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Laser DAF Cut: A Breakthrough Approach of Die Attach Film Singulation for Thin Wafers

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Authors' contributions

This work was carried out in collaboration amongst the authors. All the authors read, reviewed and approved the final manuscript.

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ABSTRACT

Today, semiconductor world is becoming more inclined to thinner Integrated Circuit (IC) packages. IC packages will require thinning of the internal configuration of the package, which involves the die or the wafer and the adhesive material, which is the Die Attach Film (DAF). Aligned to this, as wafers goes thinner it becomes more of a challenge in process development especially during its preparatory stages, such as wafer back grinding and sawing processes. As the die becomes smaller and thinner wafer sawing process should have minimum effect on the mechanical integrity of the silicon so as not to alter its quality.

New technologies were introduced so as to adopt to this development trend, one of this is the Dicing Before Grinding (DBG). Compared to the normal wafer preparation process that is wafer back grinding before wafer sawing, DBG flow is wafer sawing first prior wafer back grinding processes. The application of DBG technology eliminates the mechanical draw backs of the conventional wafer sawing process. In addition, with the use of DAF for thinner packages, DBG was developed together with the Die Attach Film (DAF) cutting solution, which is Laser DAF Cutting. DAF are separated using Laser as a cutting medium to address potential processability problems that may occur on the conventional mechanical blade saw.

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The paper discuss the Laser DAF cut development that covers the Design of Experiments (DoE) to understand the different characteristics of Laser DAF solution and be validated through actual simulation and wafer processing. The paper will also cover the interaction of different DAF thicknesses and Laser DAF parameters in order to define the critical characteristics so as to understand the behavior of different laser DAF parameters in achieving optimal DAF cutting process responses.

Keywords: Laser DAF cut; die attach film; thin wafers.

1. INTRODUCTION

Nowadays, the demand for thinner packages become one of the major drivers for package miniaturization. Complex packages require dies to become thinner. As dies becomes thinner, devices bring more challenges during its preparatory stages. Die thinning should not have any mechanical defect so as to achieve robust and high-quality package.

Thinner dies, specifically those on the range of 100 um and below dies thickness, shows significant drop in die strength. Die with thickness below 200um shows diminishing strength [1]. Also, when it reaches critical thickness, it would not be able to withstand higher load.

To attain wafer thickness below 100 um without compromising its die strength, a technology called Dicing Before Grinding (DBG) was introduced. DBG focused on the removal of backside chipping that cause breakage on the silicon area of the die, thus improving its quality [2]. However, DBG is not enough to cater the increasing demand for thinner packages. The inclusion of the Die Attach Film (DAF) [3] material attached underneath the pre-sawn grinded wafer pose another challenge for DBG. Therefore, another breakthrough process development which is the Laser DAF Cut. Laser DAF Cut focus on the singulation of the DAF material underneath the pre-sawn wafer using low power lasers. Thus, the introduction of DBG + Laser DAF Cut improves the integration of the wafer thinning process without compromising the quality requirement of thinner dies.

1.1 Dicing Before Grinding [1,2,4]

Dicing Before Grinding (Fig. 1) is a combination of processes that focuses on the processing of thinner wafers. DBG process starts with the partial cut dicing similar to wafer grooving. Rule of thumb for cut depth is the target final wafer thickness + 40um. Next is the Tape Lamination process, wherein the back grinding tape is applied on the top metal layer or the active side of the wafer for water. The tape will offer cushioning protection during wafer back grinding. Next is the wafer back grinding that involves the grinding of the wafer backside or the silicon part into the desired final wafer thickness. In addition, wafer back grinding will separate the dies with each other. Then the singulated dies would be mounted on a frame with either a dicing tape or a DAF material.

With the effect of DBG, cracks or chippings at the back of the die brought by mechanical dicing [5] process is removed during the grinding process. Backside stresses like chippings leads to the lower die strength, see Fig. 2. DBG shows significantly higher die strength compared to conventional wafer thinning and dicing technology thus will help achieve ultra-thin strong dies, good process yield and better reliability performance.

1.2 Laser DAF Cut [6]

Laser DAF Cut (Fig. 3) is a process developed for the cutting of DAF material mounted on the wafer backside after the DBG process using laser. Laser [7] is more efficient compared to conventional mechanical blade cutting. Laser DAF Cut offers resolutions on different issues with regards to wafers being processed using DBG process. Three main issuers are the Die Alignment, Blade Width and Processing Speed. After wafer back grinding, the singulated dies are more likely to move or shift in microns, known as Die Shift. Large Die Shift after grinding results to die alignment issues, wherein there is a possibility blade touching using mechanical dicing. Another potential issue is the need to have a more accurate and precise blade in order to fit into the saw street or the distance between adjacent dies. Die Shifting can also lead to slow alignment resulting to slower processing and will impact for manufacturing cycle time.

