THE IMPLEMENTATION AND CHARACTERIZATION OF ADVANCED MIX-AND-MATCH LITHOGRAPHY

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Worldwide implementation of mix-and-match lithography is continuing to gain acceptance as a valuable strategy for reducing capital costs and increasing throughput productivity in semiconductor manufacturing. A large-field, 1X i-line stepper with moderate price and high productivity provides a cost-effective approach that complements high NA reduction steppers in a mix-and-match environment. This is especially true for highly competitive DRAM and ASIC manufacturing.

Successful implementation of mix-and-match lithography between different stepper designs requires consideration of the many unique system characteristics. This includes optimal field size utilization, field orientation on the wafer, prealignment matching between steppers, optical image orientation, and wafer global and local alignment targets for each stepper design. Hence, lithography tool flexibility is crucial in meeting the goal of mix-and-match over a variety of stepper designs.

A review of advanced mix-and-match lithography implementation with each major reduction stepper supplier is presented to detail the unique aspects for each system. This analysis is derived from actual semiconductor manufacturing applications.

Finally, in any lithography scheme where multiple steppers from the same or different manufacturers are being used, the total overlay performance must be characterized for optimal results. The total overlay performance has both correctable error contributions from grid sources, lens magnification, reticle alignment, and non-correctable error sources from higher order lens distortion, reticle stage errors and reticle pattern placement errors. An additional consideration is that 1X fields are presently twice the field size of advanced reduction steppers. Therefore, the application of traditional 1:1 overlay analysis techniques to such mix-and-match scenarios does not yield optimal results. To properly characterize and optimize a 2:1 matching scheme, it is necessary to consider the types of registration errors present and their sources.

1.0 Introduction

There is growing acceptance in the semiconductor industry that fabrication and equipment costs are becoming dominant issues in the economic viability of leading-edge semiconductor fabrication plants. The financial reasons for this are well understood and have been documented by several authors [1,2]. The cost of lithographic equipment, for example, has grown arithmetically, with lithographic tools for sub 0.5 micron resolution approaching 3 million dollars. This escalation of price has made a *mix-and-match* lithography strategy more compelling than ever. Advanced mix-and-match lithography utilizes lower cost, higher throughput steppers to expose the less critical levels in a process, while the higher resolution and more expensive lithography tool is used on critical levels [3,4,5].

Higher throughput for non-critical levels can be achieved by utilizing steppers with extremely high-speed stages or large lens field size, to reduce the number of exposure steps required to completely expose each wafer. However, this larger field size must be an integer multiple of the second lithography tools field size to take advantage of the potential reduction in exposure steps. For example, the Ultratech 2244i 1X stepper has a rectangular field size of 22 by 44 mm, which is twice the 22 by 22 mm square field size of a high NA 5X reduction steppers [6].

A typical cost-of-ownership example is a 16-megabit(MB) Dynamic Random Access Memory(DRAM) process with 23 lithography layers. Typically, there is an opportunity to pattern up to 15 layers of 0.8 micron resolution using this large-field 1X stepper in a mix-and-match strategy. This approach provides dramatic cost-of-ownership advantages over the use of more expensive, critical level lithography tool, on all of the levels, with a five-year cost-of-ownership savings of $70 million or more [1].

This paper describes the essential technical issues for an advanced mix-and-match lithography tool, and presents the results of applying such a system to mix and match with reduction lithography systems such as ASM, Canon and Nikon steppers. It shows that all the requirements of a successful mix-and match strategy can be met with 1X stepper technology, and that understanding and controlling the contributors to overlay are the dominant issue, for mix-and-match lithography.

1.1 Designing for Mix-and-Match Lithography

For a lithographic system to be useful in a mix-and match environment, several key performance parameters must be compatible with the reduction stepper(s) used for the critical levels. First, the majority of leading-edge production uses i-line lithography. It is clear that the 64MB generation of DRAM will be built predominantly with i-line lithography, and this may also extend to the 256MB DRAM. For this reason, the mix-and-match stepper should also be i-line for full compatibility with existing lithographic processes [7].

Resolution and depth-of -focus (DOF) are also important parameters in the design of a mix-and-match lithography system. In the case of a 16MB DRAM, examination of the processes of major semiconductor manufacturers reveals that approximately one third of the levels have resolution and/or overlay requirements that *necessitate* the use of a high numerical aperture (NA) reduction stepper. These are the critical levels, and for a 16MB DRAM, they typically have a minimum feature size of 0.5 to 0.8 microns. For the mix-and-match tool to be viable for 16MB DRAM, it should have a resolution of 0.8 microns or better. Large DOF of the mix-and-match stepper is also required for linewidth control over topography. This is especially true since the non-critical levels tend to be the back end levels, where topography is more severe. A comparatively low NA i-line optical design for the mix-and-match stepper alleviates DOF limitations. In fact, a 1X stepper with an i-line 0.32 NA lens design provides superior DOF to higher NA reduction steppers for resolution down to 0.8 microns [6].

Cost-of-ownership benefits are dramatically driven by stepper throughput, and hence field size or steps per wafer. Thus, a major consideration in the design of the mix-and-match stepper is availability of a large field size that can accommodate multiple fields from the reduction steppers. However, there is also a need for simultaneously maintaining the resolution, DOF and distortion specifications over this large field. In the case of a 1X stepper, a field size of 22 by 44 mm has been attained in lenses that meet these optical requirements. The 1X system can align and expose two high NA reduction stepper fields simultaneously.

