Second Level Printing of Advanced Phase Shift Masks using DUV Laser Lithography.

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1. ABSTRACT

Laser lithography tools have been a staple in the photomask industry for second level printing for several years. This paper explores the overlay capabilities of the Alta4300D Deep UV (DUV) lithography system. The tool is manufactured by ETEC Systems, a part of the Mask Business Group of Applied Materials. The tool demonstrates good overlay performance, and an improved data path ensures the ability to handle large file sizes without an adverse impact on writing time. In addition to actual performance data on product masks, a simple analysis of the maximum total edge placement error of a hypothetical two level altPSM process is presented. The results show the tool is capable for many advanced phase shift overlay applications.

Keywords: Overlay, PSM, DUV Laser Lithography

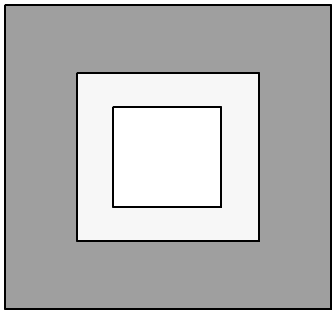
2. INTRODUCTION

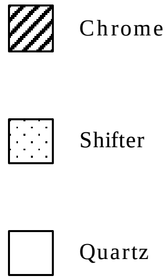
Phase shifting techniques in photolithography are an important tool for meeting ever more demanding resolution requirements. As the industry advances through 90nm, 65nm and smaller nodes, more layers will require phase shifting masks. Overlay performance will be critical. Optical overlay tools have some advantages over electron beam systems. First, charging is not an issue. Many ebeam approaches to overlay printing utilize a top coating to dissipate charge. This adds an extra coating step in the manufacturing process. Applying top coatings to resist films can have significant impact to defect levels and add to the overall complexity of the process. Also, charging is not completely eliminated. Densely patterned areas are still subject to some level of charge build up and subsequent beam deflection. Laser tools do not require these additional measures. Due to the highly parallel writing strategy of the laser tool, print times are a fraction of electron beam systems. Registration and placement of these systems are among the best in the industry.

This paper analyzes the overlay performance of 19 embedded phase shift masks and extends that analysis to simulate overall edge placement error for two-level printing. Of these 19 masks, 14 were 90nm node product and 5 were 130nm node. The first level of each mask was printed on either the Alta4300D (9 plates) or a 50KeV electron beam pattern generator (10 plates). The first level printing in all cases used either a positive or negative chemically amplified resist (CAR) and all were dry etched.

For second level printing, all plates were coated with a positive DUV CAR. The masks were aligned on the Alta4300D PSM alignment system using standard coarse and fine alignment marks for alignment. The location of each mark is measured and a regression calculation performed to determine print corrections. The PSM alignment system uses a 532nm laser source and optics separate from the 257nm laser optics utilized for printing. Prior to printing the tool performs a calibration to reconcile the coordinate systems of the two optical paths and eliminate placement errors. The system has the ability to specify offsets for process corrections that may be customized for each substrate to improve overlay print performance. Machine to machine offsets may be specified for each 1st level print tool to streamline locating the coarse marks during alignment.

Each plate had a standard overlay package consisting of a “box-in-box” pattern, printed at 16 locations outside the patterned area of the mask. These patterns are used to measure overlay. An example of the pattern is shown in figure 1 below. Figure 2 is a representation of a shifted overlay. The sign convention for the shift in figure 2 is in the negative X direction and positive Y direction.