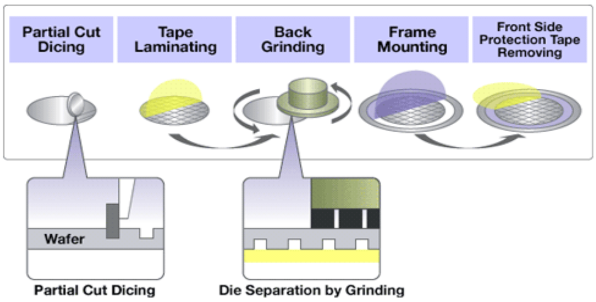

Fig. 1. DBG outline [1]

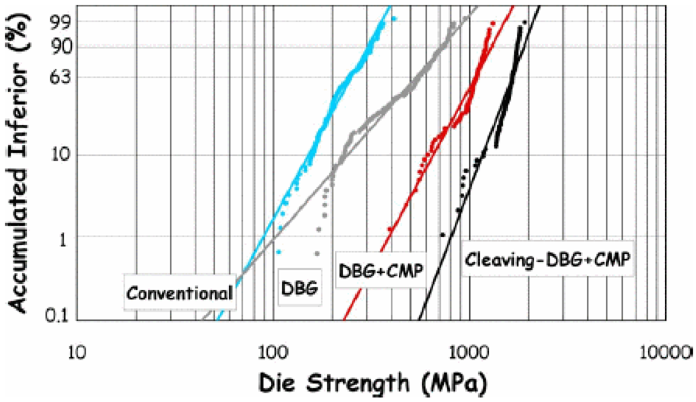

Fig. 2. A study on chip thinning process for ultra-thin memory devices (Toshiba) [8]

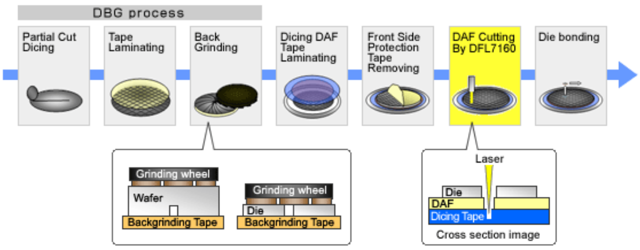

Fig. 3. DBG + DAF Laser cut process [6]

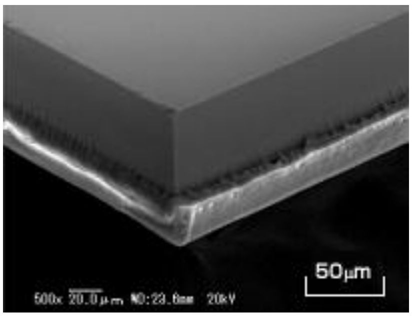

Fig. 4. Backside SEM photograph of a DAF Laser cut [6]

In connection to the above issues for a conventional sawing, Laser DAF Cut offers a solution to manufacture DBG processed wafers with DAF. Laser can adopt to the large die shifting through special alignment feature and can curved its way into the center of the saw street, thus preventing the laser beam to hit the side of the die. Also with this special alignment feature the machine can be able to increase the cutting speed thus reducing manufacturing cycle time. Lastly, one major advantage of Laser DAF Cut is the ability not to subject the Silicon wafer and DAF to any mechanical stress thus removing the possibility of chippings or burrs. A SEM photograph (Fig. 4) shows a good and smooth separation of the Silicon and DAF using DBG and Laser DAF Cut processes.

2. LITERATURE REVIEW

2.1 Lasers [9]

Light amplification by Stimulated Emission Radiation (LASER) is a condensed monochromatic [9] (one frequency) amplified light with the same phase and direction. Laser has high energy efficiency and density. In the semiconductor industry, one of the common LASERS used is the Nd: YAG (neodymium-doped yttrium aluminum garnet; Nd: Y3Al5O12).

Nd: YAG lasers are optically pumped using a flash tube or laser diodes. Nd: YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared. Nd: YAG lasers operate in both pulsed and continuous mode. Pulsed Nd: YAG lasers are typically operated in the so-called Q-switching mode: An optical switch is inserted in the laser cavity waiting for a maximum population inversion in the neodymium ions before it opens. Then the light wave can run through the cavity, depopulating the excited laser medium at maximum population inversion. In this Q-switched mode, output powers of 250 megawatts and pulse durations of 10 to 25 nanoseconds have been achieved. The high-intensity pulses may be efficiently frequency doubled to generate laser light at 532 nm, or higher harmonics at 355 and 266 nm [10].

