# FRACTOGRAPHIC ANALYSIS OF DIE CRACK SIMULATED UNDER DIFFERENT FRACTURING CONDITIONS

**Dexter Delos Santos[1]**
**Jefferson Talledo[2]**

[1]Imaging Division Failure Analysis Engineering, [2]New Product Development and Introduction
STMicroelectronics Inc., Calamba, Laguna, Philippines
dexter.delossantos@st.com, jefferson.talledo@st.com

## *ABSTRACT*

Fractography is one of the advanced techniques in analyzing die crack failures necessary for effective determination of die crack root cause. However, die fracture surfaces are not always easy to analyze. There is a need to establish a more comprehensive reference for die crack fractographic analysis. In this study, die crack was intentionally produced under different fracturing conditions with unbonded die, die bonded on substrate, and die in molded semiconductor package. Different loading rates, orientation, and force application probe tips were used. Fractographic analysis was performed and matched with the corresponding fracturing condition. With the results, a comprehensive reference for bending induced die crack is established. The generated fractography reference images would be useful for quick and accurate determination of fracturing condition and die crack root cause.

## 1. 0 INTRODUCTION

Integrated circuit (IC) die crack is one of the most common problems in semiconductor packaging. The crack could happen during or after wafer sawing when the die is not yet bonded on the substrate. When the die is already bonded on the substrate or molded, crack could also be encountered. In many cases, this die crack is induced when there is some form of bending load applied during package assembly.

### *1.1 Fractography*

An advanced technique in die fracture analysis that could be used to obtain information on both the tensile stress and the origin of die breakage is fractography. From scanning electron microscope (SEM) image of the die fracture surface, important information could be extracted to determine the mechanism of breakage, such as direction of crack propagation, type of the stress, direction of impact and friction, and location of the origin [1]. Fractography is basically the study of fracture surface topography and its relation to crack propagation [2].

### *1.2 Die Bending*

Bending induces stress in the die whether it is not yet bonded on substrate or molded in package. In a 3-point bend as shown in Fig. 1, when force is applied from the top the die experiences tensile stress at the bottom side and compressive stress at the top side. Crack starts when the level of die tensile stress reaches its corresponding fracture strength.

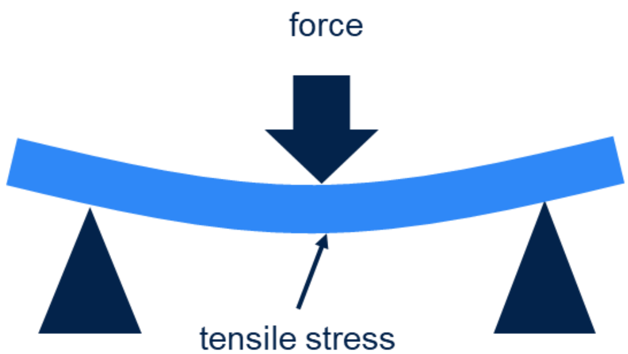


Fig. 1. Die bending with the tensile side indicated.

One previous study [3] considered fractography on silicon plate fracture from 4-point bending. It showed some reference SEM optical images with corresponding crack propagation interpretation as well as the location of the crack origin. The tensile side of the silicon plate was also determined from the SEM image of the fracture surface. However, there is scarcity in fractography studies on die crack produced by different simulated fracturing conditions.

In this study, simulated die crack under different fracturing conditions were generated and analyzed by fractography to establish a comprehensive reference fractographic reference for more accurate determination of die crack root cause.

## 2. 0 REVIEW OF RELATED WORK

Refer to 1.0 Introduction.

## 3.0 METHODOLOGY

Different die samples including die only, die on substrate, and die in molded package were utilized in this study in which crack is produced by bending at different loading rates and die or package orientation (die active side down, die active side up). Two types of probes (wedge type, pin type) were also used in the experiment for applying the force as shown in Fig. 2. The simulated crack was then analyzed using fractography technique.

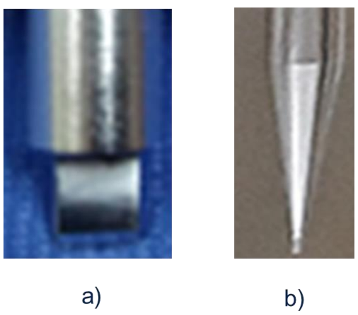


Fig. 2. Probe type used: a) wedge type, b) pin type.