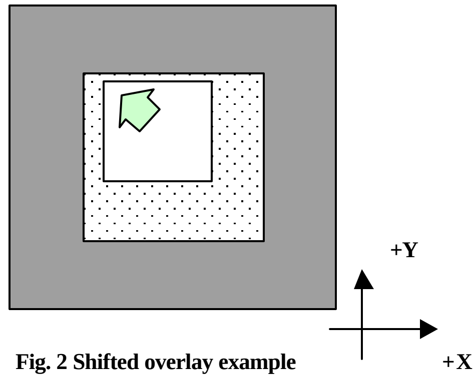


Fig. 1 Overlay "box in box" pattern

Fig. 2 Shifted overlay example

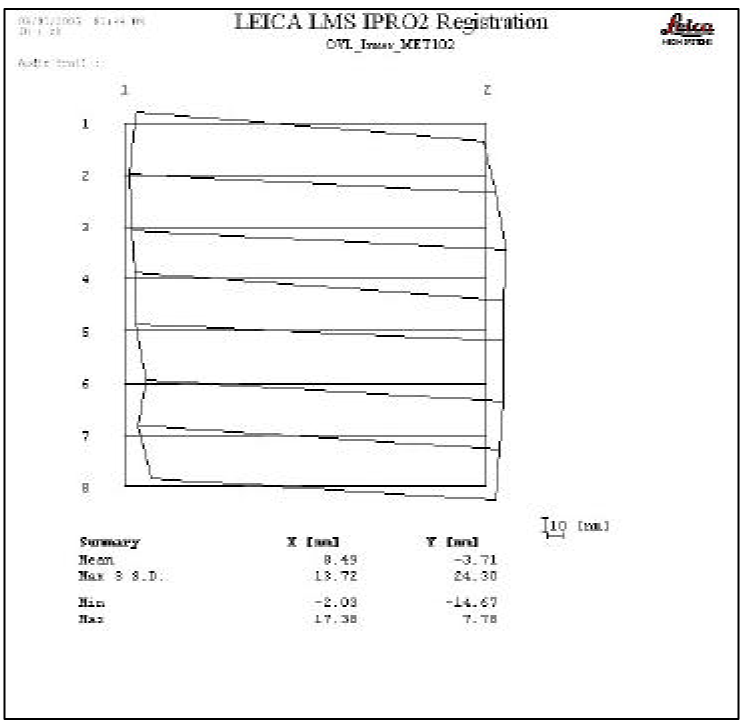


Fig. 3 Sample IPRO overlay measurement output

Overlay error was determined by measuring the placement of the outer box (shifter material) and the inner box (quartz). The measurement tool used was the Leica IPRO2. The inner box data was then overlain to the outer box data in such a way as to remove scaling attributed to the first level print. Sample overlay measurement output is shown in figure 3.

The IPRO is a reflected light measurement system. Changes in substrate and resist reflectivity have an impact on tool induced measurement error. The error on each substrate (and substrate/resist combination when resist measurements are done) needs to be quantified. For substrates used in this paper, tests show the tool induced measurement error to be 6 to 11nm.

3. DATA ANALYSIS

3.3 Total Two Level Print Edge Placement Error Calculation

The maximum total edge placement error of a two level altPSM process, according to Cheng[1], et al., is given by the following expression:

$$S \{\tfrac{1}{2}*MTT_{1st\ lvl}(CD) + \tfrac{1}{2}*MTT_{2nd\ lvl}(CD) + Overlay + 3\sqrt{\sigma^2_{1s\ lvl}(CD) + \sigma^2_{2nd\ lvl}(CD) + \sigma^2(Overlay)}\ \} \qquad (1)$$

Where MTT is defined as Mean-to-Target and Overlay is defined as the maximum deviation between the two levels. Note that pattern fidelity error is not explicitly included in the error budget calculation. A statistical distribution for each of the variables in equation (1) was derived from production data. From these distributions, a Monte Carlo simulation was performed to evaluate expected overlay performance.

3.4 First Level Tool Targeting and Uniformity

The MTT and CD uniformity from 50Kev production mask levels was used to produce the distributions used for the Monte Carlo simulation. These are pictured in figure 4.

