Novel Approach To Resolve Strip Camber At Assembly Process Of Semiconductor Packaging

Ooi Jen Wai[1], Cham Hooi Ying[2*], Tan Yin Heng[2], Tan Thian Yik[1], Theow Chiew How[1]
[1]EOL Engineering Department, ASE Electronics (M) Sdn Bhd. Hilir Sungai Kluang 4, Phase IV Bayan Lepas FIZ, Penang, Malaysia
[2]Quality Assurance Department, ASE Electronics (M) Sdn Bhd. Hilir Sungai Kluang 4, Phase IV Bayan Lepas FIZ, Penang, Malaysia
*Phone : (+60)46328505, Email : hooiying.cham@asemal.com.my

***Abstract*—Effect of strip camber in micrometer scale used to pose no risk or challenge to the back-end assembly process of semiconductor packaging. However, with the advancement of semiconductor technology, the assembly process is driving the devices to become smaller and smaller in size. Thus, a minor alteration in the substrate strip condition will pose great quality risk to the product, as the tolerance range of acceptance is greatly reduced when product miniaturization occurred. One of the most impacted processes in backend assembly is the product's singulation to separate bulk processed products into individual unit. Due to this reason, the current work aims to provide state of the art approach to resolve strip camber at backend assembly process through experimental investigation. This paper presents comprehensive study on the backend assembly process that induce strip camber. Based on the data collected, the leading contributing process towards the magnitude of strip camber was observed at molding process. Design of experiment (DOE) methods was deployed to study the key parameters influencing the camber effect. The results show that the lower the HFC (high floating chase) of 1^{st} and 2^{nd} clamping force in molding process, the lower the magnitude of strip camber observed. While the higher the packing pressure, the lower the strip camber effect was observed. In addition, the current study also compares the performance of conventional straight cutting method with novel partial cutting method at package singulation process. The data obtained shows that average Cpk enhancement of 54.67% was obtained by utilizing partial cut method in comparison to conventional straight cut method when cutting cambered strip. This shows that the partial cut method is capable of cutting substrate or strip having the camber effect.**

Keywords—strip camber, molding, singulation, warpage

I. Introduction

Over the decades, semiconductor industry has experienced consistent growth. However, a surge in worldwide semiconductor sales was observed in the year 2021. This factor was primary due to the consequences of coronavirus pandemic where the demand for consumer electronics increased. Another contributing factor includes the recent trend of electromobility and autonomous driving, which tend to increase the demand for semiconductors in vehicles [1]. This industrial growth has driven evolution in technology where products miniaturization occurs together with advances of electronic technology as predicted by Moore's Law [2]. Such advancement brings new challenges to assembly processes, especially the package singulation step. It is a cutting process where units from a piece of substrate strip is separated into individual packaged semiconductor device. Many matrix array packages have switched from punching/shearing to dicing/sawing processes as a result of ongoing reduction in package size and the unwavering desire for improved throughput without compromising cut quality. The difficulty in package singulation process intensifies when strip warpage occurred. Fig. 1 illustrates some of the common type of substrate strip warpage encountered at assembly.

Additionally, there is ongoing demand of cost reduction, and one approach to this is to encapsulate more units on a substrate strip. Fig. 2 (a) shows the standard design of 4-panel strip while Fig. 2 (b) shows the single block strip, which having more units compacted into a single strip of the same size. In general, the benefit of a 4-panel strip is that it would typically have lower strip warpage

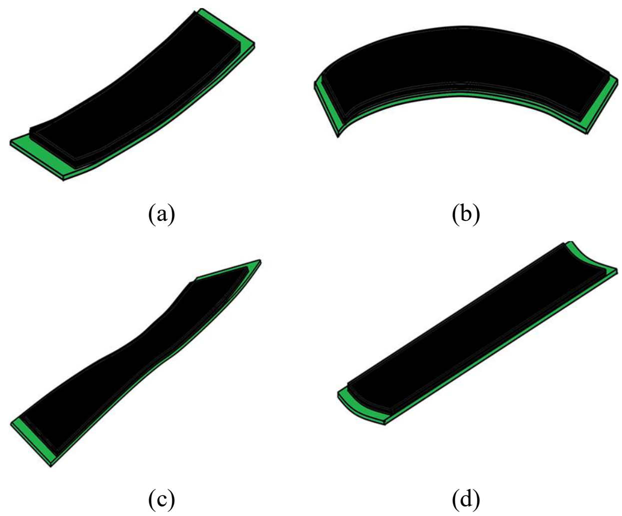


Fig. 1 Type of strip warpage encountered in assembly process. (a) bow, (b) camber, (c) twist and (d) cup

