

Using Outlier Control Technology with Feedforward Lithography to Address Die Shifting and Pattern Distortion Challenges in Fan-Out Panel-Level Packaging

John Chang¹, Jian Lu², Timothy Chang³, Keith Best⁴

Onto Innovation Inc.
Massachusetts 01887, USA
978.253.6200

¹John.Chang@ontoinnovation.com, ²Jian.Lu@ontoinnovation.com, ³Timothy.Chang@ontoinnovation.com,

⁴Keith.Best@ontoinnovation.com

Abstract

Fan-out panel-level packaging (FOPLP) is a packaging technology able to meet the requirements of heterogeneous integration while reducing costs for manufacturers. However, FOPLP faces several significant process challenges. One of these is die shifting, which is a result of the reconstitution process in die-first FOPLP. Pattern distortion is another challenge, one caused by panel deformation in redistribution layer-first FOPLP. These issues cause die and patterns to move away from their nominal positions. If die shifting and pattern distortion are not well addressed during the lithography process, they will result in overlay errors and low overlay yield. Outlier control technology with feedforward lithography is proposed to address these die-shifting and pattern-distortion challenges. Outlier control is based on site-by-site corrections and uses an algorithm to recognize outliers in the substrate, eliminate their negative impacts and optimize overlay corrections to ensure good overlay yield. Additionally, feedforward lithography can further reduce the negative impact to throughput caused by the time lost addressing site-by-site corrections. In this study, we will discuss how die shifting and pattern distortion result in yield and throughput challenges for FOPLP. Then we will demonstrate outlier control technology with feedforward lithography on a test vehicle and how the integration of these two technologies addresses the challenges. We will also review the results of the demonstration and discuss the advantages of this strategy.

Key words

5G, HPC, AI, IoT, Heterogeneous Integration (HI), Advanced IC Substrate (AICS), Advanced Packaging (AP), OSAT, Fan-out Panel-level Packaging (FOPLP), Overlay, Die Shifting, Pattern Distortion

I. Introduction

Die-first fan-out panel-level packaging (FOPLP) requires sawing the die, taking the die from the original substrate and reconstituting the die on a panel. During the reconstitution process, die errors can be generated by several processes, including pick and place and molding (Fig1). Redistribution layer (RDL)-first FOPLP has a similar problem; the pattern can be distorted by high stress and high temperature processes, such as laminating and molding. If the die error or pattern distortion is not well addressed during the lithography process, then this situation will lead to large overlay errors and poor overlay yield in the end. To address the reconstituted die errors, site-by-site (SBS) correction lithography is proposed instead of enhanced global alignment (EGA) correction lithography.

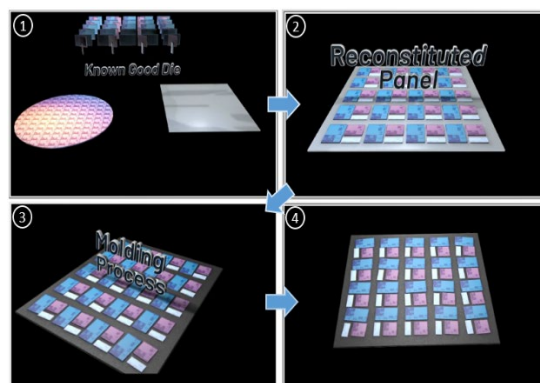


Figure 1. Die errors generated during fan-out substrate build-up. ① The KGD (known good die) are taken from original wafers. ② The KGD are placed by a robot onto a panel substrate. ③ The compressional molding process introduces die placement errors. ④ All of the processes lead to significant die errors in panel substrates.

Site-by-site (SBS) correction lithography is used to address die-shifting issues while maintaining a reasonable throughput in FOPLP. A site can contain multiple dies, such as 2x2, 3x3, 4x4 or more; this is dependent on die errors, magnitude, process specification and more. With more dies in a site, throughput can be increased, but the overlay error will become worse due to the need to correct various die errors in the site. Achieving a good balance between throughput and yield is a significant challenge.

