UTILIZING BOSSUNG PLOT TO CALIBRATE OPC OPTICAL MODEL

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ABSTRACT

Compact OPC model calibration consists of three parts: the mask model, the optical model and the resist model. Resist model is "empirical" but optical model is "physical" which strictly simulates scanner's illumination and projection system. As the "physical" property, optical model tuning is a very important step in the three parts calibration. If optical part is not well calibrated, resist part probably force to minimize the merit function RMS beyond physical range, that means model over-fitting. This paper presents a method of calibrating optical model utilizing Bossung plot. Different merit functions were studied: RMS, GRADIENT and FOCUS CENTER of Bossung plot fitted with quadratic function. Model candidates selected by these functions were analyzed and results showed that this method is a good way to search the optical model.

INTRODUCTION

Typically, compact OPC model calibration consists of three parts: the mask model, the optical model and the resist model. Mask tuning involves bias and corner chop optimization, with additional 3D effect involved in advanced nodes. Resist tuning is to minimize the cost function of a linear sum of multiple terms that represent different resist chemical effects, such as diffusion and neutralization of acid and base. In general, optical model is "physical" and resist model is "empirical", resist part has high risk of inducing model over-fitting than optical part. If the physical optical model is not well calibrated, the probability of model over-fitting will increase a lot as the resist part may try to repair the optical offset by hand of their powerful empirical nature, the consequences are: the resist terms become weird and the model becomes unpredictable.

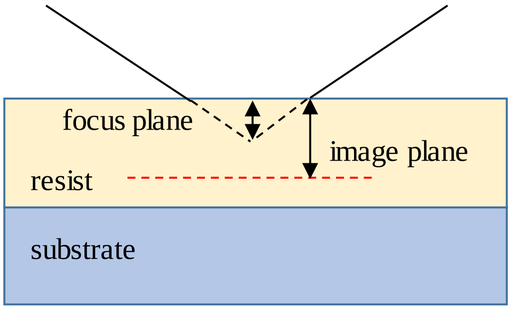

Figure 1: Illustration of Focus plane and image plane.

Optical model considers optical conditions such as wavelength, NA, sigma, etc. It simulates the image distribution of light source propagating through illumination and projection system. As shown in Fig 1, there are two main parameters to be calibrated generally: one is focus plane and the other is image plane. Focus plane is the position of film stack with respect to the scanner while image plane is where the image is been thresholded in the resist. The aim of optical model tuning is to find the best pair of focus and image plane value.

RMS is the common merit function of model tuning whether for optical or resist search, slight difference is that resist search uses nominal Litho condition while optical search usually uses FEM Litho condition. It has been proven that FEM measurements can help model explore other defocus regions and improve model prediction ability[1, 2], such defocus-aware model is more "physical". In practice, as FEM measurements has big image noise, the common model tuning method is to import FEM measurements at step of optical search, while resist tuning still uses nominal measurements. Figure 2 shows a typical example of the output of a focus-exposure matrix using CD as the response in what is called a Bossung plot[3, 4]. Bossung plot is usually used to define the process window, but here is to evaluate optical model performance by analyzing matching degree of curve simulated and measured.

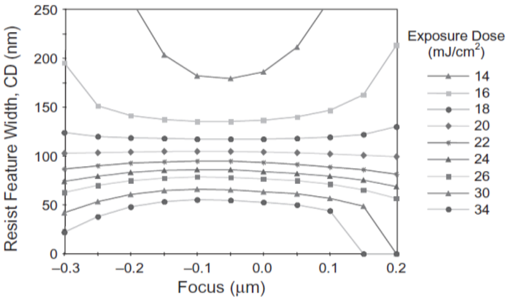

Figure 2: Example of Bossung plot. Ref[4]: Figure 8.17

METHODS

The common way to calibrate optical model is using defocus measurements. Bossung plot of points measured and simulated are analyzed to find the best optical model. The essential of making model defocus aware is trying to match the simulated curve with measured curve. Figure 3 shows examples of good matching and bad matching. A good matching curve indicates model has good prediction ability for defocus conditions. Noticed that the simulated value is not close to measured value, the reason is that the simulated is aerial image that does not contain resist terms at optical search step, but it does not affect optical model tuning as the importance here is to catch the curve trend.