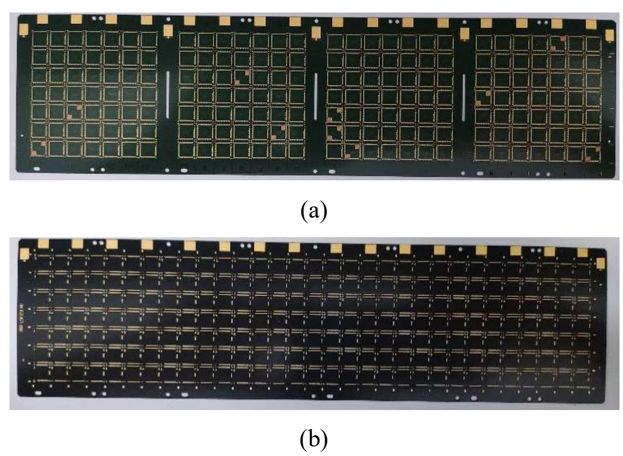


Fig. 2 Strip format (a) 4-panel strip, (b) single block strip

Mold array package (MAP) technology can be used to produce thin packages at a higher productivity and material efficiency [3]. However, it is still difficult to regulate warpage in both strip form and unit form. Although multiple studies were conducted to resolved warpage issue [4]–[6], majority of these investigations highlighted on the bowing type of strip warpage while very limited focus were given to camber type of warpage. A minor camber effect will lead to package offset during package singulation process as the tolerance for small packages design is very limited. Thus, this paper focuses on investigating the factor influencing strip camber during semiconductor assembly process and provide potential solution to resolve or mitigate the impact of strip camber at package singulation process.

II. Material Selection

A. BGA substrate

For this study, coreless BGA substrate with a thickness of 0.216mm was used. This is in line with the on-going increasing demand of thinner and higher functional assembled packages. A typical 3-layer coreless structure consist of solder mask, prepreg and via which can be observed through a cross section as shown in Fig. 3.