On a normal ablation [11], LASER to be used for semiconductors focused on cutting either Silicon or DAF materials. Typically, a YAG is used as a laser rod which is excited by a medium controlled by water cooling to eliminate breakage, the electrons will then be oscillated by a Q switch that will deliver the fundamental wavelength of 1064 nm. To be suitable for processing, wavelength needs to be converted into a lower value, see Fig. 5.

Shorter wavelengths help the receiving material absorb more light thus making it suitable for composite materials. Also, when the light has shorter wavelengths the focusing is easier and becomes suitable also for micromachining. On the above figure, the fundamental wavelength will be transferred into a second harmonic, which is almost half the fundamental wavelength, and lastly the third harmonic, which is almost one-third of the fundamental wavelength.

Another one critical parameter of the LASER to be controlled is the power output, wherein the third harmonic wavelength will be inserted into an attenuator into the laser beam path ahead of the radiation aperture. The power output, see Fig. 6, is needed to be controlled because of different light absorption on different materials. For silicon or DAF, power output should be properly controlled or configured to effectively cut each type of material.

To explain further, the process involved in today's laser machines [12] is typically known as "ablation". When the laser light irradiates a solid substance and the intensity of the laser light is over a threshold, the light is converted into electrical, thermal, photochemical, and mechanical energy. The neutral atoms, molecules, positive and negative ions, radicals, clusters, electrons, and light are released explosively, and the surface of the substance is etched [13].

There are three factors that dominate the semiconductor technology process development: cost, performance, and form factor. The performance factor of wafer level driven by the front-end semiconductor foundries struggling to keep pace with "Moore's law." The increased performance also requires thinner and improved "low-k" interlayer dielectric (ILD) materials

However, these techniques present challenges for the mechanical integrity of the chips and introduce weakness in dies, which introduce yield loss, which greatly affect the manufacturing costs.

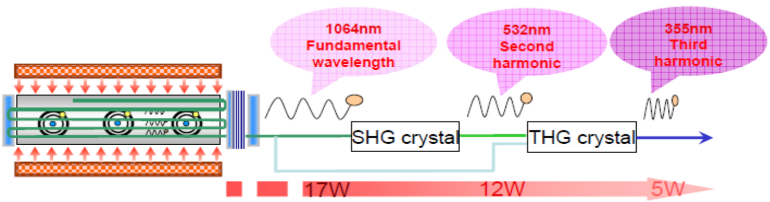

Fig. 5. Typical Laser wavelength and power conversion

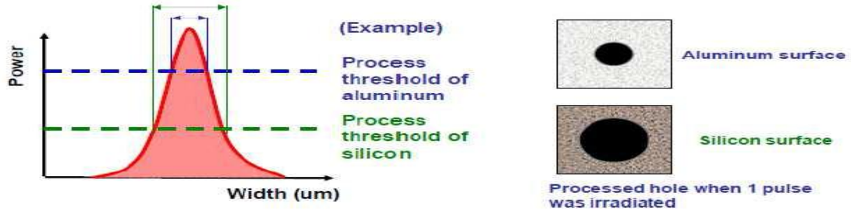

Fig. 6. Power output effect versus material

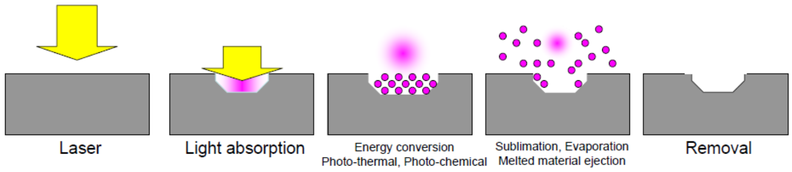

Fig. 7. Ablation process

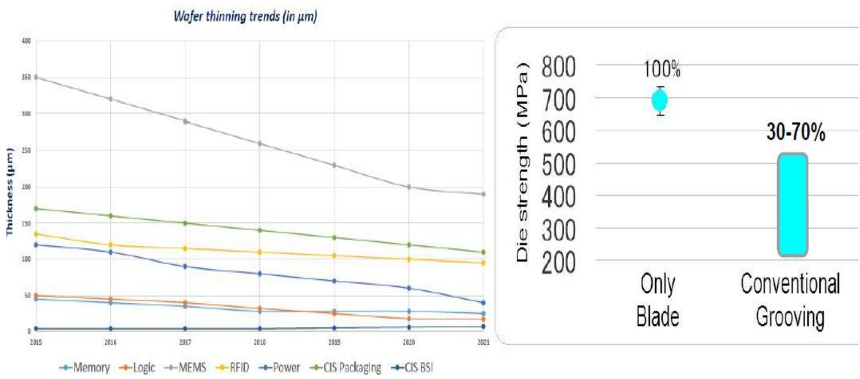

Fig. 8. Die strength comparison between standard blade and conventional laser grooving

3. METHODOLOGY

3.1 Materials

In order to understand the quality performance of the Laser DAF Cut, different process parameters, such as Frequency, Laser Power and Feed Rate; different DAF materials was evaluated; and with different thicknesses.

