New Overlay Pattern Design for Real-time Focus and Tilt Monitor

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ABSTRACT

The reduced depth of focus (DOF) caused by higher numerical aperture (NA) is making the accuracy of best focus measurement increasingly important. A new overlay pattern is developed herein to precisely measure the best focus of lithographic tools. Specially designed "bar-in-bar" (BIB) was employed to obtain the best focus by using the opposite shifting direction of inner and outer bars when defocused. The inner and outer bars are composed of various pattern sizes. When defocused, the shrinkage of the smaller patterns is more significant than that of the larger patterns, thus causing the center of gravity to shift. The distribution and pattern sizes are optimized to obtain high reproducibility and sensitive position shifting for various defocus conditions.

Employing the special BIB pattern, the best focus, tilting and field curvature can be easily measured via the conventional overlay measurement tool. By adding the special BIB to the scribe lanes of the production wafers, the best focus and tilting of the stepper can be obtained when measuring a layer-to-layer overlay shift, and can then be fed back to the stepper as a reference for following processing wafers.

Keywords: Real-time process control, bar-in-bar (BIB), focus, tilt

1. INTRODUCTION

Because the depth of focus (DOF) of advanced lithographic tools is decreasing, it is becoming more important to accurately determine the best focus position. Many techniques have been developed for measuring the best focus.[1-3] One traditional focus measurement technique is to expose a focus energy matrix (FEM) wafer, where each exposure field employs different focus and energy offsets. After developing the wafer, the best focus can be revealed at the selected energy by a scanning electron microscope (SEM). However, recent advances in photoresist (PR) have made it difficult to determine the best focus through the SEM measurement of PR linewidth, because PR maintains almost the same linewidth over a wide defocus range. The phase shifting mask (PSM) can quickly and accurately measure the best focus by employing an overlay measurement system.[4] However, this pattern can not be drawn in binary mask, which is less costly than PSM mask.

In *Process Control and Diagnostics*, Michael L. Miller, Kaihan A. Ashtiani, Editors,
Proceedings of SPIE Vol. 4182 (2000) • 0277-786X/00/$15.00

A specially designed bar-in-bar (BIB) pattern is introduced herein to measure the best focus of lithographic tools. The BIB pattern was drawn on a conventional chrome binary mask to translate focus errors into easily measurable overlay shifts on the printed resist pattern. This pattern can also be inserted in the scribe lanes of the real production mask to monitor the focus and tilt of the steppers in real-time.

2. CONCEPT OF BIB PATTERN

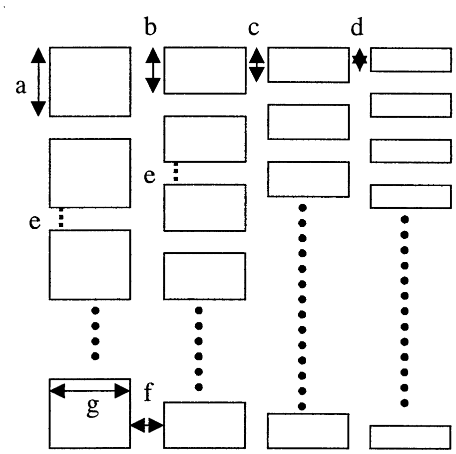
The specially designed BIB pattern was employed to measure the best focus by using the opposite shifting direction of the inner and outer bars under defocus. Figure 1 displays the concept of the specially designed BIB pattern. The center-to-center shift (this shift will also be called the "overlay shift" in the following description) of the inner and outer bars, which are mirrored to each other, under various focus setting can be easily measured by the off-line overlay measurement tools. Five different patterns, which comprise the bar "***L***" of Fig. 1, are illustrated in Fig. 2 as an experiment. These BIB patterns were exposed by the FEM method to reveal energy dependency of overlay shift. The DUV stepper has a 0.57 NA lens, and the PEB was performed at 110°C for ninety seconds. The resist films were developed in a 2.38-wt% tetramethylammonium hydroxide (TMAH)-based developer for sixty seconds.

