Extremely Large Exposure Field With Fine Resolution Lithography Technology To Enable Next Generation Panel Level Advanced Packaging

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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.**

Heterogeneous integration enables next-generation device performance gains by combining multiple silicon nodes and designs inside one package. The package size is expected to grow significantly, increasing to 75 x 75 mm and 150 x 150 mm, within the next few years. For these requirements, an extremely large exposure field with fine resolution lithography will enable packages well over 250 x 250 mm without the need for image stitching while exceeding aggressive overlay and critical uniformity requirements for these packages.

The lithography challenge to fulfill the need of heterogeneous integration is the limitation of exposure field size of the currently available solutions in the market. Multiple shots with stitching is used and this affects not only productivity performance but potential yield loss at the stitching boundary. Addressing the critical lithography challenges described above becomes an important task in heterogeneous integration, and an extremely large exposure field with fine resolution lithography is one of the best solutions for this task.

In this paper, a 515 mm x 510 mm panel is selected as the test vehicle, and we will demonstrate an extremely large exposure field with fine resolution technology on this panel. This demonstration provides the results and details about how this new technology will address the challenges of large package size processes.

Keyword,
Advance packaging, Advanced IC substrate, large exposure field, fine resolution, panel level packaging, heterogeneous, overlay, stitching, throughput.

I. INTRODUCTION

Heterogeneous integration requires to integrate multiple chips and increased functionality into a single 75 mm x 75 mm or 150 mm x 150 mm large package will be a new challenge for manufacturing processes. For current advanced packaging lithography systems, to process such large package sizes, current steppers are required to use multiple exposure shots to complete a package because of the limitation of the exposure field size. This method, known as "stitching" requires multiple reticles, and has low throughput, which increases costs. Increasing the stepper field size removes the need for stitching and increases throughput significantly.

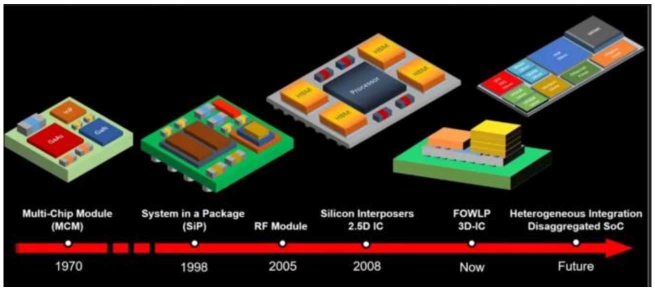
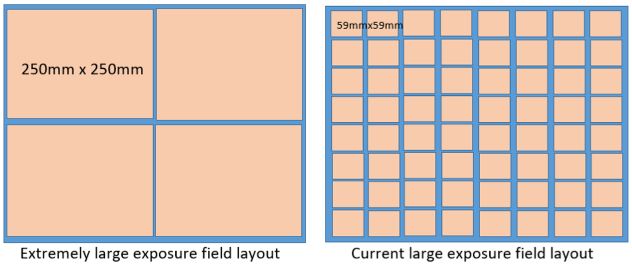


Fig1. Heterogeneous integration enables next-generation device performance gains by combining multiple silicon nodes and designs inside one package, so the package size is expected to grow significantly. (fig1 source: Cadence)

The extremely large (250 mm x 250 mm) exposure field allows the user to process more large packages in a single shot, and less shots to complete a substrate panel. This brings a significant throughput increase over the regular exposure field. However, there are significant process challenges, such as panel warpage and distortion that impact critical dimension control. The extremely large field size requires a modification of the panel exposure layout. Fig 2 shows the exposure layout of an extremely large exposure field and a regular exposure field lithography on a 510 mm x 515 mm panel. With the extremely large exposure field, a panel can be completed with just four (4) shots; with a regular exposure field, a panel requires 64 shots to complete.



Extremely large exposure field layout

Current large exposure field layout

Fig 2. The exposure layout comparison of extremely large exposure field and current large exposure field. The left figure is the exposure layout example of extremely large exposure field, the right figure is the exposure layout of regular exposure field.

