Improved performance of multi tone masks by advanced compensation methods

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Abstract

The drive towards lowering costs and increasing frame rates results in new panel designs and thereby new photomasks designs. One common way to reduce cost is to reduce the number of production steps. For this multi tone photomasks (MTM) are needed. MTMs contain more information and increases photomask placement requirements. Increasing frame rates lead to shrinking geometries. The combination of HTM and shrinking geometries drastically increases the requirements imposed on the pattern generators used to print the photomasks. New methods are therefore needed to enable future photomask manufacturing. This paper introduces three advanced image quality enhancing methods.

1. Introduction

Multi tone photomasks are different compared to binary photomasks in the sense that they contain information not only in black and white, but in the colors white, *gray* and black (see fig. 1 below).

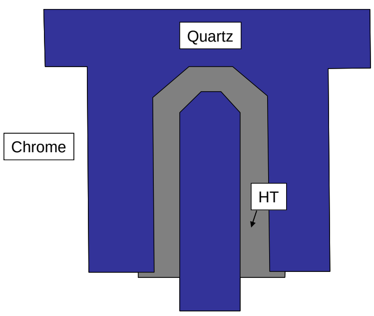


Fig. 1. TFT channel area design example where three gray levels are used on the photomask.

Two exposures are therefore needed to produce the final photomask and alignment between the two exposed layers is therefore crucial.

To achieve good alignment accuracy it is no longer sufficient to match the two layers by using the alignment marks around the pattern area. The reason for this is that the photomask blank is resting on the stage in the pattern generator. Hence, contamination and air bubbles trapped inbetween the stage and photomask will alter the shape of the photomask blank in between loadings. It is therefore not possible to achieve good local overlay between the two exposures without compensating the second layer for the distortion differences. A special function in the pattern generator - flatness compensation - has been developed for this purpose.

In previous display designs, separate chips where used to drive the TFT array. These chips where placed beside or under the active display area. Today, as electronic circuits are being integrated into the panel along the borders of the display area, the density of the pattern is different in the driver area compared to the TFT area. As a consequence, it is very difficult to keep the same mean CD all over the pattern area due to the different pattern densities. In addition, the size of the photomasks used keep increasing and keeping the CD performance of photomasks almost four square meters large has become a real challenge.

As shown in the next section, global repeatable CD errors in the process chain of the photomask can be efficiently reduced using a so called CD-mapping function in the pattern generator.

Pattern density related CD errors can also be compensated for in the pattern generator using the newly developed so called Process Equalizer™ function.

2. Experimental

2.1 Placement related errors

In the pattern generator the photomask blank is resting on a flat surface (see fig. 2 below).

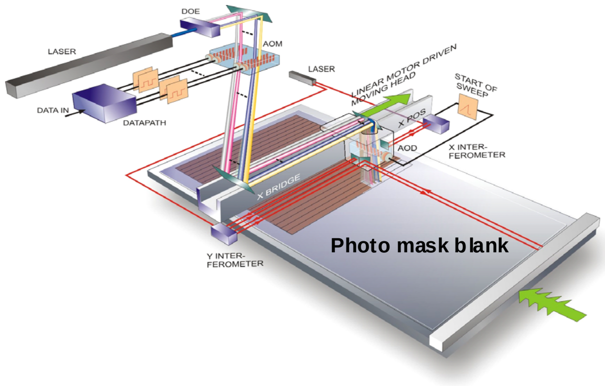


Fig. 2. Image showing the pattern generator. The photomask is resting on a flat surface.

Particles and air trapped in between the stage and photomask blank will distort the blank differently during the first and second exposure. These distortions have a direct – and significant – impact on the final image unless they are compensated for. To avoid these errors, the glass flatness is measured in the pattern generator prior to the first pass exposure (see fig. 3).

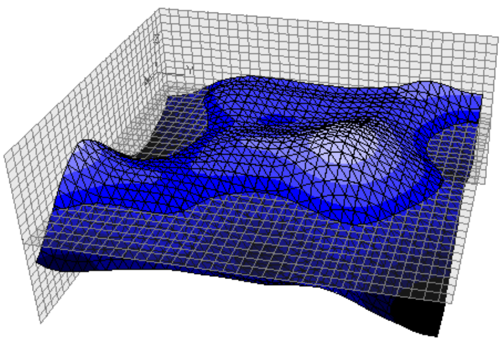


Fig. 3. A typical distortion map example prior to exposure. The range is around 20 um.

This measurement will serve as the reference for the second exposure. Prior to the second exposure the photomask shape is measured again. The difference in shape compared to the first loading is now used to adjust the physical placement of the second layer pattern in order to better fit on top of the already exposed pattern. This function, flatness compensation, is a part of the more general patented functionality, Z-correction [3]. In fig. 4, a one dimensional model is presented. In practice this model has been extended to two dimensions [1].