Different DAF thickness was considered in order to assess the applicability of Laser DAF cut. Different DAF thickness offers different advantages in Integrated Circuit Manufacturing. Thin DAF enables die stacking which increases the integration of different die within the same package height. On the other hand, Thick DAF increases the integrity of package which minimizes the effect of thermal expansion during thermal cycling. Both these advantages was considered to check if Laser DAF cut is applicable across all package requirements during new product development stage.

3.2 Process Scope

Design of Experiments (DOE) focused only on the DAF cutting process. The paper will not discuss the details of the DOE done for DBG.

All wafers were processed using the same parameters and conditions at DBG and will be mounted on different DAF thickness which is part of the Laser DAF Cut DOE.

3.3 Laser DAF Design of Experiment

Design of Experiment was conducted to understand the effect of 3 critical laser parameters, namely, Laser Power, Repetition rate or Frequency and Feed rate.

Laser Power refers to the amount of energy being directed by the laser towards a medium or the material to be cut.

Repetition rate or Frequency refers to the amount of laser pulses on a certain time.

Feed Rate refers to the speed of the working table during laser cutting.

Table 1. DAF Material Evaluation Matrix

DAF Supplier	Adhesive Thickness
DAFS#1	7 um
DAFS#2	20 um
DAFS#1	25 um
DAFS#3	30 um

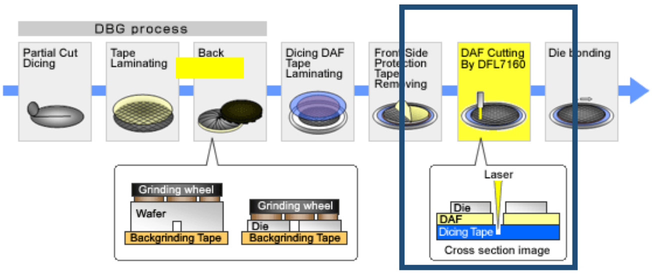

Fig. 9. DBG + DAF Laser cut process [6]

Defocus amount refers to the height on top of the just focus or the focused position, wherein laser is being penetrated. Typically, –Defocus is equal to the die thickness of the DBG material. Therefore, throughout the DOE, defocus amount is set to -50 that is equivalent the 50um die thickness.

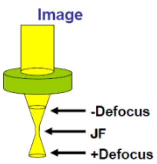

Fig. 10. Just focus representation

In order to identify the characteristics and suitable parameters on each of the DAF supplier and material thickness, Fractional Factorial DOE was conducted.

3.4 Quality Requirements

The experiment results were assessed based on the following criteria: (1) depth value higher than the DAF Thickness + 5um (2) Width typically equal to minimum kerf width to 3x DAF Thickness

4. RESULTS AND DISCUSSION

The experiment results are analyzed through a statistical analysis which is JMP. The evaluation matrix has been analyzed through prediction and contour profiler. Variability gauge analysis was also conducted to check the interaction between parameters and identify what parameters greatly affects the Depth and Width of the Laser DAF Cut.

4.1 DAFS#1 – 7um DAF Thickness

First, Laser DAF Cut DOE was conducted using a 7um thick DAF using Fractional Factorial. Profilers (Fig. 11) shows that the effect of the laser parameters, specifically Feed Speed and Laser Power, versus the process responses (Depth and Width) have a wider process window for 7um DAF Thickness.

On the other hand, prediction profiler has shown that the increasing feed speed will result to both depth and width decreased in value, meaning the increase of feed speed will have a shallower and narrower laser DAF cut.

In addition, in terms of laser power, the prediction profiler shows that the increasing laser power results to increasing in value meaning that the increase of laser power will significantly deepens and widens the laser DAF cut.

As a result, feed speed should be decreased so as to ensure good DAF cut width, on the other hand, laser power must be increased so as to attain sufficient depth and width through the 7um DAF cut.