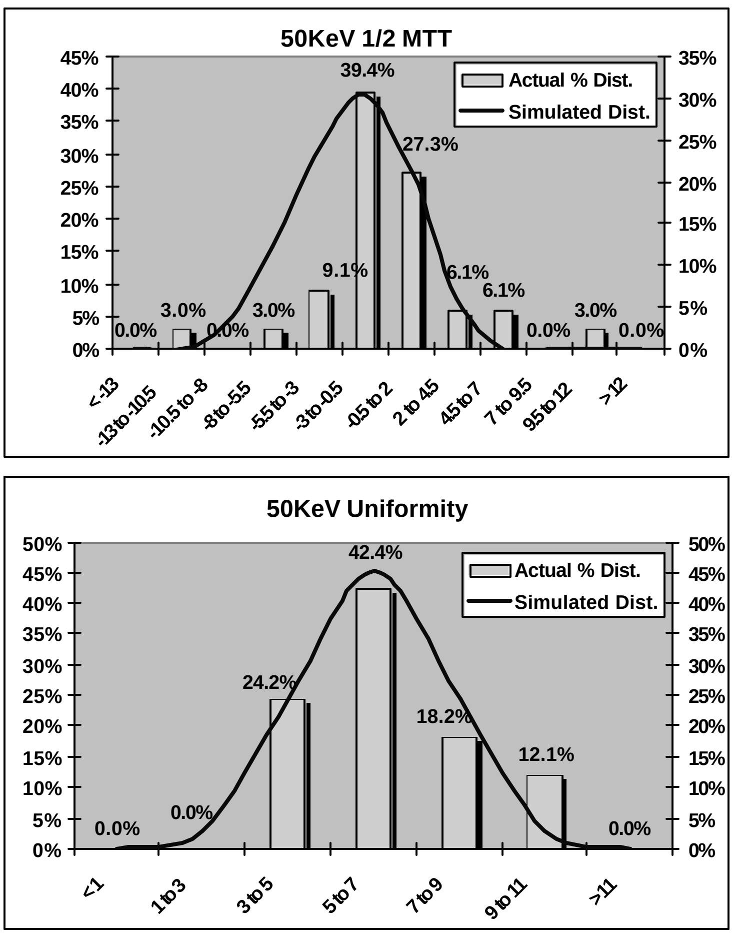


Fig. 4 1st Level Targeting and Uniformity on 50KeV

3.5 Second Level Tool Targeting & Uniformity

Similarly, Alta4300D production mask data was used to determine MTT and uniformity distributions. These distributions were used to approximate the Alta4300D 2nd level performance for these parameters. These distributions are plotted in figure 5.

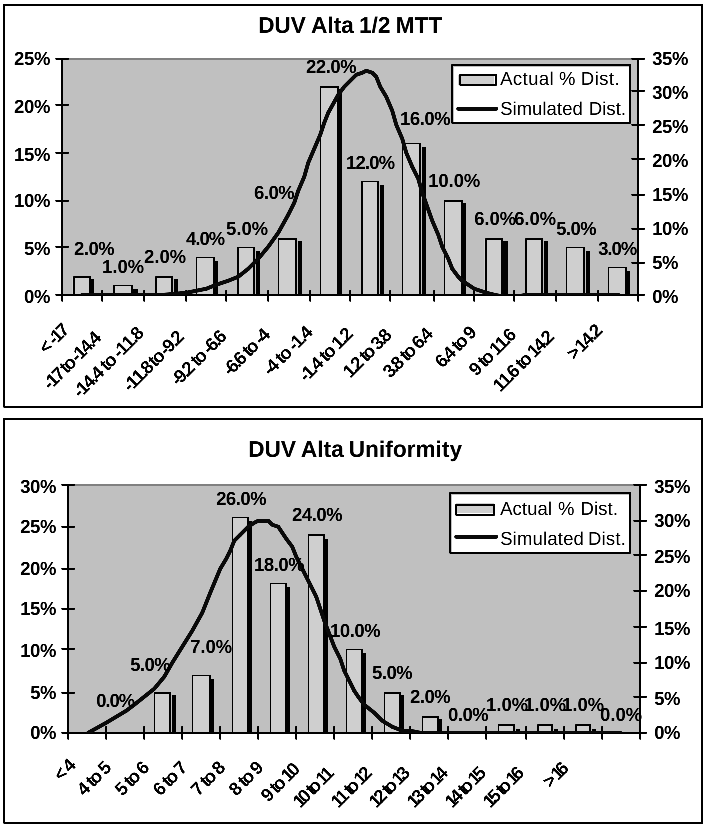


Fig. 5 2nd Level Targeting and Uniformity on DUV Alta

3.6 Overlay Metrics

A convenient metric for examining overlay behavior on any individual mask is the sum of the overlay and the overlay 3σ errors. Figure 6 shows the chronological overlay performance expressed as the sum of the mean and 3σ errors for each axis for 19 production jobs. Figure 7 is a plot of the distributions of the overlay mean and 3σ errors for the worst-case axis of this 19 plate sample.