### *1.1 Die Only*

In this experimental simulation with die only, crack was produced in a 3-point bending as shown in Fig. 3. The active side of the die is where the circuit metal traces are found. The active side is also considered the front side of the die. Table 1 and Table 2 show the different experimental legs conducted.

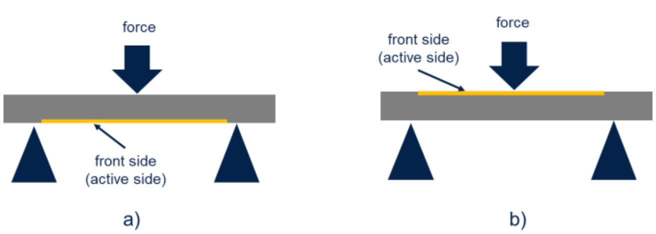


Fig. 3. Experimental setup with die only considering different orientations: a) die active side down, b) die active side up.

Table 1. Experimental Simulation Matrix for Die Only (Wedge Probe)

| Leg | Sample Type | Orientation | Loading Speed (mm/minute) | Probe Type |
|---|---|---|---|---|
| 1 | Die Only | Active side DOWN | 0.10 | Wedge |
| 2 | Die Only | Active side DOWN | 50 | Wedge |
| 3 | Die Only | Active side DOWN | 1500 | Wedge |
| 4 | Die Only | Active side UP | 0.10 | Wedge |
| 5 | Die Only | Active side UP | 50 | Wedge |
| 6 | Die Only | Active side UP | 1500 | Wedge |

Table 2. Experimental Simulation Matrix for Die Only (Pin Probe)

| Leg | Sample Type | Orientation | Loading Speed (mm/minute) | Probe Type |
|---|---|---|---|---|
| 7 | Die Only | Active side DOWN | 0.10 | Pin |
| 8 | Die Only | Active side DOWN | 50 | Pin |
| 9 | Die Only | Active side DOWN | 1500 | Pin |
| 10 | Die Only | Active side UP | 0.10 | Pin |
| 11 | Die Only | Active side UP | 50 | Pin |
| 12 | Die Only | Active side UP | 1500 | Pin |

### *1.2 Die Bonded on Substrate*

For the die bonded on substrate, the setup is shown in Fig. 4. Table 3 and Table 4 show the different legs performed to produce the intended die fracture when the die is already bonded on substrate.

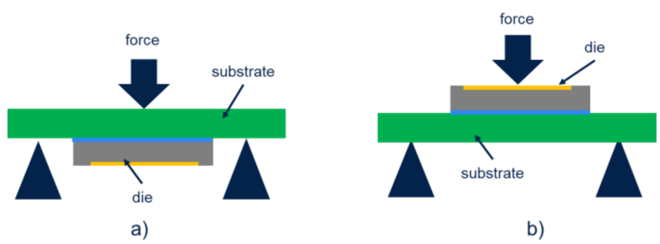


Fig. 4. Experimental setup with die bonded on substrate considering different orientations: a) die active side down, b) die active side up.

Table 3. Experimental Simulation Matrix for Die Bonded on Substrate (Wedge Probe)

| Leg | Sample Type | Orientation | Loading Speed (mm/minute) | Probe Type |
|---|---|---|---|---|
| 13 | Die on Substrate | Active side DOWN | 0.10 | Wedge |
| 14 | Die on Substrate | Active side DOWN | 50 | Wedge |
| 15 | Die on Substrate | Active side DOWN | 1500 | Wedge |
| 16 | Die on Substrate | Active side UP | 0.10 | Wedge |
| 17 | Die on Substrate | Active side UP | 50 | Wedge |
| 18 | Die on Substrate | Active side UP | 1500 | Wedge |

Table 4. Experimental Simulation Matrix for Die Bonded on Substrate (Pin Probe)

| Leg | Sample Type | Orientation | Loading Speed (mm/minute) | Probe Type |
|---|---|---|---|---|
| 19 | Die on Substrate | Active side DOWN | 0.10 | Pin |
| 20 | Die on Substrate | Active side DOWN | 50 | Pin |
| 21 | Die on Substrate | Active side DOWN | 1500 | Pin |
| 22 | Die on Substrate | Active side UP | 0.10 | Pin |
| 23 | Die on Substrate | Active side UP | 50 | Pin |
| 24 | Die on Substrate | Active side UP | 1500 | Pin |

### 1.3 Die in Molded Package

Shown in Fig. 5 is the experimental setup for the die in molded package. The different legs for die in molded package are indicated in Table 5.

