Study of EB Resist Simulation for EUV Resist Evaluation

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We are now beginning to see the application of extreme ultraviolet (EUV) lithography to the mass production of 7 nm node logic devices, primarily for smartphones. This lithography technology currently attracts the most interests due to its expected use in upcoming mass production of 5 nm node and beyond for semiconductor devices. The development of EUV resists are one of the key research areas. However, EUV exposure instruments are extremely costly, and there are currently no tools that can be used for resist development. To promote the development of EUV resists, we investigated an evaluation method based on EB exposure for EUV resist. Due to similar exposure reaction mechanisms to EUV exposure, EB exposure offers a practical alternative. This paper examines the use of EB exposure simulations to advance EUV resist development.

Keywords: EUV resist, EUV lithography, EB lithography, Resist development analyzer, Development rate measurement, EB direct writing equipment

1. Introduction

We are now beginning to see the application of EUV lithography to the mass production of 7 nm node logic devices, primarily for smartphones. This lithography technology currently attracts the most interests due to its expected use in upcoming mass production of 5 nm node and beyond for semiconductor devices [1–3]. The development of EUV resists is a key research theme in developing increasingly finer designs. However, EUV exposure instruments are extremely costly, and there are no EUV exposure tools that can be used for resist development. To promote the development of EUV resists, we investigated an evaluation method based on EB exposure. Due to exposure reaction mechanisms similar to those for EUV exposure, EB exposure offers a practical alternative. The present report examines the use of EB exposure simulations [4] to advance EUV resist development.

2. Overview of instruments used to measure development rate and the flow of simulation

The flow of EB lithography simulation for EUV resist evaluations are as of follow:

1. Measurement of development rate and calculation of development parameters [5,6].
2. Measurement of optical (ABC) parameters A, B, and C [7,8].
3. Execution of the simulation based on the input of the development parameters and ABC parameters obtained into the EB lithography simulator.

First, the EUV resist is exposed with EB exposure to measure development rate. We used the following method and instrument to measure development rate: For development rate measurements, a coated wafer was exposed with the open frame exposure tool (uniform exposure to a pattern less 5 × 5 mm square area) and resist development rates was measured at varied exposure doses using a resist development analyzer (RDA). Figure 1 shows a conceptual diagram of the open frame exposure instrument.

Next, the wafer undergoes post exposure bake (PEB). The development rate is measured using the RDA. Figure 2 gives an overview of the RDA setup.
We selected a monitoring wavelength of 365 nm to achieve compatibility with thin film resists. Monochromatic light emitted from the LED travels through the emitter lens before irradiating on the wafer surface. After PEB, the wafer is immersed in developer for inspection measurement. In this setup, light reflected by the wafer enters the receiver lens, and the intensity of the light is converted into a digital signal and transmitted to the PC, and Leap Set development rate analysis software calculates resist film thickness during development.

Figure 3 illustrates the measurement principle. Immersing the exposed resist in the developer solution initiates the development process.

Fig. 1. EB open frame exposure instrument and exposed wafer.

Fig. 2. Measuring the development rate of an open frame exposure sample using RDA.

Fig. 3. Relationship between development process of exposed sample and thin-film interference during development.
Monochromatic light irradiated onto the resist is reflected from the surface of the resist and from the boundary plane between the resist and the substrate. These two reflections generate thin-film interference.

Film thickness changes as the development process progresses. Thin-film interference causes cyclic strengthening and weakening of the reflected light, producing a signal characterized by a sinusoidal waveform. When the resist is completely dissolved, substrate material will be exposed and thin-film interference will stop. This results in measurement of constant light intensity.

Using the formula below, we can calculate residual film thickness during the development process based on the thin-film interference waveform.

The change in film thickness from one positive peak to the adjacent negative peak of the interference wave can be expressed as follows:

\[ T = \frac{\lambda}{4n} \]  

Here, \( T \) is the change in film thickness that takes place from a positive peak to the adjacent negative peak of the interference wave (nm), \( \lambda \) is the monitoring wavelength, and \( n \) is the refractive index of the resist at the monitoring wavelength. Figure 4 shows how to convert the interference wave to the film thickness by using above formula.

Plotting the change in film thickness onto a thickness vs. development time graph shows the relationship between the remaining film thickness and the development time. The slope of this residual film thickness curve corresponds to the development rate. We can calculate development parameters after determining the relationship between exposure dose and mean development rate.