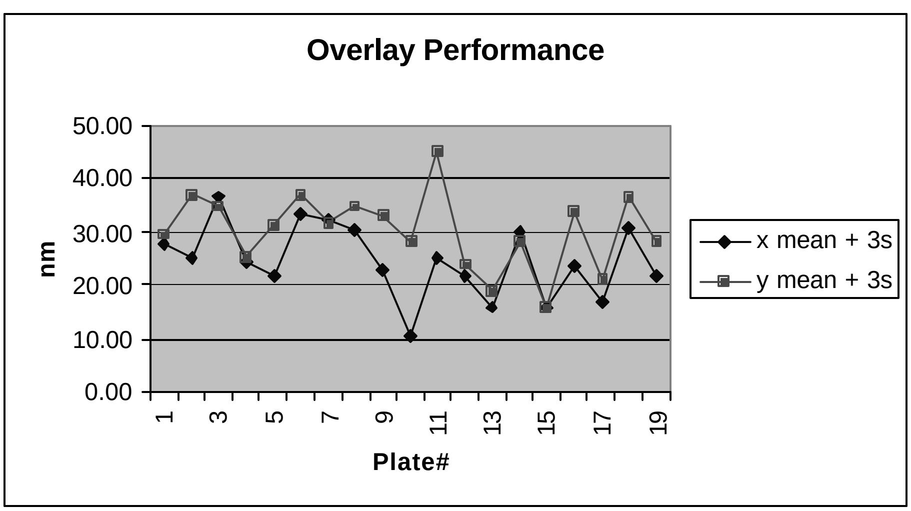
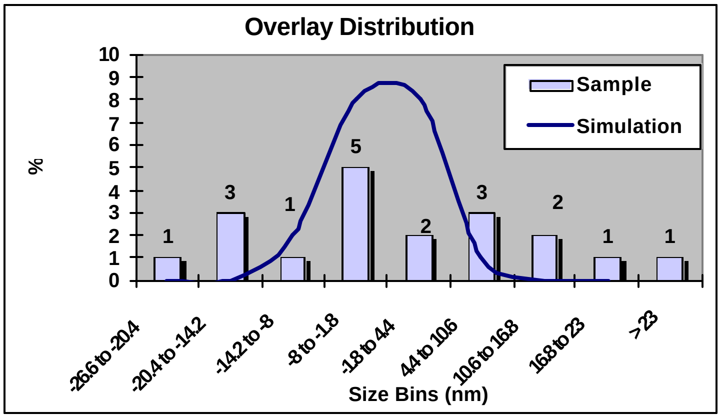