Another important consideration is the alignment target strategy. All wafer targets are required to fit within the scribe lanes. At present, some manufacturers have scribe lanes of 80 microns in width. Wafer targets should be less than 80 microns in size. Finally, the mix-and-match stepper should be compatible in terms of throughput, mechanical interface, and communications protocol with track and other lithographic support equipment.

1.2 Mix-and-Match Implementation

In the implementation of mix-and-match between a 1X i-line stepper and 5X reduction steppers, there are several parameters that must be controlled to ensure smooth integration. These can be divided into the broad categories of dose matching, prealigner matching and overlay matching:

1.2.1 Dose Matching

To avoid confusion and increase consistency, many manufacturers match the dose control systems between steppers. The goal is to ensure that a specified dose on two different steppers produces the same linewidth on a developed wafer, while all other parameters are identical. Since each stepper manufacturer calibrates their own stepper’s dose control system, there are several reasons why a specified dose on one stepper model could give a different linewidth to the same dose specification on a different stepper type. For example, if a 1X stepper has a substantially broader exposure spectrum than the reduction steppers this will affect the amount of energy coupled in to the photoresist, and thus the resultant linewidth.

To support dose matching, the mix-and-match stepper should allow a calibration factor to be applied to the dose. In practice it has been found that a system level dose calibration factor is the best solution. The stepper user runs two exposure matrices (preferably on the same wafer), and then develops and inspects the wafer with an in-line SEM. The exact dose required for the target dimension would then be determined for each stepper as well, and a correction factor. This correction factor would then be entered in a look-up table in the stepper’s software. This technique has been used to match feature sizes to within ±1% between stepper types.

1.2.2 Prealigner Matching

Wafer prealignment is the process whereby the wafer is located in X, Y and theta on the wafer stage of the stepper. Prealignment is of particular importance in a mix-and-match environment since alignment target capture depends on how accurately the wafer is placed on the stage. If the first level of the process is exposed on a reduction stepper, then the mix-and-match stepper must prealign the wafer and repeatably capture the targets laid down by the reduction stepper.

Conversely, if the first level is exposed on the mix-and-match stepper, then the prealignment of the wafers must be accurate and repeatable enough for the reduction stepper to consistently capture the wafer alignment targets.

In practice, each stepper manufacturer has a different technique for wafer prealignment. While prealignment *repeatability* is well controlled, there are often consistent *offsets* between stepper types. For example, when a reduction stepper prints the first level, and the mix-and-match stepper must align to this level, it is common to find that the wafer centering is consistently offset by several hundred microns. For this reason, it is important that the mix-and-match stepper have the ability to apply system level prealignment offsets. These offsets in X, Y and theta allow the mix-and-match stepper to capture alignment targets on wafers generated on any other stepper type. This feature is essential for automatic operation in a production environment since it eliminates the need for operator intervention.

1.2.3 Overlay Matching

Overlay matching encompasses many aspects of system performance. The overlay requirements of each level must be weighed against the stepper specifications in deciding if a particular level may be exposed on the mix-and-match stepper with sufficient process latitude. The parameters to be considered for overlay are as follows:

1.2.3.1 Image Orientation and Magnification

Both image orientation and image magnification must be accounted for in any mix-and-match scheme. Figure 1 shows the orientation of images printed on Ultratech steppers, and on a reduction stepper relative to the reticle image. The second issue is mask-to-image magnification, which, can vary between 5X and 1X magnification. These resulting image orientation and magnification differences are due to the inherent lens designs for each stepper. Thus, it is necessary to understand both for successful reticle manufacturing. The common approach is to compensate for image orientation and magnification differences after circuit design and layout on the data tapes used for mask manufacturing.

1.2.3.2 Wafer Orientation and Field Utilization

The need to determine optimal wafer orientation and field utilization in mix-and-match lithography is essential due to the inherent lens field sizes for each stepper [5]. For each specific die size, this requires calculating the required field size and shape of each stepper. The reduction stepper maximum field sizes are commonly 22 x 22 mm square, while the Ultratech 1X lens field area increases for rectangular shapes such as 22 x 44 mm.

1.2.3.3 First Level Placement

In many processes, the first lithographic level is classed as non-critical for resolution. However, since subsequent levels must align to the first level, it is important to ensure that the first-level grid is placed with sufficient accuracy and precision. This is especially important when using a 2:1 mix-and-match strategy since the 1X stepper will be unable to fully correct for errors in the first level that affect the relative positions of adjacent fields. Figure 2 illustrates the case of first-level field rotation. The parameters for first-level placement are listed in Table 1 and shown in Figure 3. The effect of these five parameters on 2:1 matching is also given. In most cases, the reduction stepper is used to define the first level in a process to ensure the best possible grid.

1.2.3.4 Lens Distortion

In deciding which levels may be exposed on the mix-and-match system, the lens distortion must be included in the overlay budget. The pattern of the distortion vectors is critical. These patterns are frequently modeled into standard classes of errors. The types of errors are described in details below.