Figure 3 displays the overlay shift of the five different BIB patterns shown in Fig. 2. Clearly, only pattern (e) in Fig. 2 responds well to the defocus. The overlay shift performance of patterns (a)~(d) is not good for the focus monitor, possibly because the asymmetric design of these patterns are not sufficiently sensitive during the defocus. However, using a polynomial equation to describe the overlay shift of pattern (e) and accurately determine the best focus is not easy. Therefore, a split table is generated to test the performance of this pattern. Table 1 lists five combinations of different sizes, while Fig. 4 illustrates the measured overlay shifts.

Clearly, a second order polynomial equation can fit the behavior of combination 3 well. Therefore, the best focus can be determined by taking the derivative of the fitting curve, and is located where the derivative is zero. Owing to the performance of this pattern, it was chosen as the focus monitor pattern.

Table 1 Split table of BIB pattern (Unit: μm)

	1	2	3	4	5
a	0.4	0.3	0.22	0.35	0.25
b	0.35	0.25	0.2	0.3	0.22
c	0.3	0.22	0.17	0.25	0.2
d	0.25	0.2	0.15	0.22	0.17
e	0.2	0.2	0.2	0.2	0.2
f	0.1	0.1	0.1	0.2	0.2
g	0.4	0.4	0.4	0.4	0.4
W	1.9	1.9	1.9	2.2	2.2



3. EXPERIMENTAL RESULT

Figure 5 displays the overlay shift of the BIB pattern combination 3 under various energy levels. Exposure energy ranges from 3.3 to 5.6 times E_0, where E_0 is the energy to clear (12 mJ/cm^2 in this work). The second order polynomial equation fits the experimental results best when the exposure energy is about 49 mJ/cm^2. The overlay shift is more sensitive to the distance from the best focus when the exposure is lower. The curve is distorted when the energy is continuously lowered, while increasing the energy flattens the curve and decreases the sensitivity to the focus shift. However, the minimum overlay shift is clearly located at the same position for both higher and lower energy conditions. Restated, the second order polynomial equation can still fit the distorted experimental result and obtain an accurate best focus value of the stepper.

Figure 6 illustrates the FEM result of 0.2 μm isolated contact hole, as well as the overlay shift of the special BIB. Three different levels of exposure energy were employed to expose the defocused contact hole and BIB pattern. Based on the criterion of ±10% target CD, the DOF and best focus can be determined for different energy levels. Simultaneously, the best focus can also be determined by the BIB pattern. The good correlations between these two results demonstrate the agreement between them.

Figure 7 presents the SEM pictures of the BIB pattern of the two focus levels. The small cavities observed around the best focus become rounded when the wafer moves away from the best focus. Due to the light diffraction, the image becomes blurred and overlaps with adjacent patterns, thus rounding the edge of the bar. Because the overlay measurement tools take the center of gravity of the bar, the small cavities will not influence the measurement results.

From the previous derivation, it is clear that the special BIB can be employed to precisely determine the best focus of lithographic tools. To further verify the behavior of the BIB patterns, the simulation program PROLITH/2 was employed to acquire the aerial image profile. Figure 7 displays the partial aerial image of the BIB bar for best focus (F*) and defocus (F* + 0.8 μm). Running the simulation program obtains the center position of each bar under various focus settings, and thus the overlay shift. Figure 8 illustrates the overlay shifts measured by metrology tools and those calculated by simulation results. The agreement between these two results confirms the validity of the focus monitoring pattern proposed herein.

4. APPLICATIONS

Obviously, the special BIB pattern can be employed to measure the best focus of the lithographic tools. By inserting the BIB at four corners of the exposure field, the tilt of the leveling system of stepper can be monitored. Furthermore, increasing the BIB patterns at the scribe lane within the exposure field also allows the field curvature of the lens to be measured. Although this pattern can provide the previous information, we remain interested in the focus or tilt conditions of each production lot. From the drawing of Fig. 5, it is clear that this BIB pattern can provide the required focus information over a wide range of energy settings. Although only one pattern size (0.2 μm isolated contact hole) is demonstrated herein, we are extremely confident that this pattern can be used as a focus and tilt monitor. If the fitting curve is not closely correlated to specific processes (for example, different photoresist, pattern size, duty ratio, energy, etc), minor tuning of the size or space of the pattern is sufficient. Besides the focus and tilt monitor, the focus measurement of each wafer within a processing lot (for example, 25 wafers) can provide information on lens heating.