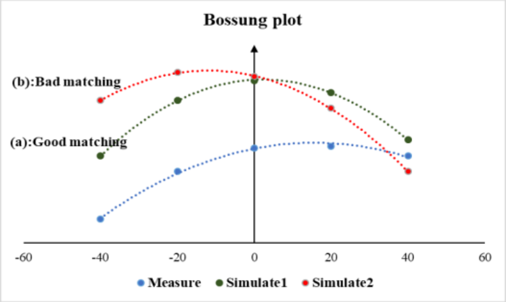

Figure 3: (a) a good matching Bossung curve; (b) a bad matching Bossung curve.

Firstly, the Bossung plot is updated by using quadratic function to fit the values of different defocus conditions:

$$\mathrm{f} = \mathrm{a}X^2 + bX + c\#(1)$$

Then as illustrated in Figure 4, we can extract 3 types of parameters from the updated Bossung plot: (1) the absolute value of each point: X. (2) the gradient value of each point derived from quadratic function: G. (3) the extreme point (minimum or maximum) of the quadratic function: F. Here, X, G, F are used to calculate RMS, GRADIENT and FOCUS CENTER respectively, details are described in below sections.

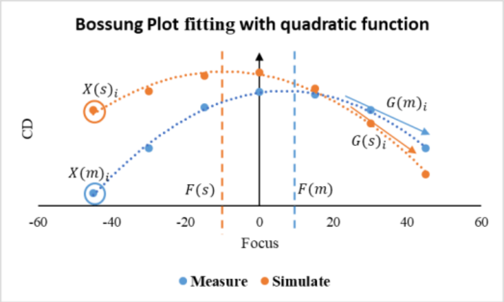

Figure 4: illustration of updated Bossung plot with 3 parameters: (1) absolute value X, (2) gradient value G, (3) focus center F.

RMS

Root mean square (RMS) is the golden merit function for model evaluation especially in resist model tuning task. It is defined as below:

$$\mathrm{RMS} = \sqrt{\frac{\sum_{i=1}^{N}(X(m)_i - X(s)_i)^2}{N}}\#(2)$$

In which m represents measured value, s represents simulated value.

It is still suitable for optical model tuning even with defocus measurements. This function will consider each measurement as an independent individual regardless of focus conditions. As shown in Figure 4, actual absolute measurements $X(m)$ and simulated values $X(s)$ participate in RMS calculation.

GRADIENT

G is the derivative of quadratic function at each point:

$$G = 2\mathrm{a}X + \mathrm{b}\#(3)$$

In order to distinguish with traditional RMS, GRADIENT is used to represent the difference of G between simulated and measured values with a similar formula:

$$\mathrm{GRADIENT} = \sqrt{\frac{\sum_{i=1}^{N}(G(m)_i - G(s)_i)^2}{N}}\#(4)$$

FOCUS CENTER

F is the extreme point (minimum or maximum) of the quadratic function:

$$F = \frac{-b}{2a}\#(5)$$

As the function is with respect to focus, F is explained as focus center of Bossung plot. Similarly, FOCUS CENTER (FC) is used to represent the difference of F between simulated and measured values:

$$\mathrm{FC} = \sqrt{\frac{\sum_{g=1}^{N}\left(F(m)_g - F(s)_g\right)^2}{N}}\#(6)$$

Different with RMS and GRADIENT, each Bossung plot only has one F value, so here subscript g represents a group of defocus points plotting one Bossung plot.

AVE

Besides the 3 merit functions mentioned above, the weighted average value AVE of the three functions was also calculated:

$$\mathrm{AVE} = \frac{w_r * \mathrm{RMS} + w_g * \mathrm{GRADIENT} + w_f * \mathrm{FC}}{w_r + w_g + w_f}\#(7)$$

It is a balance of RMS, GRADIENT and FC, and determined by users demand through adjusting weight w_r, w_g, w_f.