1.3 Overlay Modeling

To obtain maximum overlay performance when using multiple lithographic systems, each system must be calibrated or matched to the other systems [8,9]. Extensive analysis and modeling of overlay errors has been developed for the matching of the same model or similar systems. These overlay errors can be divided into two categories: intrafield and interfield systematic sources. The intrafield sources (dX and dY) model the overlay error sources within one field [10,11,12]:

$$dX(x,y) = T_{ix} + M_x x - \Theta_i y + \Psi_x xy + \Psi_y x^2 + D_3 x(x^2+y^2) + D_5 x(x^2+y^2)^2 \quad (1)$$

$$dY(x,y) = T_{iy} + M_y y + \Theta_i x + \Psi_y xy + \Psi_x y^2 + D_3 y(x^2+y^2) + D_5 y(x^2+y^2)^2 \quad (2)$$

where x and y are the coordinate location inside the field. For these equations, the linear terms include die shift in x (T_{ix}) and y (T_{iy}), magnification in x (M_x) and y (M_y) and rotation (Θ_i). The nonlinear terms include trapezoid in x (Ψ_x) and y (Ψ_y), third order (D_3) and fifth order (D_5). The interfield sources (E_X and E_Y) model the grid stage motion errors across the wafer [11,12]:

$$E_X(X,Y) = T_{gx} + S_X X - \Theta_g Y - \Phi Y \qquad \textbf{(3)}$$

$$E_Y(X,Y) = T_{gy} + S_Y Y + \Theta_g X \qquad \textbf{(4)}$$

where X and Y are the coordinate location on the wafer. The interfield sources include translation error in X (T_{gx}) and Y (T_{gy}), the wafer scaling magnification in X (S_X) and Y (S_Y), wafer rotation (Θ_g), and wafer orthogonality (Φ).

These intrafield and interfield models are based on the field sizes between the two lithography systems being identical, which implies 1:1 interfield matching. However, it has already been established that mix-and-match lithography frequently utilizes n to 1 field matching. The application of 1:1 registration analysis techniques to such mix-and-match scenarios does not yield optimal overlay results. A interfield grid model specifically for 2:1 field matching has been developed [13].

However, equations (1) through (4) can still be used to identify the correctable and non-correctable sources of overlay error that impact overlay performance in mix-and-match lithography. Table 2 lists the common sources. The items in italic designate correctable components. It is important to note that these components are not mathematically independent. The components can be grouped into two categories: separable and inseparable. Components that are inseparable describe errors that are fully correctable by adjustments at either stepper. In contrast, separable components require independent corrective action on both steppers to achieve zero overlay error [13].

Optimization of overlay for mix-and-match lithography can use several techniques since multiple systems are involved. Two complementary optimization techniques are frequently utilized, the first assumes corrective action only on the mix-and-match stepper aligning to a level patterned on the reduction stepper. A more sophisticated approach requires corrective actions on both the mix-and-match and reduction steppers [13]. Both of these techniques can be applied to mix-and-match experimental data to suggest a specific set of corrective actions that could be applied to both steppers. A three step scheme can be invoked to apply the suggested corrections, measurement of the resulting overlay, and reanalyze the overlay performance.

2.0 Mix-and-match Characterization

2.1 Lithography Equipment

In this study, the 2:1 field matching scheme utilizes an Ultratech Stepper Model 2244i as the mix-and-match stepper. The 2244i is based on the 1X Wynne-Dyson Hershel lens design applied to i-line lithography with a field size of 22 x 44 mm [6]. The projection lens system consists of five optical elements arranged in two groups. The lens is folded, symmetrical, and catadioptric which results in unitary magnification. This inherently simple design is free from many of the distortion errors inherent in more complicated reduction lens designs. The 2244i lens employs 0.32 numerical aperture i-line optics with a broadband of illumination of 20 nanometers (355 to 375 nanometers).

2.2 Mix-and-match Alignment Description

All of the mix-and-match examples in this study use the reduction stepper to pattern the base layer (level 1). Level 2 is then patterned on the 2244i using alignment targets placed on level 1. For each stepped position, the 2244i simultaneously patterns two horizontally spaced reduction stepper fields. For example, a set of four mix-and-match fields matched to a set of eight reduction fields would overlay as shown in Figure 4. Implicit in the mix-and-match field grid corrections are the contributions from both the left and right reduction fields. This occurs because the 2244i is simultaneously sampling two alignment targets per mix-and-match field, one from the left reduction field and one from the right reduction field.

Alignment signal detection is facilitated by scanning alignment targets at each Enhanced Global Alignment (EGA) field location [6]. Typically, from five to nine EGA field locations are sampled on the wafer for grid correction over the entire wafer. After sampling the EGA sites, the 2244i calculates grid corrections based on the grid model equations (3) and (4), which are applicable for the mix-and-match field stepper coordinate system. Standard linear regression techniques are then applied and the derived grid corrections are utilized to position all the exposure field locations. During both EGA and exposure, the 2244i was configured for local focus and image leveling field, referred to as tilt correction, to compensate for wafer flatness irregularities.

2.3 Overlay Characterization

Optimization of total overlay in a multiple stepper environment requires attention to the various sources of error as described in section 1.3. Typically, in a manufacturing application the lithography engineer would apply corrections to provide optimum overlay performance.

To properly characterize the total overlay performance of the 2244i to two reduction fields, it is necessary to quantify intrafield, interfield and interwafer error contributions. This involves extensive overlay measurements per field, multiple fields per wafer and multiple wafers. In addition, sampling of overlay measurements in fields out to the full extent of the wafer is essential to properly determine the wafer grid source errors as shown in equations (3) and (4). Since there are six source terms for determination, this requires sampling a minimum of three fields. Any additional fields will provide an estimation of non-systematic grid errors. In all of these case studies, a minimum of 10 fields per wafer are used.

Intrafield effects contribute to the total overlay as described in equations (1) and (2). The magnitude of higher order distortion and lens magnification terms increase with radial position from the center of the lens field. Consequently, it is necessary to sample overlay out to the full extent of the field. In the following case studies, a KLA 5700 Coherence Probe Microscope is used for overlay measurements.

2.4 Mix-and-match Examples

The following examples describe mix-and-match lithography with the Ultratech 2244i and each major reduction stepper supplier. This information is presented to detail the unique aspects for each system. The analysis is derived from actual semiconductor manufacturing applications.