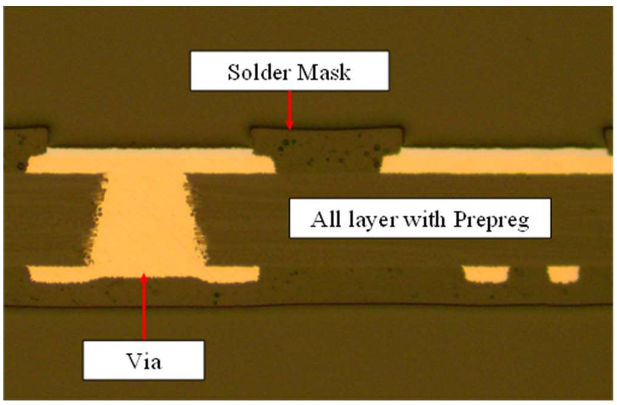


Fig. 3 Cross section of BGA substrate

B. Sawing blade

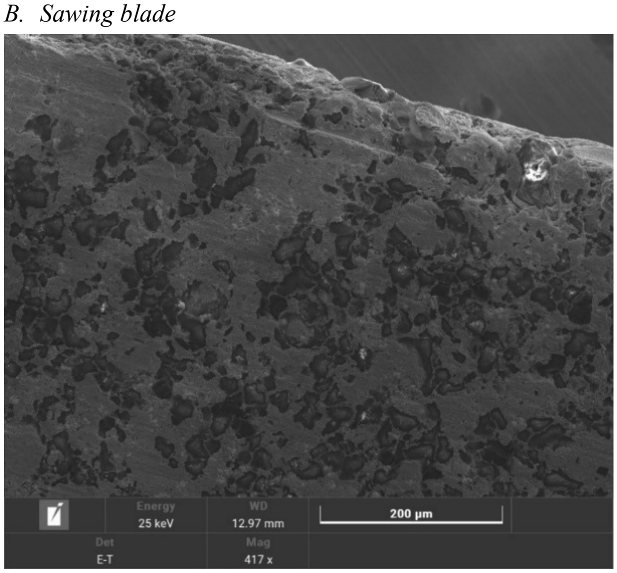


Fig. 4 SEM topology of sawing blade

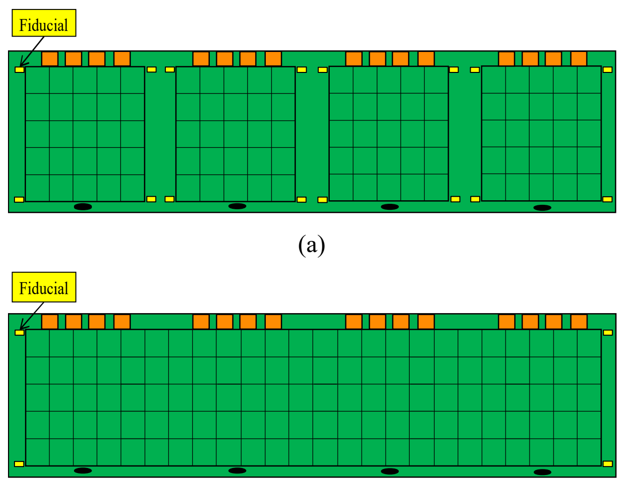
In the package singulation process, sawing blade with small diamond grit size are used. The Scanning Electron Microscope (SEM) image of the dressed blade is shown in Fig. 4, where the dark irregular shaped particles represent the diamond composition in the blade. No holes or pockets was observed from the surface topology of the blade. This indicated that the blade used are dressed accordingly as the diamond are exposed.

III. Methodology

The experimental component of this work is split into three sections. One is the identification of assembly process that induces substrate strip camber using actual quantitative assessment. Followed by DOE (Design of Experiment) methodology with key parameters of the process to mitigate the impact of strip camber. The third section is the optimization of the cutting sequence evaluation at package singulation process to resolve the camber defect.

A. Identifying the assembly process causing strip camber

Identification of the process that induces substrate strip camber is crucial as the impact of the defect can only be detected during package singulation process. This is because the magnitude of camber is in micrometer scale, where the impact is not visible through visual inspection. Hence, the substrate strip camber was quantified by measuring the offset value of the fiducial points with the aid of vision system from package sawing machine. For this investigation, 4-panel substrate strip format were selected, as the strip format contains 6 more fiducial points per row as compared to the single block format. Using the 4-panel format will able to ease the investigation by allowing better understanding of the nature of the substrate strip camber effect. The location of the fiducial used for this investigation is shown in Fig. 5.



(a)

(b)

Fig. 5 Location of fiducial in (a) 4-panel format and (b) single block format

As package singulation is the end assembly process, an upstream investigation was deployed to study the process that triggers the camber defect as well as to study the nature of the camber mode. Fig. 6 illustrates the BGA assembly processes from bare substrate until the package singulation step. However, wafer preparation steps were excluded as this research focuses on the camber effect of the substrate strip. Process that involves high temperature are illustrated with red color background. Process that involves high temperature and material changes on the substrate condition were taken to measure the magnitude of strip camber. Hence, the magnitude of the substrate strip camber was measured after the process of:

1. Substrate bake
2. Die attach cure
3. Molding
4. PMC (Post Mold Cure)
5. Reflow

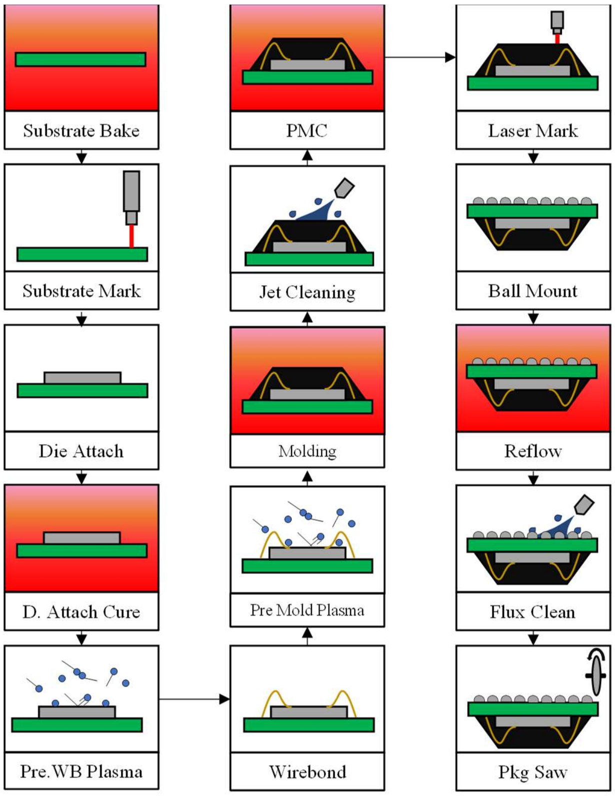


Fig. 6 BGA Assembly process flow

Based on the data collected, the spike in magnitude of strip camber was observed in molding process. However, further details analysis of data would be discussed in the results and discussion section. Thus, the DOE evaluations method would be based on the key parameters in molding process.

