ANALYSING BACKSIDE CHIPPING ISSUES OF THE DIE AT WAFER SAW

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ABSTRACT

With shrinking technologies evolving, new products are launched in fine pitches, not only from a pad pitch standpoint but also from a reduction in distance between line widths, narrower scribe widths with e-test patterns built on the scribes, after a straight shrink in dimensions. The need for backgrind wafers has become critical with package thickness reducing to as low as 0.7mm. Thinner wafers are more prone to cracks even before saw because of the stress management during the backgrind process. This paper focuses mainly on backside chipping issues as a result of crack propagation during saw. With the critical parameters like saw blade and cutting speed, one can control this process to some extent for these thin and narrow saw streets between dies on a wafer. The maximum stress analysis effectively indicates the location of maximum bending stress on the die during dicing process while the principle of fracture mechanics subsequently predicts the theoretical critical crack length for which the presence of micro-void or crack will propagate, thus leading to a brittle fracture on the backside of the die. This paper begins with the material aspects of the bare wafer and goes on to explain a simple mathematical model that illustrates maximum bending (tensile) stress on the die during dicing process. The principle of fracture mechanics explains the occurrence of brittle fracture on the backside of the die. This paper concludes to explain that the non-rigid support on the die and the presence of external force acting along the cutting edge can result in the forming of the bending stress.

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1.0 Introduction

With shrinking technologies evolving, new products are launched in fine pitches, not only from a pad pitch standpoint, but also from a reduction in distance between line widths, narrower scribe widths with e-test pads built on the scribes, post shrink. So, can the current saw process be the same as before? Are thinner wafers better for narrower scribes at the saw process? How does warpage affect the saw process? All of these questions become significantly predominant when we investigate the sawing process in real detail especially on thin wafers with narrow saw streets. The combination of clean wafers with good stress management at backgrind and saw can control the microcrack from propagating to the backside of the wafer. Sawing / Dicing is a process of abrasion utilizing abrasive particles (diamonds) embedded in a solid binder, a rotating blade cuts through a silicon wafer. At saw, alternating compression and tensile stresses, applied to the material by the traversing diamonds, generate axial and lateral cracks. Those cracks propagate along dislocation planes and join to form chipouts. To better illustrate the crack mechanism, it is important to know the affected layers in the die schematic diagram shown below (Figure 1).

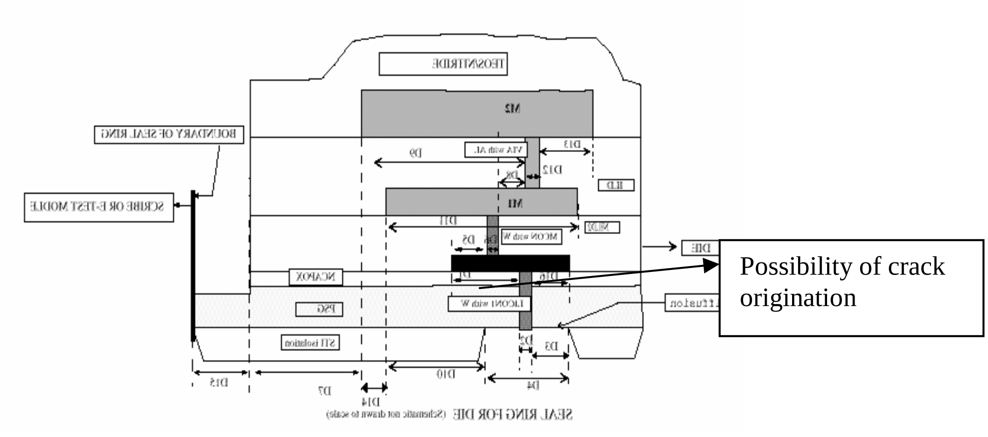


Figure 1 – Die Schematic showing the layers

Cracks that evolve during the dicing process usually originates from the BPSG (Boron Phosphosilicate Glass) side due to the porosity of this layer and can propagate through the structure to the bottom which is another highly stressed area from the back grind process. Back-side chipping (BSC) occurs on the bottom surface of the wafer, as micro-cracks propagate away from the bottom of the cut and join together into chip out. The interaction of the blade with the substrate creates a network of micro-cracks in the substrate. When these micro-cracks join, they cause particles of the substrate to loosen and be removed. Backside Chipping (BSC) becomes a yield issue when micro-cracks exceed a certain length, which may increase the sensitivity of the devices to thermal cycling and lower their reliability. Dice intended for flip chip packages are even more sensitive. When packaging these dice, the backside of the die is exposed to the molding material. If the backside edges of the die are cracked and chipped, the molding may be imperfect, including air bubbles near the chipping. During the packaging process, these bubbles may cause mold cracking, which can cause yield loss. Back-side chipping is more pronounced in polyimide-coated wafers where there are heavy metal layers in the streets, or where heavy back-grinding has produced high tensile residual stress at the bottom of the wafer. The wafer is a given in most assembly lines; therefore, the tools available to the process engineer for controlling backside chipping are limited to blade selection and process parameter optimization.

2.0 Material Aspects of the wafer - Oxygen content in Bare Silicon

In this paper we will first discuss the influence of starting silicon material on the effect of chipping. The starting material is mainly influenced by the variability of the O_2 content. At the company where I worked, the starting material that was used (bare Silicon wafer) has a small variation of O_2 of about 2 ppm. We looked into the chipout response of different suppliers who made wafers with with different O_2 levels[1]. The different suppliers we considered had ppm levels shown in Figure 2 below. X & Y are wafer numbers.