2.4.1 Ultratech 2244i to Nikon 9ic

In this example, the mix-and-match overlay performance of the Ultratech 2244i to a Nikon 9ic reduction stepper is characterized. A field size of 20.2 by 40 mm was used for the Ultratech 2244i with a corresponding Nikon field size of 20.2 by 20 mm. The lithography process consists of alignment of a polysilicon level on the 2244i to a field oxide level patterned on the Nikon. Figure 5 illustrates the field layout scheme, where nine overlay measurements per Nikon field were collected. The wafer layout consists of 32 Nikon or 16 2244i steps per 6-inch wafer as shown in Figure 6. Overlay was measured on all the 2244i fields.

Figures 7 and 8 illustrate histograms of the total overlay error for 2:1 mix-and-match of the Ultratech 2244i and a Nikon 9ic stepper. The overlay results are based on 18 measurements per field, 16 fields per wafer, over seven wafers for a total of 2016 measurements. The mean offsets are -0.066 and -0.017 microns for *x* and *y* respectively. The 3 sigma overlay variations are 0.302 and 0.278 microns for *x* and *y*. These results represent non-optimized total overlay, since there was no attempt to apply corrections to either the mix-and-match or reduction field stepper.

A major contributor to the alignment errors is the Ultratech to Nikon lens matching. Figure 9 displays the KLA modeled lens and reticle matching corrections between the systems based on KLASS III intrafield modeling. The major modeled distortion correction is a *y* reduction. It is also apparent that the modeled distortions for the left and right halves of the 20.2 x 40 mm field are similar, implying the reduction lens is a major source of matching error.

Table 3 shows an Analysis of Variance (ANOVA) of the sources of overlay error. The sources studied are wafer number, field location and test site location in the field. While all three sources are statistically significant, the coefficients have different magnitudes. For both *x* and *y* overlay error the largest variation is from wafer-to-wafer. This type of analysis can lead to process improvements to enhance mix-and-match lithography.

2.4.2 Ultratech 2244i to Canon 2500i2

The second example of 2:1 mix-and-match is an Ultratech 2244i and Canon 2500i2 stepper on 8-inch wafers. In this example, the lithographic process is alignment of a nitride dielectric level on the 2244i to a metal level patterned on the Canon stepper. Figure 10 illustrates the field layout measurement scheme where 33 overlay measurements per Canon field were collected. This includes sampling of overlay measurements out to the full 22 mm extent of the reduction field. The 8-inch wafer layout consists of a total of 48 Canon fields or 24 2244i fields per wafer as shown in Figures 11a and 11b. A total of 10 Ultratech fields were measured on each wafer at the locations designated by a P as shown in Figure 11a.

Histograms of the total overlay are depicted in Figures 12a and 12b for a data set consisting of 66 measurements per field, 10 fields per wafer, over three wafers for a total of 1980 measurements. The mean offsets are -0.077 and 0.06 microns for *x* and *y* with a 3 sigma variation of 0.360 and 0.300 microns for *x* and *y*. The visual appearance of both histograms suggests a non-normal behavior. This was verified by a Shapiro-Wilk normality test of the *x* and *y* distributions as shown in Table 4. Thus, 3 sigma terminology is misleading as an indicator of 99.7% overlay performance. A better indicator is the 99.5% range based on quantiles, which are 0.292 and 0.267 microns for *x* and *y*. As in the previous example, these results represent non-optimized total overlay since there was no attempt to apply corrections to either the mix-and-match or reduction field stepper.

2.4.3 Ultratech 2244i to ASM 5500/80

The last example is 2:1 mix-and-match of the Ultratech 2244i and an ASM 5500/80 stepper on 6-inch wafers. In this example, the lithographic process is alignment of a nitride dielectric level on the 2244i to a metal level patterned on the ASM stepper. A field size of 20.9 by 41.8 mm was used for the Ultratech 2244i with a corresponding ASM field size of 20.9 by 20.9 mm. Figure 13 illustrates the field layout measurement scheme for this example, where 17 overlay measurements per ASM field were collected. The 6-inch wafer layout consists of 36 ASM or 18 2244i steps as shown in Figures 14a and 14b respectively. A total of 12 Ultratech fields were measured on each wafer at the locations designated by a P as shown in Figure 14a.

Histograms of the total overlay are presented in Figures 15a and 15b for a data set consisting of 17 measurements per field, 6 fields per wafer, over 21 wafers for a total of 4158 measurements. Summary statistics for this lot are listed in Table 5, which includes all interwafer, intrawafer, and intrafield error sources. The 3 sigma total overlay results for *x* and *y* respectively are 0.265 and 0.305 microns. Application of a KSL test for normality shows that the *x* and *y* distributions are non-normal. Again, 3 sigma terminology is misleading as an indicator of 99.7 % overlay performance. A better indicator is the 99.5% range based on quantiles, which is 0.188 and 0.272 microns for *x* and *y* respectively. In this case the 3 sigma the *x* and *y* values indicate a larger 99.7% number than those based on quantiles.

3.0 Conclusions

With the continued escalating costs of advanced lithography equipment for the semiconductor industry, the advantages of mix-and-match lithography as a cost control measure are gaining worldwide recognition. A stepper designed for mix-and-match must be compatible with a wide range of reduction steppers. Although mix-and-match requires some careful engineering, it is straightforward and provides dramatic cost-of-ownership savings.