B. DOE of Mold Process Parameters

In this work, the molding process was optimized using the Design of Experiment (DOE) approach. It is a resourceful methodology to review the overall process optimization. DOE is a systematic process used in controlled settings to investigate an undetermined response and provide a hypothesis of the effect. Using the full factorial design where it has at least two elements, each of which has different values or levels. This investigation will take into account every single possible combination of the levels and all other variables. It also enables the research of how each factor (cause) interacts with the response (effect), as well as how factors (many causes) interact with one another and the response (effect).

Factorial design of k=3, 2^3 is employed in this investigation. Three variables have been taken into account which are HFC (High Floating Chase) 1st clamp, HFC 2nd clamp and packing pressure. Based on the baseline of the existing molding recipe and a preliminary technical reason, the amounts of the variables are summarized in Table I. In a 3 factor 2 level factorial design, the combinations of 2x2x2=8 experiment will consist of eight degree of freedom. Three degrees of freedom are correlative with the primary factors of A, B and C. Four degree of freedom are associated with interactions; with each one of AB, AC and BC and one with ABC. JMP statistical software tool was utilized to generate the experimental legs based on the three key parameters as shown in Table II. HFC 1st clamp, HFC 2nd clamp and packing pressure are represented by A, B, and C respectively.

Table I Factorial level setting

Factors	Key Parameter	Low	High
A	HFC 1st Clamp (ton)	6	13
B	HFC 2nd Clamp (ton)	13	20
C	Packing Pressure (kg/cm^2)	60	100

Table II DOE format with key parameters

Leg	A, HFC 1st Clamp (ton)	B, HFC 2nd Clamp (ton)	C, Packing Pressure (kg/cm^2)
1	+	+	+
2	+	+	-
3	+	-	+
4	+	-	-
5	-	+	+
6	-	+	-
7	-	-	+
8	-	-	-

C. Package Singulation Cutting Method

As aforementioned in the earlier section, the impact of the camber substrate strip will cause difficulty during package singulation process. The camber effect will lead to offset saw reject which eventually caused lost in production yield. A typical offset saw unit will have an unequal grit x or grit y distribution. Each side of the unit is represented by grit x (x1 and x2) and grit y (y1 and y2). Fig. 7 shows the consequences of sawing cambered substrate strip, where the package edge to ball measurement is not the same at grit y (y1 is not equal to y2). This type of saw reject is known as “offset saw”. The conventional straight cutting method in package singulation process is by sawing a straight line from panel 1 to panel 4 without rotating the chuck table as shown in Fig. 8. For this study, the partial cutting method is deployed. In partial cutting method, the cutting sequence will stop at end of panel 2 and then rotate the chuck table to begin cutting the line from the other end (panel 4 to panel 3) as shown in Fig. 9. For this study, the BGA package were cut using conventional cutting method and partial cutting method. After that, dimension of grit x and grit y were measured and collected. The performance of the conventional cutting method and partial cutting method is compared by measuring the process capability index (Cpk) of each cutting method.

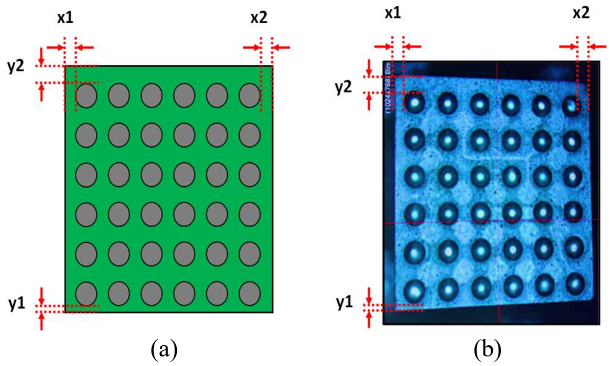


Fig. 7 Off center saw unit in (a)illustration format and (b) actual unit under low power scope.

