Fully automated quality management after singulation for reliable failure prediction

DISCO Hi-TEC Europe GmbH

Abstract

DIS100 is a unit that picks up die from the wafer after singulation and measures the die thickness, chipping, backside surface roughness, and die strength using a fully automatic process. Efficient and highly accurate measurement is achieved by automating all of the existing manual processes. In addition, DIS100 also records and stores measurement data, improving traceability as required for purposes such as quality audits of automotive devices.

"The true logic of this world is in the calculus of probabilities" – James Clerk Maxwell

1. Introduction

Semiconductor device manufacturing is most likely one of the most advanced industries when it comes to 24/7 mass production. Hundreds of billions of die are manufactured each year and the recent trends towards electrification will increase their future demand. One critical step in the semiconductor process chain is the separation of a wafer into individual die, which is directly linked to the yield of the back-end process.

Fig.1 Fully automatic die inspection tool DIS100

The general need to reach thinner silicon thicknesses for power devices in order to improve the electrical performance and for memory devices in order to realize higher capacity by stacking die is increasing the demand for highly robust and reliable processing. One of the approaches used to investigate the mechanical robustness of singulated die is the 3-point bending test. The 3-point bending test is a destructive test, and is for example, applied using sample sizes of 25 and 40. Comparing the median bending strength of the data set is often used during process development, for example to evaluate which parameter set gives the nominal highest strength and will be used for process qualification. However, the die that will break later in the field and customer returns are most likely not the ones that have median breaking strength values. Much more of interest are the 0.10% or 1.00% strength values, defining the lower edge of the process robustness, and for semiconductor device manufacturing in which a large number of die are manufactured, the overall amount of these low-performance die is not negligible.

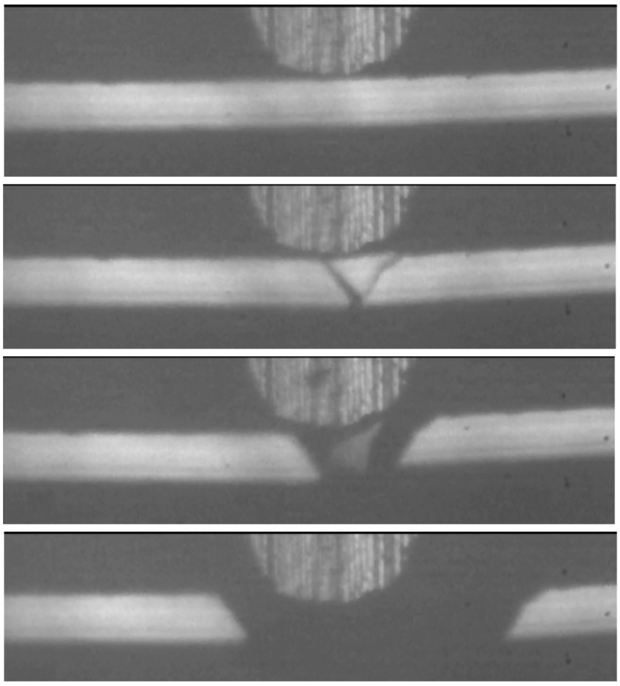

Fig.2 Images taken with a high speed camera during bending strength monitoring

To make a good prediction of these values, a large amount of sampling is necessary. However, this is usually hard to achieve, as previously, measurements were done by a human operator picking up each die with tweezers and placing them on a universal measurement tool, which is time consuming and occasionally faces difficulties with repeatability and accuracy due to different setups and handling methods. DIS100 (Fig.1), a fully automatic die inspection tool, can overcome these problems. DIS100 reduces handling-induced measurement variations and errors, and maximizes the sampling size to make more accurate predictions in terms of failure probabilities.

2. Equipment

DIS100 operates by repeating the following process flow automatically for each individual die in a customer's set sampling size and pick-up position on the wafer (Fig.3).