Figure 9 displays the reticle layout for the measurement of focus, tilt, and field curvature. The measured nine focus values in x and y directions are illustrated in Fig. 10 and 11, respectively. The astigmatism, which is focus difference between x and y direction, is also illustrated in Fig. 12.

5. CONCLUSION

The above verification demonstrates that the special BIB can provide fast and accurate focus value of lithographic tools. Inserting the BIB pattern into the scribe lane of the production mask can obtain the focus and tilt information, and this information can be fed forward to the next production wafers. This BIB pattern can also provide information on lens heating if more than one focus value is obtained within a lot.

ACKNOWLEDGEMENTS

This work was supported by the National Science Council of R.O.C. under contract 88-2215-E009-045.

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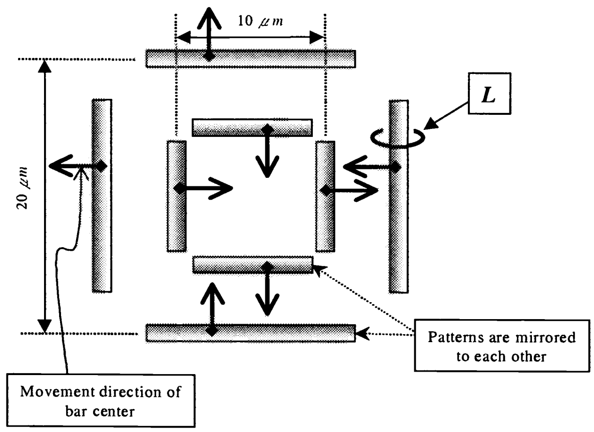


Fig. 1 Specially designed bar-in-bar pattern

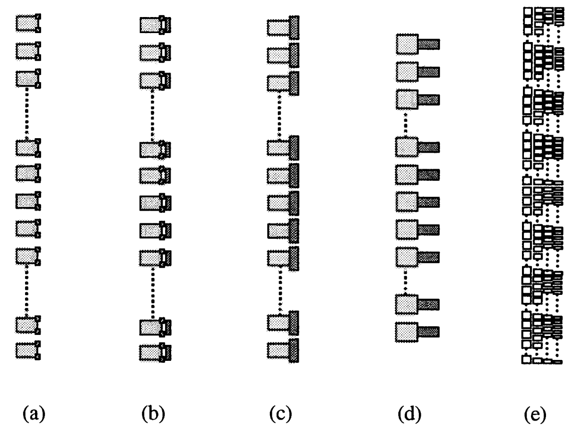


Fig. 2 Different pattern design for focus measurement

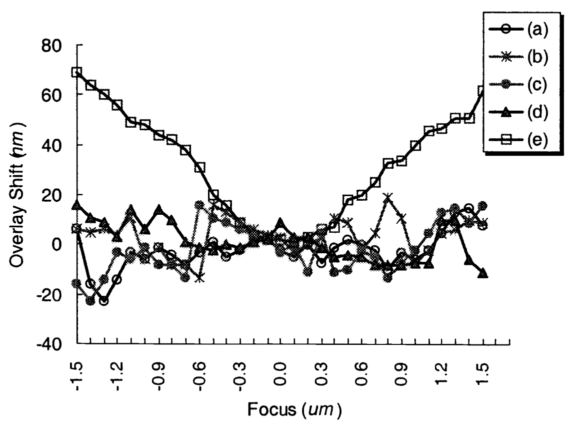


Fig. 3 Overlay shift of pattern types (a) ~ (e)

