# Adaptive Shot Technology To Address Severe Lithography Challenges For Advanced FOPLP

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**ABSTRACT**

Fan-out wafer level packaging (FOWLP) is a popular new packaging technology that allows the user to increase I/O in a smaller IC size than fan-in wafer level packaging. Market drivers such as 5G, IoT, mobile and AI will all use this technology. According to Yole Développement's analysis, the fan-out packaging market size will increase to $3 billion in 2022 from $2.44 hundred million in 2014, validating the market requirement for fan out packaging. While FOWLP has been used for many years, there is still a relentless drive to reduce the cost, and fan-out panel level packaging (FOPLP) has been proposed as one possible solution. FOPLP allows users to put more chips on a substrate, meaning more product output and a higher substrate utilization percentage. According to Yole's analysis, the FOPLP market size will increase to $2.79 hundred million with 79% CAGR, showing that more people are adopting FOPLP.

FOPLP has many advantages and low cost potential, but it faces significant process challenges, such as die placement error and substrate warpage control. One of the key challenges is the trade-off between overlay, yield, and throughput during the lithography processing steps. A user exposes multiple dies per exposure shot to increase throughput, but this can result in lower overlay yield because of "pick and place" die placement error. To overcome the low yield issue, each die needs to be aligned, but this impacts throughput, so a compromise is required. To find the balance point between throughput and overlay is one of the biggest challenges for FOPLP.

In this paper we address the tradeoff between throughputs and overlay yield, we demonstrate an integrated feedforward adaptive shot solution. This feedforward approach uses a third party metrology system to measure reconstituted panel die location data and sends the data to the stepper via a network. With feedforward algorithm technology, the stepper uses smart adaptive shot technology to generate an optimized variable shot size layout. This layout ensures the overlay yield is within specification with the minimum number of exposure steps. With feedforward adaptive shot technology, the user can maximize the throughput of the stepper and ensure the overlay yield at the same time.

Key words: advanced packaging, die placement error, FOWLP, FOPLP, overlay, yield, feedforward.

**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 any panel with die error, we need to add more alignment points to address the die error condition, or it will cause low overlay yield. However, adding additional alignment points lowers the throughput. In some cases, increasing the number of alignment points still won't provide an acceptable overlay yield. Therefore, we must reduce the number of die per shot to ensure the overlay meets requirements, but this then impacts the throughput, which increases the cost per panel. To find the balance between quality and cost, users must spend money and time to find the "sweet spot" between throughputs and die per shot. All FOPLP players will encounter these challenges in their lithography process. To overcome these lithography challenges, a new concept: "feedforward adaptive shot technology" is presented to address these challenges, and this new technology contains two features: "feedforward" and "adaptive shot" that are highly integrated together in a system.

*FEEDFORWARD* uses an offline metrology AOI tool to collect die location data on substrates and feed the data to a stepper for site by site correction exposures, Fig 1 shows the feedforward scenario.

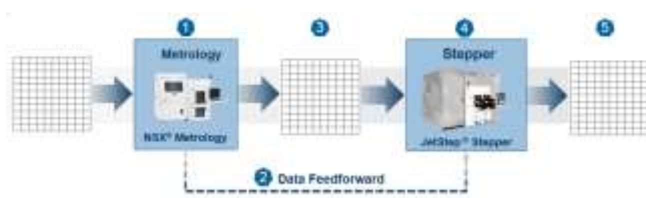



**Figure 1.** Feedforward scenario 1) an offline metrology tool measures the die location data, 2) Metrology data feeds to the stepper, 3) the substrate loads into the stepper 4) stepper uses the die location data to do site by site exposure, 5) substrate completed.

*ADAPTIVE SHOT* is an advanced software algorithm that uses the die location data and considers the customized parameters such as field size, overlay yield and throughput to automatically generate an optimum exposure layout. This layout supports various field sizes, to ensure overlay yield and throughput within an acceptable range based on customer requirements for FOPLP applications. Fig 2 is an example of the adaptive shot concept with a panel substrate. Every dot in the figure represents a die. The left figure uses the largest 8x8 shot size, so it has the highest throughput, but lowest yield, compared with the other two. The middle figure uses adaptive shot software to generate a layout with various shot sizes, it has a better yield than the first layout while maintaining good throughput. The right figure uses adaptive shot software to generate the best yield layout compared with others, but has lower throughput.