(i) Set the frame cassette manually or via OHT
(ii) Pick up the die from the dicing tape
(iii) Sidewall inspection,* Backside inspection**
(iv) Die flip (only if front side needs to be measured)
(v) 3-point bending strength measurement***
* Chipping and die thickness measurement
** Backside roughness measurement
*** High-speed camera monitoring

OHT compatibility, sidewall inspection, backside inspection, and high-speed camera are additional specifications (not standard).

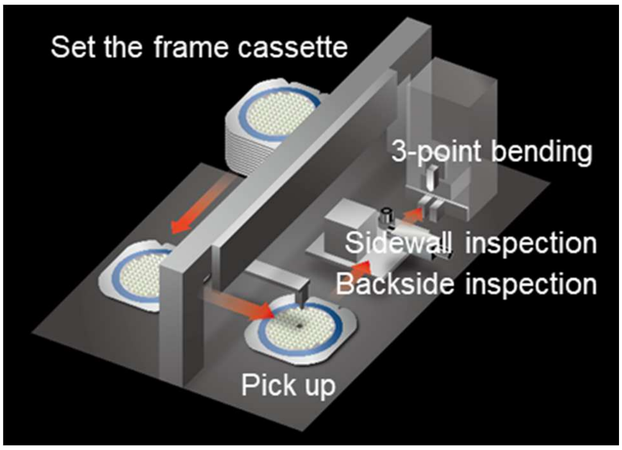

Fig.3 Process flow of DIS100

The ability to measure the thickness of the sample with a resolution of 0.2 µm is also highly valuable due to the quadratic influence on the final result of testing (Eq1.1). Especially for thin devices below 100µm, a total thickness variation of several microns cannot be ignored and can lead to misinterpretation if not measured accurately. An alternative method that is often used is to measure the thickness at two positions of the wafer, one at the edge and another at the center, and assume that the surrounding die have a similar thickness. However, there is a possibility that the thickness of each die may vary using this method. DIS100 measures the thickness of each die, and accurate die strength can be calculated using these values.

Pre-damage of the die in the form of chipping of the sidewall can also be detected by an investigation prior to breaking, similar to the surface condition of the backside in terms of roughness (Fig.4). DIS100 measures and records die processing quality data. Therefore, this data can be useful for failure prediction by taking the correlation of the processing and die strength into consideration, as well as for improving traceability.

For advanced monitoring, the use of a high-speed camera with a sampling rate of up to 2M frames per second is an interesting feature. Fig.2 shows four selected images at different time stamps of a silicon die during bending strength measurement. It is clearly visible that the crack starts in the center of the die where the force is applied, and that the deflection of the die is low, and both are key criteria for the 3-point bending measurement assuming a linear bending behavior.

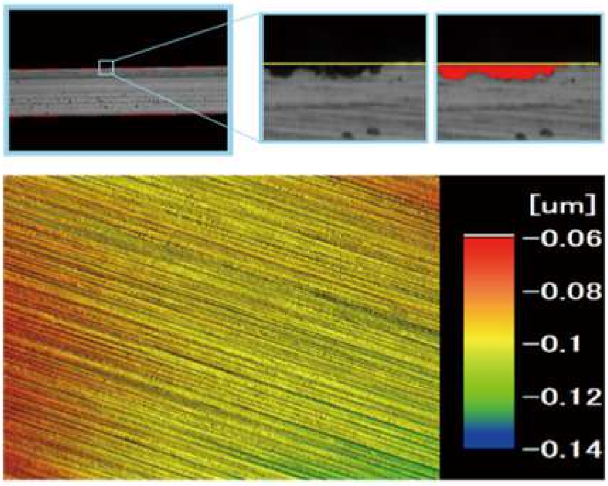

Fig.4 Chipping analysis (upper images) and backside roughness measurement (lower image)

By utilizing a wafer map, more efficient testing and failure analysis can be realized. Two examples are introduced below. One is to utilize an electrical characteristics testing wafer map for the probe test process. With this, only electrically dysfunctional dies are picked up and measured by DIS100, and this can be used for quality management during high volume manufacturing. The other is utilizing a color-coded wafer map of the bending strength results of individual die (Fig.5) for breakage analysis. With this, different kinds of failure modes can be found depending at the wafer and lot level. Repeatable low mechanical robustness on the edge area of the wafer might be an indicator of systematic weakness inside the process chain, whereas localized weak positions on a single wafer are most likely due to a single event, such as a particle laminated between the tape and wafer, which can damage the die or lead to reduced performance in the dicing and grinding processes.

