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Fracture Strength Characterization of the Die Active Side and Back Side for a Realistic Die Crack Assessment

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Author's contribution

The author performed the actual experimental testing in this study and also read and reviewed the final manuscript.

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Short Research Article

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ABSTRACT

This paper discusses the characterization of an integrated circuit (IC) silicon die fracture strength to have a realistic die crack assessment. The evaluation was conducted using a 3-point bend test setup to measure the die strength of actual IC dies. Both the active side and the back side of the IC die were tested for 2 types of dies with different active side circuit layout. Results showed that the difference in the die active side circuit layout or structure has impact on die strength. It was also found that the active side was weaker than the back side. This implies that both the active side and the back side of an actual IC die must be subjected to fracture strength characterization to have an assessment that would be in a better agreement with real condition. Using only the strength of the back side would result in over-estimating the die strength. The common approach of using the fracture strength of the die back side to characterize the die strength is not realistic and can mislead the assessment of die crack or semiconductor package robustness.

Keywords: Die strength; die fracture strength; die crack; 3-point bend test; die active side; die back side; silicon die.

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1. INTRODUCTION

A semiconductor package has an integrated circuit (IC) silicon die with a set of functional electronic circuits. When a die crack happens, the circuits will be damaged and makes the device non-functional. The strength of the silicon die is very important to have a robust semiconductor package with high yield and good reliability. With silicon die being a brittle material, die crack occurs when the die is subjected to a stress that is equal or higher than its fracture strength. Semiconductor package assembly process like die mounting (die attach) can cause die crack [1] and Fig. 1 shows one example of such process-induced die crack.

Die fracture strength or simply die strength is commonly measured using a 3-point bend test [2,3]. A 4-point bend test could also be used [4] and there is even a new method called ball-on-ring microforce test [5]. However, the 3-point bend test is the one widely used and an international standard [6-8] is already established for it. It is also easier to set up for the test sample considered in this study. Most studies on die strength characterization [9-14] are focused on evaluating the effects of surface damage due to processes like back grinding, polishing, and singulation. There is no die strength measurement comparison done between the die back side and the die active side (circuit side). It appears that the die strength is just taken as the strength of the die back side, which is affected by wafer backgrinding or polishing. Knowing the need to characterize not only the strength of the die back side but also the strength of the die active side, this current study characterized the strengths of both sides of the die using the 3-point bend test method to have realistic basis for die crack assessment.

2. DIE FRACTURE STRENGTH CHARACTERIZATION

The die fracture strength characterization was done using an Instron MicroTester with a 3-point bend fixture compliant to the international standard SEMI G86-0303 for measurement of die strength [6]. The 3-point bend setup and testing procedure were based on that SEMI standard.

2.1 Testing Equipment and Setup

The Instron MicroTester equipment used is shown in Fig. 2. It has a load cell that measures the amount of force applied to the specimen in a 3-point bend setup as illustrated in Fig. 3. The silicon die is supported at the bottom by 2 stationary anvils and force is applied from the top with the movable upper anvil.

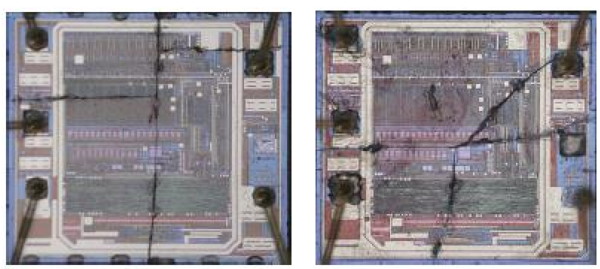

Fig. 1. Die crack caused by die attach assembly process [1]

Fig. 2. Instron MicroTester

The Instron MicroTester measures the maximum load before the die breaks (Fig. 3) and the die strength is then calculated using the following equation [6]:

$$\sigma = \frac{3FL}{2bh^2} \quad (1)$$

Where,
σ = die fracture strength
F = die breaking force (maximum load before breaking)
L = span or distance between supports
b = die width (parallel to the support axes)
h = die thickness

In the measurement of the strength of the active side of the die, it was oriented such that the die active side was facing downward or toward the 2 anvil supports shown in Fig. 3. and the back side was facing the upper anvil applying the force. In this condition, the active side would be subjected to tensile stress during bending. On the other hand, the strength of the die back side was measured with back side facing downward subjecting this side to tensile stress until the die was broken. The maximum force was recorded, and the fracture strength calculated for each die according to equation (1).

2.2 Silicon Die Samples

There were 25 die samples tested as shown in Fig. 4 and taken equally from 4 different locations in the wafer (north, south, east, west, center). There were also 2 different types of dies tested: (1) MM die, (2) PP die. MM die is for one product and the PP die is used for another product variant but the main difference is only the conductive metal trace circuit pattern. Overall dimensions and thickness are the same. The die thickness is 180 microns for all the dies tested. Both types of dies were subjected to the same back side grinding and polishing processes or surface treatment. Therefore, the back side surfaces of the 2 types of dies were expected to be of the same surface condition. However, the active side of MM die would be different from the PP die because they have different electronic circuit layout.