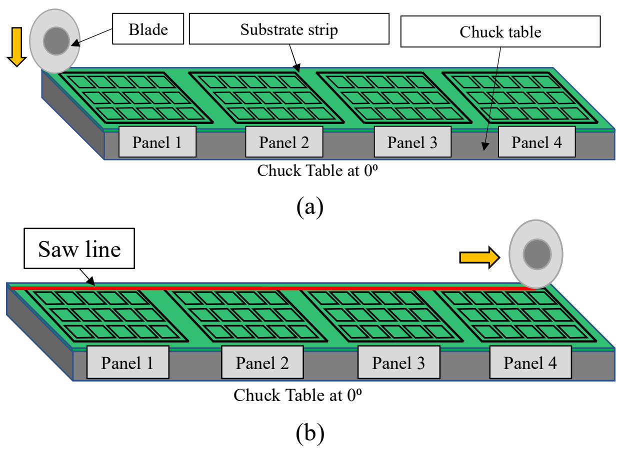
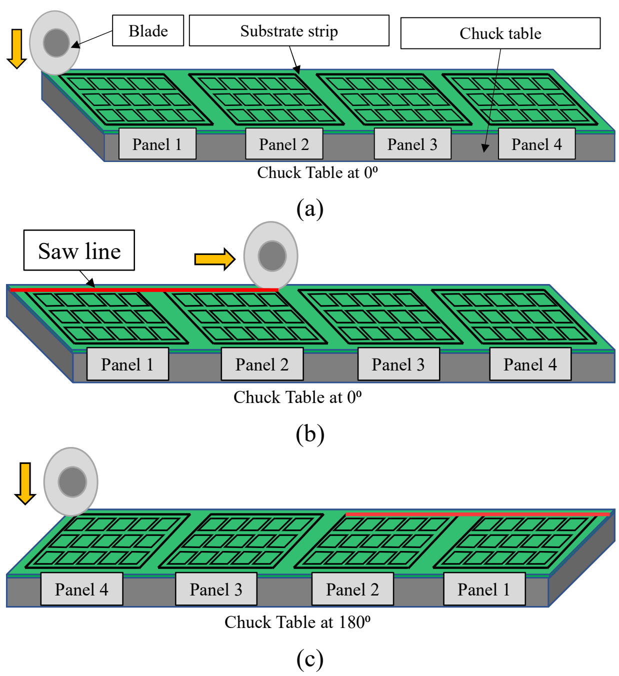


Fig. 8 Conventional cutting method (a) start position of cut line at panel 1 and (b) end position of cut line at panel 4



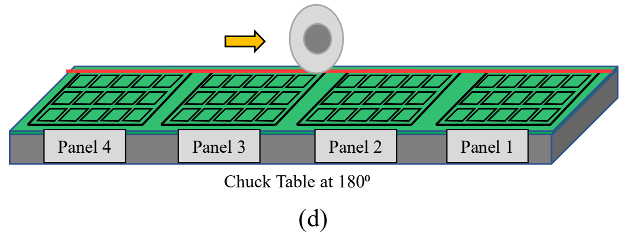


Fig. 9 Panel cutting method. (a) Start position of cut line at panel 1, (b) end position of cut line at panel 2 (c) start position of cut line at panel 4 with chuck table rotated at 180º and (d) end position of cut line at panel 3.

IV. RESULTS AND DISCCUSSION

A. Assembly process causing strip camber

Five assembly process steps were considered to be the main contributing factors of causing substrate strip camber. This is due to the fact that the selected five process steps as aforementioned in the previous section, involves high temperature and material change elements. The similar strips were processed until the package saw step and after the five processes, the strips were taken to measure using the vision system from the sawing machine which have a scope magnification of 60x. The changes in the fiducial value from the past process were recorded and analyzed. The results shows that the highest changes in fiducial offset value occurred after molding process. The defect nature of the substrate strip was observed to curve inwards to the mold gate. It is noteworthy to mention that the measurement value presented in Fig. 10 indicates the delta value (difference) from the previous process. Although substrate bake, DA Cure, PMC and Reflow do observed a certain degree of delta value in strip camber. The most significant peak observed triggered after molding process as shown in Fig. 10. Thus, the subsequence evaluations are focus on molding parameters to evaluate the leading parameters contributing to strip camber signature.

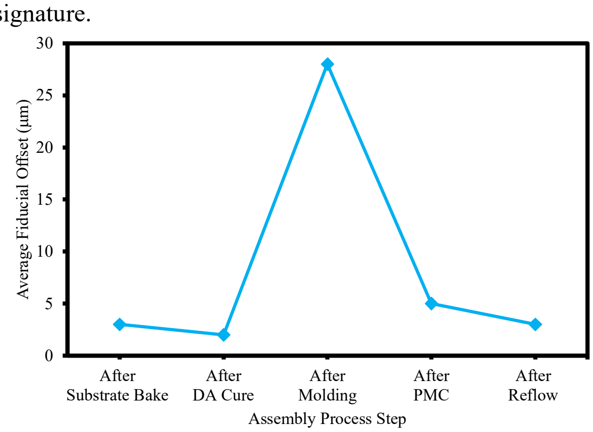
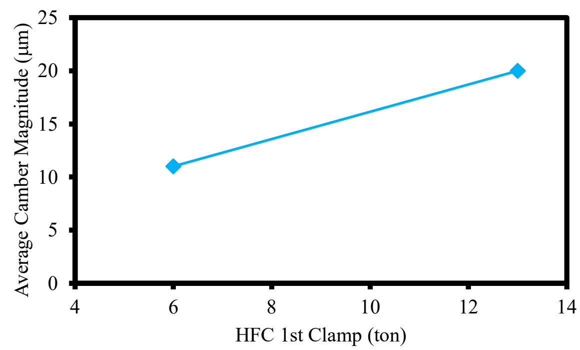