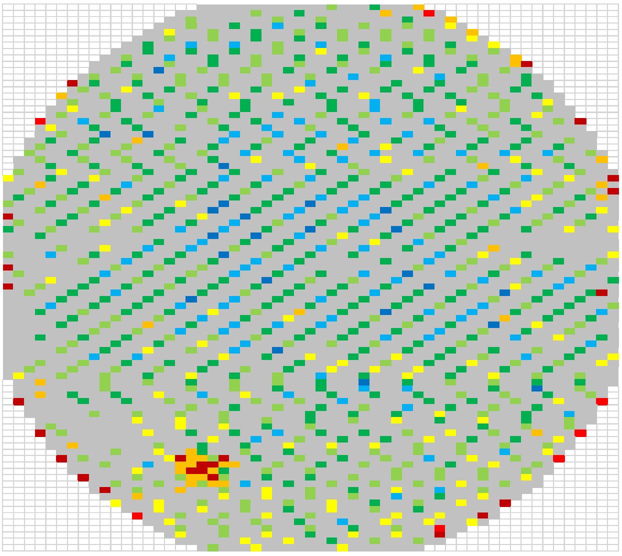

Fig.5 Color-coded wafer map indicating the bending strength of each die

3. Experiment

The goal of this study is to investigate the influence on the low percent values of the bending strength test by manipulating the sample sizes used for Weibull parameter fitting. Data sets were generated based on 1000 measurements for two different separation approaches and then were split into different sub group sizes for statistical analysis.

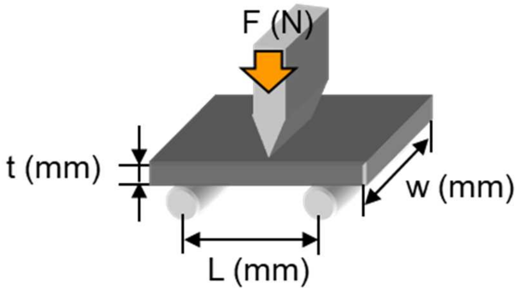

Fig.6 3-point bending test

All testing was done using the 3-point bending approach and die strength was calculated using (Eq.1).

$$\sigma = \frac{3}{2}\frac{FL}{wt^2} \qquad \text{(Eq.1)}$$

Here, σ is the die strength (MPa), F represents the applied load (N), L is the span of the lower support pins (mm), w is the width, and t is the thickness of the die (mm) (Fig.6). The Weibull distribution probability was calculated using (Eq.2).

$$\ln\left(\ln\left(\frac{1}{1-Q(\sigma)}\right)\right) = \beta\ln(\sigma) - \beta\ln(\alpha) \qquad \text{(Eq.2)}$$

Here, Q(σ) = (i-0.3)/(n+0.4) defines the quantile of the sampling, ß is the shape, and α is the scale parameter. A Weibull distribution was used to determine the low percentage bending strength values of 0.10% and 1.00% (Fig.7).

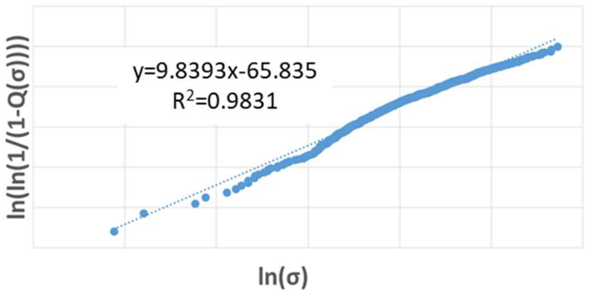

Fig.7 Weibull distribution probability plot

The first data set of a thousand die was split into individual smaller sets of n=25, n=40, n=200 and n=500. For each individual set, the Weibull distribution was calculated, and low percentage values were fitted. Table 1 shows that for sample sizes of 25 and 40, the 0.10% value deviated by 87 MPa from each other, and the values were one factor higher and one factor lower compared to the outcome achieved using higher sample sizes of 1000.This fluctuation is too large to make predictions for reliable failure analysis. For n=500 the shape and scaling parameters are close to the values gathered from n=1000.