Advanced packaging and advanced IC substrates (AICS) are currently being employed to support ultra high density (UHD) panel fan out. This approach uses an RDL first process, where many layers of RDL and ABF are processed on both sides of the panel. Once these layers are complete, the final bumping layer is defined, and the HI chips affixed. Fig 3 shows the one of the benefits of moving to panel format as compared to 300 mm wafers.

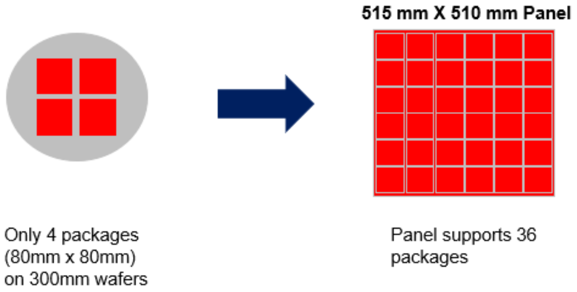


Fig 3. Comparison of number of packages exposed on 300 mm wafer compared to panel.

II. EXPERIMENT DETAILS

A. *Test Vehicle*

In order to demonstrate the extremely large exposure field with fine resolution in fan out panel level packaging, a suitable test vehicle is defined. A 510 mm x 515 mm CCL+ABF substrate was selected as test vehicle for resolution test, 510 mm x 515 mm glass substrates were selected as test vehicles for overlay and uniformity. The exposure job for this demonstration uses 250 mm x 250 mm exposure field size, and four (4) shots to fully expose the test vehicles, this is shown as Fig 4.

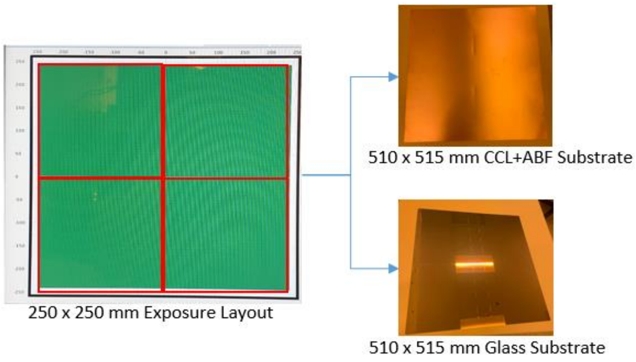


Fig 4. Exposure layout with four (4) ea. x 250 mm x 250 mm exposure field shots, 4 shots on 510 mm x 515 mm CCL+ABF substrate and 510 mm x 515mm glass substrate.

B. *Processing Conditions*

Due to AP and AICS process requiring thicker resist films than front-end processes, and variations in substrate topography, large depth of focus capability is a must have. The projection lens of the lithography system used in this demonstration is designed with low NA to increase the depth of focus (DOF) and support the imaging of high aspect ratio features with thicker resist films. Achievable resolution and DOF are determined by the following equations:

$$R = k_1\lambda/\mathrm{N.A.}$$

$$\mathrm{DOF} = k_2\lambda/\mathrm{N.A.}^2$$

Where k1 and k2 are process factors, λ is wavelength.

In this study, the selected conditions to demonstrate the resolution performance of the extremely large exposure field with fine resolution lithography are described in Table 1.

Resist	Film Thickness (um)	Line/Space (um)	VIA (um)
DryFilm	10	3	na
DryFilm	25	5	na
DryFilm	25	6	na
DryFilm	40	na	15
DryFilm	40	na	20

Table 1. Shows the selected conditions used to demonstrate the resolution performance of the extremely large exposure field with fine resolution lithography.

C. *Extremely Large Exposure Field Lithography Tool*

The lithography system employed in this study was a JetStep® X500 system. This system supports 510 mm x 515 mm glass panels or CCL substrates. The system is equipped with a 2.2x magnification projection lens, which enables up to 250 mm x 250 mm exposure field size, with 3 µm line/space resolution, ± 400 ppm magnification compensation and ± 100 ppm anamorphic magnification compensation, with overlay < 1 µm.

