# Advanced Outlier Die Control Technology in Fan-Out Panel Level Packaging Using Feedforward Lithography

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***Abstract*— The growing demand for heterogeneous integration is driven by the 5G market that includes smartphones, data centers, servers, HPC, AI and IoT applications. Next-generation packaging technologies require tighter overlay to accommodate a larger package size with finer pitch chip interconnects on large format flexible panels.**

**Fan-out panel level packaging (FOPLP) is one of the technologies that is able to achieve market requirements, but also faces several signification processes challenges. One critical challenge for FOPLP is die placement error, which is a result of the reconstitution process. Die placement error can cause high overlay error, which induces low overlay yield. To address this situation, site by site correction exposure with feedforward lithography is proposed. Site by site correction exposure can overcome the die placement error to achieve an acceptable overlay yield, and feedforward lithography is used to improve the throughput when using site by site correction exposure. An issue was observed when using feedforward site by site correction method: when one or more reconstituted dies suffered large displacement error, these large error dies affect the correctable accuracy of the site and induce poor overlay to all the dies in the site. To address this issue, which could induce poor overlay, advanced outlier control technology is proposed. Advanced outlier control technology is used for identifying the large error dies and processing these large error dies to prevent the situation.**

**In this paper, we demonstrated advanced outlier control technology with feedforward lithography on a selected test vehicle, which is a 510 mm x 515 mm panel. 400 simulation dies were built on this panel and part of the dies were designed with a large displacement error. The panel was processed using advanced outlier control technology with feedforward lithography in the demonstration. This demonstration showed how these two technologies integrated together and how this integration strategy worked for the FOPLP process. We also review and discuss the results for how this integration technology can maintain yield and throughput under such challenging conditions.**

**Keyword: 5G, HPC, AI, IoT, Heterogeneous, integration, fan out, panel, panel level packaging, FOPLP, overlay, yield, displacement, die error, outlier, feedforward, lithography.**

## I. INTRODUCTION

Fan-out panel level packaging requires sawing the die, taking the die from the original substrate, and reconstituting the die on a panel. During the reconstitution process, die error will be generated by pick and place, molding, and other processes. For the reconstituted dies with significant error, die by die exposure lithography is proposed to address the serious die error to ensure good overlay yield. In the following content, the die with large displacement error is named as "outlier" or "outlier die".

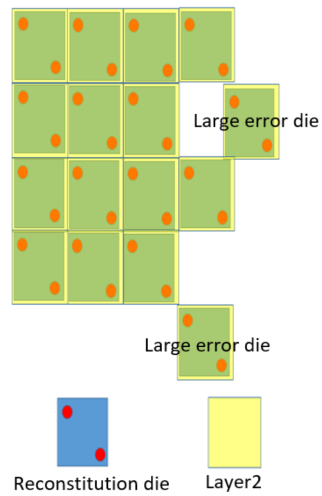


**Fig 1**. This figure shows reconstitution dies on a substrate, two dies with large die error are observed.

Die by die exposure lithography takes more than double process time or above, which compared to regular global alignment exposure lithography. To reduce the process time and ensure the yield at the same time, feedforward lithography is proposed to achieve all of the requirements. An offline metrology tool is used to measure the dies' location before running an exposure process, and will feedforward the die location information to a lithography system to perform die by die exposure. Fig 2 shows the working scenario of feedforward lithography. Even feedforward lithography can significantly reduce the die by die exposure process time, but higher throughput is required, then feedforward site by site lithography is proposed. Fig 3 shows an example of the comparison between die by die exposure and site by site exposure. In this example, the site by site exposure is about four times faster than die by die exposure. With a full size 510mm x 515mm panel, the site by site lithography can perform up to 10 times faster than die by die exposure.

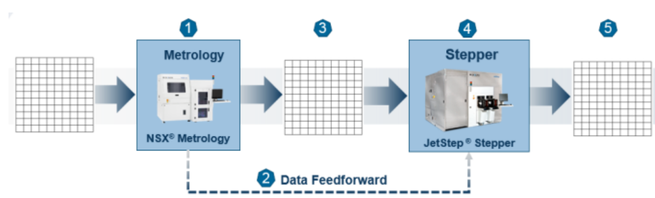


**Fig 2**. Feedforward lithography working scenario. (1) an offline metrology tool measures the die location data, (2)

Metrology data feeds to the stepper, (3) the substrate run the following processes, (4) stepper uses feedforwarded data to perform site by site or die by die exposure. (5) Substrate completed feedforward lithography and release to following processes.