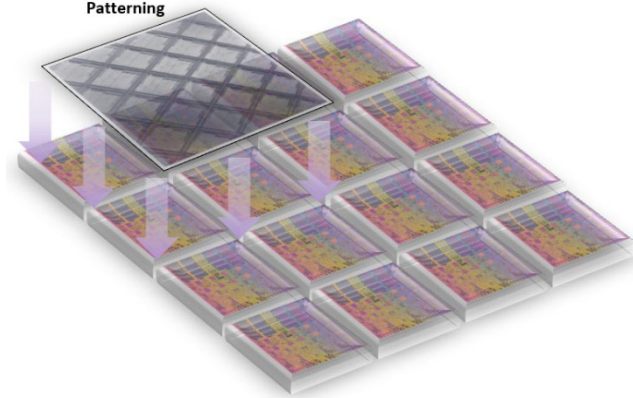


Fig 2. Exposing 2x2 dies in a single shot. In FOPLP, site-by-site correction is used to address die-shifting issues and maintain a reasonable throughput.

However, a serious challenge occurs when using site-by-site correction: outliers. An outlier is identified as a die with a large error or that demonstrates a large shift away from the nominal position when compared to a regular die error in the panel or process (Fig 3). When a site contains one or more outliers, site corrections may be improperly calculated; if those calculations are used during exposure, they may lead to large overlay errors (Fig 4).

Fig 3. Outlier dies in a FOPLP substrate. In this figure, two dies with significant shifts from nominal positions are observed. These dies are identified as outliers in this study.

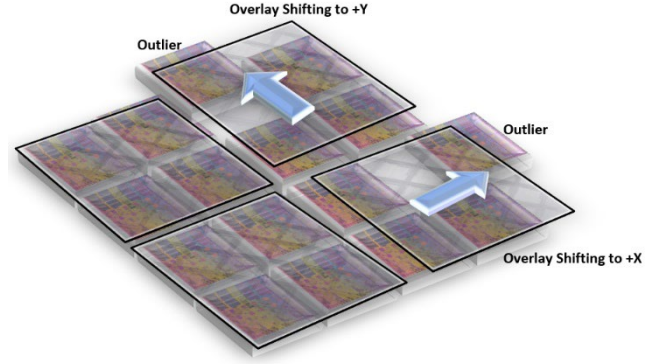
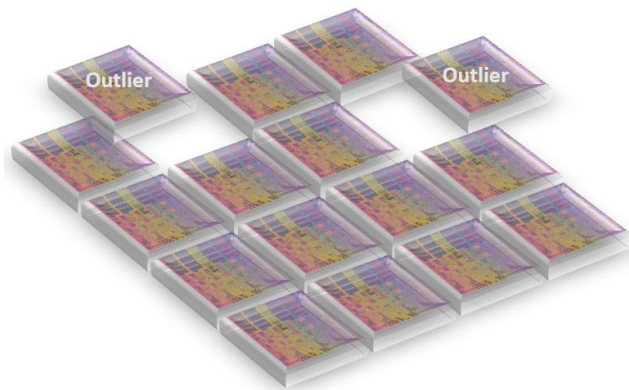


Fig 4. Outliers lead to large overlay errors.

Feedforward lithography is used to improve site-by-site correction lithography. To perform site-by-site corrections, the system needs to measure die or site positions on a panel and then generate the corresponding site corrections. This is a time-consuming process. Feedforward lithography uses an offline metrology tool to measure the position of each die before the process reaches the lithography step; software then generates corresponding site corrections based on these measurements and feeds the corrections forward to the stepper for use during exposing. This eliminates stepper metrology time and increases throughput.

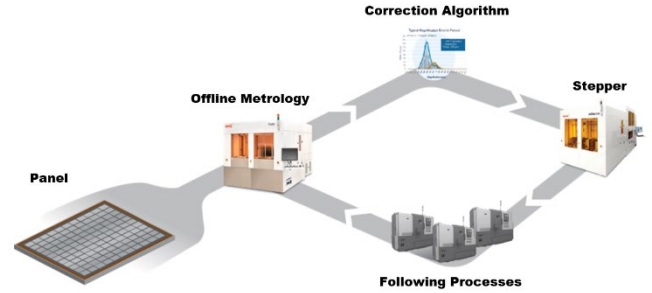


Fig 5. Feedforward lithography scenario. ① An offline metrology tool measures die location data. ② A correction algorithm then uses the metrology data to calculate site corrections. ③ The site corrections are feedforwarded to the stepper to complete site-by-site correction during exposure. ④ The panel moves to other processes to complete the layer.

In this study, outlier control technology is proposed to address the overlay challenge caused by outliers when using site-by-site exposure. Feedforward lithography will also be used and integrated with outlier control technology in the study to demonstrate increased throughput. Using these two technologies, the overlay challenge posed by outliers to FOPLP can be addressed to ensure good overlay and increased throughput during the lithography process.