Critical dimension, overlay and critical dimension uniformity are the keys to achieve a practicable lithography, the extremely large exposure field system must consider how to achieve these requires. The lens distortion is one of the keys to achieve the overlay and uniformity requirement in extremely large exposure field lithography, Fig 5 shows the lens distortion vector map over the 250 mm x 250 mm exposure field. Accurate step and settle movement is a key to achieve good overlay in a stepper. Fig 6 shows the lithography system stage equipped 8 motors to ensure accurate step and settle when a weight substrate loaded.

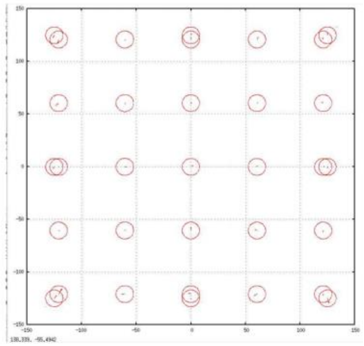


Fig 5. The lens distortion map of the exposure tool in this study. From the data, it shows < 1 µm distortion error over the 250 mm x 250 mm exposure field.

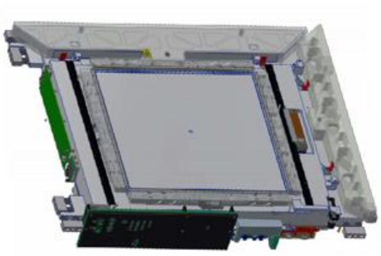


Fig 6. the lithography system stage equipped 8 motors to ensure accurate step and settle when a weight substrate loaded

During the FOPLP substrate build process, many layers of RDL and ABF are added to the panel. These films distort the panel in X, Y and Z during thermal cycling. Magnification compensation is one of the key parameters to compensate for the panel distortion. Magnification compensation is used to isotropically enlarge or shrink the apparent size of original patterns on the reticle, anamorphic magnification is used to anisotropically enlarge or shrink the apparent size of original patterns in order to correct for the distorted panel registration errors. These adjustments are necessary to achieve good overlay and maintain high package yields. Fig 7 shows the difference of magnification and anamorphic magnification.

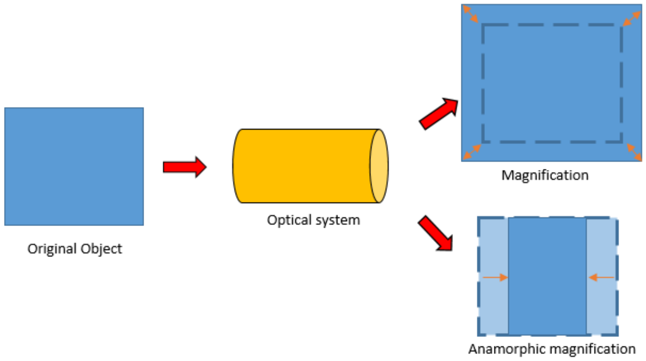


Fig 7. Magnification and Anamorphic magnification compensation. Red arrows show the light path in the optical system. The lens magnification compensation can isotropically and anisotropically adjust the final image placement.

D. 3 µm Line / Space Resolution Results

Fig 8 to Fig 11 show the results of the 3 µm line / space resolution demonstration. Best dose and best focus were determined using a focus exposure matrix (FEM) prior to the resolution demonstration. A CCL+ABF substrate with 10 µm thick dry film resist was selected for this demonstration. This is just over 1: 3 aspect ratio.

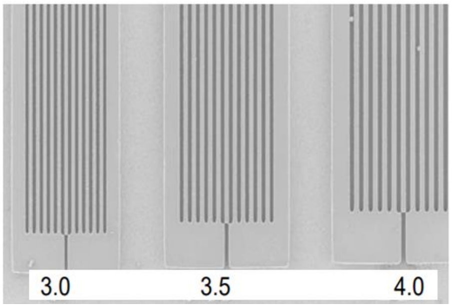


Fig 8. The isolated and dense area fine line / space resolution results. From left to right shows 3 µm line / space, 3.5 µm line / space and 4 µm line / space resolution.