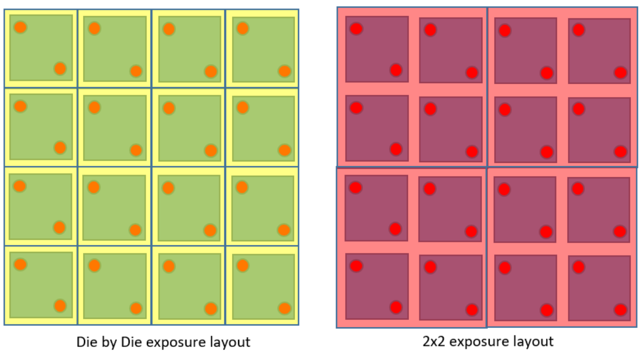


**Fig 3**. Left figure shows die by die exposure layout on a panel, it requires 16 shots to complete a panel. Right figure shows 2x2 site by site exposure layout on a panel, it requires 4 shots to complete a panel, which is 4 times faster than die by die exposure.

A serious issue is observed when using feedforward site by site lithography in a production line. When one or above outlier dies in a site, the correctable values could be calculated to an improper number, and this can induce poor overlay on all the dies of the site. Fig 4 shows a typical example of this issue. Three outlier dies are observed in a substrate, then this panel runs with 2x2 site by site exposure lithography, it results in bad overlay for three sites which had outliers, meaning 75% yield loss because of 18.75% bad dies in a substrate.

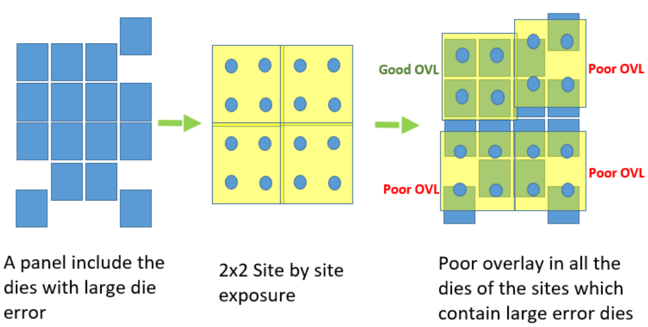


**Fig 4.** A panel with outlier dies has poor overlay when using site by site exposure.

In this study, advanced outlier control technology is proposed to address the poor overlay issue that is caused by outliers when using site by site exposure. Feedforward lithography will also be used and integrated with advanced outlier control technology together in the demonstration. With these two features, we can ensure throughput and yield at the same time.

## II. Experiment Details

### *A. Test Vehicle*

In order to demonstrate advanced outlier control technology in FOPLP using feedforward lithography, a suitable test vehicle is defined. A 510mm x 515mm panel is selected as the test vehicle, which is the most common substrate size in fan out panel level packaging.

To simulate random outliers in a panel, 400 dies are built in a 510mm x 515mm panel, 4 x 4 dies per cluster, 5 x 5 clusters per panel. The first three rows are created included outlier dies purposely. The details layout refers to Fig 4 and Fig 5. Without advanced outlier control technology, we expect all dies in the first three rows to suffer poor overlay when using site by site exposure.

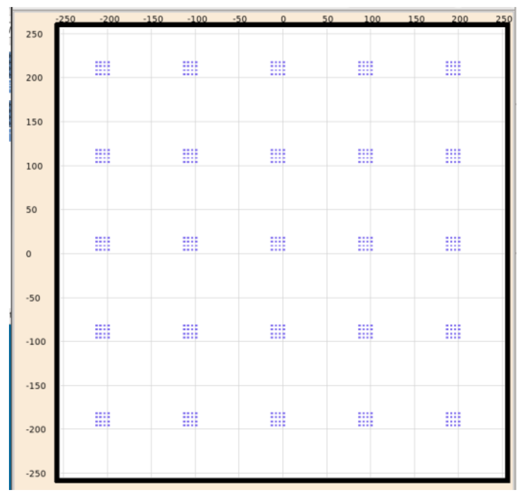


**Fig 4.** Die layout of the 510mm x 515mm test panel in this study. 4x4 dies in a cluster, 5x5 clusters in a panel. First three rows are built with outlier dies purposely, the last two rows are built with dies at nominal position.