Supplier	mm	σ_m	ws	σ_w	se	σ_s
X	24	0.5	25.6	0.15	25.5	0.31
Y	24.3	0.35	25.6	0.17	25.4	0.3

Figure 2 – O_2 content in Bare Silicon Wafer

Analysing the data further, we plotted a probability plot (Figure 3) which indicated that the difference between Silicon materials was minimal and a t-test further verified this. At significance level of 0.05%, the t- critical value of the 1.96 vs a t-statistic of 1.97 which is too small a difference and so the null hypothesis ($\mu_1 = \mu_{mm} = \mu_{se} = \mu_{ws}$) cannot be rejected (Figure 4). This implies that there is no significant difference in the oxygen level content of the bare silicon wafers.

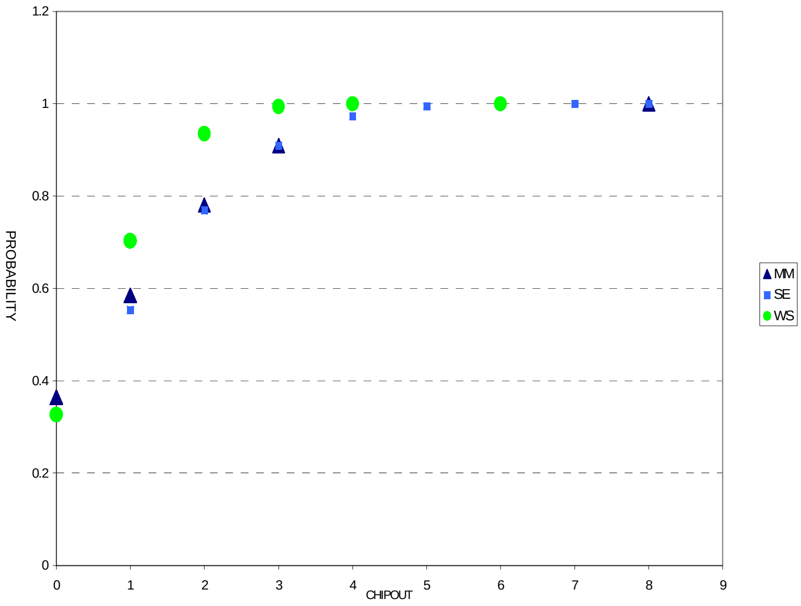
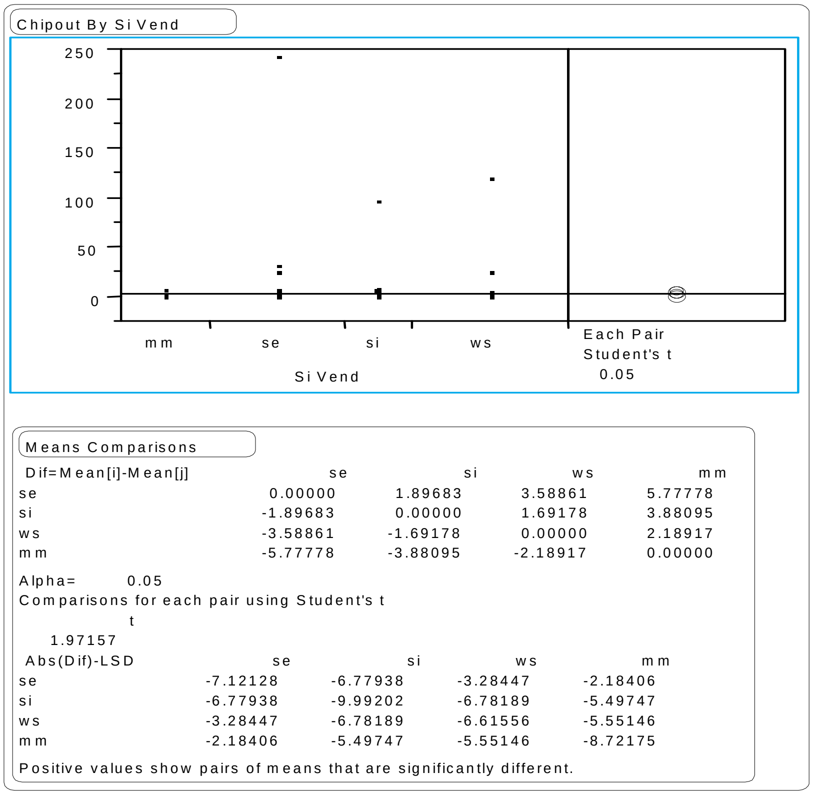


Figure 3 – Probability plot showing O_2 content of different wafer suppliers

And, such small differences cannot be the reason to the conditions of chipout at the wafer at saw. So now, one has to analyze these cracks from the processes at saw so that we could reduce them by locking the optimum process parameters.



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Dif=Mean[i]-Mean[j]        se          si          ws          mm
se                    0.00000     1.89683     3.58861     5.77778
si                   -1.89683     0.00000     1.69178     3.88095
ws                   -3.58861    -1.69178     0.00000     2.18917
mm                   -5.77778    -3.88095    -2.18917     0.00000
Alpha=      0.05
Comparisons for each pair using Student's t
            t
     1.97157
Abs(Dif)-LSD          se          si          ws          mm
se              -7.12128    -6.77938    -3.28447    -2.18406
si              -6.77938    -9.99202    -6.78189    -5.49747
ws              -3.28447    -6.78189    -6.61556    -5.55146
mm              -2.18406    -5.49747    -5.55146    -8.72175
Positive values show pairs of means that are significantly different.
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Figure 4 showing no differences on O_2 in wafers of different suppliers

3.0 Theoretical Basis

In the process of wafer sawing, fragmentation along the cutting edge can occur both at the top and bottom of the die surface. Top surface fragmentation is critical because this may lead to chipping on the top surface of the die. The condition will be worse off if the chipping propagates into the active circuit of the IC, leading to reliability failure of the units. This defect can be screened at 2nd optical inspection easily after wafer sawing and so it can be controlled. (See Figure 5). One can also control this process by performing an SPC (statistical process control) monitor by inspecting wafers immediately after saw so that one could control the quality of the wafers during saw[1].