Fig. 6 Overlay plus 3s errors for each mask



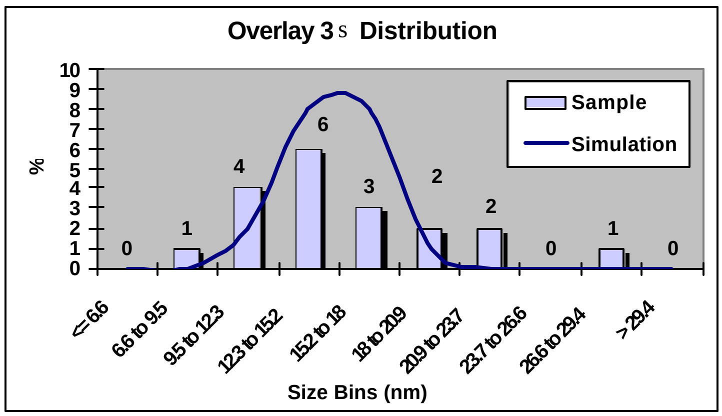


Fig. 7 Overlay and Overlay 3s error distribution

4 SIMULATION RESULTS AND DISCUSSION

4.1 Monte Carlo Simulation

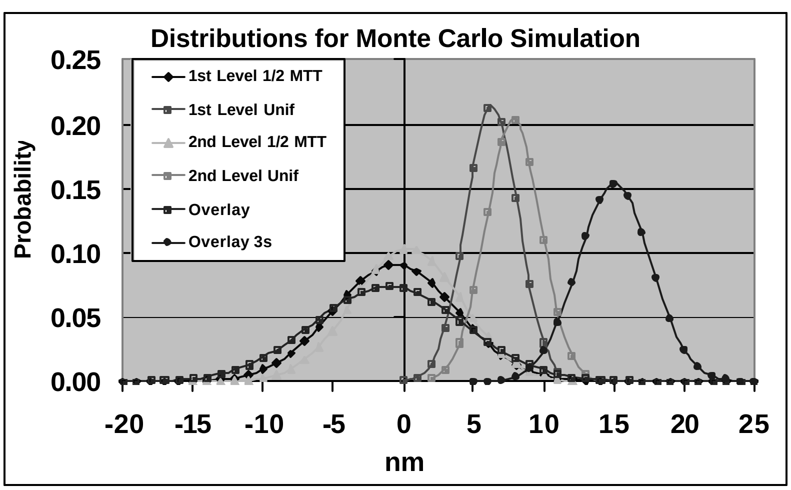
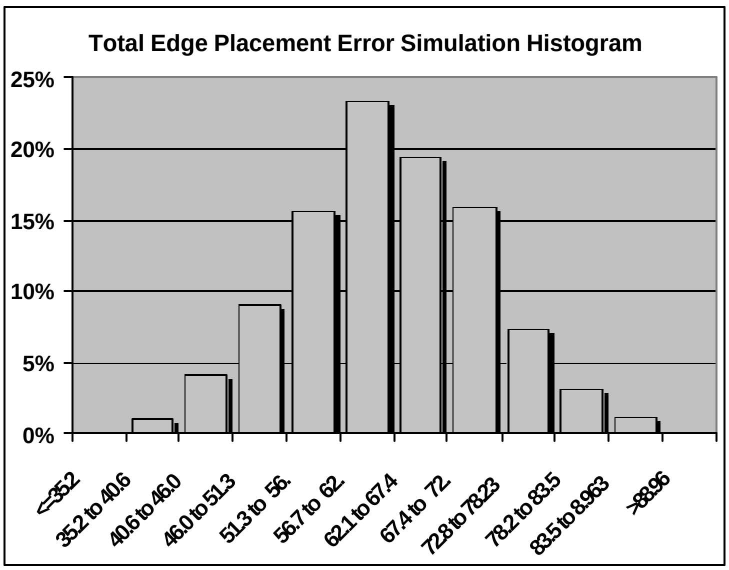


Figure 9 Distributions used for simulation

Having derived the required distributions, a Monte Carlo simulation was performed to estimate performance on a hypothetical two level AltPSM over a large number of trials. For the simulation, an Excel™ add-in package named Risk Analyzer™ from Macro Systems was used. Table 1 lists the constraints used for the distributions applied to each of the variables in equation (1). This table is a more detailed description of the distributions depicted in figures 4,5, and 7.

Input Variable	Minimum Allowed Value	10th Percentile	Mean Value	90th Percentile	Maximum Allowed Value	Distribution
1st Level 50KeV Tool ½MTT	-12.3	-6.2	-0.6	4.7	11.5	Normal
1st Level 50KeV Tool CD Uniformity	3.6	4.4	6.1	8.6	11.0	Normal
2nd Level Alta DUV Tool ½MTT	-11.0	-4.6	0.3	5.2	10.5	Normal
2nd Level DUV Alta Tool CD Uniformity	4.3	5.6	7.8	10.3	15.7	Normal
Overlay Mean	-26.6	-7.8	-1.1	5.9	23.0	Normal
Overlay Uniformity	7.0	10.9	15.2	18.5	24.0	Normal

Table 1. Summary of Distributions used for Input Variables



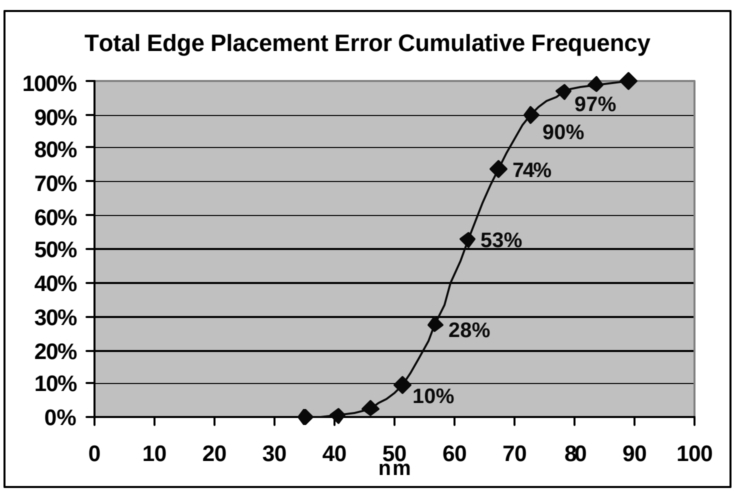


Figure 10. Monte Carlo simulation results

There were a total of 1000 individual simulations run using these distributions. Figure 10 summarizes the results. The cumulative frequency chart shows a total edge placement error of 72.8nm at a 90% capability level.