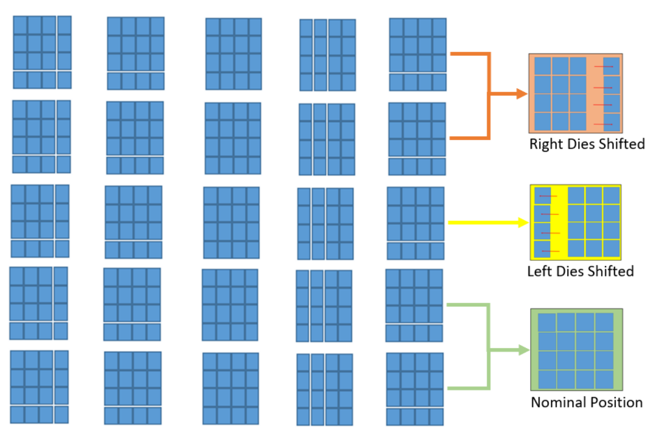


**Fig 5**. Designed outlier's layout on the test panel. Top-right shows the first two rows' die layout; the right dies are shifted 100µm to right direction in X axis from their nominal position. Middle-right fig shows the third rows' die layout; the left dies are shifted 100µm to left direction in X axis from their nominal position. Bottom-right figure shows nominal die layout for the rest of two rows of the test panel.

*B. Process Flow*

A panel with outlier dies which described in above is loaded into an offline metrology tool to collect the die location, errors and necessary information. An advanced outlier algorithm will analyze the metrology data, and identify the outlier dies based on the customized setting. In this study, any die over 20µm die error will be identified as an outlier. Outliers are marked and their information are discarded during the correctable calculation. The processed data is feedforwarded to the stepper, and used for perform 2 x 2 site by site exposure process. Fig 6 shows the working scenario of feedforward lithography and advanced outlier technology in a fan out panel level package process. Fig 7 shows the expected overlay results with / without advanced outlier technology.

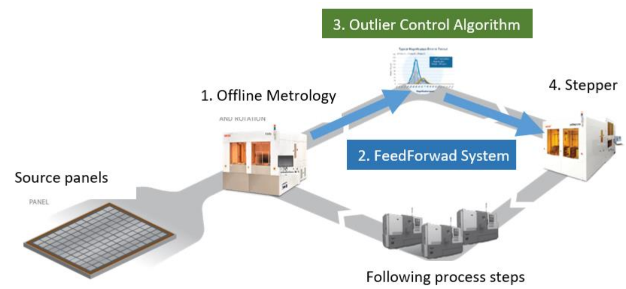


**Fig 6.** Feedforward lithography and advanced outlier technology integration and working in FOPLP process. ① A panel is processed by an offline metrology tool. ② The metrology data is fed forward to outlier control algorithm. ③ Outlier control algorithm to identify the outliers. ④ The processed metrology data is fed forward to the lithography tool for site by site or die by die exposure process.

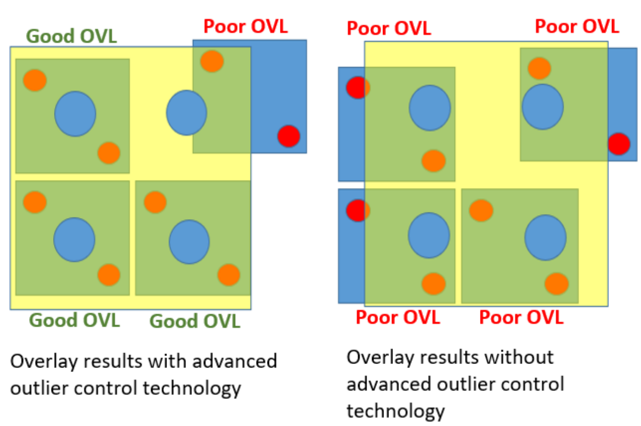


**Fig 7.** Expected overlay results with / without Advanced outlier control. Left figure shows the good overlay results which exclude outliers when using outlier technology. Right figure shows that all the dies suffer poor overlay when outlier technology is not used.