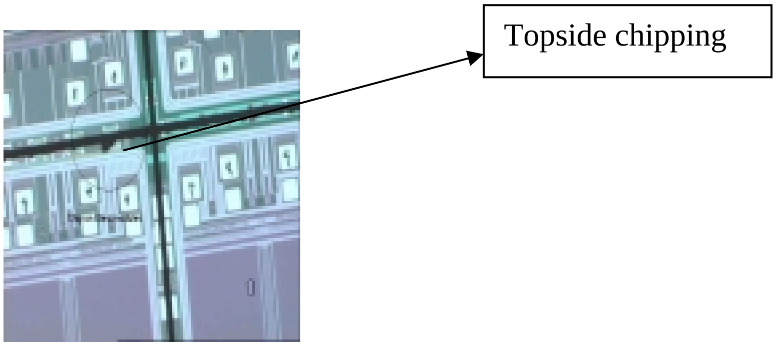

Figure 5 showing a topside chipout

On the other hand, backside fragmentation is aesthetic in nature if the backside chipping is well monitored such that the crack does not propagate upwards to the top surface of the die, causing damage to the active circuit of the IC. However unlike the topside chipping, this form of back surface defect on the die cannot be easily detected after die attach because it will be covered by an epoxy compound. A sample of the backside chipping after die mounting is shown in Figure 6 below. The figure 6a shows cracks on the backside before removal of the tape. In this photo the fractured die edge seen has a clamshell shape. Figure 6b shows A SEM photo of a die edge after removal from tape: Area 1 is die side face; area 2 is die backside.

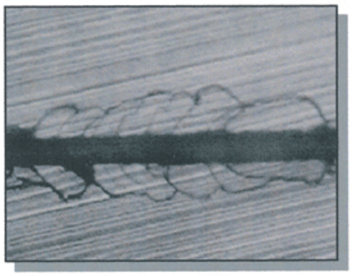

Figure 6a

Figure 6b

An investigation of the backside has found that immediately after sawing, the crack lines have already been formed on the backside of the die near the periphery[2]. It was also found that these crack lines after sawing, will result in total chipping off the backside of the die after processing through die attach. The mechanism of backside chipping has not been fully explored for achieving better understanding and control of the wafer sawing process. Figure 7 shows the stress points at the bottom just above the mounting tape.

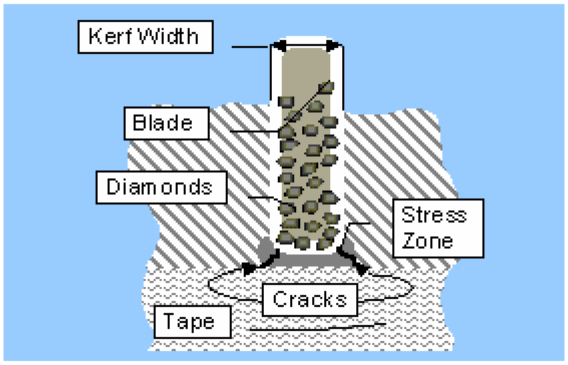

Figure 7 showing Stress Zone Area

Consider (Figure 8) the boundary condition of die A and B. Die A has no rigid support from its left adjacent die. Die B has one edge on the right uncut and fully supported by its right adjacent die. The UV-tape in the process sawing becomes loose, thus unable to provide enough rigid support for the backside of the remaining unsawed die. The die edges in contact with the cutting blade drying saw will experience a side thrust force due tot vibration.

Refer to figure 8 on page 10. Let the Side thrust force be q N/m. It will result in a bending stress (tensile) on die A at location “x”, whilst a compressive stress will be developed on die B at location “y”. Since only tensile stress can result in brittle fracture and actual crack is found propagating from the lagging end of die A, the analysis on die A can be carried out as follows:

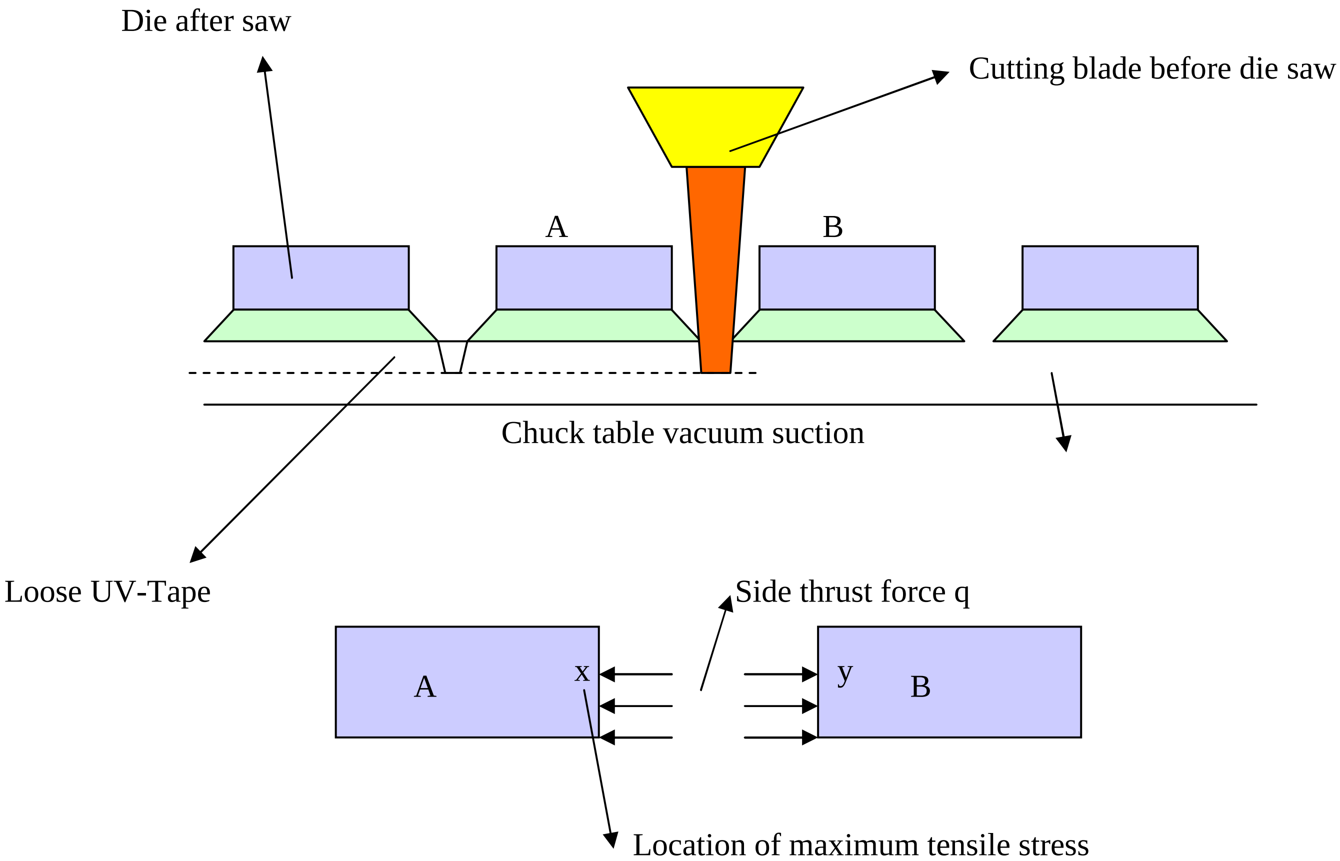

Figure 8 – Non rigid support on Die

The basic assumptions [5] for the stress analysis are :

- Simple beam bending due tot transverse loading from the cutting edge.
- Static uniform loading along the cutting edge.

The maximum bending stress at location “x” on die A can be expressed as follows:

$$\text{Maximum Bending Stress } \sigma_x = M_x / I * (h/2) = \frac{\tfrac{1}{2}\, ql^2}{1/12\ bh^3} * (h/2)$$

$$= 3ql^2 / bh^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where M_x : Max Bending Moment at "x"

I : Second Moment of Inertia

h : Width of Die A

l : length of Die A

q : Loading per unit length due to side thrust force

b : Thickness of Die A

Equation (1) provides a good approximation for the actual tensile stress acting at location "x" on die A. In addition the relative magnitude of the shear stress τ_x can also be included such that :

$$\frac{\sigma_x(\max)}{\tau_x(\max)} = 2l/h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The assumption that uniform side thrust force acting along the cutting edge has resulted mathematically that both bending and shear stress are maximum at the location "x" except that the maximum shear stress occurs at the neutral axis while the maximum bending stress occurs at the cutting edge on the die surface. In order to calculate the stress level on the die, the magnitude q must be determined. It is possible to obtain q with the following relationship:

$\delta = 6Fr_1^3 / Er_2e^3$

$= 6qlr_1^3 / Er_2e^3$ ………(3) (See Figure 9)

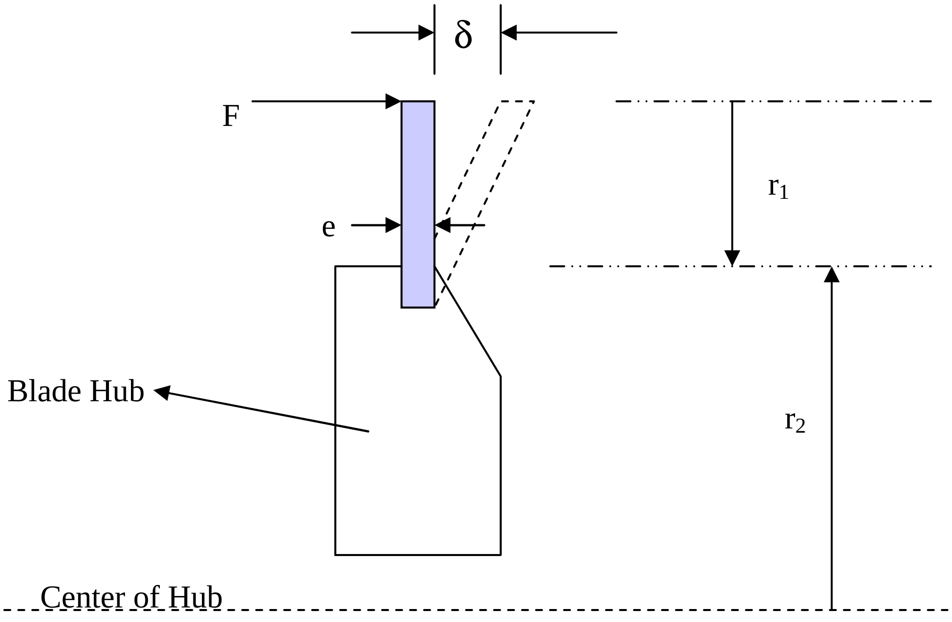

Figure 9 showing a schematic diagram of the saw blade

Where δ : displacement at the tip of the blade perpendicular to the original plane of the cutting blade