Table 1 Weibull fitting parameters and bending strength values for different sample sizes

	Die strength [MPa]		Shape β	Scaling α [MPa]	Least Sq. R^2
	0.10%	1.00%			
n=25	171	218	9.45	355	98.18
n=40	258	289	20.33	363	95.45
n=200	219	260	12.51	367	99.65
n=500	234	274	14.99	373	99.54
n=1000	235	275	14.82	375	99.46

The second data set also consisting of an overall sample quantity of a thousand die was partially split into 5 subgroups of 25 samples each. Table 2 shows the Weibull fitting and Figure 4 displays the calculated values for 1.00% distribution. For the full sample size of 1000, the value was found to be 519 MPa, and therefore measurement set n3 for example, is already off by around 20%. Overall the confidence level for a sample size of 25 seems to be insufficient, and the fluctuation from measurement to measurement is significant.

Table 2 Weibull fitting parameters and bending strength values for 5 measurements with a sample size of 25

	Die strength [MPa]		Shape β	Scaling α [MPa]	Least Sq. R^2
	0.10%	1.00%			
n=25	171	218	9.45	355	98.18
n=40	258	289	20.33	363	95.45
n=200	219	260	13.51	367	99.65
n=500	234	274	14.99	373	99.54
n=1000	235	275	14.82	375	99.46

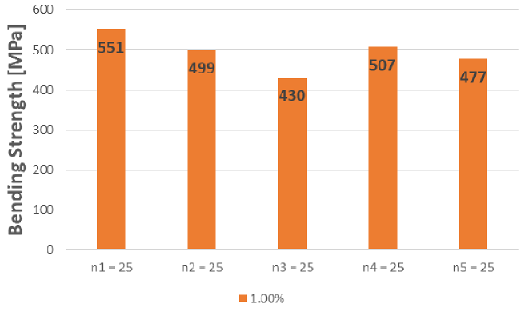

Fig.6 Fluctuation of the 1.00% values for 5 measurements with a sample size of 25

The last experiment was used to investigate the influence of the die width ("w" in Fig.6) on the bending strength outcome. Usually, a certain technology spans several different die sizes called basic types, and each size is designed to fit in a defined package. As the same die stack architecture and an identical dicing kerf with the same process for singulation are mostly used, similar stress levels are induced on the die sidewall during the separation step. In general, the width is part of the 3-point bending (Eq.1) equation, and it is widely expected that measuring the strength of one basic type is representative of the whole portfolio. In Table 3, the median values are displayed with respect to die widths of 2 mm, 2.5 mm, and 3 mm for a fixed stack and die length. It is clearly visible that an increased die width leads to a lower bending strength. One possible explanation might be the difference in stack and layer thickness of patterned devices, which influences the applied load on the sidewall of the die. Therefore it is necessary to test all relevant basic types individually to get reliable feedback about the process' robustness.

Table 3 Influence of the die width on the bending strength result for a certain stack configuration

Die width [mm]	2.0	2.5	3.0
Die strength [MPa]	657	528	471

4. Summary

To get a clear picture of the mechanical bending strength after the separation process, it is necessary to increase the sample size compared to previous approaches that used a size of 25 or 40 samples. Accurate values based on high statistics for reliable failure rate predictions can be achieved using the DIS100 by minimizing handling-induced errors due to the fully automatic process flow. . The ability to use advanced inspection items like thickness, chipping, and roughness measurement adds additional value to the accuracy of the testing outcome and can prevent wrong interpretations of a certain result.