Another validation on the interaction of parameters was conducted using the variability gauge (see Fig. 12). Result shows that the incremental values of parameters have an incremental effect for the width and depth. In terms of width, the lower feed speed plus the incremental value of laser power will have a significantly wider laser DAF cut while the feed speed with 150mm/s that is increasing laser power shows that there is no big increase in terms of laser width. While in terms of depth, incremental value of laser power does show no significant increase when Feed Speed is increased. For laser power there are improvement seen on the laser cut depth thus showing the effects on the cutting penetration power of the laser DAF Cut.

4.2 DAFS#2 – 20um DAF Thickness

The second material experimented has a thicker DAF material, 20um thickness. The profilers (Fig. 12) shows that the effect of the laser parameters, specifically Feed Speed and Laser Power, versus the process responses (Depth and Width) have a tighter process window for 20um DAF Thickness compared to the 7um thickness.

Further analyzing the parameters using prediction profiler, result shows that feed speed and laser power is inversely proportional in terms of width and depth. The incremental value of feed speed shows narrower and shallower cut while on the other hand, the incremental value of laser power is showing incremental effect for the depth and cut width.

Using the variability gauge analysis (see Fig. 13), result shows that the laser power parameter plays a major role to increase the depth and width of the laser DAF cut. On the other hand for the feed speed, the two graphs shows no significant change for both width and depth but shows that there were small amount of decreasing value of depth and width when increased.

4.3 DAFS#1 – 25um DAF Thickness

To further strengthen the data gathered for two thin DAF thickness. Additional DOE was performed to cover the 25um DAF thickness. The contour profilers (Fig. 15) shows that process parameter window become narrower. This shows that the interaction of the 3 different parameters is becoming interconnected.