F : Total side thrust Force in N acting on the blade

r_1 : blade exposure length

r_2 : radius of blade hub

E : Elastic modulus of blade

E : Blade thickness

Equation (3) can be rearranged to read as $q = Er_2e^3\delta / 6lr_1^3$ ………………….(4)

Substituting Equation (4) into (1), the maximum bending tensile (bending) stress at location "x" on die A can be calculated.

4.0 The Principle of Fracture Mechanics

The fundamentals of brittle material dicing by an abrasive wheel are presented in a model formulated by Evans and Marshall, which describes the forced penetration of the abrasive particle, formation of cracks and removal of the cracked substrate. According to this model there are threshold loads for brittle materials; if a given material's load is exceeded, the material cracks. The length of the cracks depends on the applied load – the higher the load the longer the crack.

According to the theory of Fracture Mechanics, surface defects will render the backside of the silicon wafer to exhibit brittle fracture, in the presence of a tensile stress acting on the surface [3]. Assuming that a particular defect such as a void at a location "x" on die A is subjected to maximum tensile stress due to Bending Moment M_x (max) which arised from the simplified loading assumption;

$K_C = \sigma_x Y \sqrt{(\Pi a_c)}$ ....(5)

Where K_C : material fracture toughness

a_c : critical crack length after crack propagation [4] will begin

σ_x : stress at which unstable propagation of crack length will begin

Y : Flaw geometric parameter

Here the geometric parameter refers to relative size of the crack to the width of the specimen, the geometric boundary, the loading orientation etc. Mathematically, the critical crack length which will result in backside chipping of the die can be calculated based on the assumption that the geometric parameter represents a "single edge cracked pure bending" such that ;

$K_C = 6M/bh^2 \sqrt{(\Pi a_c)} * Y(\alpha)$ ....(6)

Where $\alpha = a_c / h$

If $a_c \ll h$, then $\alpha = 0$ and the geometric parameter = 1.122

Thus by rearranging, the crack length $a_c = (K_C b / 6M_x Y)^2 h^4 / \Pi$ …………..(7)

If one assume uniform loading at the cutting edge; then $M_x = ql^2/2$ can be substituted into equation (7) to solve for a_c. So in reality if the surface defect is greater than this mathematically modeled value of a_c, then it will lead to brittle fracture on the backside of the die after dicing[3].

Usually, the quality criteria for diced silicon wafers are as follows: if the size of the back side chipping is below 10µm, it is disregarded. On the other hand, when the size is greater than 25µm, it is considered potentially damaging. An average size of 50µm may be accepted, however, depending on wafer thickness.

5.0 Blade Exposure and Saw Speed

As wafers are diced at various feed rates, with similar blades, the blade interaction force increases linearly with the increase of feed rate (Figure 10). When feed rate reaches a certain value, however, an abrupt increase in force is observed. Further increase in feed rate causes an exponential increase in cutting force. Examination of the cut quality (b on Figure 10) reveals that this increase is accompanied by severe backside chipping (BSC) .

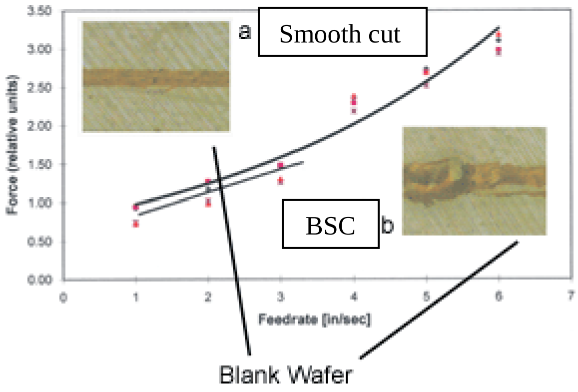

Figure 10 showing Change in Force vs Feed rate

The current draw of the motor that powers the spindle to which the dicing blade is attached is proportional to the interaction force between blade and substrate. The monitor samples the spindle current on an ongoing basis. The data obtained by sampling is filtered and analyzed and simultaneously displayed on a screen. As shown in Figure 11, the dicing system's process monitor systematically tracks the process.

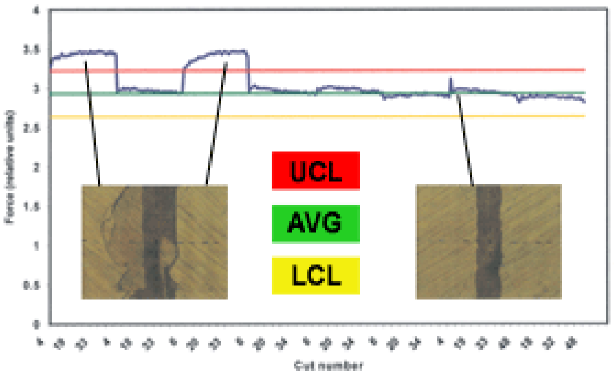

Figure 11 showing a process control system

The UCL and the LCL (Figure 11) are the upper and lower force value limits allowed for the process. The monitor determines these values based on statistical (SPC) considerations for varying sample sizes. Deviation of measured force values from the upper limit indicates significant changes in the dicing process, which are accompanied by damage to the wafer in the form of backside chipping. The monitor can be programmed to alert, or alert and stop, the dicer.