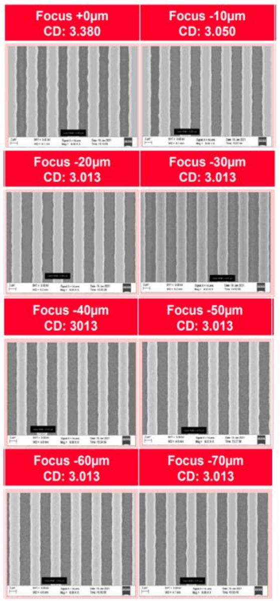


Fig 9. 3 µm line / space focus matrix results. Best dose is used in this demonstration, these pictures show 3 µm resolution performance from focus 0 µm to focus -70 µm. The CD of focus -10 µm to -70 µm have less than 10% deviation.

The FEM work generated data to construct a Bossung plot (Fig 8). This Bossung plot shows > 60 µm depth of focus was achieved for the 3 µm l/s in 10 µm thick dry film resist.

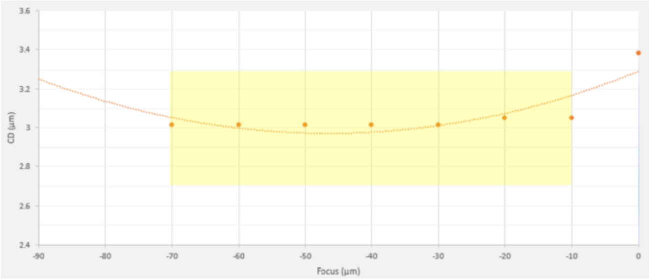


Fig 10. Bossung curve of 3 µm L/S in 10 µm thick dry film resist. The X axis is focus (µm) and the Y axis is CD (µm). 60 µm depth of focus was observed in 3 µm line / space with 10 µm thick dry film resist.

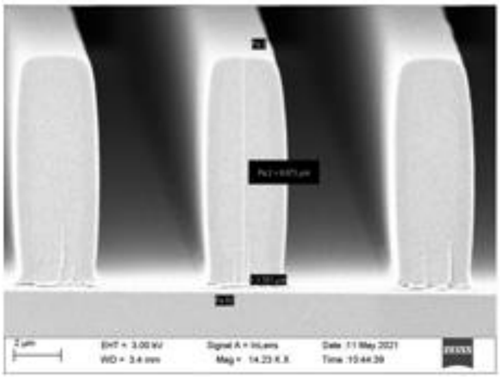


Fig 11. Cross section image of 3 µm L/S in 10 µm thick dry film resist. The line critical dimension is 3.181 µm, the resist height is 9.873 µm in the cross section image.

E. 5 µm & 6 µm Line / Space Resolution Results

Larger feature sizes were also investigated. Fig 12 to Fig 17 show the results of the 5 µm line / space and 6 µm line / space resolution demonstration. Best dose and best focus were determined using a focus exposure matrix (FEM). A CCL/ABF substrate with 25 µm thick, dry film resist was selected for this demonstration. This is about 1: 5 aspect ratio.

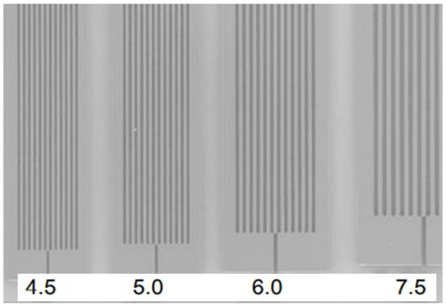


Fig 12. The isolated and dense area line / space resolution results. From the left to right shows 4.5 µm line / space, 5 µm line / space, 6 µm line / space and 7.5 µm line / space resolution.

