Simultaneous optimization of dose and focus controls in advanced ArF immersion scanners

Tsuyoshi Toki*, Pavel Iziksonb, Junichi Kosugi, Naruo Sakasai, Keiko Saotomea, Kazuaki Suzuki, Daniel Kandelb, John C. Robinson**d Yuji Koyanagi
c
aNikon Corporation, 201-9, Miizugahara, Kumagaya, Saitama, 360-8559, Japan
bKLA-Tencor Corporation Israel, Haticshoret St., P.O.Box 143, Migdal Haemek 23100, Israel
cKLA-Tencor Corporation Japan, 134 Godo-cho, Hodogaya-ku Yokohama, Kanagawa 240-0005, Japan
dKLA-Tencor Corporation, One Technology Drive, Milpitas, California 95035, USA

ABSTRACT

We have developed a new scheme of process control combining a CD metrology system and an exposure tool. A new model based on Neural Networks has been created in KLA-Tencor’s “KT Analyzer” which calculates the dose and focus errors simultaneously from CD parameters, such as mid CD and height information, measured by a scatterometry (OCD) measurement tool. The accuracy of this new model was confirmed by experiment. Nikon’s “CDU master” then calculated the control parameters for dose and focus per each field from the dose and focus error data of a reference wafer provided by KT Analyzer. Using the corrected parameters for dose and focus from CDU master, we exposed wafers on an NSR-S610C (ArF immersion scanner), and measured the CDU on a KLA SCD100 (OCD tool). As a result, we confirmed that CDU in the entire wafer can be improved more than 60% (from 3.36nm (3σ) to 1.28nm (3σ)).

Keywords: lithography, process control, CDU, scatterometry, OCD measurement, Neural Network

1. INTRODUCTION

ArF water immersion lithography is expected to be used down to 22nm hp node until EUVL becomes mature. The process margin is very small from 45nm hp node and double patterning techniques are required below 35nm hp. This is clearly shown in the ITRS roadmap for CDU (Figure 1).

CDU requirement on ITRS

*toki.tu@nikon.co.jp

**John.Robinson@KLA-Tencor.com; phone 1 512-231-4221

Proc. of SPIE Vol. 7640  764016-1

In order to obtain sufficient CD uniformity (CDU) with enough margin, especially for high volume manufacturing, optimization of dose and focus controls is indispensable. A similar physical model to describe the dependence of pattern on dose, focus and blur measured by scatrometry was reported by C.P. Ausschnitt and T.A. Brunner in 2007 [2]. KLA has developed “KT Analyzer” which derives both Dose and Focus information out from OCD measurement result simultaneously [3]. Nikon has developed “CDU master” to calculate the proper inter- and intra-field control parameters out from the Focus and Dose information. Using “KT Analyzer” and “CDU master”, CD uniformity can be greatly improved and continuously managed.

In this paper, rather than showing estimations and simulation result, we introduce actual data to show the accuracy of our new model and how much improvement can be achieved.

2. IMPROVING CD UNIFORMITY BY DOSE AND FOCUS

2.1 Procedure
The procedure mainly consists of four parts
1. Create a Focus and Dose model using Focus Exposure Matrix (FEM) (see Figure 2)
2. Expose wafer to be the reference and measure CD
3. Calculate Focus and Dose errors based on reference CD simultaneously through the created model (see Figure 3)
4. Expose wafer with Focus and Dose corrections and verify improvements.

In order to enable this procedure, KT Analyzer of KLA-Tencor and CDU master of Nikon were introduced.

![Figure 2. Create model from FEM wafer.](image1)

![Figure 3. Procedure to expose wafer with Focus and Dose correction.](image2)
2.2 KT Analyzer FEM module

The FEM module of KT Analyzer is a fully automated neural network package with more accurate modeling capabilities compared to existing solutions and the ability to select optimum number of model parameters (Figure 4). This module is equipped with a flier removal engine, graphical representation and basic statistic analysis of model accuracy. The model’s input can be any parameter from scatterometry CD: Top CD, Mid CD, Bottom CD, Pattern Height, Side Wall Angle (SWA), Footing etc. In this experiment, Mid CD and Pattern Height were used to create the neural network model and also to calculate focus and dose error information. The role of FEM module in KT Analyzer in the overall CDU improvement process is shown in Figure 1 and 2. The output can go to any system, including Nikon CDU Master.