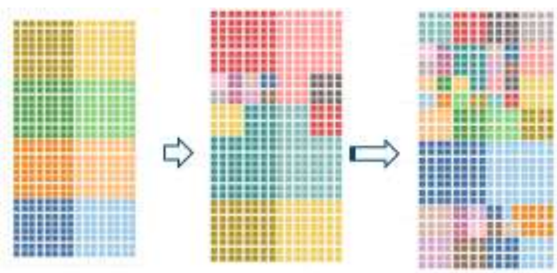


**Figure 2.** Adaptive shot concept layouts.

## EXPERIMENTAL DETAILS

### Feedforward

In order to demonstrate that the applied feedforward corrections would be effective and that the accuracy of the metrology system would be sufficient to meet FOPLP overlay requirements, a suitable test vehicle was defined. The test vehicle consisted of a 510 mm x 515 mm glass panel patterned with test structures using the stepper and a test reticle containing predefined pattern offsets.

In this study, a group of 2 x 2 packages were used for the pad layer (Fig 3). The via layer utilized a single die with no offsets, which after corrections were applied, generated the via to pad overlay structures that were used to assess the accuracy of the corrections. The offsets for the pad layer were defined with site 1 (S1), die 1 (D1) and site 1 (S1) die 2 (D2) as the control (i.e. no offsets).

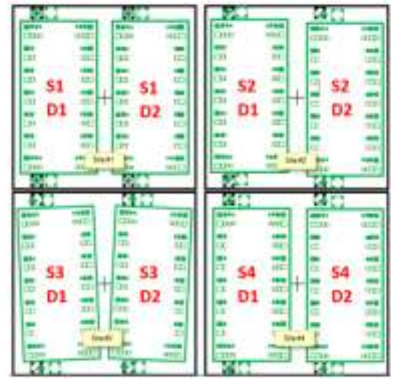



**Figure 3.** Offset die and package locations

To assess feedforward overlay accuracy, every die (S1D1, S1D2, S2D1, S2D2, S3D1, S3D2, S4D1 and S4D2) was measured at three locations (top, middle and bottom) to measure overlay error. Fig 4 shows details of the overlay structure. Fig 5. shows an AOI system capturing via and pad images from the test vehicle, this was then converted into overlay data.

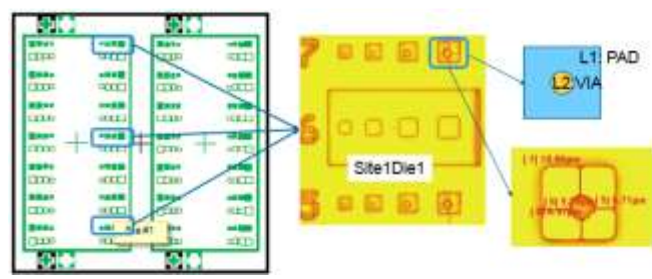



**Figure 4.** Via and pad overlay error measurement structure.

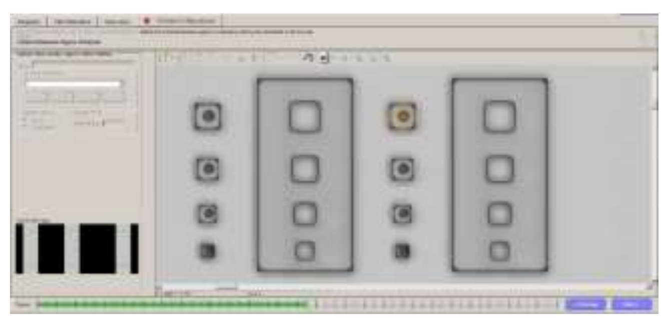
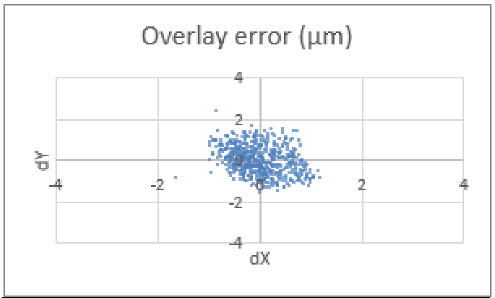


**Figure 5**. AOI system captures via to pad overlay images.

For more details please refer to previous FOPLP studies: Ref [1] and [2], these studies proved the basic feedforward concept worked as designed and the accuracy of the offline metrology system to be within +/- 2.3µm (Fig 6.)




| | Mean | Min | Max | Range | Std |
|---|---|---|---|---|---|
| dx | 4.5E-06 | -1.6298 | 1.1914 | 2.821 | 0.4670 |
| dy | 4.2E-07 | -1.5700 | 2.4130 | 3.9831 | 0.6828 |

**Figure 6.** Stepper to offline metrology correlation.

### Test Vehicle for Feedforward Adaptive Shot

A 510 mm x 515 mm panel was selected as the test vehicle for this study. Fig 7 shows the test pattern that was used to simulate a die on product panel, and the complete layer 1 layout in this study; where there are 4 x 2 dies in a cluster, and 9 x 9 clusters form an array to build layer 1. 44% of the dies on the test vehicle were selected to have large shifts from their original location, this was to simulate the die error generated during the reconstitution process. With a normal exposing method, these shifted dies will have poor overlay, but with adaptive shot technology, the overlay of these shifted dies will be corrected and result in good overlay.