3. RESULTS AND DISCUSSION

The representative load-deflection curve is shown in Fig. 5 for the MM die active side, which only differs from the PP die active in terms of circuit layout or conductive metal trace structure. It shows an increasing force applied to the die until it drops after reaching a maximum value or the die breaking point. The drop in load signifies the breaking of the die. The variation in the breaking load for the active side of all the MM dies tested appears to be low with the values close to each other. This is also clearly shown in the boxplot (Fig. 7) for the MM die active side (MM_Active).

From the load-deflection curve of the back side of MM die (Fig. 6), it can be observed that the breaking load is higher than that of the active side. However, the variation is also higher, or the values are farther from each other. Since the strength of the back side of the die is affected by the surface damage due to wafer back side processing, result seems to show that the surface condition is better as reflected by a higher fracture strength.

Based on the comparison of the die strength results shown in a boxplot (Fig. 7), the strength of the die active side is consistently lower compared to the strength of the die back side for both the MM die and PP die. As shown, the strength of the PP die active side (PP_Active) is at approximately 690 MPa average and obviously lower as compared to 860 MPa for the PP die back side (PP_Back). Looking at the strength of the die active side, it shows that MM die is generally weaker compared to the PP die (570 MPa vs 690 MPa), which could be attributed to the difference in the circuit metal structure and pattern. However, when we look at the strength of the die back side, MM die seems to be of comparable strength with the PP die. This is expected for the strength of the back side since both PP die and MM die have the same back side surface condition. It can also be observed that the values obtained in this study (400 MPa to 1,200 MPa) are within the range of values presented in another previous die strength study using the same method [12].

The die strength results were also analyzed statistically with one-way ANOVA (Analysis of Variance). Fig. 8 shows the comparison using the one-way ANOVA in Minitab statistical software. Analysis indicates that in terms of the strength of the die back side, MM die and the PP die have no significant difference with result showing about 880 MPa for MM_Back and 860 MPa for PP_Back. The reason for this is the fact that both types of dies were subjected to the same wafer backgrinding and polishing processes. With that, we could expect the same degree of surface damage or flaws. Thus, the strength is also expected to be of the same level.

However, the strength of the die active side and the strength of the die back side have significant difference for both MM die and the PP die. Since the strength of the die active side is lower than the strength of the die back side, using only the back side to characterize the die strength is not realistic. When the die active side is subjected to a tensile stress below the strength of the die back side, it could already break. As we can see from the results, it would not be correct to do die crack assessment based on the strength of the die back side only.

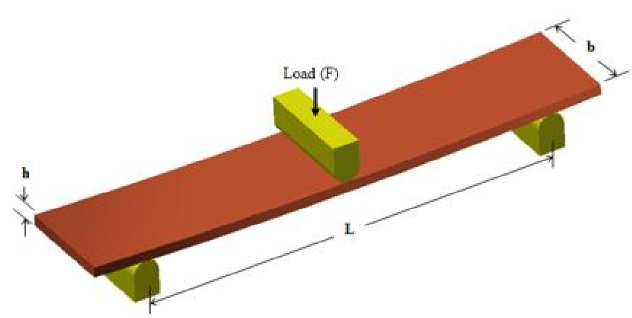

Fig. 3. Schematic of the 3-point bend setup

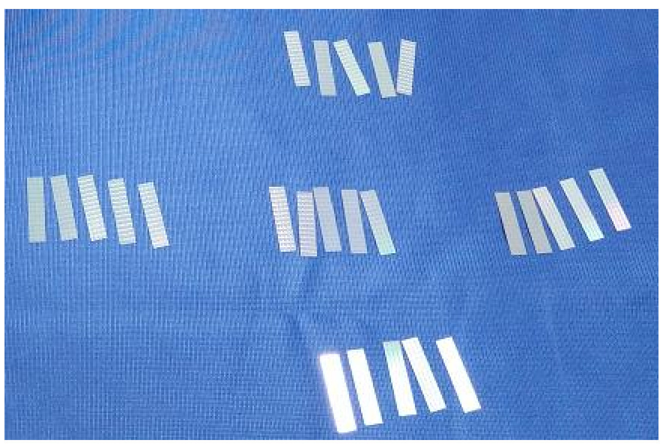

Fig. 4. IC silicon die samples

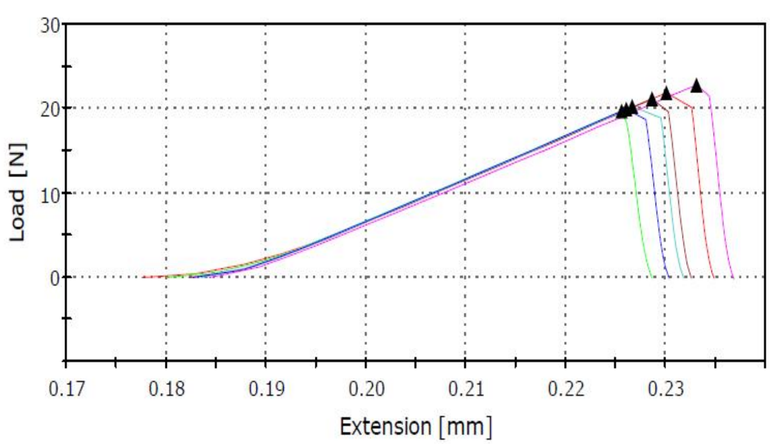

Fig. 5. Representative load-deflection curve (MM die - active side)