This paper has examined the performance of the Ultratech 2244i as a mix-and-match lithography tool with each major reduction stepper supplier. The non-optimized results for all three cases are summarized in Table 6:

Stepper	X Mean	X 3 Sigma	Y Mean	Y 3 Sigma
Nikon 9ic	-0.006	0.302	-0.017	0.278
Canon 2500i2	-0.077	0.360	0.006	0.300
ASM 5500/80	-0.086	0.265	0.170	0.305

Table 6: Summary statistics for the Ultratech 2244i as a mix-and-match lithography tool.

These results could be improved through the optimization of grid and intrafield lens corrections for both the narrow and widefield steppers. Investigations are in progress to implement these corrections. Preliminary results suggest a residual 3 sigma error of approximately 0.250 microns [13]. The mean translation errors will be simultaneously reduced through these corrections, which will further reduce the mean plus 3 sigma, or total overlay error.

An additional approach to predict the optimized total overlay error for 2:1 mix-and-match lithography is to use a Root Mean Square (RMS) analysis. Previous RMS analysis of the 3 sigma overlay performance using published stepper specifications also indicate 0.250 micron capability [14]. As stepper specifications and optimization techniques improve, the total overlay error will continue to decrease.

4.0 References

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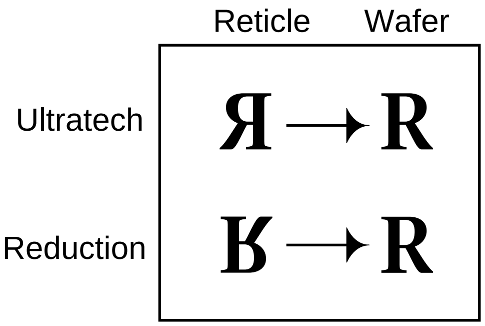


Figure 1: Orientation of images printed on Ultratech and leading reduction steppers.

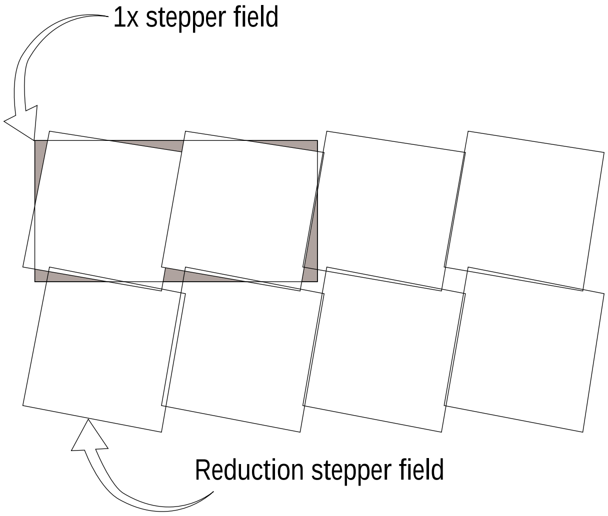


Figure 2: Effect of First Level Field Rotation on 2 to 1 Mix-and-Match

Parameter	Source of Error	Remarks
X Grid Magnification or X(x)	Stage Stepping	
Y Grid Magnification or Y(y)	Stage Stepping	No effect on 2 to 1 field matching
X Grid Skew or X(y)	Stage Stepping/ Mirror ortho.	No effect on 2 to 1 field matching
Y Grid Skew or Y(x)	Stage Stepping/ Mirror ortho.	No effect on 2 to 1 field matching
Field Rotation	Reticle Rotation	
Grid Rotation	Stage Stepping/ Rotation	

Table 1: Sources of Grid Error

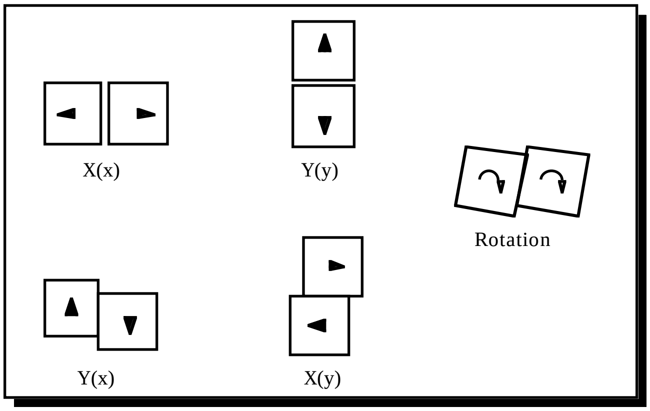


Figure 3: Possible Errors in First Level Placement

Sources of Overlay Error	Components
Staging Corrections for 2244i	*x and y scale* *rotation* *orthogonality*
Staging Corrections for 5X stepper	*x and y scale* *rotation* *orthogonality*
Reticle Sources for 2244i and 5X	different reticle manufacturing systems
5X Lens and Reticle Stage Corrections	*lens magnification* *reticle rotation* reticle platen tilt *reticle offset*
2244i Lens and Reticle Stage Corrections	*reticle rotation* *reticle platen tilt* *reticle offset*

Table 2: Correctable and non-correctable sources of error that impact overlay performance in mix-and-match lithography.