Another reason for alert is identification of a trend that may result in deviation. If force is increasing continuously, while process parameters are not changed, this is an indication for increased interaction of cutting blade and substrate. The increased interaction may indicate blade vibration or clogging. In both cases, the warning for deterioration in process is given when the probability of damage formation is high, providing time to correct the problem before yield loss occurs.

Other more significant factors are also discussed. They are blade design, spindle speed and critical saw parameters like water flow rate etc. With e-test modules located on these scribes, there is a chance of build up of Aluminum (a soft metal) on the blade during the saw process. This build up tends to increase the effective width of the mounting, which results in larger kerf widths and higher chances of chipouts. Therefore choice of spindle speed in combination with the right blade is critical. Typical saw spindle speeds are about 20,000 to 35,000 rpm depending on the blade exposure condition.

Figure 12 shows the breakdown of some critical variables that affect the saw performance. Factors like blade clogging, flow rate, spindle rpm, feed rate and wafer condition are some critical parameters to control and lock.

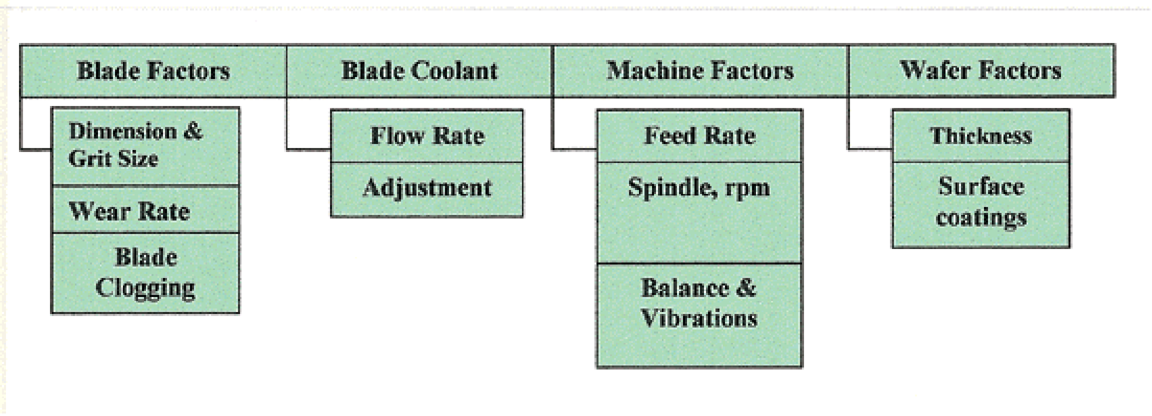

Figure 12 showing the critical variables at wafer saw

5.1 Blade Usage Calculation

Blade exposure is another important criteria in characterization of this process. The lifetime of a blade depend on how much the exposure the blade has.

To calculate the number of wafers that can be sawn with current exposure:

Lets say;

Blade Exposure =0.51mm

Wafer Thickness =0.35mm

Machine Safety Factor 0.05mm

Cut Into Tape =0.02mm

Balance Blade Exposure = 0.09mm

Assume that estimated Blade Wear Per Wafer=0.012mm

Therefore estimated Number of Wafers That can be sawn =0.09/0.012=7pcs of wafers

Now if Blade Exposure can be increased to 0.640mm, then Balance of blade exposure = 0.22mm

Then estimated number of wafers that can be sawn = 18pcs of wafers

Additionally if wafer thickness can go down from 14 to 12 mils, then we can saw 22pcs of wafers.

5.2 Condition of Mounting

The 65 micron saw process is therefore possible with the right choice of blade, the contamination on the mounting, spindle speed and the feed rate. After sawing several cut counts, the mounting can get burrs which prevent the blade from being mounted in parallel. Therefore the gap (spec 3 μm) is closely monitored every 3-4 days and if this exceeds 3 μm, mounting or whobble conditioning and dressing of the blade is carried out. The condition for acceptance of the blade mounting would be to check for parallelism after mounting.

5.3 Dressing (See Figure 13)

The role of the dressing in determination of cut quality must never be overlooked. In non-monitored dicing systems, the dressing procedure is established by a set of time and material consuming trial-and-error cycles. In monitored systems the end point of the dressing is more rapidly and accurately detected by measured force data, which allows optimal dressing procedure to be established.

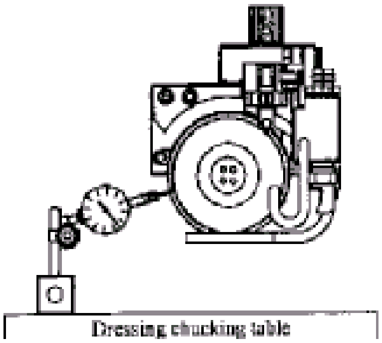

Figure 13- Dressing of the Blade

A two-fold advantage is achieved by monitoring the dressing procedure. The dressing duration is just as long as needed to obtain a fully dressed blade; no margin time is needed to assure optimal blade performance. Second, there is no yield loss due to poor quality that results from dicing with a partially dressed blade.

A common procedure for dressing is based on incrementally increasing the substrate feed speed at a constant rate. Since the cut speed is increased at a constant rate the cut force increases linearly.