*C. Lithography Tool*

The lithography system employed in this study was an Onto Innovation JetStep® 3500 System. This system supports up to 720 mm x 600 mm glass panels or up to 510mm x 515mm CCL substrate based on the process requirement. The system is a 2:1 magnification optical system, which enable up to 59mm x 59mm exposure field. The optic system can achieve 2µm resolution with ± 400ppm magnification compensation, which is required in a fan out process to correct the die errors. In this study, the tool supports the 510 mm x 515 mm glass panel that is used.

The system utilizes a pattern recognition system which allows the user to train a unique pattern within the field of view as the alignment site. Moreover, this alignment system can be used to measure the X, Y, position of patterns across the panel, and this feature enables local die by die exposure and site by site exposure capability. The system also supports site by site exposure by using feedforward metrology data, which is what this study needed.

*D. Offline Metrology tool*

In this study, an Onto Innovation Firefly® AOI system was used to assess the die placement error and die location. This tool supports up to a 510mm x 515mm substrate. With using the pattern recognition system of the tool, the die location and error data will be collected and automatically sent to the outlier algorithm and stepper via feedforward system.

*E. Experiment Results*

Fig 8 and Fig 9 show the die error histogram of the metrology data from the offline metrology tool. Fig 8 shows the dx distribution of the dies on the test panel. The maximum X deviation was around +100µm and the minimum X deviation was around -100µm, which matched the die errors that we designed on this panel. Fig 9 shows the dy distribution of the dies on the test panel. The deviation range is from -2µm to +4µm, which is a normal deviation and as expectation.

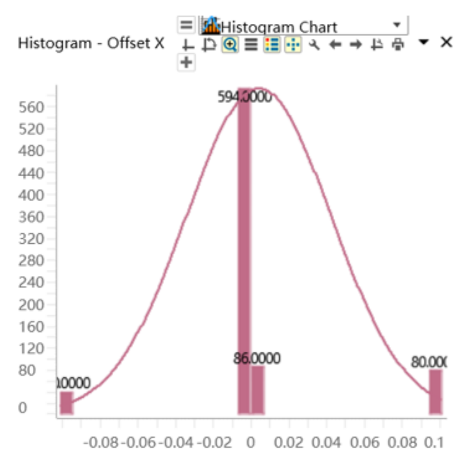


**Fig 8.** Deviation X histogram. Die error distribution in X axis of panel, the dx range is from +100µm to -100µm, which matched the designed die error of the test panel.

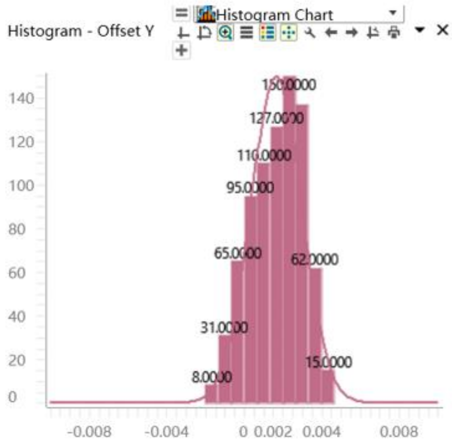


**Fig 9**. Deviation Y histogram. Die error distribution in Y axis of the panel. The Dy range is from +4µm to -2µm. A normal die error is observed, which matched as expectation.

Fig 10 and Fig 11 show heat maps of the die error in X axis and Y axis on the test panel, which was processed metrology data from the outlier algorithm. On Fig 10, the right dies of first two rows are marked in red color, which means the die error was around +100µm. The left dies of the third row are marked in blue color, which means the die error was around -100µm. Fig 11 shows no peak error in the Y axis is observed. In the study, any die with over 20µm error will be marked as an outlier and discarded during site by site exposure to ensure good overlay for the rest of the dies.