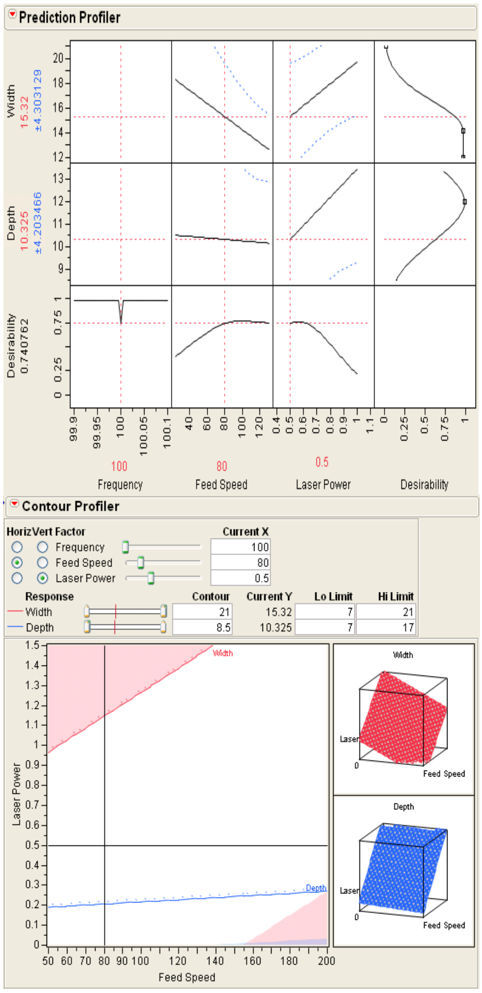

Fig. 11. DAFS#1 – 7um DAF Thickness Profiler results

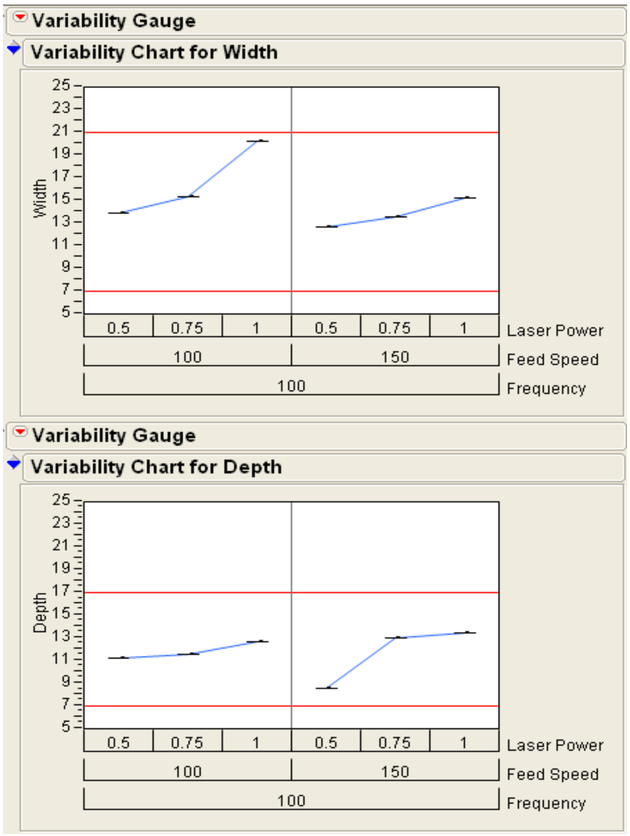

Fig. 12. DAFS#1 – 7um DAF Thickness Variability Gauge

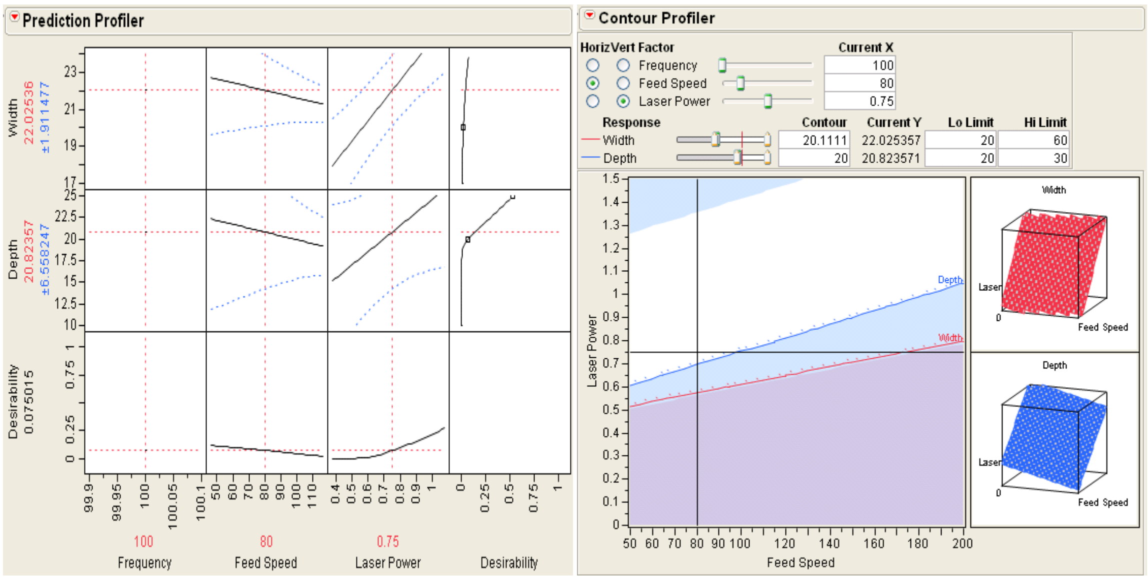

Fig. 13. DAFS#2 – 20um DAF Thickness Profiler results

Prediction profiler result shows that, feed speed and frequency versus laser power is inversely proportional in terms of width and depth. The incremental value of feed speed and frequency shows narrower and shallower cut which supports the data from the latter DOE covering 7um and 20um DAF thicknesses, which is same with the laser power wherein the incremental value does support the increase on depth and width.