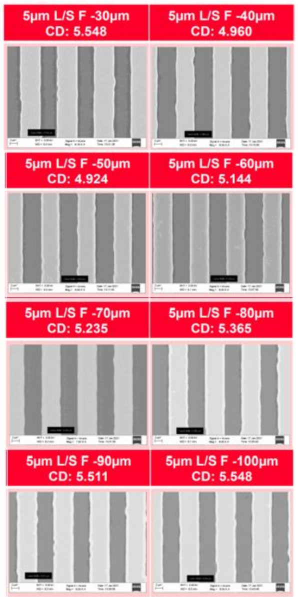


Fig 13. 5 µm line / space focus matrix results. Best dose is used in this demonstration, these pictures show 5 µm resolution performance from focus -30 µm to focus -100 µm. The CD of focus -40 µm to -80 µm have less than 10% deviation.

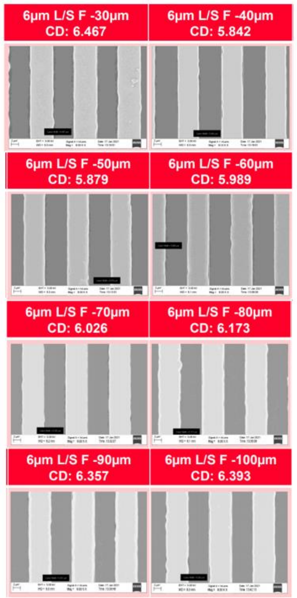


Fig 14. 6 µm line / space focus matrix results. Best dose is used in this demonstration, these pictures show 6 µm resolution performance from focus -30 µm to focus -100 µm. The CD of focus -30 µm to -100 µm have less than 10% deviation.

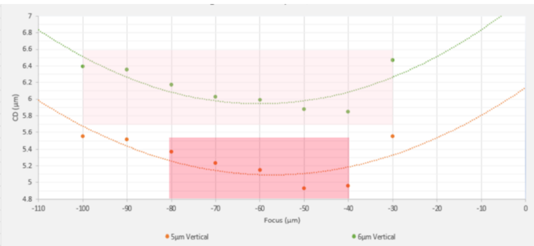


Fig 15. Bossung curve of 5 µm and 6 µm line / space resolution in 25 µm thick dry film resist. The X axis is focus (µm) and the Y axis is CD (µm), red chart indicates 5 µm and green chart indicates 6 µm. 40 µm depth of focus was observed in 5 µm line / space with 25 µm thick dry film resist, 70 µm depth of focus was observed in 6 µm line / space with 25 µm thick dry film resist.

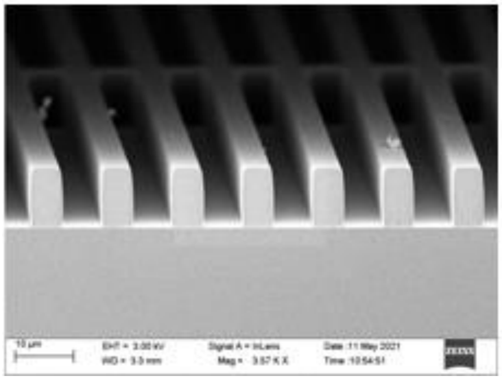


Fig 16. Cross section image of 5 µm L/S in 10 µm thick dry film resist.

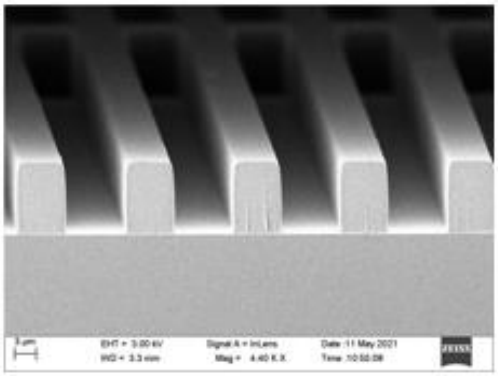


Fig 17. Cross section image of 6 µm L/S in 10 µm thick dry film resist.