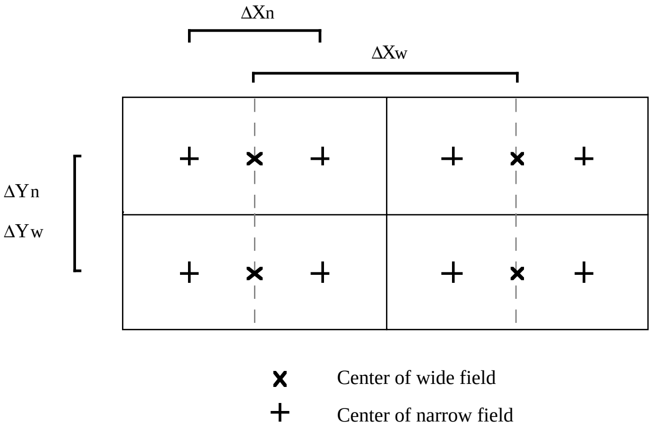
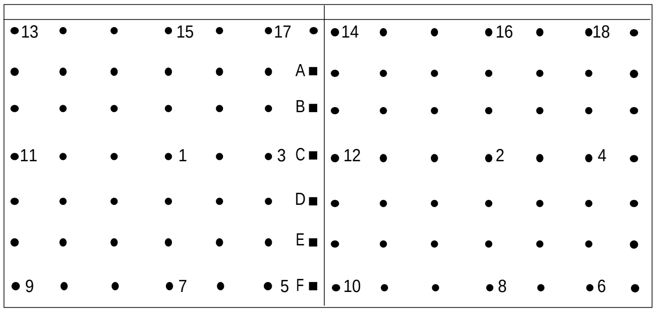


Figure 4: Four mix-and-match fields matched to eight reduction fields for horizontal 2:1 field matching.



● KLA structures (1 to 18) measured over the 20.2 x 40 mm field for quantifying 2244i to Nikon overlay

■ KLA overlay sites for measuring Nikon blindstepping performance of adjacent fields

Figure 5. 2:1 Field layout for overlay measurements of 2:1 field matching of the Ultratech 2244i to Nikon 9ic.

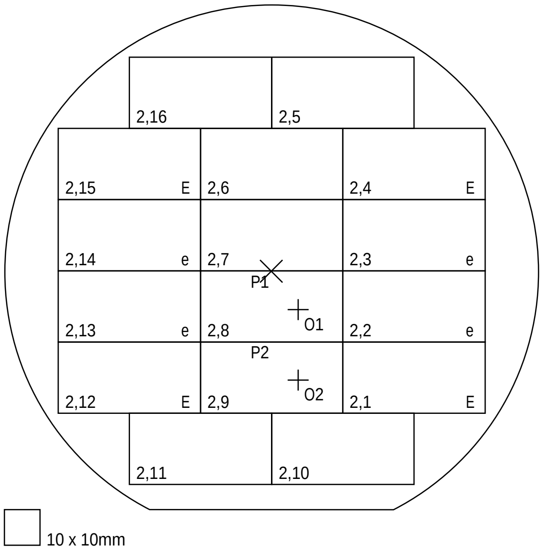


Figure 6. Wafer layout for 2:1 field matching of the Ultratech 2244i to Nikon 9ic

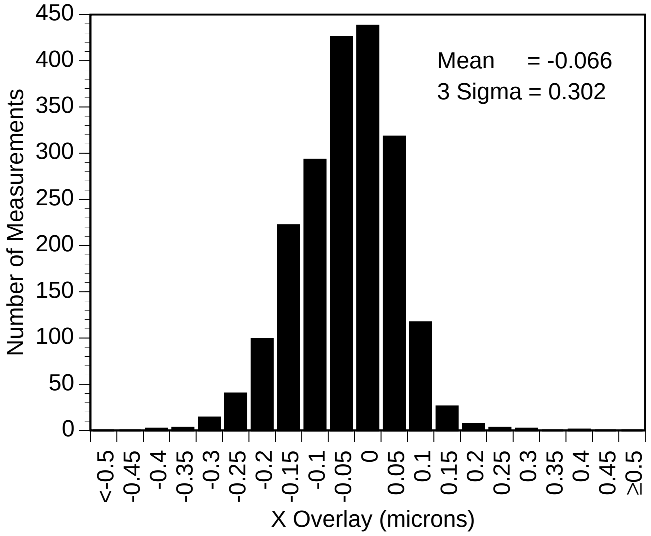


Figure 7: Histogram of X overlay error for the 2:1 field matching of the Ultratech 2244i to Nikon 9ic.

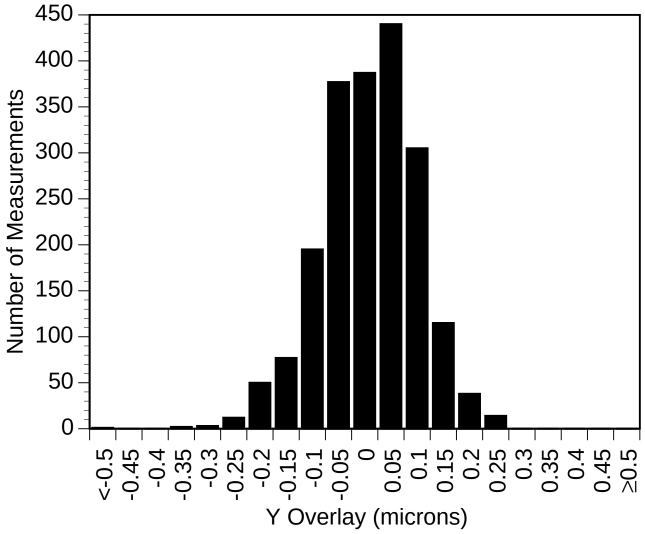


Figure 8: Histogram of Y overlay error for the 2:1 field matching of the Ultratech 2244i to Nikon 9ic

