bonding process conditions

At first, Young's modulus of BCB ring has been changed from 1 MPa to 3 MPa at the step of 1 MPa. The increase rate of bonded area is estimated 88 % for 1 MPa, 70 % for 2 MPa, and 63 % for 3 MPa respectively. Poisson ratio of BCB ring has values of 0.34, 0.40, and 0.45 makes increase rate to be 63 %, 61 %, and 56 % respectively. Larger poisson ratio is not positive to get large bonding area, which is due to its negative factor into transversal direction. Thus, smaller Young's modulus and smaller poisson ratio are better to get larger bonding area. For BCB ring, it is recommended that it is better to cure it with polymerization rate less than 75 % because it has around 2 MPa of  $E_{BCB}$  when it has more than 80 % polymerization rate [11].



(a) Young's modulus

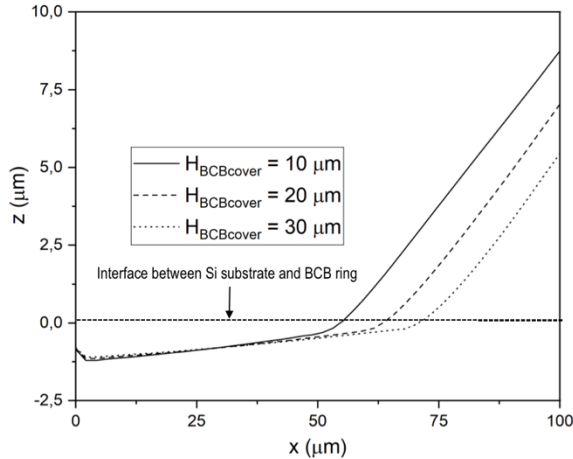


(b) Poisson ratio

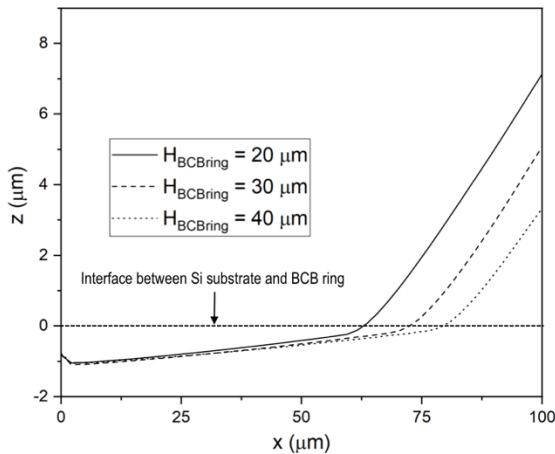
Fig. 10 Effect of BCB ring material properties

The effect of BCB layer thickness is also studied as the geometical design can be a way to compensate non-flat BCB ring. As BCB cover thickness increases, bonded area of BCB ring is also increased. BCB ring thickness makes same tendency as the BCB cover thickness. It would be

effect of length of BCB layer which means longer one makes larger deformation at same applied load when strain of the material is maintained. Note that BCB ring non-flatness defined in Fig. 6 (b) has been applied for all the BCB ring thickness and thicker BCB layer has demerits in view of mechanical stress and process cost.



(a) BCB cover thickness



(b) BCB ring thickness

Fig. 11 Effect of BCB cap geometries

#### IV. CONCLUSIONS

BCB ring flatness plays an important role to achieve uniformly sealed ring packaging, which is experimentally proved. Typical photosensitive BCB polymer creates nonuniform morphology due to multilayer coating on prepattern underlayer. BCB ring patterned with dry etching

is an effective solution to avoid partial bonding of BCB sealing ring. Through FEM modeling, it is found that Young's modulus of BCB polymer influences much more than poisson ratio, which lead to propose that cure rate of BCB less than 75 % would be an alternative way to improve BCB ring bonding. Besides, geometrical parameters such as thickness of BCB cap have been studied and found to be effective for the issues related with BCB ring flatness.

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