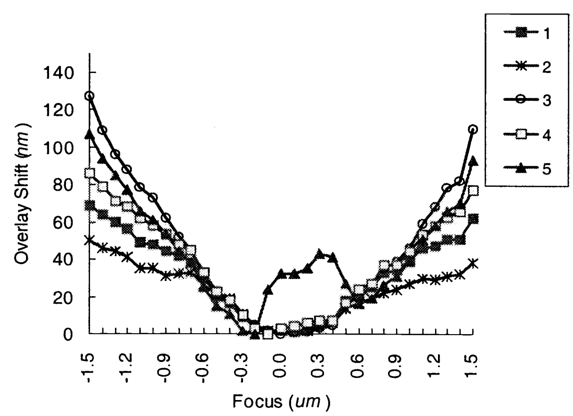


Fig. 4 Overlay shift of pattern (e) under different split conditions

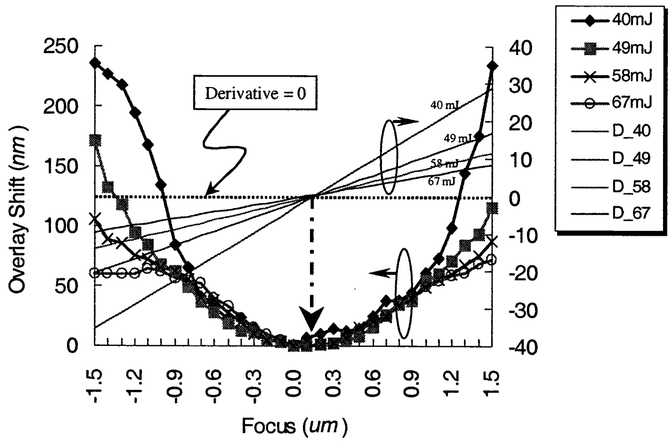


Fig. 5 Overlay shift under different energy levels

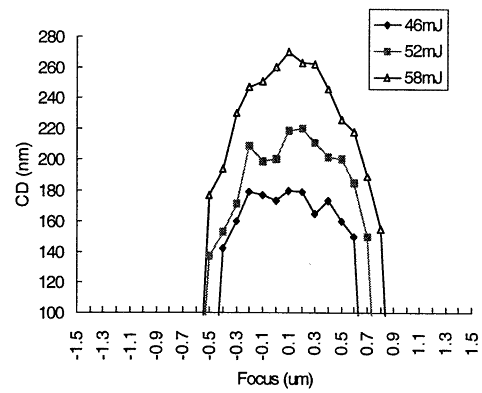
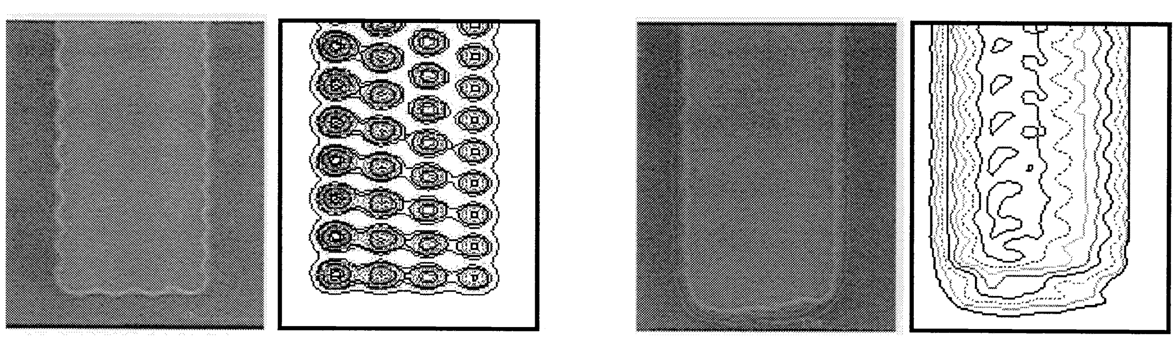