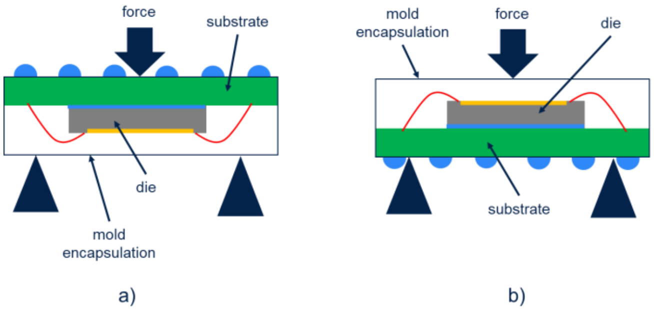


Fig. 5. Experimental setup with die in a molded package considering different orientations: a) die active side down, b) die active side up.

Table 5. Experimental Simulation Matrix for Die in Molded Package

| Leg | Sample Type | Orientation | Loading Speed (mm/minute) | Probe Type |
|---|---|---|---|---|
| 25 | Die in Molded Package | Active side DOWN | 0.10 | Wedge |
| 26 | Die in Molded Package | Active side DOWN | 50 | Wedge |
| 27 | Die in Molded Package | Active side UP | 0.10 | Wedge |
| 28 | Die in Molded Package | Active side UP | 50 | Wedge |

## 4.0 RESULTS AND DISCUSSION

Analysis of results from different experimental legs is discussed in this section. This covers the different SEM and optical images of cracks produced from 24 experimental legs.

### 4.1 Fractography Results for Die Only

For die only, results from the first 12 legs were analyzed. Fig. 6 shows the SEM images in which the crack was produced by bending the die with active side down and using wedge probe (legs 1-3). Analysis of the fracture surface indicates that the tensile side is indeed the active side of the die. It is where a smoother crack surface is observed. At the compression side, some hackle marks could be seen. The surface is rougher with corrugated instabilities. This agrees with the bending orientation applied. With die active side down, tensile stress is induced at the active side. Fracture surfaces appear similar for the different loading rates.

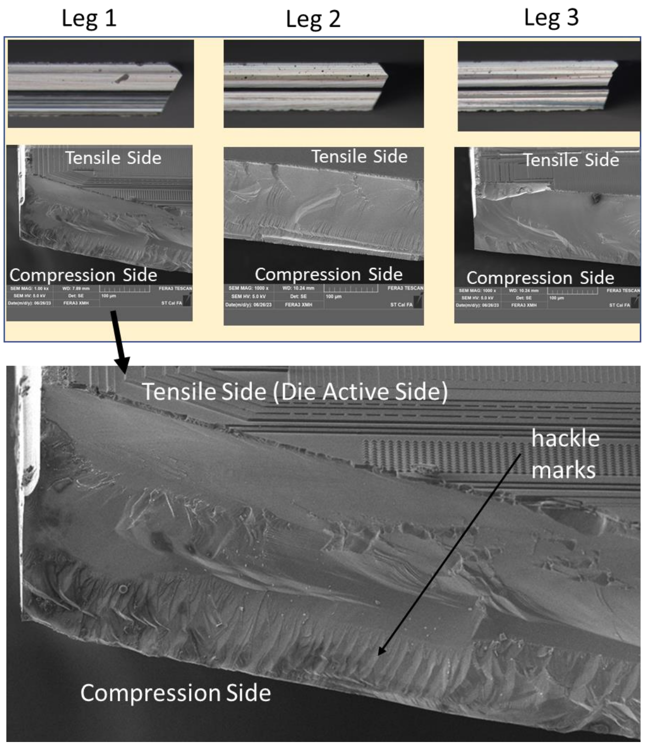


Fig. 6. Optical and SEM images for die only with wedge probe (bending with die active side down).