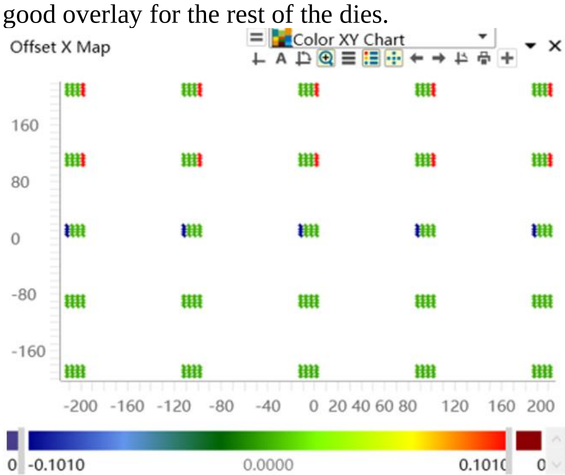


**Fig 10.** Heat map of die error in X axis. First two rows' right dies have +100µm error. Third row left die has -100µm error, which matched the expectation.

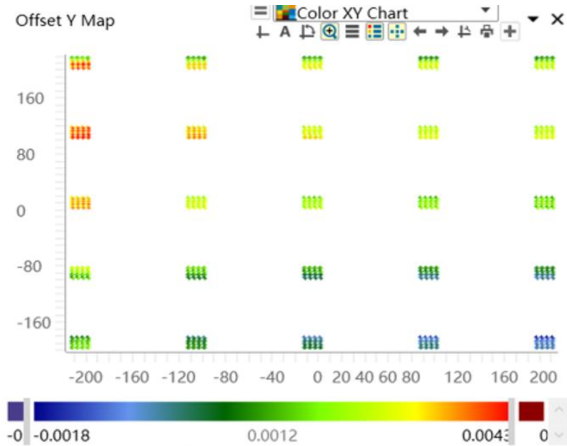


**Fig 11.** Heat map of die error in Y axis. All the dies' error within -2µm to -4µm, no peak die error is observed in Y axis.

Fig 12 and Fig 13 show the prediction residue X and Y values after correcting the die error with using 2 x 2 site by site exposure. The site by site exposure is run using the processed metrology data that was fed forward by the outlier control algorithm. Fig 12 shows the residue value of most points are within ±3µm. The residue values for the rest of the points are distributed out of +100µm and -100µm. Fig 13 shows all the data points have a very small residue value in the Y axis, which is within ±2µm. Fig 14 shows the final prediction overlay yield is 85%, which is using the 2x2 site by site exposure and the overlay threshold is set to ±15µm. The prediction residues and yield number are the features of the feedforward system.

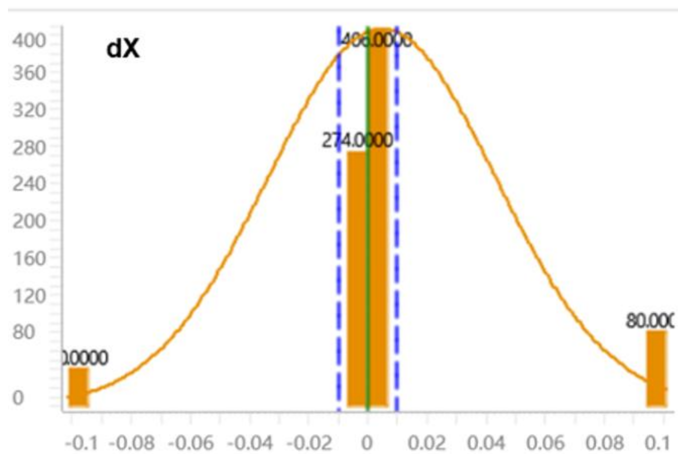


**Fig 12.** Prediction residues in X. Two groups are observed out of 100µm, which are from the designed outliers, the rest of the data points are within ±3µm.