Fig. 10 Changes in fiducial offset value after each selected process step.

B. DOE results at molding process

For this section, the JMP statistical software program is employed to thoroughly analyze the contributing mold parameters in response to the substrate strip camber. JMP was utilized as it provides in-dept analysis of the data collected and gave an in-sight of the potential explanation of the strip camber response with respect to the factors studied. Before performing full factorial DOE on the key parameters. Few mold process parameters were evaluated such as the mold transfer speed, packing time, type of compound and compound pre-heat time. However, no response was found in regard to the strip camber. The key parameters were only detected when changes to the HFC 1st clamp, HFC 2nd clamp and packing pressure parameters were made. Thus, the optimization study is conducted on the parameters showing high correlation to strip camber effect. Fig. 11 shows the results of key parameters in response to the average camber magnitude of the substrate strip. From the data collected, it is observed that at higher HFC 1st and 2nd clamp based on Fig. 11 (a) and (b), the higher the magnitude of strip camber observed. While vice versa was occurred in the case of packing pressure parameter where the higher the packing pressure, the lower the strip camber magnitude as shown in Fig. 11 (c).



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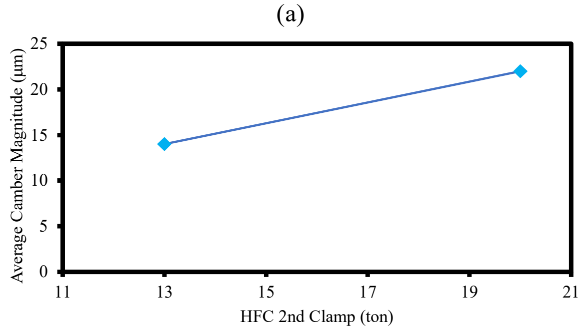

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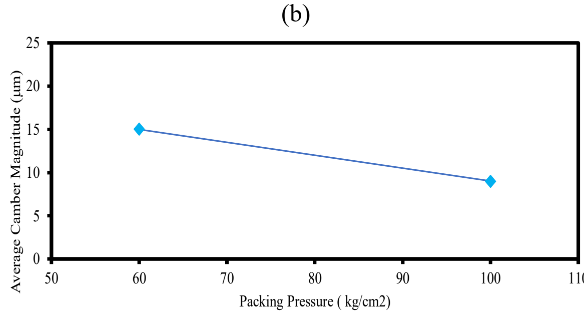
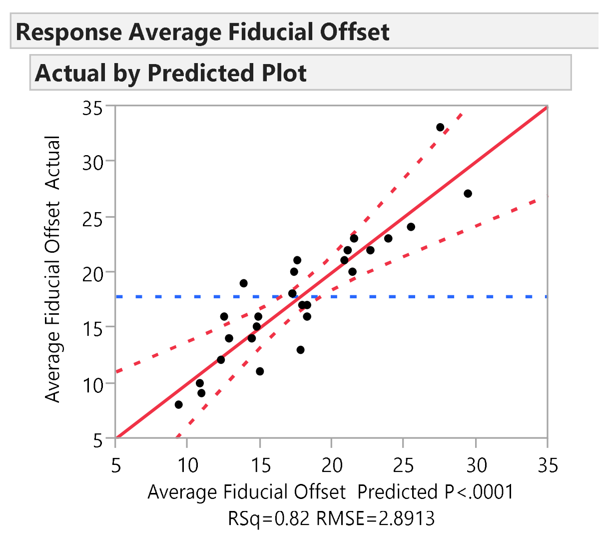


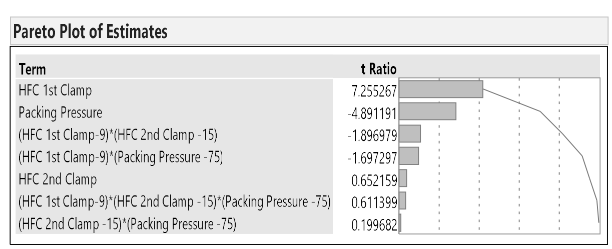
(c)