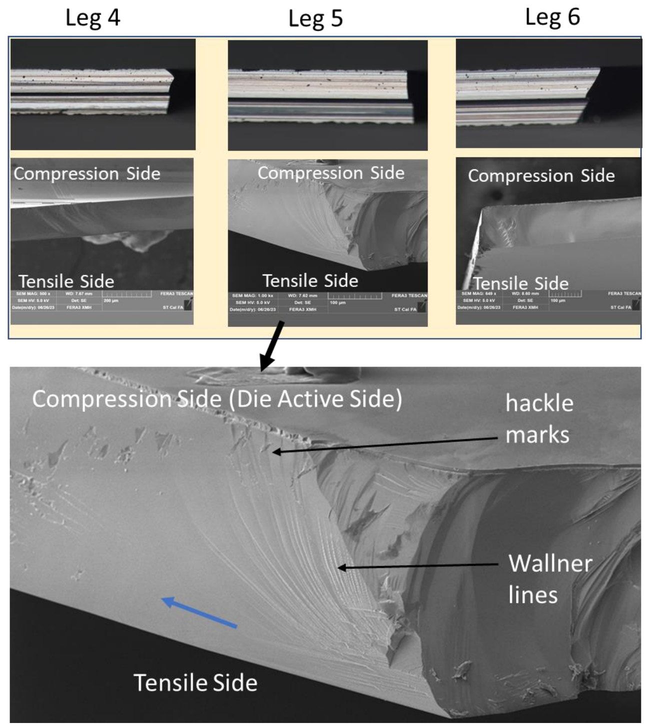


Fig. 7. Optical and SEM images for die only with wedge probe (bending with die active side up).

For cracks produced in bending with the die active side up shown in Fig. 7 (leg 4-6), the tensile stress is now at the back side of the die. The active side is now in compression. Consistent with previous observation, the compression side is still showing hackle marks and with rougher surface than the tensile side. Wallner lines could be seen and indicates crack propagation from right to left.

For the pin probe with die active side down during bending (legs 7-9), the tensile side shows similar identifying crack surface topography as shown in Fig. 8. It is consistent with the expectation of having the die active side in tensile stress. In Fig. 9, the location of the tensile stress also changes to the die back side when bending is done with die active side up (legs 10-12).

As observed on cracks produced by bending, the location of the tensile side shows similar topography. The compression side is always rougher and mostly with hackle marks. However, the type of probe used, and the loading rates could not be easily deduced from analysis of the crack surface. No significant difference could be observed from SEM images.

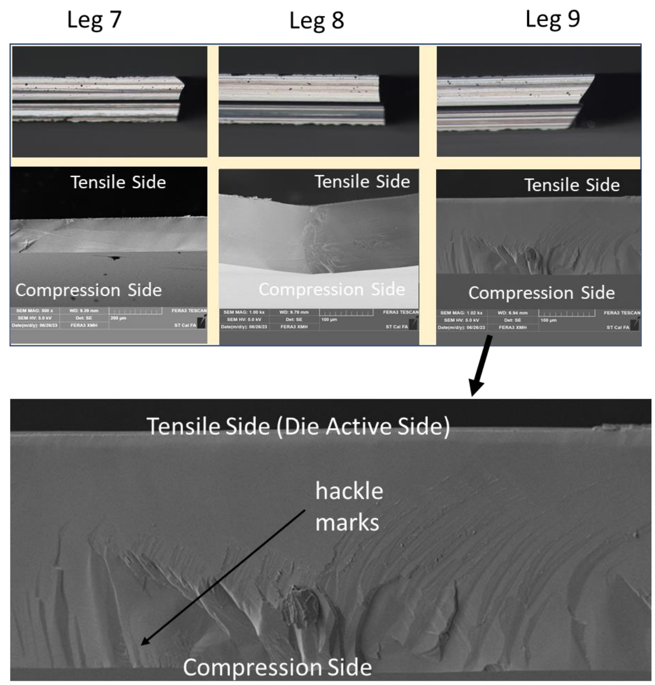


Fig. 8. Optical and SEM images for die only with pin probe (bending with die active side down).