II. Experiment Details

A. Test Vehicle

To demonstrate outlier control technology in FOPLP using feedforward lithography, a suitable test vehicle was defined. A 510mm x 515mm panel was selected as the test vehicle, which is the most common substrate size in FOPLP; 400 dies were built on a 510mm x 515mm panel, 4x4 dies per cluster and 5x5 clusters per panel. The first three rows were designed to include outliers with errors; these rows made up the experimental group. The last two rows have dies at the nominal position; these rows made up the control group. The detailed layout of the test vehicle is shown in Fig 6 and Fig 7.

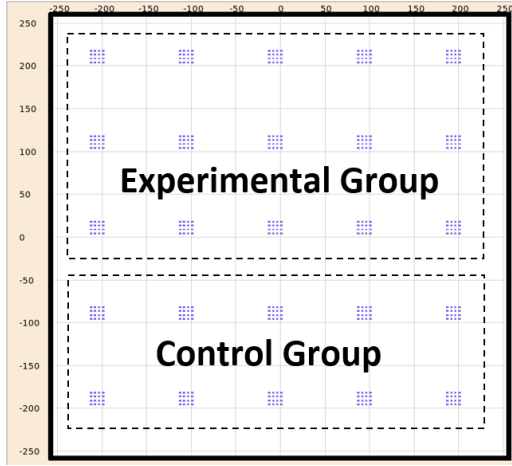


Fig 6. Panel layout of the 510mm x 515mm test vehicle in this study, 4x4 dies in a cluster and 5x5 clusters in a panel. The dies in the first three rows were designed to contain outliers; the last two rows were designed to contain dies at the nominal position.

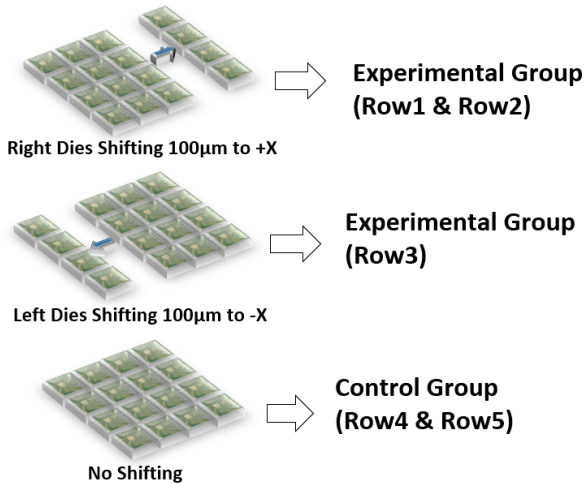


Fig 7. Outlier layout on the test vehicle. Top figure shows the die layout of the first two rows; the right dies were shifted 100µm in the right direction in the X axis from their nominal position. The middle figure shows the die layout of the third row; the left dies were shifted 100µm in the left direction in

the X axis from their nominal position. The bottom figure shows nominal die layout for the remaining two rows of the test vehicle.

B. Lithography Tool

The lithography system employed in this study was an Onto Innovation JetStep® 3500 system. This system supports up to 720mm x 600mm glass panels or up to 510mm x 515mm copper clad laminate (CCL) substrate-based panels. The system employs a 0.5x magnification optical system, which enables an exposure field up to 59.4mm x 59.4mm. The optical system can achieve 2µm l/s resolution with ± 400 ppm magnification compensation, which is required in a fan-out process to correct die/pattern errors. The system utilizes a pattern recognition alignment 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 and Y positions of patterns across the panel; 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 requires.

C. Offline Metrology Tool

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

D. Process Flow

A panel with outliers that was described in the previous section was loaded into an offline metrology tool to collect die location, errors and other necessary information as a first step. The metrology data was then sent to an outlier algorithm to identify outlier dies based on a customized setting. The algorithm then generated a set of site corrections, which eliminated the effect of outliers. The site corrections were then feedforwarded to the stepper for complete site-by-site correction. In this study, any die with a die error more than 20µm was identified as an outlier.