Fig. 11 Results of key parameters in response to camber magnitude with (a)HFC 1st clamp, (b) HFC 2nd clamp and (c) packing pressure

The fit least squares of the evaluated model are shown in Fig. 12 which obtained R-squared value of 0.82. The R-squared number measures how well the model fits the observed data and it varies from 0 to 1, where the value of 0 indicating that the model does not completely accounts for the variability in the data while the value of 1 indicates a strong agreement. Thus, the current model shows a reasonably strong fit with a R-squared value of 0.82. The integrated model obtained also shows it is significant as the p value obtained is less than 0.001. From the pareto plot of estimates data shown in Fig. 12 (b), the most important factors are HFC 1st clamp pressure and packing pressure which have the highest t-ratio magnitude of 7.26 and 4.89 respectively while interaction between key parameters observed significantly lower t-ratio magnitude. Thus, the interaction between key parameters may not be a significant contribution to strip camber. The 3D cube plot which shown in Fig. 12 (c) visualized the relationship between the three key parameters evaluated. The evaluation range of the three parameters are also displayed on cube plot with each corner representing the highest and lowest of the evaluation value. The response is indicated at the eight corners of the cube with values of the average strip camber. From the cube plot, the parameters HFC 1st clamp, HFC 2nd clamp and packing pressure at 6 ton, 12 ton and 90kg/cm^2 respectively at the bottom left vertex of the back plane which observed the lowest value of the strip camber among all others. Similarly to the cube plot result, the prediction profiler provided the same parameter setting with the best desirable outcome which in this investigation is minimum strip camber value as observed in Fig. 12 (d) From the DOE evaluation, it shows that mold process parameters only capable of mitigating the strip camber effects and not able to entirely eliminate it. Thus, the partial cutting method is introduced to tackle the camber effect of the strip to prevent any saw offset, which will be discussed in the next section.



(a)



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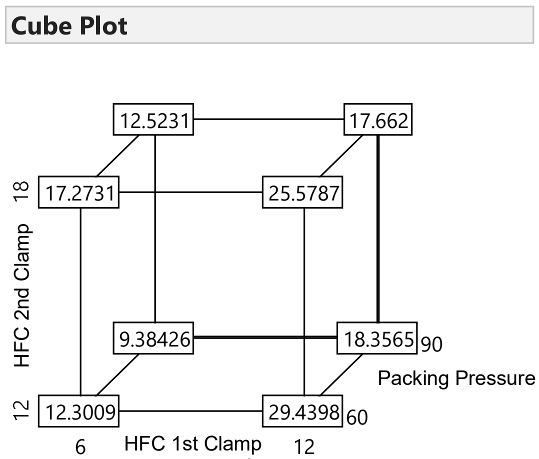

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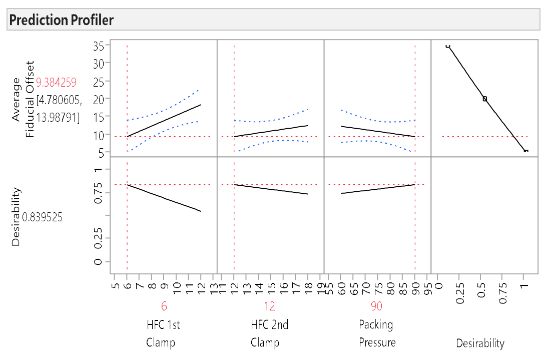


(d)

Fig. 12 DOE results withs (a) Fit least square model, (b) prediction profiler for optimized parameter, (c) cube plot of strip camber response and (d) the pareto plot estimates of the key parameters.

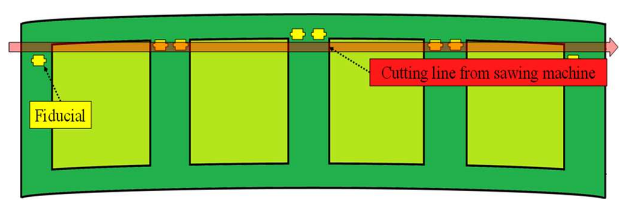
C. Performance comparison of cutting method at sawing process

The cutting quality of the cambered strip depends on several factors, one of which is the cutting method used in manufacturing process. This section presents the performance of two cutting method which is the conventional straight cut method and the novel partial cutting method. Process capability index (Cpk) measurement is used to evaluate the capability of each method to produce products within the specification limits. Table III shows the results each cutting method. The data obtained shows that the grit x measurement yielded minimum improvement by using the partial cutting method. However, this is expected as the strip camber direction only impacting the grit y direction. In the case of grit y, significant improvement of Cpk was observed. The Cpk of y1 increases from 0.202 to 1.386 while y2 increases from 0.270 to 1.350. The average Cpk improvement of 54.67% was obtained when the cutting method changes from conventional straight cut to novel partial cutting method. This indicate that the new partial cut method introduced is more effective in producing products that meet the specified limits as well as reduced the risk of offset saw.