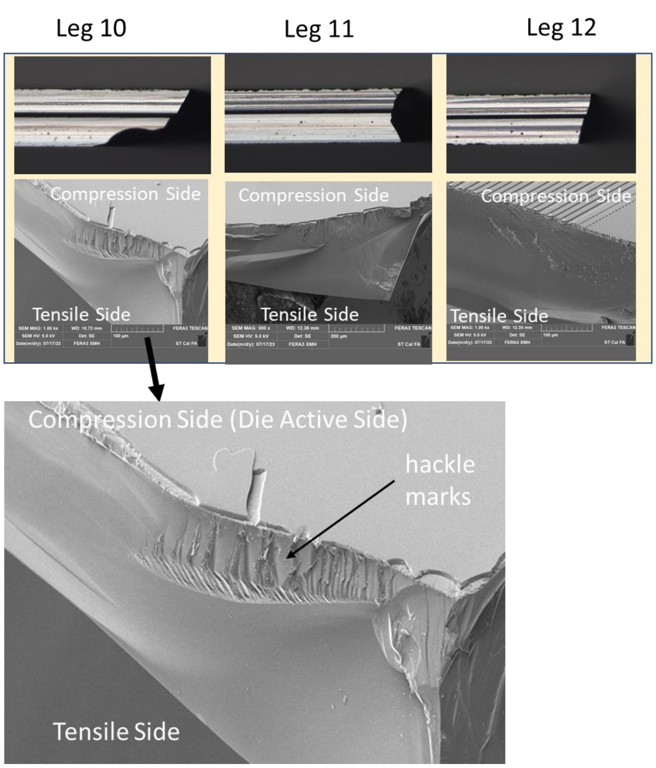


Fig. 9. Optical and SEM images for die only with pin probe (bending with die active side up).

### *4.2 Fractography Results for Die Bonded on Substrate*

For die bonded on substrate, surface topographic features that could be observed are consistent with the location of the tensile side as well as the compression side. Fig. 10 shows the surface SEM images of cracks generated by bending with the active side down with wedge probe (legs 13-15). In this fracturing condition, the active side of the die is subjected to tensile stress. At the tensile side of the die, the crack origin could also be recognized based on the crack surface topography. The back side of the die facing the substrate is now in compression. With the die active side up (legs 16-18), a change in location of tensile stress and crack surface topography could be observed as shown in Fig. 11.

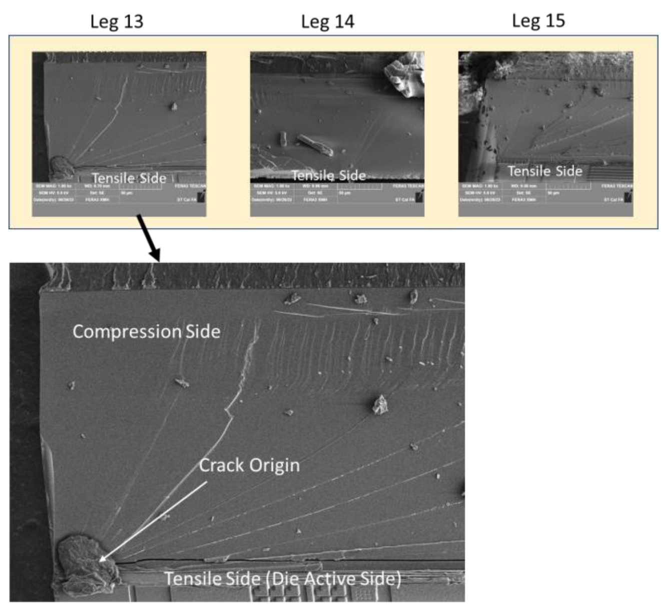


Fig. 10. SEM images for die bonded on substrate (wedge probe and bending with active side down).