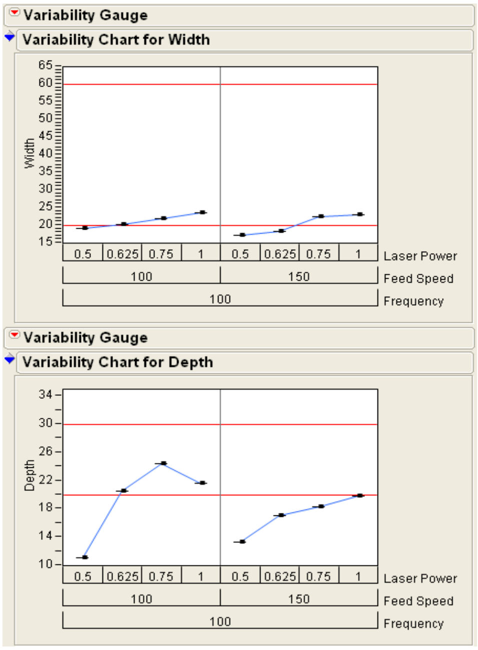

Fig. 14. DAFS#2 – 20um DAF Thickness Variability Gauge

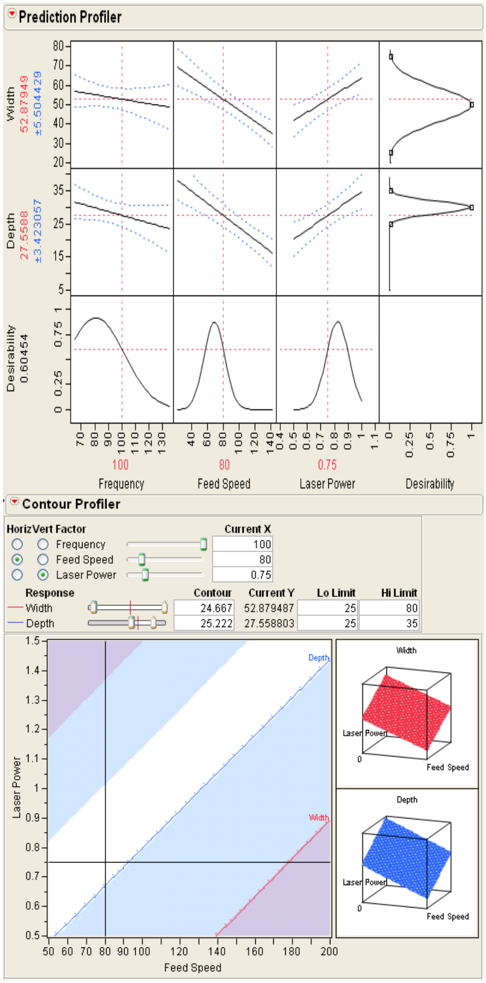

Fig. 15. DAFS#1 – 25um DAF Thickness Profiler results

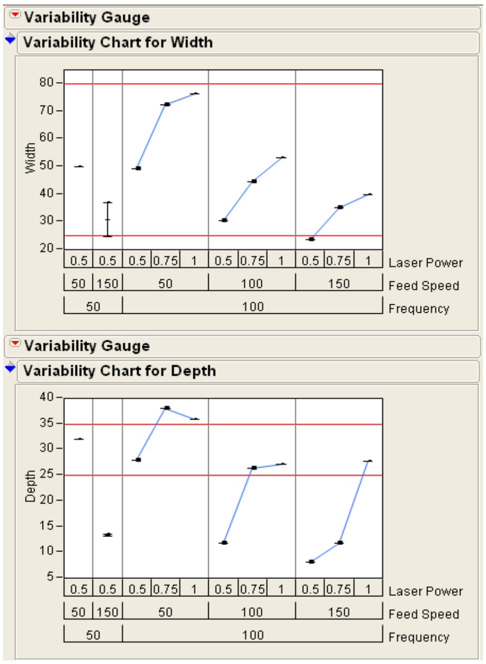

Fig. 16. DAFS#1 – 25um DAF Thickness Profiler results

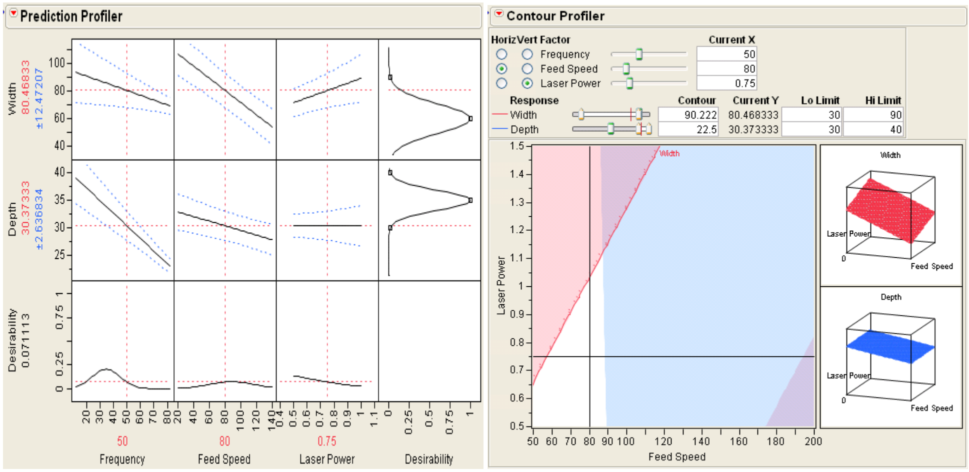

Fig. 17. DAFS#3 – 30um DAF Thickness Variability Gauge

On the other hand, using the variability gauge analysis (see Fig. 16) result shows that the increasing value of the feed speed parameter results to decrease in terms of the cut depth and width. While the laser power still shows significant effect on both the width and depth of the laser DAF cut process.