2.3 CDU master

The method of controlling dose in order to correct CD and improve CDU has been used for many process/product in the field. However, in many cases determination and setup of control parameters for each shot is difficult. CDU Master is an application software with which users can easily achieve higher CD uniformity for finer CDs on NSR (exposure tools supplied from Nikon). The distinctive feature of CDU Master is given in Figure 5. CDU Master will not only optimize to compensate for the measured dose and focus, but will also optimize the control within the available control limits of NSR and thus derive the most optimal CDU that can be achieved on the system. Further, because an input for CDU master is focus and dose error information in the wafer, there is no limitation for the measurement device.

Output of CDU master will be the control parameter values for focus and dose for each shot in a sub-recipe style. Table 1 shows the focus and dose correction condition on CDU Master. Dose can be tuned for X and Y direction individually. Focus distribution can be tuned by height and leveling control of wafer stage during a scanning exposure.

---

Table 1. Focus and Dose correction condition available with CDU master.

<table>
<thead>
<tr>
<th></th>
<th>Field common</th>
<th>Individual field</th>
<th>Control per field</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>≥2nd order</td>
<td>Linear</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>≥2nd order</td>
<td>Linear</td>
<td></td>
</tr>
<tr>
<td><strong>Focus</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiltX(Y)</td>
<td>≥2nd order</td>
<td>≥2nd order</td>
<td></td>
</tr>
<tr>
<td>Z(Y)</td>
<td>≥2nd order</td>
<td>≥2nd order</td>
<td></td>
</tr>
</tbody>
</table>

---

Figure 4. Function of KT Analyzer FEM module.

Figure 5. Feature of CDU master.
3. EXPERIMENT

3.1 Experimental conditions

Total CDU improvement flow was confirmed with the following setup:

- **Exposure Tool**: NSR-S610C [4]
- **Illumination condition**: NA1.3 Cross pole Azimuthally Polarized
- **Exposure Map**: 87 fields (field size: 26 x 33mm)
- **Pattern**: 50nm L / 200nm S (1:4)
- **Stack**: TARF-P6278N(100nm)/AR103(40nm)/AR26(35nm)/Si
- **Measurement Tool**: KLA SCD100
- **Measure point**: 25 points per each field

![Figure 6. Exposure map in wafer (Left), Measured points within a field (Center), Illumination condition shape (Right).](image)

3.2 Model creation and its Accuracy

An FEM wafer was analyzed in KT Analyzer to build a model for focus and dose. In order to confirm the accuracy of the model for focus and dose prediction, comparison between setting dose or focus value and modeled one for FEM wafer is shown in Figure 7. Mid CD and Pattern Height of exposed pattern were then measured with an OCD tool followed by KT Analyzer to calculate focus and dose. Figure 7 shows that the prediction accuracy of focus and dose is 0.012μm (3σ) for Focus and 0.146mJ/cm² (3σ) for dose, respectively. This accuracy as a total accuracy including measurement accuracy, reticle error, wafer flatness error, and focus /dose stability of NSR is extremely good and it proves to be useful in manufacturing process.

![Figure 7. Accuracy of the Focus and Dose model (Comparison between setting values on NSR and Modeled ones).](image)
3.3 Data process

After the model is created, focus and dose error information was derived from the measurement results of the reference wafer (CDU and Pattern Height, process 1 in Figure 8) using KT Analyzer. It simulated the expected CDU variation after calculated error is perfectly corrected as shown in Figure 8. Error information of Focus and Dose as an output from KT Analyzer was then transferred to CDU Master as shown in Figure 9. CDU Master calculated the correctables for focus and dose per each field (process 1 in Figure 9). Note that for this experiment, we did not use the full correction condition available in CDU Master. Correction conditions are applied in the data is listed in Table 2. Correction information in the sub-recipe format was sent to NSR for the corrected exposure (process 2 in Figure 9).