EXPERIMENTS AND RESULTS

A line/space layer was tested in this paper. The total 4 merit functions described above were calculated at step of optical model tuning and further used to select candidates for resist model tuning. The method of tuning optical model is ranging focus plane and image plane from resist top (0nm) to bottom (max) with a step s (e.g. 5nm) separately. At step of optical model tuning, besides traditional RMS, the distribution of focus center difference was analyzed to help judge the quality of optical model, which is defined as below:

$$errF = F(s) - F(m)\#(8)$$

Table 1 shows all pairs of focus plane and image plane (here marked as P(F, I)). For convenience, below table only shows two RMS values for comparison and omits the GRADIENT, FC and AVE values. P(F45, I60) is the minimum RMS location with RMS value of ***a***, while all minimum GRADIENT, FC and AVE location point to P(F40, I55) with RMS value of ***b***, while ***a*** < ***b***. Optical model with P(F45, I60) is called OM1, and the other model with P(F40, I55) is called OM2.

Table 1. Pairs of focus plane and image plane.

Focus Image	0	5	…	40	45	…	max
0	x	x	x	x	x	x	x
5	x	x	x	x	x	x	x
…	x	x	x	x	x	x	x
55	x	x	x	***b***	x	x	x
60	x	x	x	x	***a***	x	x
…	x	x	x	x	x	x	x
max	x	x	x	x	x	x	x

Figure 5 shows the histogram of errF of OM1 and OM2. We can observe that though RMS of OM2 is bigger than that of OM1, more points of OM2 have converged to ZERO regarding errF. Such improvement indicates more simulated Bossung plots match measured Bossung plot. In fact, Figure 3 is an actual example of same gauge extracted from the two models (Figure 3(a) (good matching) is from OM2 while Figure 3(b) (bad matching) is from OM1). Comparing of Bossung plot of Figure 3(a) and 3(b), $errF$ is improved from OM1 with ~25nm to OM2 with ~10nm.

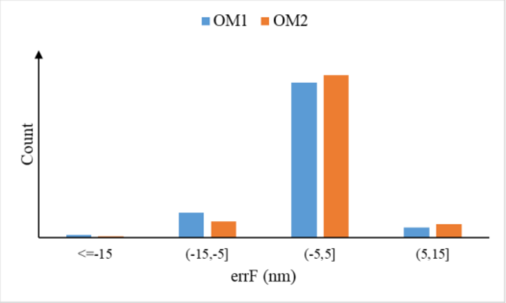

Figure 5: $errF$ histogram of OM1 and OM2.

Lastly, the two optical candidates were used to tune resist model, corresponding resist model were called RM1 and RM2. Figure 6 shows the final RMS of different pattern types for RM1 and RM2. These types consist of 1D and 2D type, but still almost all types RMS are improved with RM2 except for Type2 with negligible difference. RM1 failed though the corresponding OM1 won.

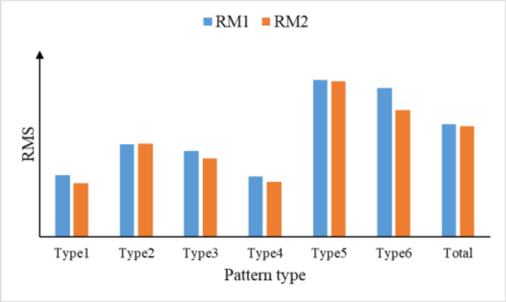

Figure 6: resist model RMS of RM1 and RM2.

CONCLUSIONS

By exploring Bossung plot, GRADIENT and FOCUS CENTER are proposed in this paper. It is demonstrated that trying to match Bossung plot similarity is a better way to search the best optical model comparing to traditional RMS. The better matching Bossung plot, the better prediction of defocus conditions. What's more, the more physical optical model is probably to bring a more robust resist model with smaller final RMS.

REFERENCES

[1] J. Schacht, K. Herold, R. Zimmermann, J. A. Torres, W. Maurer and Y. Granik. "Calibration of OPC models for multiple focus conditions", Proc. SPIE 5377, Optical Microlithography XVII, 2004.

[2] J. A. Torres, T. Roessler, and Y. Granik. "Process window modeling using compact models", Proc. SPIE 5567, 24th Annual BACUS Symposium on Photomask Technology, 2004.

[3] J. W. Bossung. "Projection Printing Characterization", Proc. SPIE 0100, Developments in Semiconductor Microlithography II, 1977.

[4] C. Mack. "Fundamental Principles of Optical Lithography", The Science of Microfabrication, 2007.