In order to guard band their model against phase defect generation during the glass etch step, Cheng[1], et al., stipulated that the total edge placement error calculated from equation (1) should be half the size of the feature being printed. While they cite the hidden phase edge-type alt-PSM as an example where this guard band is appropriate, they admit this is a worst-case situation. As an illustration, the capability from the Monte Carlo simulation has been compared to the International Technology Roadmap for Semiconductors (ITRS) nominal mask CD sizes for the next five years. The roadmap plots the expected nominal CD size by year of production. According to the most recent ITRS[2], 2005 is the first year of full production for 90nm designs, and 2007 is the first full production year for 65nm designs. The Monte Carlo simulation data show that using the current Alta4300D configuration as part of a two level alt-PSM manufacturing strategy should be suitable for 90nm designs. Beginning with the introduction of 65nm production in 2007, the capability falls to 80% and declines rapidly thereafter. This is shown graphically in figure 11.

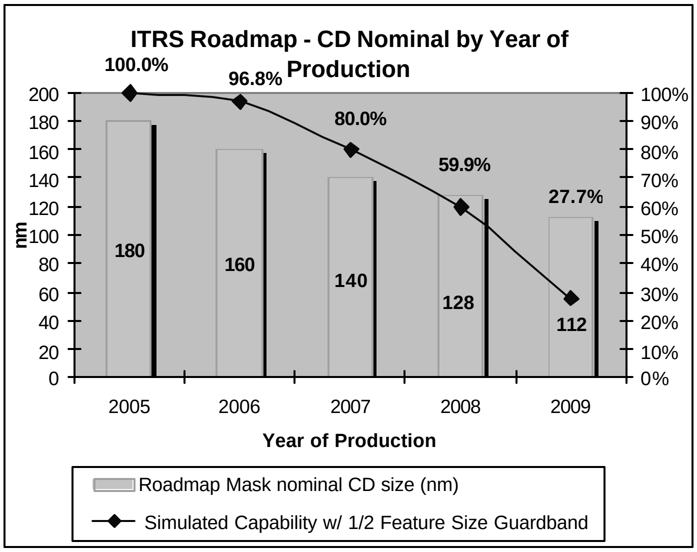


Figure 11. Simulated capability by year of production

Figure 12 is a Pareto chart of the average error for each variable in equation (1). The chart shows overlay uniformity errors as the largest contributor to overall edge placement in the simulation. When the overlay uniformity error is separated by first level litho tool (figure 13), the 50KeV tools show a tighter range. The reason is currently not understood, but may be due to the improved CD uniformity provided by the 50KeV tools on the alignment marks since the 1st level pattern placement of the Alta4300D is better than the 50KeV tools. Since the mean overlay uniformity is roughly the same as for the entire 19 plate population (15.6 for 50KeV 1st level vs. 15.4 for all) the impact on simulated capability is negligible (fig. 14). For the revised simulation shown in figure 14, the standard deviation of the distribution was estimated from the 50KeV overlay uniformity range. It is reasonable to assume the overlay uniformity the 50KeV tools exhibit is indicative of 65nm node production. The current Alta4300D configuration will not meet the CD requirements necessary for first level printing of 65nm designs.