The following can be drawn from the on-line monitor studies:

- The blade interaction force is a reliable indication to the process robustness.
- The blade force can be on-line monitored and used to warn of potential problems.

- The monitor can be used for optimization of dressing procedure and dicing process.
- On-line monitor is an important tool for statistical process control.

Figure 14 shows the change in blade force while performing the dressing of the blade. If the force increases in a non-linear manner after a certain cut count, then it is important to change the blade and check the burr on the mounting.

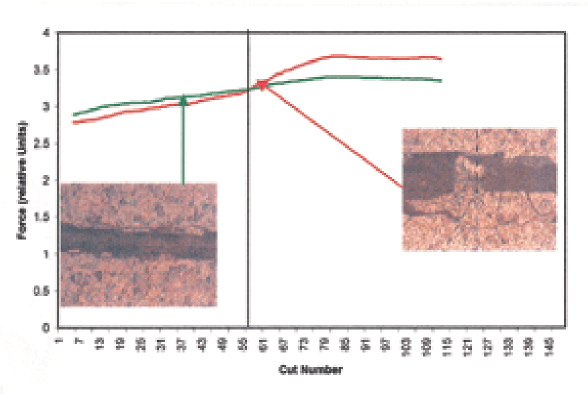

Figure 14 showing change in blade force during dressing

With regular monitoring of the blade and mounting, one measures the burr with a gauge as shown in figure 13. The data can be plotted as a function of time interval in a scatter plot.

Figure 15 shows a section of the wheel mount that should be mounted without losing any parallelism to the hub. The whole mounting must be inspected for smoothness after with a magnifying glass or a scope, whichever is applicable. If there are any rough surfaces on the wheel mount, then one should condition this with a smoothening material without causing any damage to the mounting.[1]

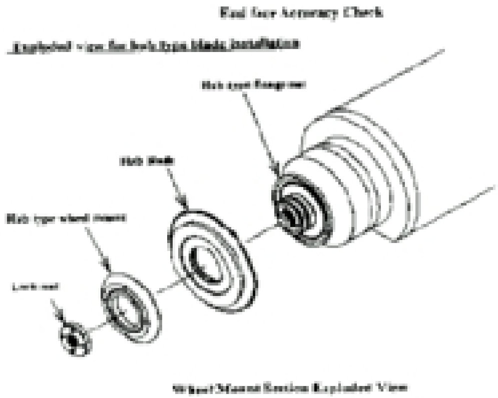

Figure 15 showing Section of Wheel Mount

The scatter plot on the next page (Figure 16) was unable to provide perfect information we needed, however, by correlating the surface burr condition of the mounting, to the defect PPM, we found that the higher the burr, higher was the defect level for chipout, which means that the kerf width exceeded the mean of 65 +/- 3σ [1]

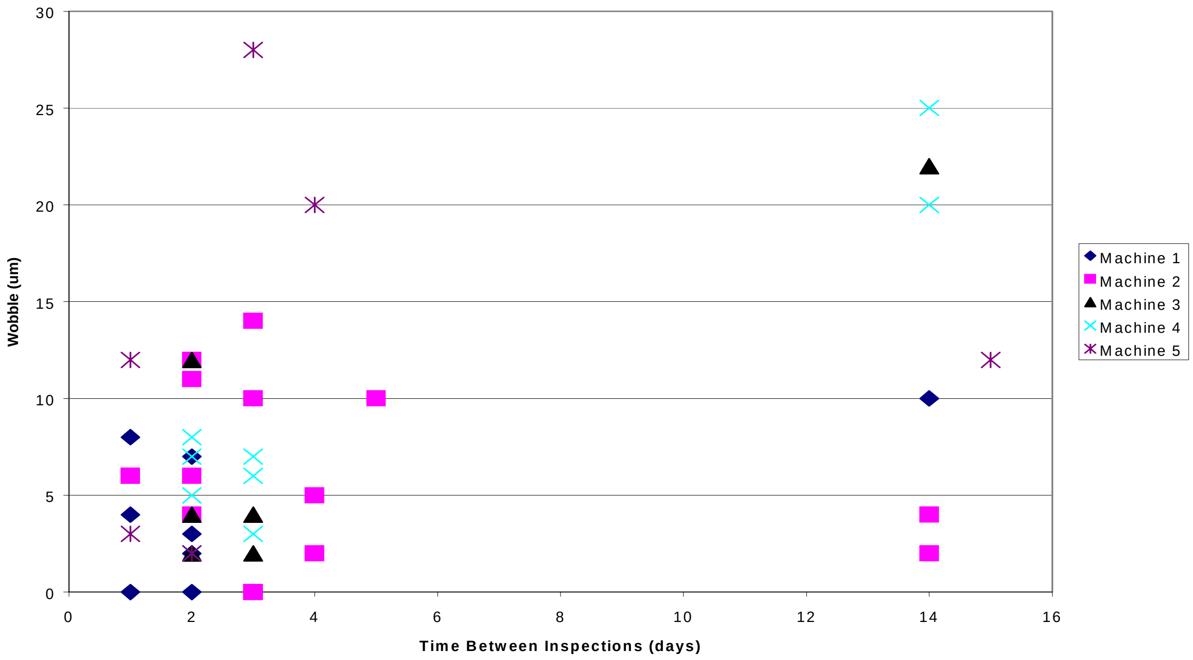

Figure 16 showing inspection of the whobble with time

6.0 Experimental Work

In summary, a realtime study on the efforts of improving the saw process for critical scribe width shows that a 3σ process can be achieved by making the following changes[1]:

- Blade selection for narrow scribes.
- Conditioning the whobble every 3-4 days, while utilizing the saw at 24/7.
- Right saw speed settings with critical parameters locked.