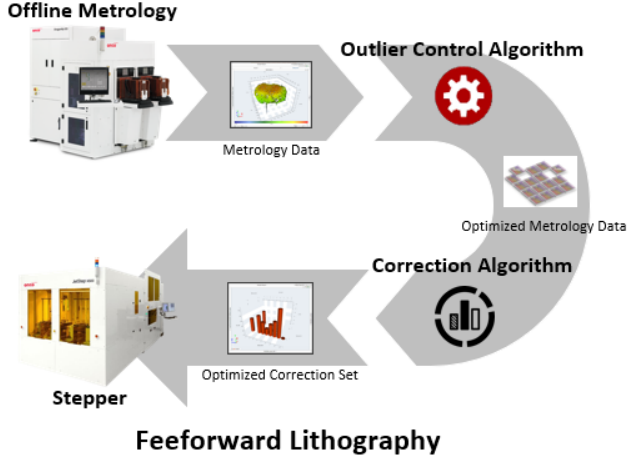


Fig 8. Working scenario of outlier control technology integrated with feedforward lithography. ① A panel was processed by an offline metrology tool. ② The metrology data was feedforwarded to the outlier control algorithm; the algorithm identified the outliers and eliminated the effect of outliers. ③ A correction algorithm calculated corrections based on the metrology data, which was optimized by the outlier control algorithm. ④ The final site correction was feedforwarded to the lithography tool for site-by-site or die-by-die exposure process.

E. Experiment Results

Fig 9 shows the histogram for test vehicle die errors. The left histogram indicates the deviation X distribution; three groups are observed: $+100\mu\text{m}$, $0\mu\text{m}$ and $-100\mu\text{m}$. The first group, $+100\mu\text{m}$, is in row 1 through row 2 of the test vehicle. The second group, $-100\mu\text{m}$, is in row 3 of the test vehicle, which are the outliers that we built in the test vehicle. The right histogram indicates deviation Y distribution. All the die deviations in the test vehicle are around $+4\mu\text{m}$ to $-2\mu\text{m}$, which comes from regular dies in the test vehicle.

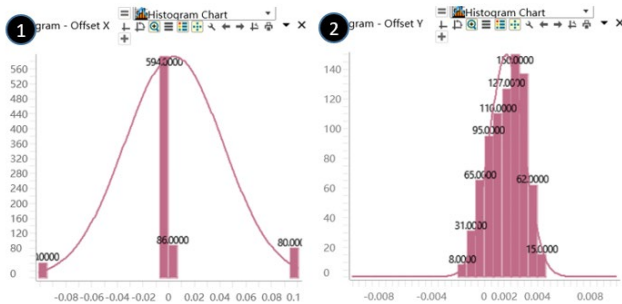


Fig 9. Die error histogram in the test vehicle. ① Die error distribution in X of the test vehicle. Three groups are observed, $+100\mu\text{m}$, $0\mu\text{m}$ and $-100\mu\text{m}$; $+100\mu\text{m}$ and $-100\mu\text{m}$ groups indicate outliers in the test vehicle, and $0\mu\text{m}$ indicates regular dies. ② Die error distribution in Y of the test vehicle.

One group with $+4\mu\text{m}$ to $-2\mu\text{m}$ die error is observed, which are from regular dies.

Fig 10 shows heat maps of the die error in the X axis and Y axis on the test panel. A dot indicates a die. A red dot indicates the die contains positive errors, while a blue dot indicates the die contains negative errors. In the left figure, which is the X die error heat map, the error range is from $-100\mu\text{m}$ (blue) to $+100\mu\text{m}$ (red). From the figure, dies in the first two rows are indicated as red, and dies in the third row are indicated as blue, which matches design errors on the test vehicle (see Fig 6 and Fig 7). In the right figure, which is a Y die error heat map, all die errors are within $-1.8\mu\text{m}$ to $-4\mu\text{m}$. No peak die error is observed in Y, as expected.

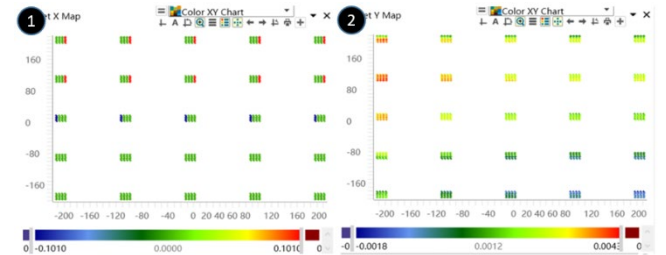


Fig 10. Die error heat map in the test vehicle. ① Dies in the first two rows contain $+100\mu\text{m}$ errors on the right side. Dies in the third row contain $-100\mu\text{m}$ errors on the left side, which match the designed error in Fig 7. ② Heat map of die error in Y axis. All die errors are within $-1.8\mu\text{m}$ to $-4\mu\text{m}$. No peak die error is observed in Y axis.