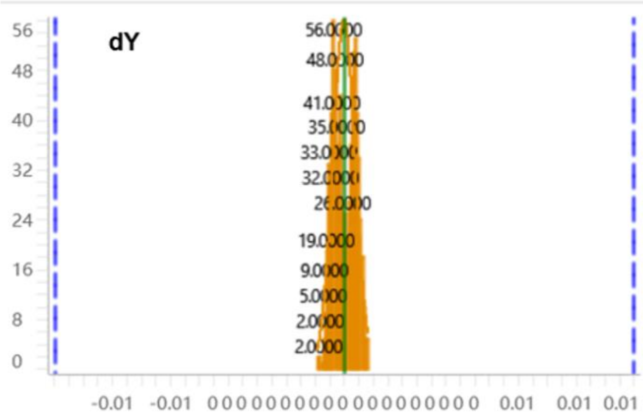


**Fig 13.** Prediction residues in Y. All the prediction residues are within ±2µm, which matches expectation.

| Ef Num | Yield | Offset Threshold | Outlier Shot Num | Outlier Point Num |
|---|---|---|---|---|
| min | | min | min | |
| 25.0000 | 0.8500 | 0.0150 | 0.0000 | 120.0000 |

**Fig 14.** Prediction yield of the test panel is 85%. Yield prediction is one of the features of the feedforward system that used in this study. The overlay threshold is set to ±15 µm.

After all the processes (feedforward processed metrology data, site by site exposure and developing), the test panel actual overlay results are measured by an offline overlay metrology tool. The overlay metrology tool used here is the Onto Innovation Firefly® system. The actual overlay results are shown in Fig 15 and Table 1. Fig 15 shows the overlay heat map of the test panel where a dot indicates a die. A blue dot indicates the overlay of the die is within specification; the overlay threshold is set to ±15µm. A red dot indicates the overlay of the die is out of specification, which means the overlay error out of ±15µm. The heat map is a perfect match to the predicted and expected results. Table 1 is the good dies' overlay statistics in the test panel; the dx and dy range are less than 5µm, and all numbers are within overlay threshold, which is ±15µm.

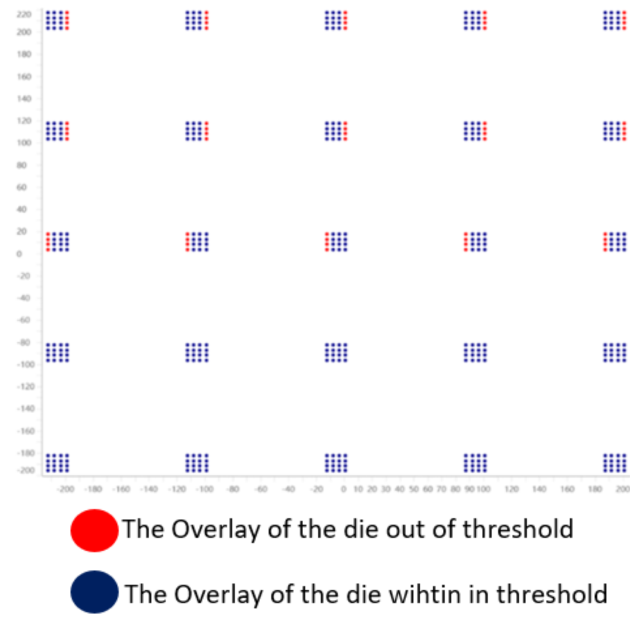


**Fig 15:** Heat map of actual overlay results of the test panel. The heat map is created by offline metrology tool. A blue dot indicates the die overlay within overlay threshold, a red dot indicates the die overlay out of overlay threshold. The distribution of good / bad overlay dies is matched the design layout and expectation with outlier control enabled.

| | Average | Max | Min | Range | Std. Dev |
|---|---|---|---|---|---|
| dx | 1.04 | 2.20 | -0.31 | 2.50 | 0.60 |
| dy | 0.25 | 1.40 | -0.75 | 2.15 | 0.34 |

**Table 1.** The statistics of good dies of the test panel. All the numbers are within ±2.5µm, and within overlay threshold, which is ±15µm.