F. 15 µm and 20 µm Square Via Resolution Results

In addition to the line space work, via resolution was also investigated. Fig 18 and Fig 20 show SEM micrographs of the 15 µm and 20 µm via imaging performance. Best dose and best focus were identified using a FEM and a CCL/ABF substrate with 40 µm thick, dry film resist, was selected for this demonstration. Bossung plots were generated for both via sizes, these are shown in Fig 19 and 21.

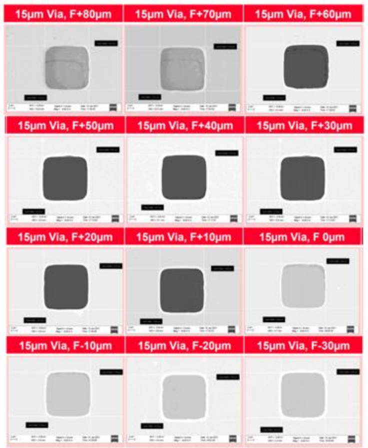


Fig 18. SEM micrographs of 15 µm via imaging results from focus -30 µm to focus + 80 µm.

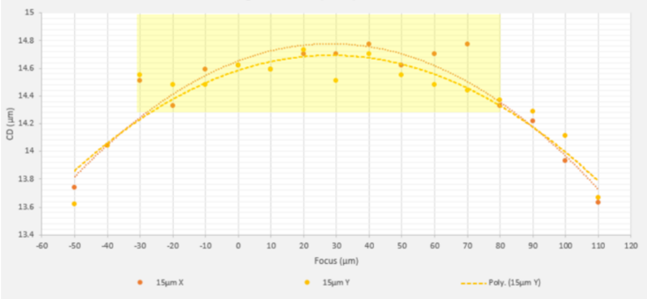


Fig 19. Bossung plot of 15 µm via resolution. The X axis is focus (µm) and the Y axis is CD (µm). Bossung plot of 15 µm via shows a 110 µm depth of focus.

Fig 20. SEM micrographs of 20 µm via imaging results from focus -50 µm to focus +110 µm.

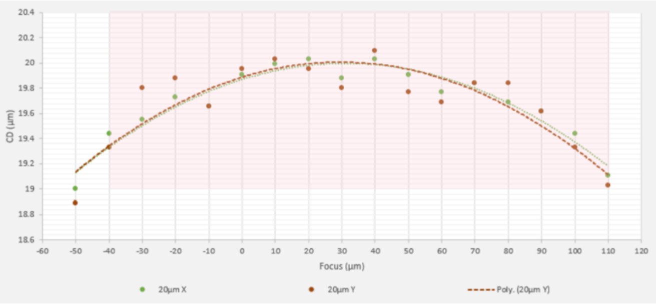


Fig 21. Bossung plot of 20 µm via resolution. The X axis is focus (µm) and the Y axis is CD (µm). The Bossung curve of 20 µm via shows 150 µm depth of focus.

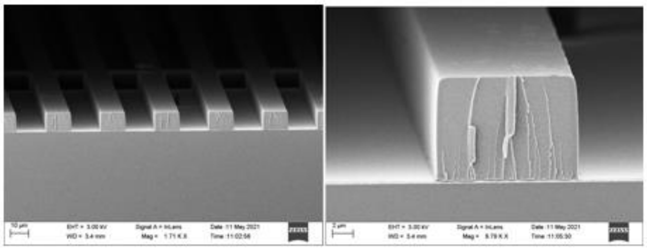


Fig 22. Cross section image of 15 µm L/S in 10 µm thick dry film resist.