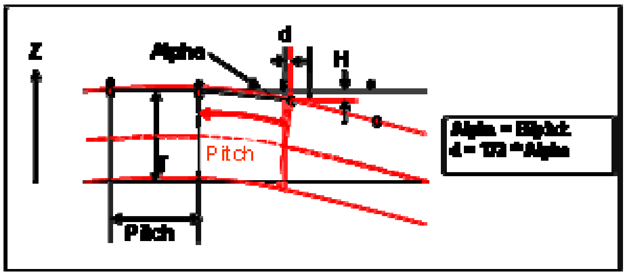


Fig. 4. The deviation of an individual position can be calculated using above model.

As can be seen in the figure the distance between two points will change with the distance *d* due to the bending of the plate. By measuring *H*, *d* can be calculated when the *pitch* and the thickness *T* of the plate is known.

After subtraction of the reference Z map from the second measurement the local *deviation* of a point can be expressed as:

$$deviation = T/2 * (H - Href)/pitch$$

Where *H* is the height difference between two points from the second measurement and *pitch* is the distance between the points. *Href* is the height difference between the same points in the reference map (the first measurement). *T* is the thickness of the glass blank.

The deviation map, dev(x,y), is tabulated in a matrix form and used to adjust the coordinate system used during the second pass exposure. For a photomask with 13-15 mm thickness a deviation matrix with the pitch of typically 20, 20 mm is measured covering the whole glass blank.

2.2 Global repeatable CD errors

Systematic CD variations occur when large photomasks are developed and etched. As CD requirements get tighter these errors start to represent a significant part of the total CD error budget. The developing and etching tools may give spatial systematical variations of the CD. These variations are both pattern dependant and not pattern dependant.

To address the non-pattern dependent CD errors a stand alone software – *CD Map* - has been developed. When a new process is developed several test photomasks are written. On these photomasks a special CD pattern resides in a matrix manner. The CD in each cell of the matrix, CD(x,y) is measured and averaged using all the photomasks. The nominal CD is then subtracted from the CD average to get the CD-error (x,y), where x,y is the cell coordinate in the matrix. During exposure of the pattern the CD is corrected by using different doses locally over the photomask. Figure 5 below illustrates this process.

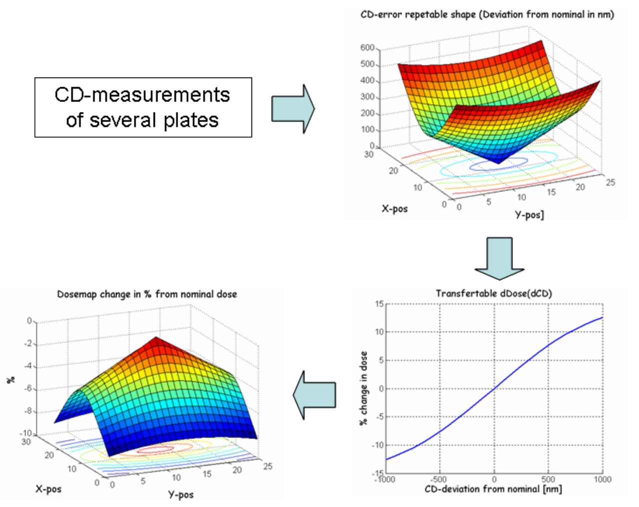


Fig. 5. The process steps for building a CD correction map in the dose domain.

A transfer table is used to map the CD-error(x,y) to percentage change in dose (see fig 5). During calibration of the transfer table the CD-error is measured for a number of different doses. Linear interpolation is used in this table for retrieving the correct dose change for compensating the CD-error.

2.3 Pattern density related CD errors

The developing and etching process may also give pattern density dependant variations of the CD. This effect gets more crucial when geometries shrink and other electronics, like drivers, are integrated on the active TFT area. As pattern density varies inbetween these different areas of the photomask, the mean CD will vary accordingly after the photomask has been processed.

To compensate for the pattern dependent CD variations, a compensation software - *Process equalizer*^{TM} [2]- has been developed. The software was originally developed to minimize pattern dependant CD errors on semiconductor photomasks, but is now adjusted to fit display pattern generators.

From the pattern data special algorithms are used to calculate the Global Density Map from the pattern data. A convolution kernel, normally a symmetrical Gaussian with tunable width and strength (see fig 6), is experimentally determined. Besides the linear convolution by the kernel, also a non-linear transfer function, is used to correct for any nonlinearity between density and the CD-error.

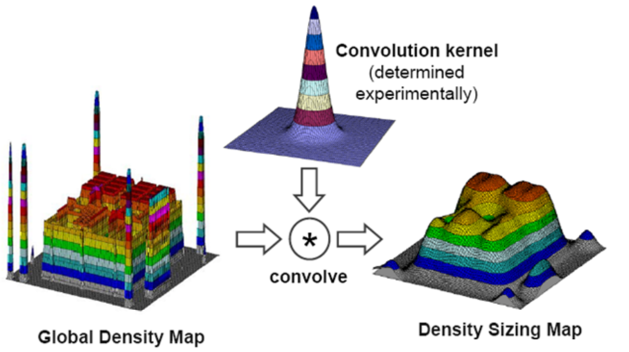


Fig. 6. The process to make a density sizing map

Special test patterns are used to determine the parameters of the kernel, a so called Point Spread Function (PSF). In iterations where several photo-masks are exposed and measured the parameters for the kernel are determined so that the CD-error is minimized. In Fig. 7 below this loop is illustrated.