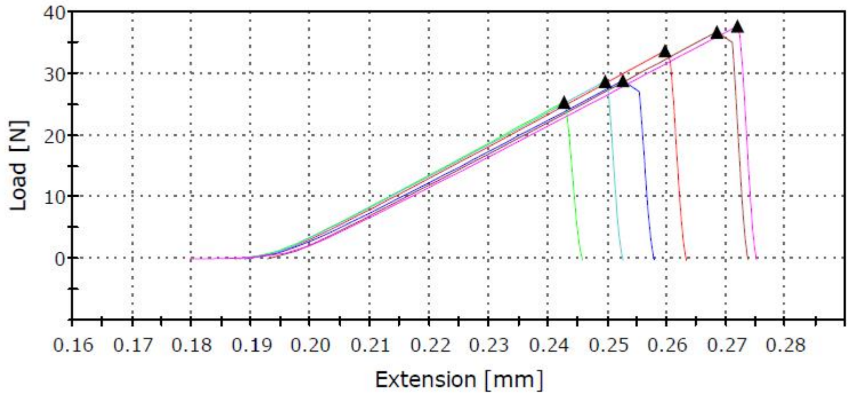

Fig. 6. Representative load-deflection curve (MM die - back side)

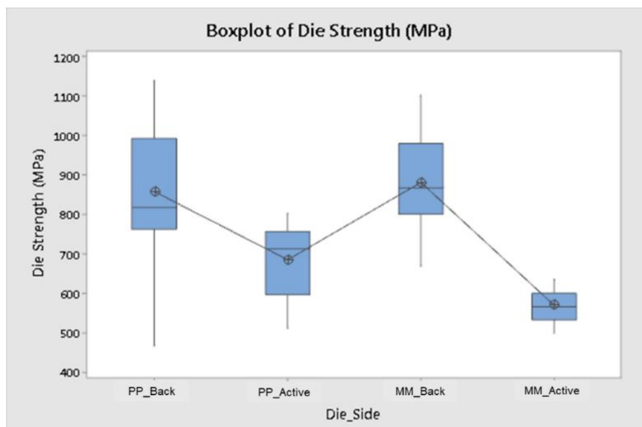

Fig. 7. Boxplot of die strength for MM die and PP die with back side and active side comparison

One-way ANOVA: Die Strength (MPa) versus Die_Side

Die_Side	N	Mean	Grouping
MM_Back	25	881.1	A
PP_Back	25	857.8	A
PP_Active	25	685.4	B
MM_Active	25	570.04	C

Means that do not share a letter are significantly different.

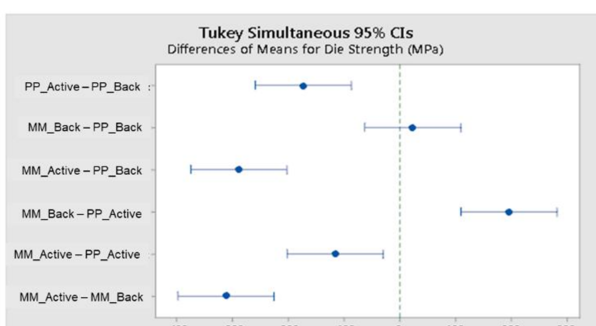

Fig. 8. One-way ANOVA for MM die and PP die with back side and active side comparison

4. CONCLUSION

For the two different types of dies having different metal trace patterns or circuit layout on the active side, the fracture strength of the back side of the die would have no significant difference when the same back side processes are applied. Results show that the difference in trace patterns on the active side of the die would not affect the strength of the other side of the die. However, the strength of the active side of the die could have significant difference as it depends on how the metal traces of the electronic circuits are laid out for each type of die. The difference in the die active side circuit layout or structure has impact on the resulting die strength of the active side.

It was also found out that the fracture strength of the back side of the silicon die is significantly different from the strength of the active side of the die where the electronic circuits are located with the two types of dies considered. In this current study, the active side is weaker than the back side of the die and using only the strength of the back side for die crack assessment would be an over-estimation of the die strength. Therefore, characterization of the strength of both the active side and the back side of the die is important to make a realistic assessment of die crack. This prevents over-estimating the strength of the die and failing to foresee higher risk of die crack.

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

Author has declared that no competing interests exist.

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