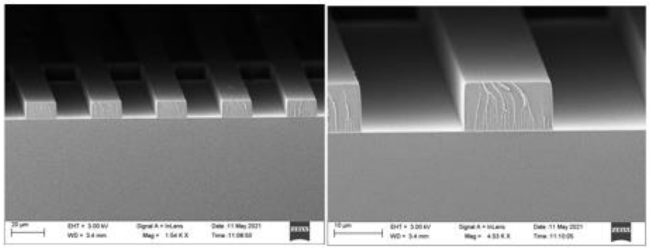


Fig 23. Cross section image of 20 µm L/S in 10 µm thick dry film resist.

G. Uniformity Results with 250 x 250 mm Exposure Field

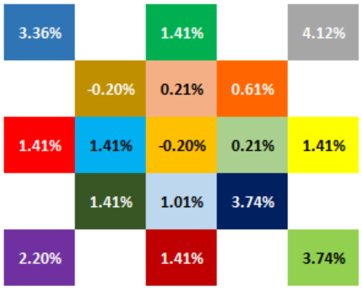
A 510 mm x 515 mm glass panel with 1.4 µm thick liquid film was selected for the extremely large exposure field lithography demonstration of 3 µm line / space uniformity performance. From uniformity data of Fig 24, the maximum CD is 3.258 µm and the minimum CD is 2.988 µm, the average CD is 3.099 µm, the uniformity is 4.32%, this number proves a good uniformity can be achieved in extremely large exposure field, which is 250 mm x 250 mm.

Fig 25 show 3 µm CD deviation contribution map in 250 mm x 250 mm exposure field, from the data, the minimum deviation at center location, which is -0.12%, and the maximum deviation at top-right location, which is 4.12%, overall, these are as expected.

3.209		3.086		3.258
	2.988	3.013	3.037	
3.086	3.086	2.988	3.013	3.086
	3.086	3.062	3.233	
3.135		3.086		3.233

Max	Min	Average	STD	Uniformity
3.258	2.988	3.099	0.087	4.32%

Fig 24. 3 µm CD plot in 250 mm x 250 mm exposure field. The maximum CD is 3.258 µm and the minimum CD is 2.988 µm, the average CD is 3.099 µm, the uniformity is 4.32%.



3.36%		1.41%		4.12%
	-0.20%	0.21%	0.61%	
1.41%	1.41%	-0.20%	0.21%	1.41%
	1.41%	1.01%	3.74%	
2.20%		1.41%		3.74%

Fig 25. 3 µm CD deviation contribution map in 250 mm x 250 mm exposure field. The center location has minimum deviation and the deviation trend up to 2.2% to 4.12% at corner locations, the maximum deviation is 4.12% which at top-right corner. Overall, the deviation as our expectation.

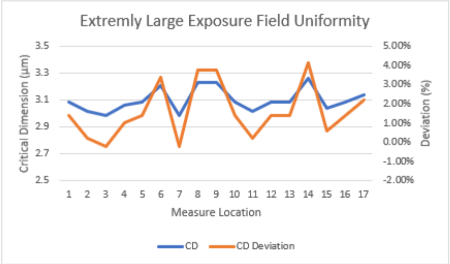


Fig26. 3 µm CD and CD deviation chart, no trending or peak is observed. This chart indicates the CD performance with 250 mm x 250 mm exposure field is very stable.

H. Overlay Results with 250 mm x 250 mm Exposure Field

Overlay is one of the keys to achieve extremely large exposure field lithography. A 510 mm x 515 mm glass panel with 1.4um liquid resist was selected as overlay test vehicle. First, 1st layer was built on test panel, 1st layer exposure layout is 250 mm x 250 mm exposure field a shot, 4 shots a panel, then run wiht site by site correction to build 2nd layer, then check the error between layer 1 and layer 2 to determine the overlay performance of extremely large exposure field.

The overlay error was determined by reading the overlapped verniers in certain locations, each exposure field contains 3 x 3 measurement points, and 2 x 2 shots a panel were measured to determine the overlay performance of the extremely large exposure field system. Fig 27 shows the overlapped verniers that for demetermine the overlay performance of extremely larg exposure field lithgraphy. Fig 28 is the statistics table of the overlay results of extremely large exposure field lithgraphy.