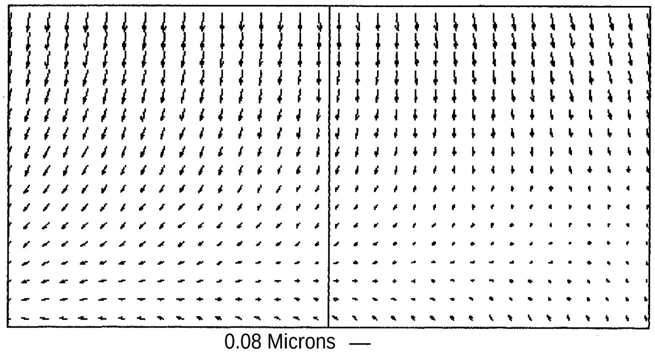


Figure 9: KLA modeled lens and reticle matching corrections between the Ultratech 2244i and Nikon 9ic

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Wafer	7	35.098	5.014	574.398	.0001
Field	15	6.099	.407	46.581	.0001
Test Site	17	4.390	.258	29.584	.0001
Residual	2263	19.754	.009		

Dependent: X Overlay Error

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Wafer	7	7.297	1.042	81.725	.0001
Field	15	.595	.040	3.111	.0001
Test Site	17	7.465	.439	34.429	.0001
Residual	2263	28.865	.013		

Dependent: Y Overlay Error

Table 3: Overlay Analysis of Variance for mix-and-match of the Ultratech 2244i and Nikon 9ic steppers.

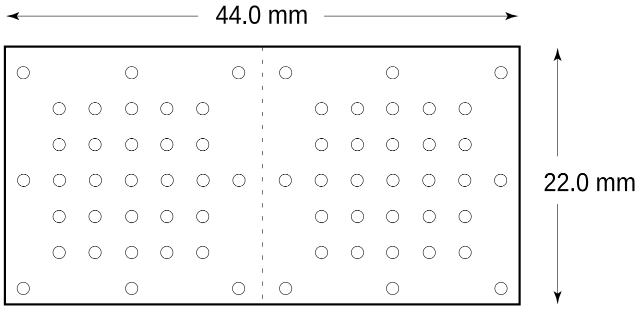


Figure 10. 2:1 Field layout for overlay measurements of 2:1 field matching of the Ultratech 2244i and Canon 2500i2 steppers.

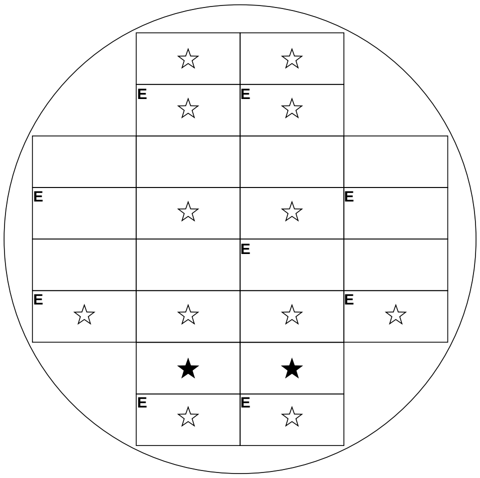


Figure 11a: Wafer layout for the Ultratech 2244i used in the Canon mix-and-match study.

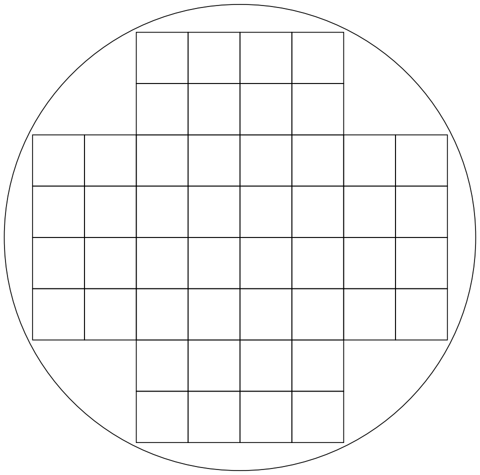


Figure 11b Wafer layout for the Canon reduction field stepper.

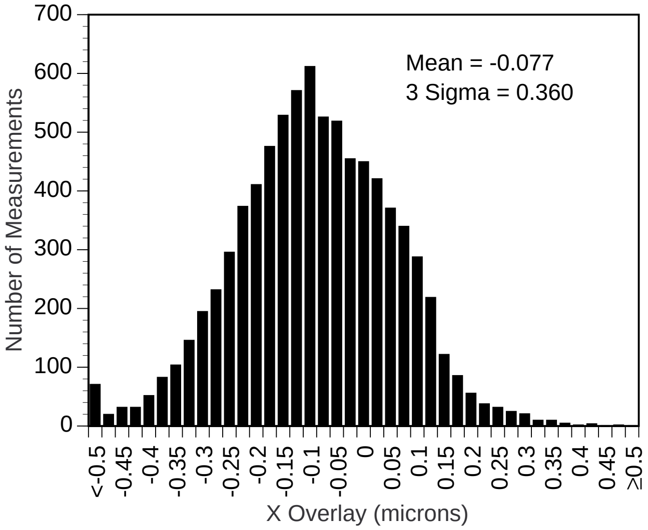


Figure 12a: Histogram of X overlay error for the 2:1 field matching of the Ultratech 2244i to Canon 2500i2.