Figure 8. Input and output of KT Analyzer.

Figure 9. Input and Output of CDU Master.
Table 2. Focus and Dose correction condition applied for this experiment.

<table>
<thead>
<tr>
<th>Dose</th>
<th>Field common</th>
<th>Individual field</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>≥2nd order</td>
<td>Linear</td>
</tr>
<tr>
<td>Y</td>
<td>≥2nd order</td>
<td>Linear</td>
</tr>
<tr>
<td>Focus</td>
<td>θ(θ)</td>
<td>Linear</td>
</tr>
<tr>
<td>Z(θ)</td>
<td>-</td>
<td>Linear</td>
</tr>
</tbody>
</table>

3.4 Experimental results

The $3\sigma$ for all measured points from complete fields improved from 3.36nm to 1.28nm. Further, $3\sigma$ of the 25 measured points of the average shot improved from 2.64nm to 0.72nm.

Figure 10. Mid CD within a wafer before and after Focus and Dose correction.

Figure 11. Intra field Mid CD before and after Focus and Dose correction.
Table 3. Summary of $3\sigma$ for each condition.

<table>
<thead>
<tr>
<th></th>
<th>Full data</th>
<th>Inter field</th>
<th>Intra field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>3.36nm</td>
<td>2.58nm</td>
<td>2.64nm</td>
</tr>
<tr>
<td>After</td>
<td>1.28nm</td>
<td>0.97nm</td>
<td>0.72nm</td>
</tr>
</tbody>
</table>

The initial CDU $3\sigma$ before correction is extremely large for both inter and intra field. The causes for large $3\sigma$ before correction include concentric distribution over wafer and common non-uniformity within a field. Here, concentric distribution in Figure 10 is caused by the temperature distribution of the hot plate for Post Exposure Bake in the track (Coater/Developer), and the intra field non-uniformity of CDU is mainly caused by slit direction dose non-uniformity. However, from these experimental results, we could show the performance of KT Analyzer and CDU Master. Using CDU Master, inter and intra non-uniformity can be greatly reduced.

4. DISCUSSION

Although we demonstrated excellent performance of KT Analyzer and CDU Master, we are still working for improvement of the system. The key for this CDU improvement procedure is to reduce the time between reference exposure and correct exposure. By reducing the time, then the frequency of correction can be increased. In order to reduce the time, reducing the sampling points for measurement has a big impact. Currently, simultaneous focus and dose control is a field by field control and thus requires calculation of intra field parameters for every field. In order to know these parameters therefore, full wafer profile metrics measurements is needed, which requires significant time in most cases. If we could decrease the number of sampling points, there will be a big impact. However, there is a challenge on how to reduce the number of measured fields without a strong deterioration in correction accuracy. One possible solution is to use optimal sampling and smart interpolation which will allow the selection of the optimal sample size at optimal locations and interpolate model parameters on unmeasured fields with the required accuracy. Figure 12 shows the preliminary result simulated from reducing sampling fields from 87 to 25. This indicates that optimal sampling and smart interpolation shows basic capabilities to reduce sample size and still keep the CDU improvement at the required level.

![Figure 12. Example of simulated CDU improvement by sampling optimization.](image-url)
5. CONCLUSION

A new model using neural networks in KT analyzer is introduced for determination of focus and dose errors from CDU measurements. CDU Master for NSR is also introduced in order to correct higher order dose and focus variations for inter and intra-fields. Experimental results prove the excellent performance for inter and intra field dose and focus controls. Exposure using these methods resulted in 62% improvement (3.36nm to 1.28nm) in total CDU (3σ).

6. ACKNOWLEDGEMENT

The authors wish to thank Daishi Tanaka, Takashi Higashihara and Takaaki Uchida for exposure and measurement support, Masahiko Okumura and Tomoharu Fujiwara for management support and Taro Ogata for valuable discussions.

REFERENCES

[1] ITRS Lithography 2009, in web site