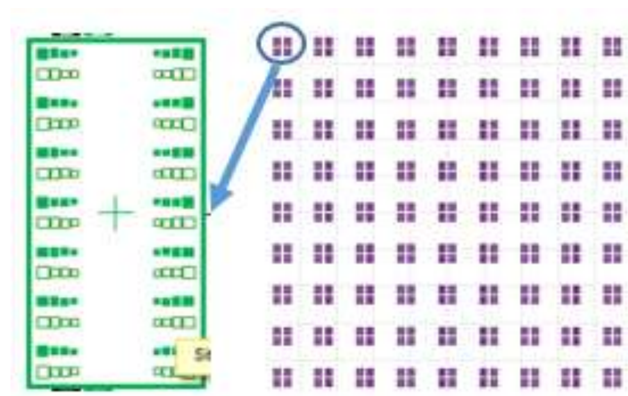


**Figure 7.** Layer 1 pattern and layout. Left figure represents the die pattern used to build layer 1. Right figure is Layer 1 full layout on test vehicle panel.

A positive tone photoresist was used to build the layer 1 pattern on the test vehicle panel. An offline metrology tool, Onto Innovation's Firefly® inspection tool was used for die location measurement. The exposure tool used in this study was Onto Innovation's JetStep® 3500 System. The die location data was fed forward to the yield prediction software and used for the overlay simulation Ref [1] and [2].

### Lithography System and process

The lithography system employed in this study was an Onto Innovation JetStep 3500 System. This system supports up to 720 mm x 600 mm panels. For this study 510 mm x 515 mm panels were used.


**Figure 8.** JetStep 3500, panel system

The system utilizes a pattern recognition system which allows the user to train any 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, this process is often referred to as "mapping". This mapping feature is used for substrates with nonlinear die errors which cannot be corrected by using the global alignment solution.
Adaptive shots contain two or more exposure field sizes. Figure 9 is a typical example to describe the challenges. In the figure, there are 4 different field shot sizes.

**Figure 9.** A typical adaptive shot layout.

For the adaptive shot process, a large stepper field size is required together with the ability to select multiple images over the reticle using reticle masking blades. Furthermore, since many image size combinations using multiple reticles may be required, the stepper must have fast reticle exchange time. This allows the system to expose more dies per shot, with minimum exposure steps, reducing the time of the exposure process resulting in higher throughput.

**Offline Metrology to Assess Die and Overlay error**

In this study a Firefly AOI system was used to assess the die placement error using a similar pattern recognition alignment method to the stepper.


**Fig 10.** Firefly inspection system.

**Control Group for Feedforward Adaptive Shot Test**

A control group panel was created using a fixed field size, 4 x 2, to build the layer 1 layout, displayed in Fig 11. The die location and die error on the test vehicle were measured by an offline metrology tool and fed forward to the yield prediction software to calculate the site correction values and predict the overlay yield.

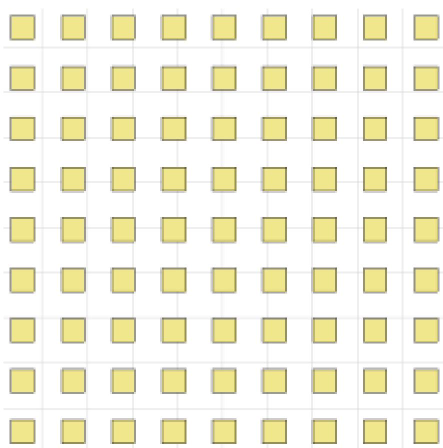


**Figure 11.** Adaptive shot control group exposure layout.

The overlay tolerance was set to +/- 15 µm for the overlay yield criteria. The final overlay yield in the control group panel was 56%, which was the expectation, since the pre-shifted dies exhibit overlay that exceeded +/- 15 µm, other dies at their original location had good overlay, within +/- 15 µm tolerance. The overlay heat map is shown in Fig 12.


**Figure 12.** Control group test panel with predicted overlay results heat map. The red dots are outside of the +/- 15 µm overlay specification.