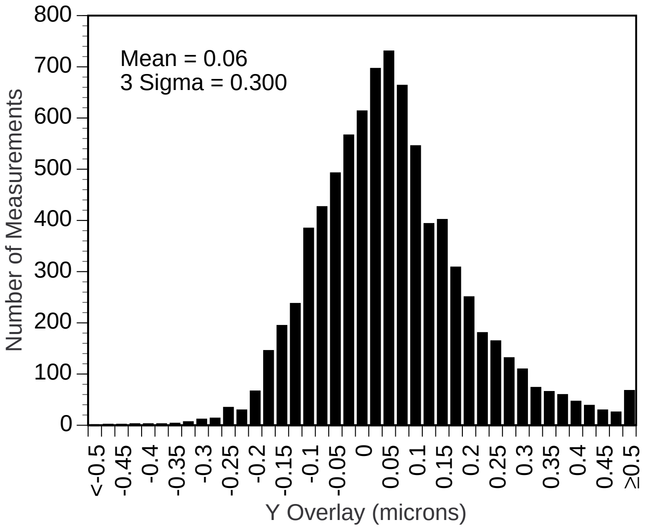


Figure 12b: Histogram of Y overlay error for the 2:1 field matching of the Ultratech 2244i to Canon 2500i2.

Test Lot (1964 Measurements)	Mean	3 Sigma	Shapiro-Wilk W	W Test Prob. < W	99.5% Range
X Data	-0.077	0.360	0.978	0.000	0.292
Y Data	0.006	0.300	0.988	0.574	0.267

Table 4: Summary statistics for three wafers the Canon 2500i2 mix-and-match lot.

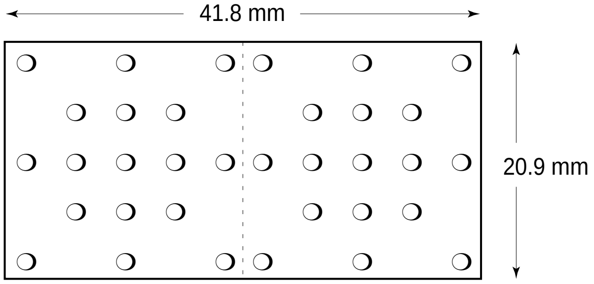


Figure 13 Field layout for 2:1 field matching example three.

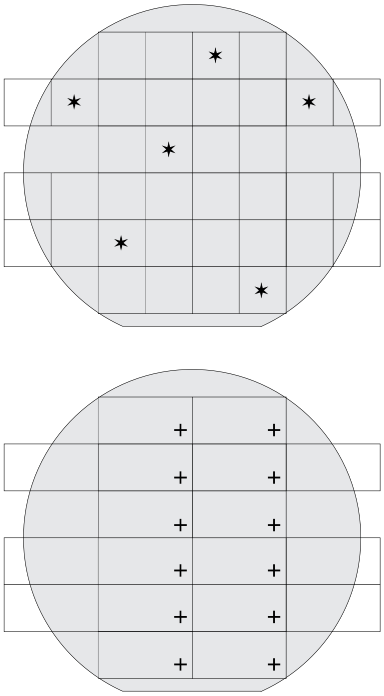


Figure 14a and 14b: 2:1 wafer layout for ASM and Ultratech fields in example three.

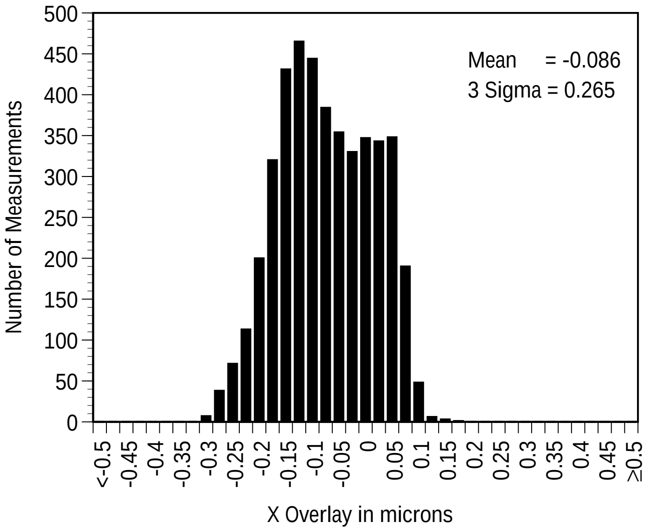


Figure 15a: Histogram of X overlay error for the 2:1 field matching of the Ultratech 2244i to ASM 5500/80.

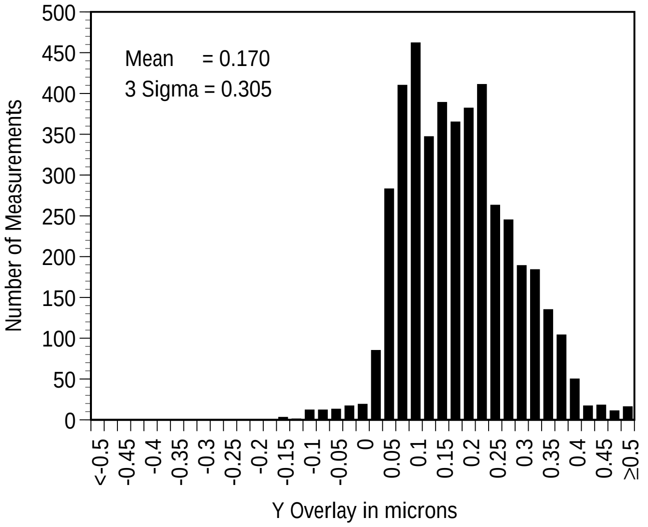


Figure 15b: Histogram of Y overlay error for the 2:1 field matching of the Ultratech 2244i to ASM 5500/80.

Silicon Lot (4443 Measurements)	Mean	3 Sigma	Normality KSL Test	99.5% Range
X Data	-0.086	0.265	0.0531	0.188
Y Data	0.170	0.305	0.0526	0.272

Table 5: Summary statistics between the Ultratech 2244i and the ASM 5500/80.