4.4 DAFS#3 – 30um DAF Thickness

Lastly to complete the DOEs performed from 7um, 20um and 25um DAF thickness, DOE was also conducted at 30um DAF thickness. The contour profilers (Fig. 17) shows that process parameter window become even narrower compared to the first 3 DAF thicknesses. This concludes that the interaction of parameters versus the DAF thicknesses will result to a narrow process window for Laser DAF Cutting.

Prediction profiler also shows that the frequency and feed speed should be decreased in order to achieve more DAF width and depth. On the other hand, laser power is indeed proportional with respect to the cutting efficiency of DAF cut.

Lastly, the interaction profiler does shows that the incremental value of frequency and feed speed will result to a narrower and shallower DAF cut. In contrast, laser power affects wider

DAF cutting thus plays a critical role for ensuring good cutting response.

4.5 Revalidation Phase

To check the effectiveness of the cutting parameters defined for the different DAF thicknesses, revalidation run was performed on different die size but with the same configuration. Below are the results.

On Fig. 19, the established Laser DAF cut parameters does shows good DAF cut separation and achieve no silicon edge cutting. Thus concluding that the parameters defined are ready for full qualification.

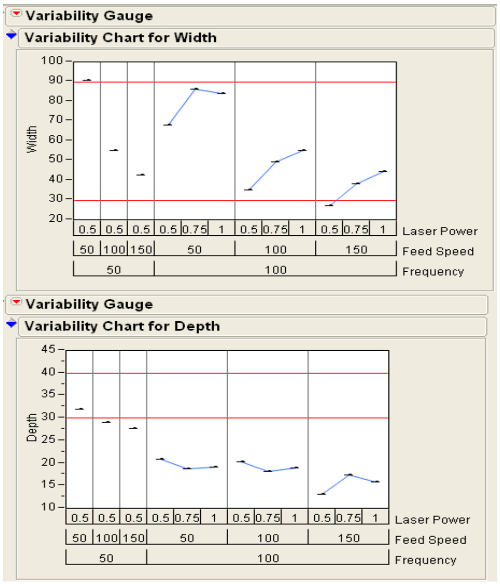

Fig. 18. DAFS#3 – 30um DAF Thickness Variability Gauge

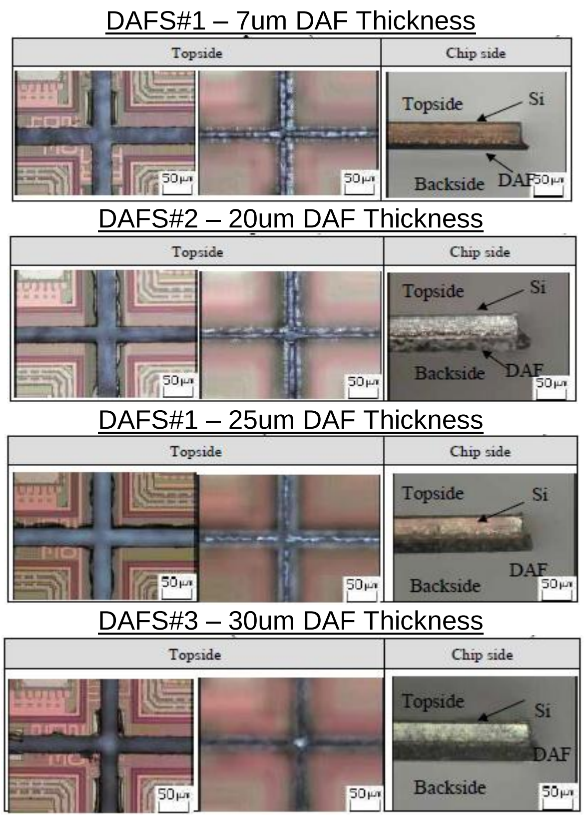

Fig. 19. Laser DAF revalidation results

5. CONCLUSION

Based on the evaluation and revalidation of results, it has been identified that the laser DAF process parameters interaction versus cut depth and width does shows that the increasing DAF thickness results to a narrower process window. Thus, showing the criticality of DAF thickness selection to be used for development.

Feed Speed and Frequency as a function of time, does shows slower laser penetration time results to a wider and deeper DAF cutting effect.

Laser Power as a function of energy, does shows higher laser penetration energy results to a wider and deeper DAF cutting effect.

6. RECOMMENDATIONS

For thinner die plus DAF configuration, Laser DAF cutting is a good solution for achieving DAF separation through laser penetration.

During the Laser DAF DOE, extensive DOE is critical to achieve good laser cut process response, especially if thicker DAF materials will be used.

During the definition of Laser DAF parameters, the following critical characteristics must be considered.

- Feed Speed and Frequency are inversely proportional to cut depth and width.
- Laser Power is directly proportional to the cut depth and width.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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