Fig 11 shows the predicted residue X and Y values after correcting die errors using 4x4 site-by-site correction lithography. Site-by-site correction lithography uses a set of corrections that are processed and feedforwarded by the outlier control algorithm and feedforward algorithm (see Fig 8). Fig 11 shows predicted overlay residue error (after correcting die error) in histogram X and Y. In the left figure, which predicts overlay X residues, three groups are observed. The middle group is around $0\mu\text{m}$; residues for the left and right groups are $-100\mu\text{m}$ and $+100\mu\text{m}$. In the right figure, which predicts overlay Y residues, all the data is within $\pm 2\mu\text{m}$. Table 1 shows the prediction yield number is 85%, with a $15\mu\text{m}$ threshold. Yield prediction is one of the features of the feedforward system, and the feature is qualified in high-volume manufacturing fabs and demonstrates the prediction capability of these technologies. Fig 1, Fig 12 and Table 1 indicate the outliers on the test vehicle are identified correctly, eliminating effects when calculating site-by-site correction sets in this system.

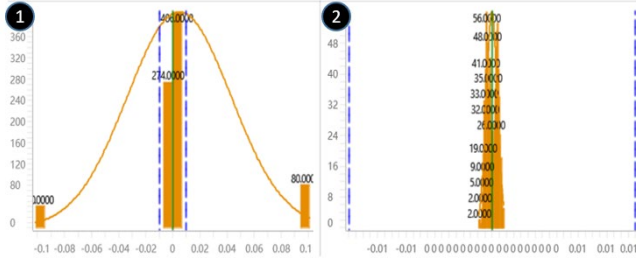


Fig 11. Predicted overlay residue error histogram (die error corrected) on the test vehicle. ① Prediction X residues after correcting die errors. Two groups are observed at $+100\mu\text{m}$ and $-100\mu\text{m}$, which are from the designed outliers on the test vehicle. The rest of the data points are within $\pm 3\mu\text{m}$. ② Prediction Y residues after correcting die errors. All the prediction residues are within $\pm 2\mu\text{m}$, which is expected.

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

Table 1. Test vehicle prediction overlay yield is 85% with a $15\mu\text{m}$ threshold. Regular exposure would result in 40% overlay yield.

The final overlay results of the test vehicle were measured by an offline metrology tool. The overlay results are shown in Fig 12 and Table 2. Fig 12 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 $\pm 15\mu\text{m}$. A red dot indicates the overlay of the die is outside specification, which means the overlay error is out of threshold. With outliers identified and their effect in the demonstration eliminated, we can ensure good overlay for the rest of the dies. The heat map is a perfect match to the expected results. Table 2 shows die overlay statistics are within threshold in the test panel. The dX and dY range are less than $5\mu\text{m}$, and all numbers are within overlay threshold, which is $\pm 15\mu\text{m}$.

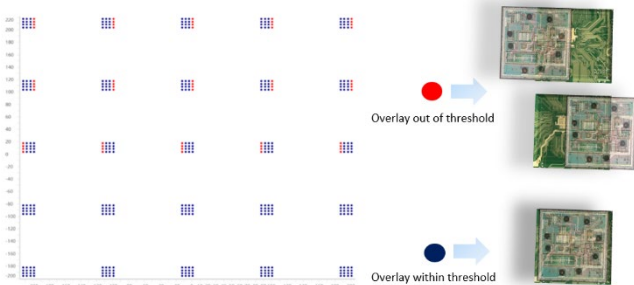


Fig 12: A heat map showing the final overlay results of the test vehicle. A dot indicates a die. Blue indicates the die overlay is within the threshold, and red indicates the die

overlay is outside of threshold, which is $\pm 15\mu\text{m}$. The distribution of out of threshold dies matches expectations.

	Average	Max	Min	Range	STD Dev.
dX	1.04	2.2	-0.31	2.5	0.6
dY	0.25	1.4	-0.75	2.15	0.34

Table 2. Die overlay within threshold. From the data, the maximum overlay error is $2.2\mu\text{m}$ in X and $1.4\mu\text{m}$ in Y. This indicates the overlay of the regular dies are well controlled during the lithography process and the large error effect from outliers has been eliminated.

III. ANALYSIS AND DISCUSSION

A. Outliers Control Technology Discussion

From the metrology data (Fig 9 and Fig 10), the outliers contain large die errors ($+100\mu\text{m}$ and $-100\mu\text{m}$) when compared to the regular dies on the test vehicle. Using prediction data (Fig 11 and Table 1), the outlier control algorithm successfully identifies the outliers with a customized setting, which is a die error over $20\mu\text{m}$ in this study. The effect of outliers is eliminated when calculating the corrections, and the resulting overlay of regular dies are controlled and within threshold (Fig 12 and Table 2). The demonstration proves outlier control technology can identify outliers correctly and work with a feedforward system to eliminate the effect of outliers, ensuring the overlay for the rest of the dies as expected.