## III. ANALYSIS AND DISCUSSION

### *A. Outliers Control Technology Discussion*

In the metrology data, the outliers show large die error compared to other nominal dies. The outlier control algorithm correctly to identify all of the outliers with a customized setting of die error over 20µm, the outliers are marked and discarded in the following exposure processes (this is a customized option), the rest of the dies maintains good overlay, based on the demonstration, outlier control technology works as expectation. Fig 16 shows the layout of designed outliers, the outliers map which identified by outlier control algorithm and the actual overlay results is a perfect match as designed and expected.

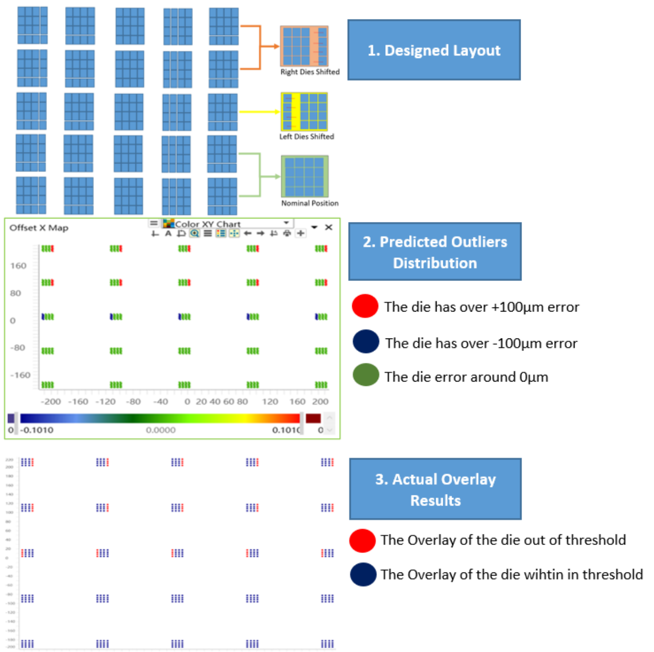


**Fig 16.** The comparison of designed, predicted and actual outlier distribution. A dot indicates a die. Top figure is the designed outlier distribution, middle figure is the predicted outlier's distribution during outliers control processing, and bottom figure is actual overlay results. The outliers are correct identified and discarded during processing, so the final actual overlay results can be matched expectation.

### *B. Discussion of Yield and Throughput with Feedforward Lithography with Outlier Control Technology*

In this discussion, the process condition of the test panel and the stepper system in this study are used for the yield and throughput analysis. Table 2 is a comparison table showing yield and throughput with various conditions. With regular die by die lithography, the yield is 100% but the throughput is only three pieces per hour. With site by site lithography, the throughput is increased to 32 pieces per hour but the yield drops to 25%. With outlier control technology and feedforward lithography, the throughput is increased to 62.7 pieces per hour and the yield is maintained at 85%. Of course, the number could be different when using different processes , but with using feedforward lithography and outlier control technology, a significant improvement in yield and throughput still can be expected.

| | Features Used | | | | Shot number (ea) | Yield (%) | Throughput (pcs/hr) | Throughput Improved (%) |
|---|---|---|---|---|---|---|---|---|
| | Die by Die | Site by Site | Outlier control | Feedforward | | | | |
| Condition1 | v | | | | 400 | 100 | 3 | na |
| Condition2 | | v | | | 25 | 40 | 32 | 966.67% |
| Condition3 | | v | v | | 25 | 85 | 32 | 966.67% |
| Condition4 | | v | v | v | 25 | 85 | 62.6 | 1986.96% |

**Table 2.** Yield and throughput comparison table.

## IV. CONCLUSION

This study proves that outlier control technology can accurately identify the outliers in a panel and is able to process the metrology data based on customized settings. The processed metrology data can be sent to a lithography tool for site by site exposure via a feedforward system. All of these technologies can be integrated together and work well in a FOPLP process line. Based on the demonstration, outlier control technology improves 45% yield, when compared with regular exposure, the throughput improved 1986%, when compared with local die by die exposure. Outlier control technology provides a reliable solution to ensure quality for outlier challenges in the fan-out process and when integrated with a feedforward system, can enhance the throughput as well.

## ACKNOWLEDGEMENT

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