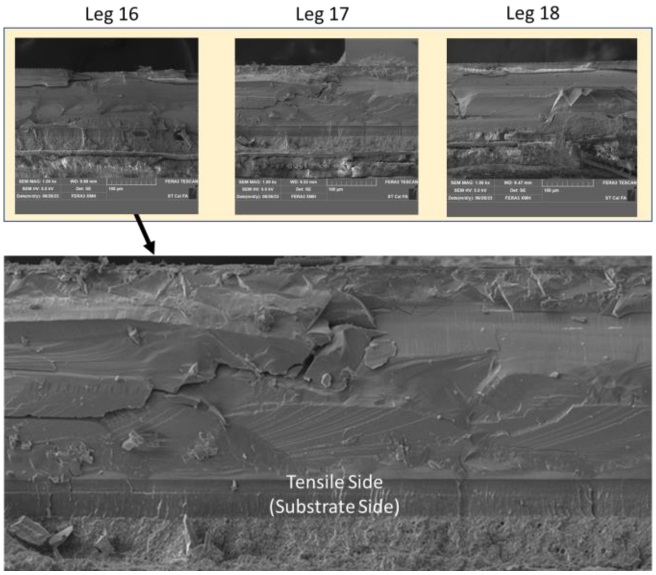


Fig. 11. SEM images for die bonded on substrate (wedge probe and bending with active side up).

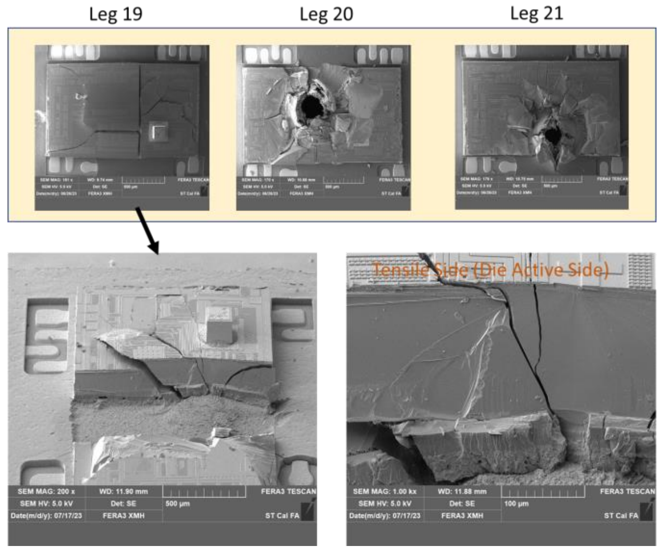


Fig. 12. SEM images for die bonded on substrate (pin probe and bending with active side down).

Analysis of cracks produced from bending of die on substrate sample having die active side down orientation with pin probe (leg 19-20), similar tensile side cack surface distinguishing features could be observed (Fig. 12). In this bending condition, the tensile side is the die active side. The crack opening and propagation could be seen from the active side going towards the die back side. At higher loading rates (legs 20-21), the damage is more severe but tends to be more localized at the pin probe contact region. For bending with active side up (legs 22-24), only top view SEM images were taken as the die seems to be heavily fractured into small pieces as shown in Fig. 13. A comparison of the whole die crack optical images is shown in Fig. 14. This shows the difference in crack at different loading rates and probe types.

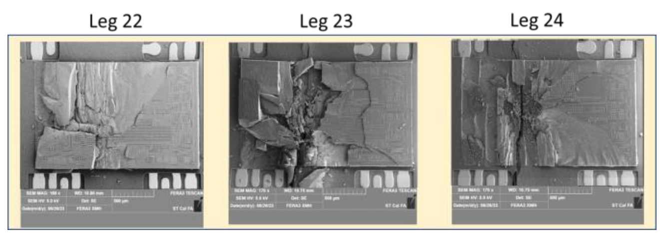


Fig. 13. SEM images for die bonded on substrate (pin probe and bending with active side up).

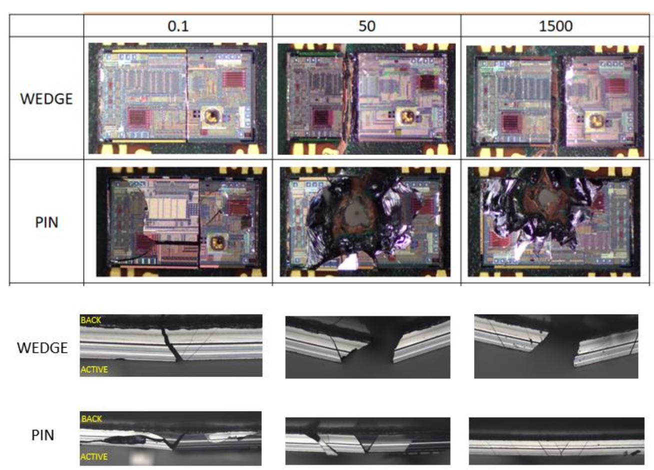


Fig. 14 Optical images of cracks with bending (active side down) at different loading rates and probe types.