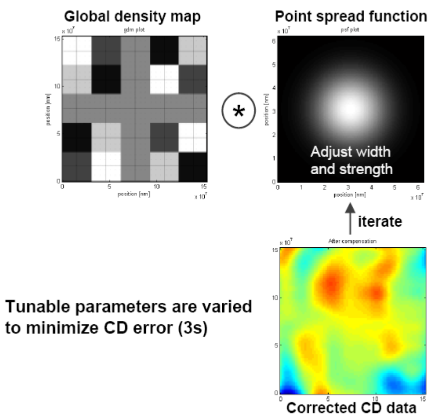
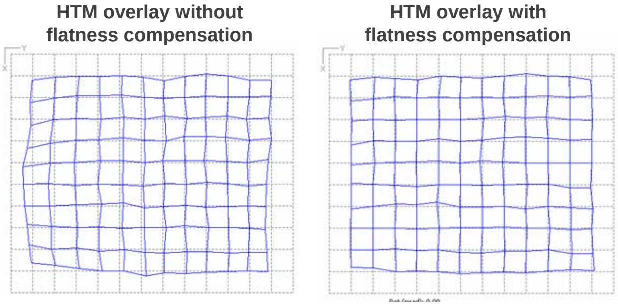


Fig. 7. The kernel iteration process.

Instead of adjusting the dose a re-sizing of the pattern it-self is done when using this function. It is also possible to make a global CD compensation using this function (pattern sizing) instead of the CD map function described in the previous section which works in the dose domain.

3. Results and discussion

The methods presented in this paper are used to enhance the CD and placement performance of the photomask. In figure 8 below the difference of using and not using flatness compensation is demonstrated.



	X	Y
Range	363	357

	X	Y
Range	208	132

Fig. 8. Pattern overlay between 1st and 2nd exposure of a HTM photomask.

CD variations that are not pattern dependant can be corrected using the *CD map* function. An example is presented in figure 9.

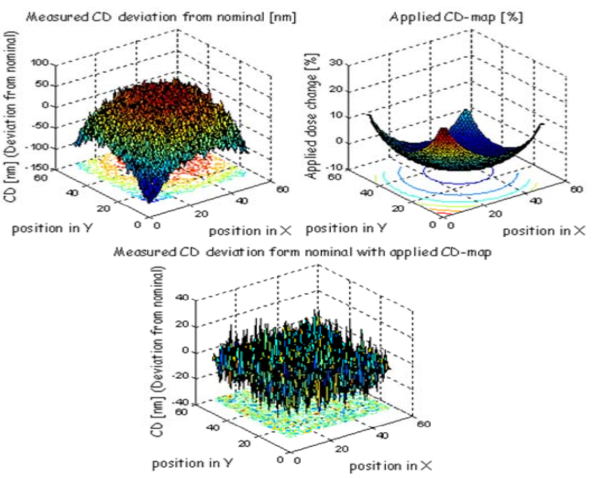
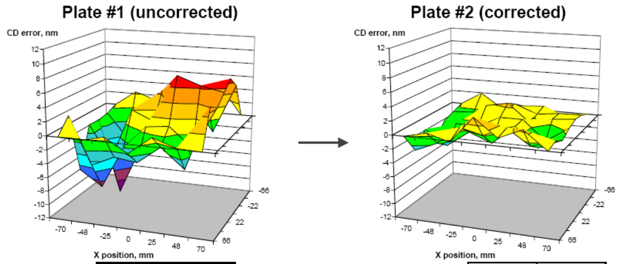


Fig. 9. The remaining CD-error after an applied CD map is shown in lowest graph.

In figure 10 a result where a pattern dependant CD-map has been applied is presented. In this example, the *Process equalizer^{TM}* function is used and the test is performed on a semiconductor pattern generator.



	X	Y
3s	13.8	11.9
Range	21.1	18.9

	X	Y
3s	5.9	5.1
Range	9.7	7.0

Fig. 10. Remaining CD-error after a pattern dependant CD map has been applied.

The data used in this case was a production emulation pattern with a large variation in pattern density.

4. Summary

To fulfill the new image quality requirements imposed by the evolution of the display industry (cost reduction and increasing frame rates) Micronic has developed three new compensation methods.

Flatness compensation improves the overlay between the two exposed patterns on multi tone mask.

CD Map compensates for global repeatable CD errors.

Process equalizer^{TM} compensates for pattern density dependent CD errors and may also be used to address global repeatable CD errors.

(http://www.imid.or.kr/2009/sub0202.asp).

5. References

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2. Micronic Laser Systems, Sigma 7500 Process Equalizer^{TM}, Techical reference
3. Micronic Laser Systems, "Z correction", Japan Patent no. 4202392 (2008)