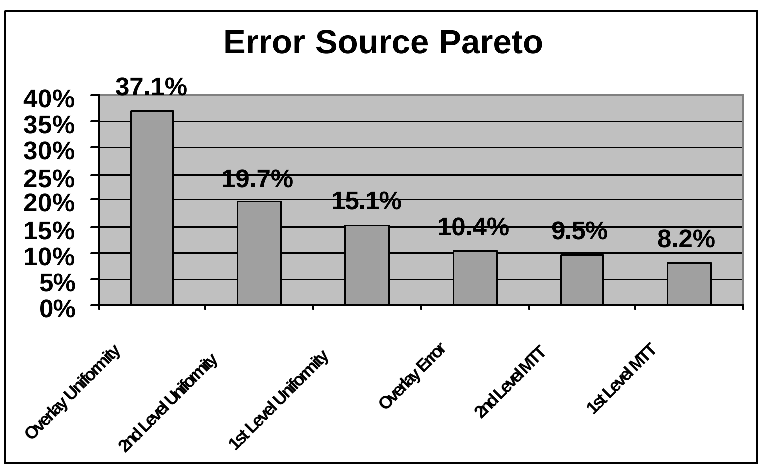


Figure 12. Total edge placement error Pareto

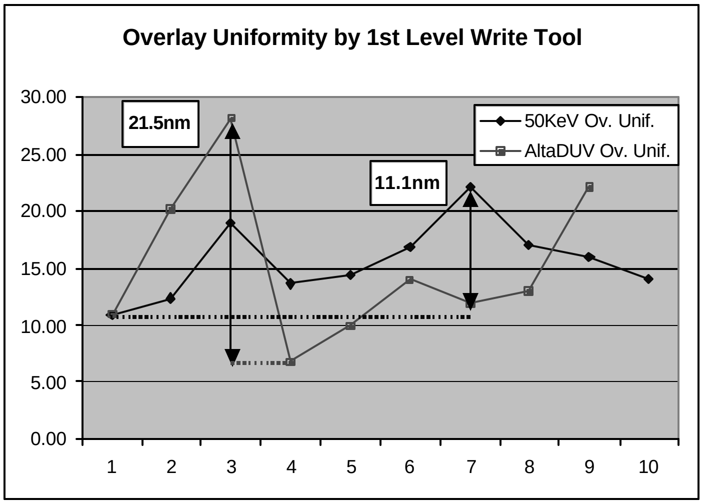


Figure 13. Overlay Uniformity by 1st Level Tool

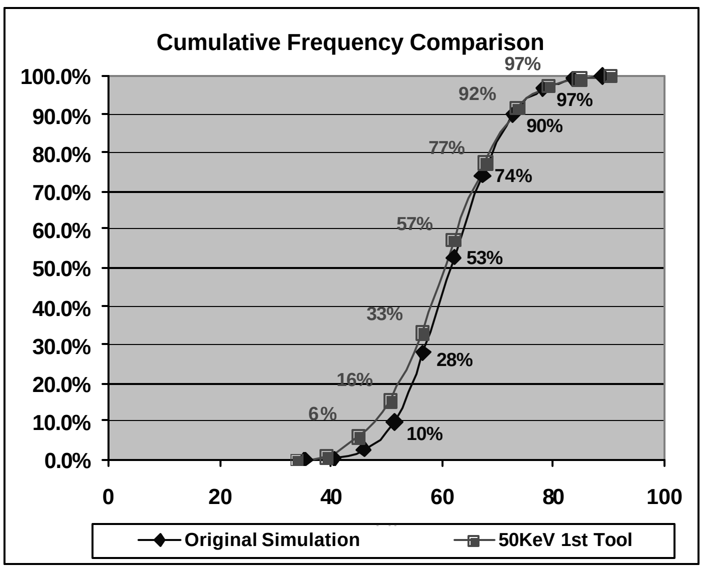


Figure 14. Modified Simulation

For the system to be ready to meet the needs of 65nm production under the total edge placement error guardband presented by Cheng[1], et. al., improvements will be needed to reduce overlay error. Several broad areas of investigation for reducing overlay uniformity errors on the Alta4300D are the following:

1. Improved alignment mark target capture techniques.
2. Improved regression techniques.
3. Improvements to the calibration of the alignment and printing optics.

5. SUMMARY

A Monte Carlo simulation was done to simulate the capability of the Alta4300D as a 2nd level write tool for alternating phase shift masks. The input variables were statistical distributions of CD and overlay metrics gleaned from manufacturing data on 19 embedded phase shift masks. The simulation shows:

1. The Alta4300D is a fully capable tool for 90nm phase shift production.
2. The tool is moderately capable for the first production year of 65nm production but declines precipitously in following years.
3. The largest error contribution to total edge placement of a two level printing using the Alta4300D is the overlay 3σ errors.

The following considerations should be taken into account:

1. It has been assumed that the AltaDUV MTT and uniformity taken from product mask chrome data will accurately model the 2nd level MTT and uniformity for an altPSM process.
2. Pattern fidelity is explicitly not considered as an error source.
3. The ½ feature size - total error guard band is a worse case example and may not be applicable to all classes of alternating PSM's.

6. ACKNOWLEDGEMENTS

AMTC is a joint venture of Infineon, AMD and DuPont Photomasks and gratefully acknowledges the financial support by the German Federal Ministry of Education and Research (BMBF) under Contract No. 01M3154A ("Abbildungsmethodiken für nanoelektronische Bauelemente". The authors wish to acknowledge Dr. Greg Hughes and Curt Jackson of Dupont Photomasks, Inc. for their advice on a number of technical issues.

7. REFERENCES

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