### *4.3 Fractography Results for Die in Molded Package*

The results for the die in molded package, bending with active side down (legs 25-26) are shown in Fig. 15. The active side of the die (tensile side) shows smoother crack surface consistent with observations on cracks produced with other sample types and different fracturing conditions. As the bending orientation is reversed (legs 27-28), the location of the tensile side changes to the die back side or the substrate side as shown in Fig. 16.

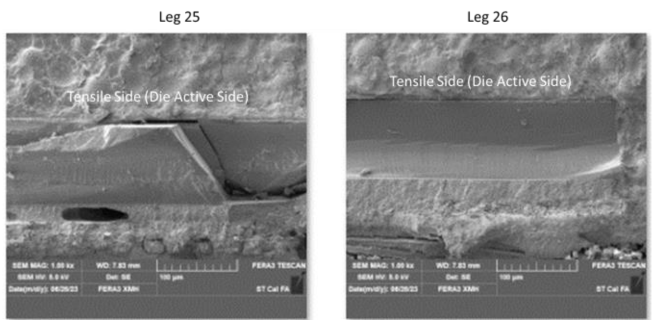


Fig. 15. SEM images for die in molded package (wedge probe and bending with active side down).

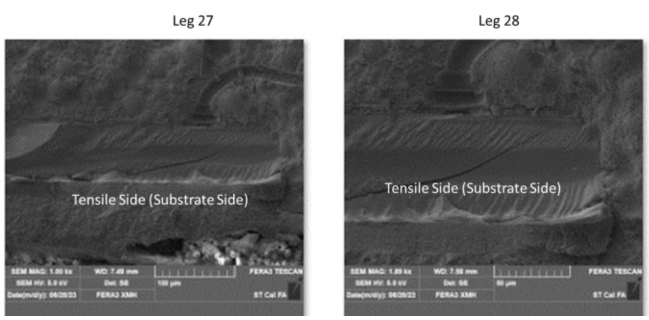


Fig. 16. SEM images for die in molded package (wedge probe and bending with active side up).

## 5.0 CONCLUSION

The study has demonstrated the usefulness of fractography in die crack failure analysis. A more comprehensive reference for fractographic analysis of die crack was also established to make future analysis easier and more accurate. With the SEM images generated from bending simulations showing different crack surface topography signatures, determining the breakage mechanism and root cause would become faster.

## 6.0 RECOMMENDATIONS

Fractography is recommended for effective and efficient determination of die crack root cause.

## 7.0 ACKNOWLEDGMENT

The authors would like to thank the STMicroelectronics management for the support in this study. The support of engineers and technicians involved in the experimental sample preparation are also acknowledged.

## 8.0 REFERENCES

1. T. Ono, R.A. Allaire, "Fracture Analysis, a Basic Tool to Solve Breakage Issues," ***CORNING Technical Information Paper TIP201***, 2021.

2. M. R. Marks, "Fracture Analysis of Silicon Die and Ceramic Package Using Fractography," ***International Journal of Microcircuits and Electronic Packaging***, 1993.

3. L. Zhao, A. Maynadier, D. Nelias, "Stiffness and fracture analysis of photovoltaic grade silicon plates." ***International Journal of Solids and Structures***, 2016.

## 9.0 ABOUT THE AUTHORS

**Dexter Delos C. Santos** is a Failure Analysis Engineer at the Quality and Reliability Department of ST Microelectronics, Inc - Division. He received his Master of Science in Mathematics from the Pamantasan ng Cabuyao and Bachelor of Science in Electronics and Communication Engineering from the Technological Institute of the Philippines - Manila. He has 10 years of experience in failure analysis in the semiconductor industry. He is also a Certified Six Sigma Green Belt.

**Jefferson S. Talledo** is a Sr. Staff Engineer with the New Product Development and Introduction, STMicroelectronics. He holds 29 US patents and has more than 20 years of R&D and design engineering experience in semiconductor material handling automation equipment and test hardware development, IC package development and materials characterization. He has worked with US multinational companies, Intel Corporation and Delta Design/ Cohu, prior to joining STMicroelectronics. He is also a Certified DFSS Design for Six Sigma Green Belt.