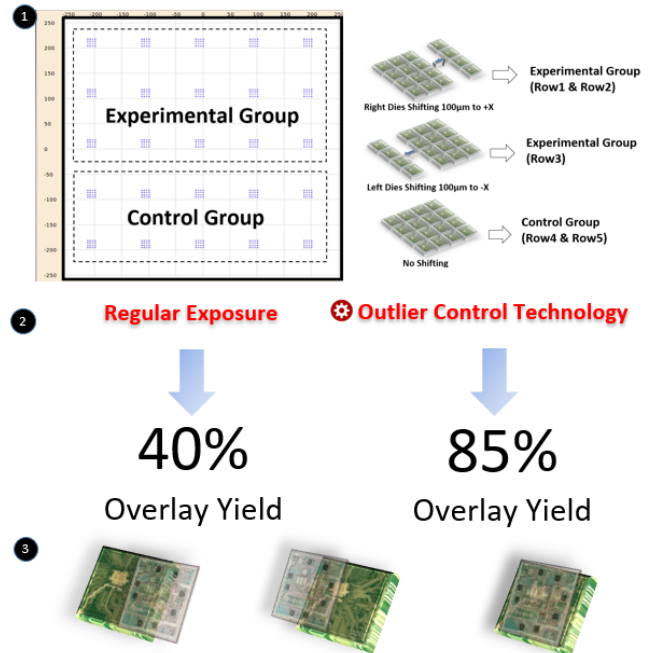


Fig 13. The outlier control technology demonstration. ① Top figure shows the experimental group and control group layout on the test vehicle. ② Final overlay yield with/without outlier technology. Due to the right dies in the first two rows

shifting to the right, without outlier control technology, the overlay will shift to right side; all the dies in the first two rows will encounter overlay shifting, resulting in a final overlay yield = 40%. With outlier control technology, the outliers will be identified, and the effect will be eliminated; this ensures overlay performance for the rest of the dies, resulting in final overlay yield = 85%. ③ Example of overlay shifting to right, overlay shifting to left and good overlay on the test vehicle.

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

In this study, the panel layout includes 400 dies built in a 510mm x 515mm panel. There are 4x4 dies per cluster and 5x5 clusters per panel. Sixty (60) outliers are contained in the test panel. Table 3 compares yield and throughput according to various conditions. With regular die-by-die lithography, the yield is 100%, but the throughput is only three panels per hour. With site-by-site lithography, the throughput increases to 32 panels per hour, but yield drops to 25%. With outlier control technology and feedforward lithography, throughput increases to 62.7 panels per hour, and yield increases to 85%. Of course, the number may vary when using different processes and devices, but with feedforward lithography and outlier control technology, a significant improvement in yield and throughput can be expected.

	Lithography Method & Functions				Shot number (ea)	Yield (%)	TPUT (pcs/hr)
	Die by Die	Site by Site	Outlier control	Feed forward			
Condition1	v				400	100	3
Condition2		v			25	40	32
Condition3		v	v		25	85	32
Condition4		v	v	v	25	85	62.6

Table 3. Yield and throughput comparison table based on the panel layout in this study. In condition 2, using site-by-site correction, the throughput can be enhanced to 32 pcs/hour, up from three pcs/hour with die-by-die correction. The overlay yield is 40%. In condition 3, with outlier control technology, the overlay yield can be increased to 85% from 40%. In condition 4, with a feedforward system integrated with outlier control technology, the throughput can be enhanced to 62.6 pcs/hour while maintaining yield at 85%.

IV. CONCLUSION

This study describes two FOPLP challenges: die shifting and pattern distortion. Site-by-site correction lithography is the method that manufacturers use to achieve a good balance between yield and throughput. But outliers, which are identified as large die error or large pattern shifts, lead to killer defects when using site-by-site correction. Outlier control technology is proposed to address outliers and killer defects. The demonstration in this study proves outlier control technology can accurately identify outliers in a panel

and eliminate the effects to ensure proper overlay for the rest of the dies or patterns.

Outlier control technology provides a reliable solution to address challenges created by outliers. When integrated with a feedforward system, these technologies can enhance throughput as well. These technologies provide users with a path to achieve better overlay yield and reduce the rework rate in advanced FOPLP.

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