The overlay error histograms of the control group panel are shown in Fig 13. The blue dotted lines in the figures represent the overlay threshold, which is +/- 15 µm. If either one of the X or Y overlay error exceeds +/- 15 µm the die will be judged as a failed die.

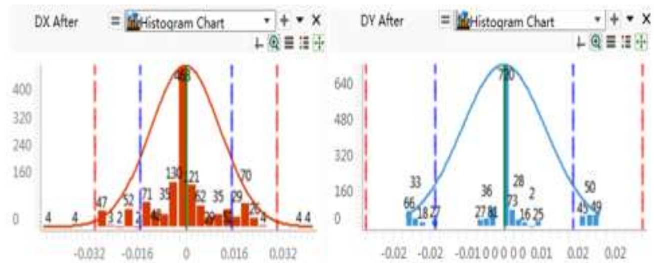



**Figure 13.** Control group test panel overlay error histograms: left figure is dx overlay error, right figure is dy overlay error.

**Feedforward Adaptive Shot**

The experimental test panel employed the exposure layout that was generated by the adaptive shot software algorithm. The adaptive shot software used the die location data which was measured by the offline metrology tool, computed the field size, overlay yield, overlay tolerance and other customized settings to generate an optimum exposure layout. Fig 14 is the optimum exposure layout for exposing the test panel with layer 2.

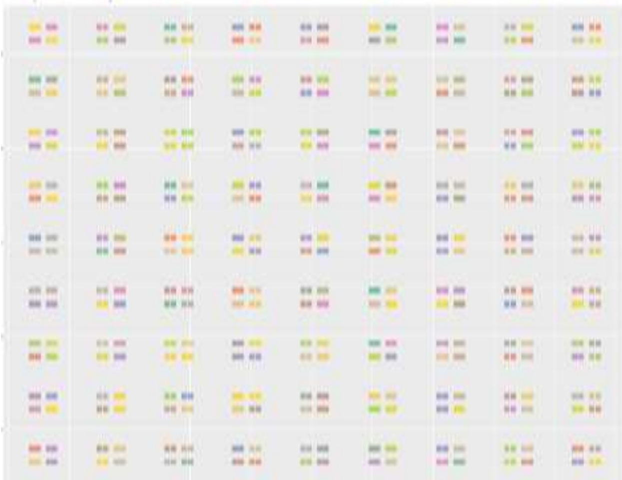


**Figure 14**. The optimum exposure layout which was generated by the adaptive shot software. Each color represents a different shot.

The experimental group test panel yield result was 100%. Figure 15 shows the heatmap overlay error of all die in the experimental group test panel and they were all within the overlay threshold, which was set to +/- 15 µm. Fig 16 shows the overlay error of the experimental group test panel which was within +/- 8 µm. Comparing this result with the control group test panel, where the overlay error was up to 30 µm, it is clear that the adaptive shot exposure layout corrected the errors for the shifted dies and generated good overlay results.

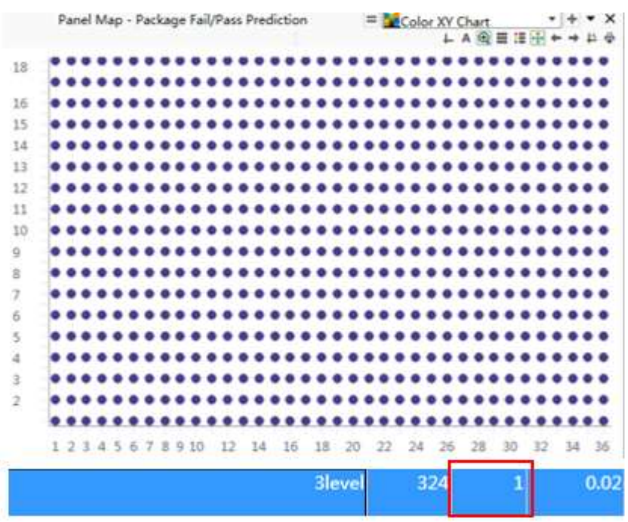



**Figure 15.** Experimental group test panel overlay results heat map.

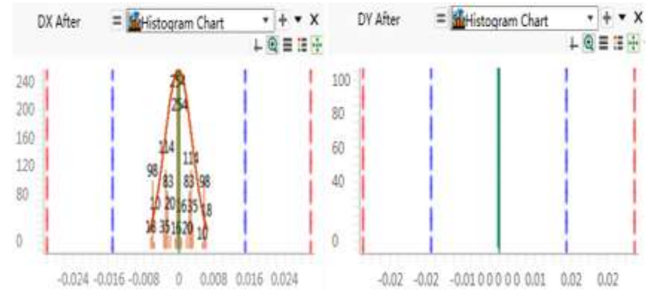



**Figure 16.** Experimental group test panel overlay error histograms: left figure represents dx overlay error, right figure represents dy overlay error.