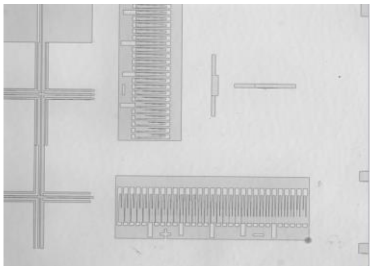


Fig 27. Overlapped verniers which built by 1st layer and 2nd layer. To determine the overlay performance of extremely large exposure field lithography by reading the verniers.

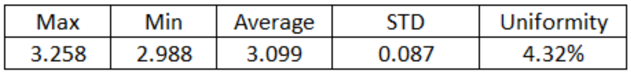
	Dx	Dy
Max	0.52	0.39
Min	-0.32	-0.39
Mean	0.2	0.2
Std	0.24	0.24
Mean+3σ	0.91	0.91

Fig 28. Overlay results table. From the data, the mean + 3 sigma in X is 0.91 µm, and the mean + 3 sigma in Y is 0.91 µm, these are very good overlay numbers and as our expected.

III. SUMMARY AND DISCUSSION

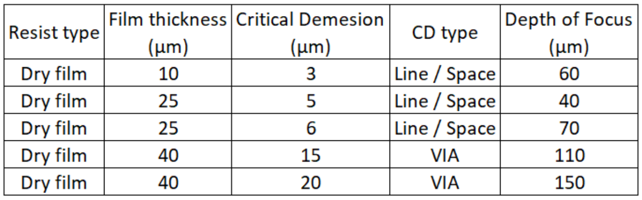
A. *Resolution, Uniformity and Overlay Summary*

Table 2, table 3 and table 4 are the test results summary of the extremely large exposure field with fine resolution lithography demonstration. Table 2 indicates 3 µm line / space uniformity performance with a 250 mm x 250 mm extremely large exposure field. According to Table 2, 4.32% uniformity was observed in 3 µm line / space with using an extremely large exposure field. Table 3 shows the extremely large exposure field depth of focus performance for various resolution and process conditions. Table 4 shows the overlay results in a 510 mm x 515 mm panel with using 250 mm x 250 mm exposure field.



Max	Min	Average	STD	Uniformity
3.258	2.988	3.099	0.087	4.32%

Table 2. 3 µm line / space uniformity performance with 250 mm x 250 mm exposure field. The uniformity number is 4.32%, which indicates good 3 µm uniformity can be achieved with extremely large exposure field lithography.



Resist type	Film thickness (µm)	Critical Demesion (µm)	CD type	Depth of Focus (µm)
Dry film	10	3	Line / Space	60
Dry film	25	5	Line / Space	40
Dry film	25	6	Line / Space	70
Dry film	40	15	VIA	110
Dry film	40	20	VIA	150

Table 3. Extremely large exposure field depth of focus performance with various resolutions and resist film thickness.

	Dx	Dy
Max	0.52	0.39
Min	-0.32	-0.39
Mean	0.2	0.2
Std	0.24	0.24
Mean+3σ	0.91	0.91

Table 4. Extremely large exposure field overlay results.

IV. CONCLUSION

In this study, an extremely large exposure field size (250 mm x 250 mm) successfully resolved 3 µm line / space features with a depth of focus > 60 µm on a 510 mm x 515 mm CCL/ABF stack. This study also demonstrated successful 5 µm, 6 µm, line / space and 15 µm, 20 µm vias with a thicker dry film resist film. Fine resolution and extremely large field size provides the user with the opportunity to increase the package size beyond 150 mm x 150 mm at high throughput. This exciting new capability will pave the way for the next generation of heterogeneous integration packages and future imaging and process studies.

ACKNOWLEDGEMENT

The authors would like to thank John Kennedy, Zhiyang Li, Karie Li and Andrew To for their work on the software algorithm, and Tom Swarbrick, Corey Shay, Ryan Tsai and Hans Lin for their support with the lithography work, and the support from all the teammates of X500 project.

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