Fig. 6 CD result of 0.2 μm isolated contact hole



(a) Best focus

(b) F* + 0.8 μm

Fig. 7 Comparison between SEM picture and the simulation result

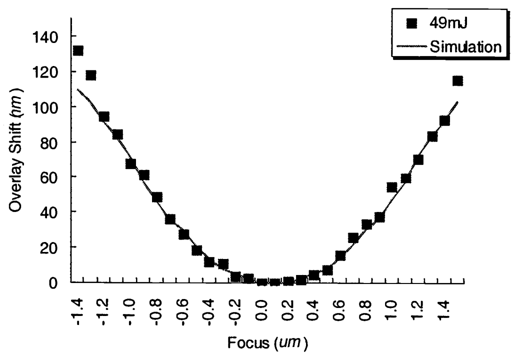


Fig. 8 Comparison between measured overlay shift and the simulation result

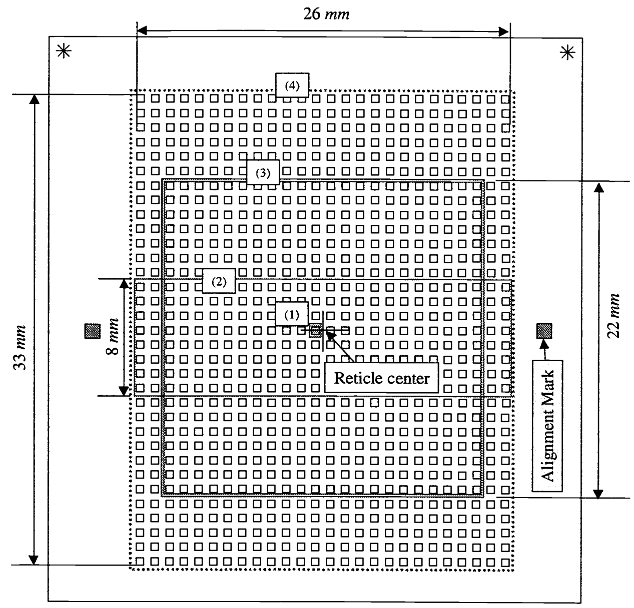
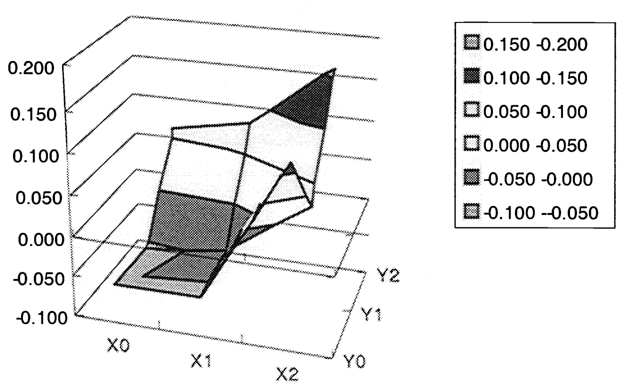


Fig. 9 Reticle layout



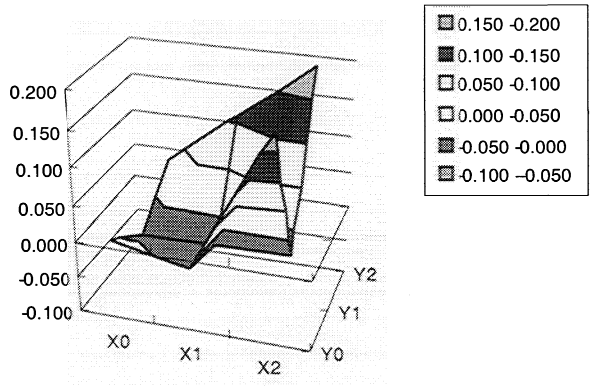
Measured Focus Value:

Y2	0.059	-0.053	0.124
Y1	-0.056	-0.043	0.029
Y0	-0.052	-0.053	0.124
	X0	*X1*	*X2*

Calculation Results:

Average focus (um):	0.009
Tilt_Rx(urad):	10.091
Tilt_Ry(urad):	29.363

Fig. 10 Nine focus values – X direction.



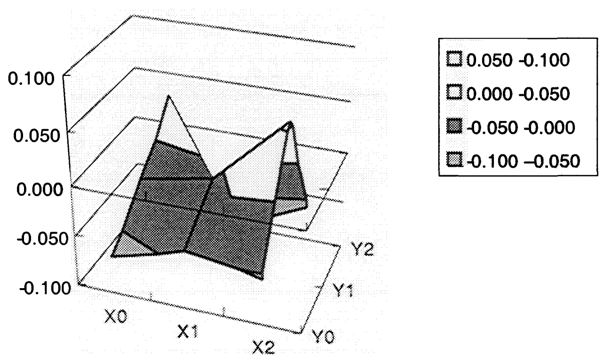
Measured Focus Value:

Y2	0.033	0.110	0.188
Y1	-0.032	-0.033	-0.028
Y0	0.011	-0.010	0.177
	X0	*X1*	*X2*

Calculation Results:

Average focus (um):	0.046
Tilt_Rx(urad):	13.909
Tilt_Ry(urad):	29.545

Fig. 11 Nine focus values – Y direction.



Calculation Results:

Y2	0.026	-0.163	-0.064
Y1	-0.024	-0.010	0.057
Y0	-0.063	-0.043	-0.053
	X0	*X1*	*X2*

Fig. 12 Astigmatism ($focus_x - focus_y$).