Figure 17 below shows the chipout trend after implementation of this new process and blade in ww27. The PPM levels dropped by a factor 10 and this process is now under control and is in normal production at company C. With the improvements in the saw process the defective PPM was brought down from a high of 700 PPM down to about 70 PPM.

7.0 Results and Discussion

From the results shown, the dicing process process is a very crucial process especially during the dicing of narrow scribe width below 65 μm. The results show a significant improvement (700 PPM to 70 PPM) in the backside chipping (See Figure 17). Based on the results and the theoretical model, it can be seen that back side chipping is related to the dynamic vibration of the spindle RPM . The non rigid support on the die and the presence of an external force acting along the cutting edge have directly resulted in the formation of the bending stress. The principle of fracture mechanics explains the existence of a theoretical critical crack length allowable. The larger crack line will propagate leading to brittle fracture at the lagging end on the die.

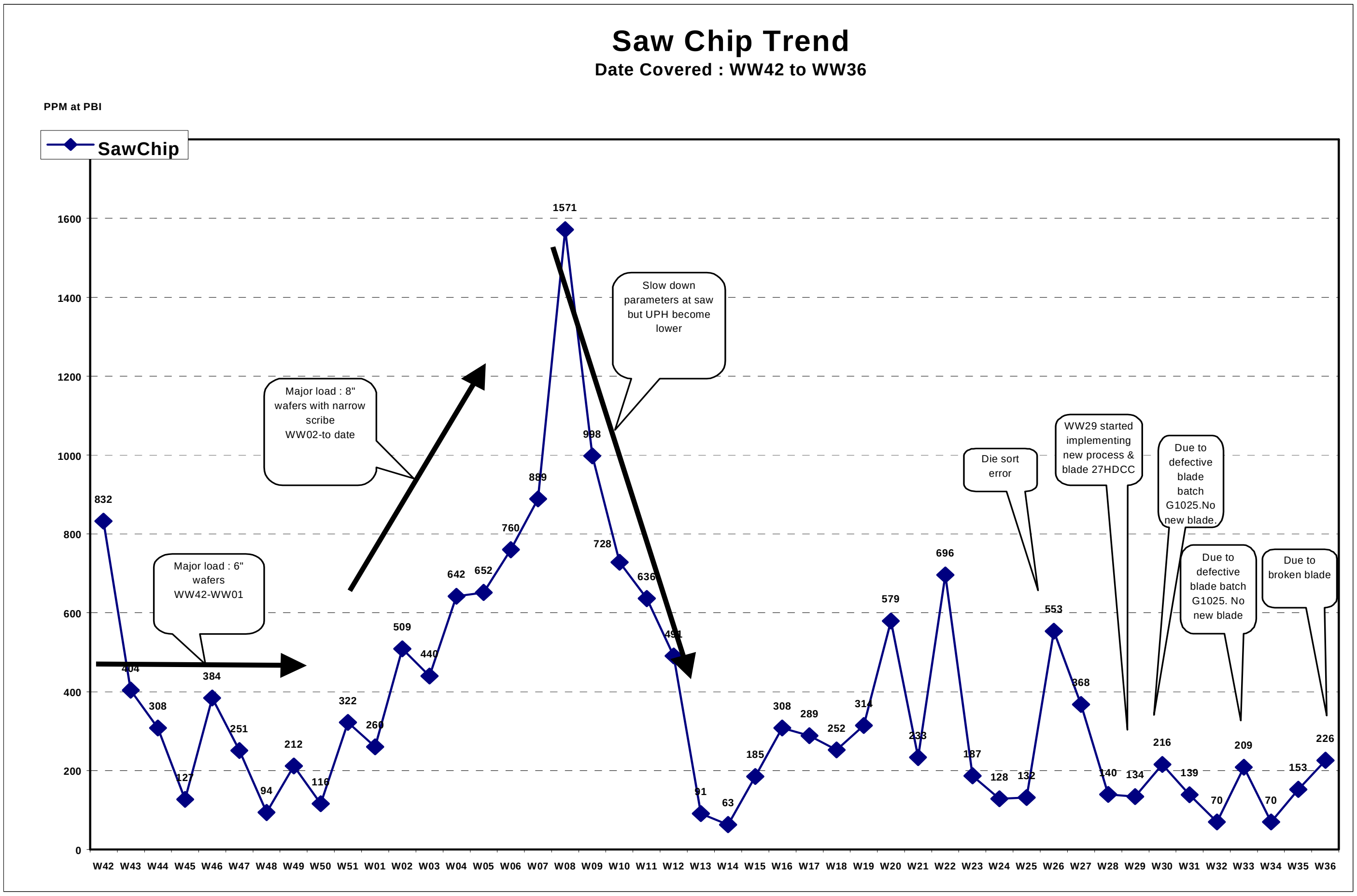

Figure 17 showing backside chipout trend before and after ww27

8.0 Conclusion

This paper has explained a number of causes that leads to a backside chipout during wafer sawing. In practice, the blade selection, the cutting speed, the mounting condition, the surface finish can result in a significant improvement in backside chipping.

A revolutionary “Dicing by Thinning Concept” [6] is a method which can overcome the mechanical damage at the chip edge induced by standard sawing methods. In this method, the dicing grooves are prepared at the wafer front side. These trench depths corresponds to projected wafer thickness. After mounting, the trenched wafer is thinned from its backside until the grooves are opened. This method can reomove residual micro-cracks with the help of the etchant being used.

9.0 References

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