Table III Cutting method comparison using Cpk measurement

Measurement	Straight Cut (Cpk)	Partial Cut (Cpk)
X1	1.561	1.739
X2	1.664	1.684
Y1	0.202	1.386
Y2	0.273	1.350
Average	0.600	1.540

This is because the partial cut method is designed to have two cutting lines at the y-directional cut or also known as the "long cut". By using two optimized lines instead of one, the chuck table is able to adjust for the best fit line, reducing the impact of strip camber on the saw. A chuck table in package sawing process is typically a mechanical device used to hold a substrate or strip. The fiducial point on the substrate is used as a reference point to align the saw blade to ensure accurate and precise cutting. Due to the alignment of the fiducial points is off in a cambered strip, it will result in offset saw if the conventional straight cut method is used, as the fiducial points will be out of the specific range limit and causes high offset from the center of the fiducial point as illustrated in Fig. 13. Thus, to mitigate the off center value, the first half of the substrate was cut using one optimized line and followed by another half of the substrate with the second optimized cutting line. The first partial cut will allow the chuck table to adjust the strip to a straight-line position given the nature of the cambered strip and similarly in the case of the second partial cut. This will ensure minimum offset to the cambered strip as illustrated in Fig. 14.



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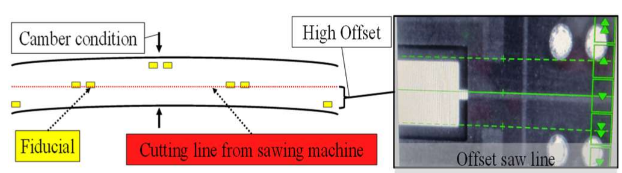
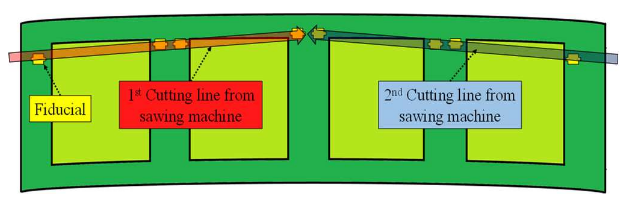
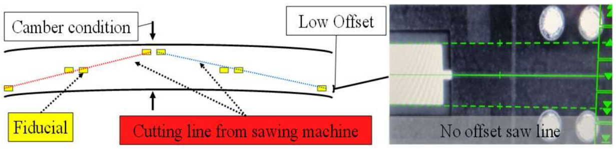


(b)

Fig. 13 Cutting line from sawing machine with strip camber condition using straight cut method, illustrated in (a) strip form and (b) single cutting line and actual image from sawing machine.



(a)



(b)

Fig. 14 Cutting line from sawing machine with strip camber condition using partial cut method, illustrated in (a) strip form and (b) single cutting line and actual image from sawing machine.

V. CONCLUSION

As a conclusion from this investigation, it is revealed that the assembly process at semiconductor packaging that induces substrate strip camber defect is at the molding process, which leads to downstream process difficulty especially the package singulation step. Key parameters contributing to the camber effect at molding process are the HFC 1st and 2nd clamping force as well as the packing pressure. A DOE approach was evaluated at the molding process to minimize the camber effect on the substrate and found that the best parameter setting for HFC 1st Clamp, HFC 2nd clamp and packing pressure are at 6 tons, 12 tons and 90kg/cm^2 respectively. However, these setting only manage to mitigate the camber effect and not eliminate it. Thus, study on the novel partial cutting method was evaluated in comparison to the conventional straight cut method. The results shows that the Cpk of the new partial cutting method yielded an average improvement of 54.67% when compared to the straight cut method. This indicate that the newly implemented cutting method are more reliable and more efficient in cutting the substrate that are prone to have camber effects. This study provides strong evidence for the efficacy of partial cut in resolving the least square problem in semiconductor assembly package saw process. By using partial cut, manufacturers can reduce the risk of offset saw caused by strip camber and improve the yield and quality of the products.

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