## DATA ANALYSIS AND DISCUSSION

### Feedforward Adaptive Shot Overlay Data Analysis

Die error correction histograms show how many correction values were used in each panel. In the control group panel, 13 sets showed correction values in the X axis, 10 sets showed correction values in the Y axis, details are shown in Fig 17.

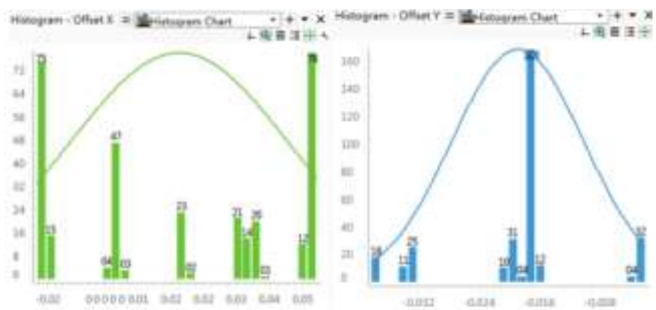


**Figure 17**. Control group test panel correction histograms: left figure is correction in X, right figure is correction in Y.

The experimental group test panel die error correction histograms, Figure 18, show more groups than the control group test panel. This is because of the optimum exposure layout containing various exposure field sizes, with more exposure steps to correct the shifted dies in order to meet their overlay threshold. In Fig 18, 18 sets show correction values in the X axis and 12 sets show correction values in the Y axis. This wider correction range, compared to the control group test panel, leads to a 44% overlay improvement between the control group and experimental group.

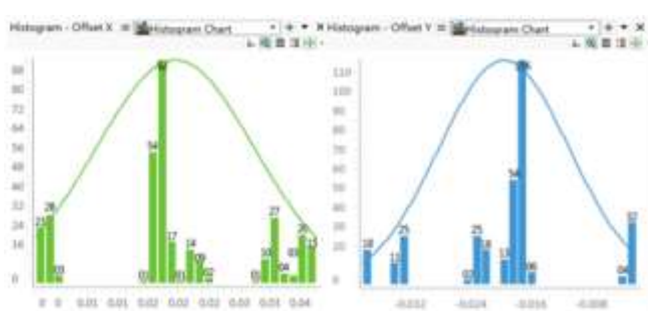


**Figure 18.** Experimental group test panel correction data: left figure represents dx overlay error, right figure represents dy overlay error.

The adaptive shot software generates the optimum exposure layout to address the die with nonlinear placement errors in the control group to ensure good overlay. Table 1 compares field size, exposure step (per test panel) and overlay yield between the control group and experimental group.

| | Control group | Experimental group |
|---|---|---|
| Adaptive shot | N | Y |
| Regular TPUT (pcs/hour) | 2.35 | 1.95 |
| Feedforward TPUT (pcs/hour) | 14.54 | 12.95 |
| Overlay yield (%) | 56% | 100% |

**Table 1.** Comparison table of control group and experiment group.

**Feedforward Adaptive Shot Throughput Discussion**

Extreme die shift conditions are to be expected in FOPLP processes. To achieve the best overlay and ensure product quality, each die must be measured and this information used to perform a die by die or site by site correction exposure. This will impact the throughput, which is unacceptable in HVM. The solution is to use feedforward adaptive shot technology and employ an offline metrology tool. Removing the metrology from the stepper increases throughput significantly; from 2 to 15 times depending on the product and process conditions. In this study, using the feedforward exposure increased the throughput to 14.54 pcs/hour from 2.35 pcs/hour, but the yield was reduced to 56%. Moreover, using the adaptive shot software, although the throughput was reduced to 12.95 pcs/hour, the overlay yield was improved to 100%. When compared with the regular exposure method, where the stepper is used for metrology, the feedforward adaptive shot technology provided an increase of 10.6 pcs/hour in throughput and the overlay yield was improved by 44%.

## CONCLUSION

In this paper, a new concept "feedforward adaptive shot technology" is proposed to address the challenges of lithography for FOPLP. The control and experimental groups' test panel results prove that feedforward adaptive shot technology provides the capability to correct for the nonlinear die placement errors using a customizable threshold software algorithm that optimizes throughput and yield to meet the manufacturing "sweet spot" requirements of the user.


## ACKNOWLEDGMENT

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