Conventionally, resist development processes first involve exposing the resist, followed by actual pattern transcription and development, and finally evaluation of shape and lithographic properties by SEM. This approach is called as the direct evaluation method. It has the advantage of producing data on the pattern profile, which is the ultimate goal of lithography. But for EUV lithography, it is often impractical to purchase an EUV scanner (which costs around 15 billion yen per unit). Even if it were possible to prepare an EUV exposure instrument, the direct method of resist evaluation is an extremely time-consuming process. Instead, we propose a resist evaluation method with simulation using development parameters or development data files obtained by open frame exposure and development rate analysis. Our method the virtual lithography model, would be low in cost and should reduce the time required for resist development. Figure 5 shows the conceptual diagram of our model.

Figure 6 lists the tools required to construct a virtual lithography model—an exposure instrument capable of performing open frame exposure, development rate analyzer, and simulator.

The resist pattern shape and lithographic properties after development can be readily obtained by inputting development parameters obtained by RDA into the profile simulator [7] (Fig. 7).

### 3. Results of EUV resist evaluation following EB exposure

#### 3.1. Measuring simulation parameters

We evaluated EUV resists subjected to EB exposure by the method outlined above. The conditions of this experiment are given below:

- **Resist**
  - Resist: mr-posEUV 0.3 (micro resist technology MRT)
  - PAB: 150 °C/60 s
  - PEB: Without
  - Thickness: 300 nm

- **Development**
  - Developer: mr-Dev 800 (Amylacetate)
  - Development temp.: 23°C
  - Development time: 60 s

- **Exposure tool** (Open frame exposure and direct patterning)
Ultra-High Speed Electron Beam Lithography Tool F7000 (ADVANCEST)
The acceleration electron voltage: 50 KeV

- Development rate measurement
  RDA-800 (Litho Tech Japan)

  Figure 8 shows the results of refractive index and ABC parameter measurements.

  Figure 9 shows the residual film thickness curves.

  Figure 10 shows the relationship between exposure dose and development rate. This EUV photoresist has high-contrast in case of EB exposure.

  Figure 11 shows the results of $E_{th}$ (resist sensitivity) measurement after development for 60 seconds. As a reference, Fig. 12 shows...
development rate curves at different exposure wavelengths. The resist in this study is a main chain-cutting type resist and its solubility was found to increase with increasing exposure energy density (i.e., shorter exposure wavelengths).

From these measurements, we obtained the following development parameters (Original Mack parameters):

\[ R_{\text{max}} = 142.3 \text{ (nm/s)} \]
\[ R_{\text{min}} = 0.1 \text{ (nm/s)} \]
\[ M_{\text{th}} = 0.230 \]
\[ n = 25.2 \]

3.2. Performing the simulation and comparing the results to SEM observation results.
We compared the results of actual patterning obtained with an EB exposure instrument to simulation results.

**EB Exposure tool:**
Ultra-High Speed Electron Beam Lithography F7000 (ADVANTEST)
The acceleration electron voltage: 50 KeV

**EB Simulator:**
LAB EB-mode (GenIsys)

The etched patterns were 200 nm and 100 nm line and space patterns. Figures 13 and 14 compare the results of SEM observation of the etched patterns to simulation results. We set the exposure dose to 340–420 μC/cm² for patterning and calculations.

The results from both the SEM observation and simulation confirmed that the pattern is not resolved at 340 μC/cm² for the 100 nm line and space pattern.
As Fig. 15 shows, the results of SEM observation are consistent with the results of simulation. As one example of further evaluations, we performed a simulation to examine the effects of acceleration electron voltage (Fig. 16). We would expect higher acceleration electron voltages could make more sharply defined rectangular profiles.

4. Summary
We investigated whether simulations based on EB exposure to evaluate EUV resists could accelerate the development of EUV resists.

Our results regarding the efficacy of the method are not conclusive, since we have yet to perform comparisons to resist patterns exposed to EUV radiation. However, we believe the method represents a promising tool in EUV resist development.

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References
1. T. Watanabe, Y. Haruyama, D. Shiono, K. Emura, T. Urayama, T. Harada, and H. Kinoshita, *J. Photopolym. Sci. Technol.*, 25 (2012) 569.
2. T. Watanabe, H. Hada, H. Kinoshita, Y. Tanaka, H. Shiotani, Y. Fukushima, and H. Komano, *Proc. SPIE*, 6153 (2006) 615343.
3. T. Watanabe, H. Hada, Y. Fukushima, H. Shiotani, H. Kinoshita, and H. Komano, “Synchrotron Radiation Instrumentation: Ninth International Conference”, AIP, 879 (2007) 1470.
4. T. Watanabe, K. Emura, D. Shiono, Y. Haruyama, Y. Muramatsu, K. Ohmori, K. Sato, T. Harada, and H. Kinoshita, *J. Photopolym. Sci. Technol.*, 26 (2013) 635.
5. K. Emura, T. Watanabe, M. Yamaguchi, H. Tanino, T. Fukui, D. Shiono, Y. Haruyama, Y. Muramatsu, K. Ohmori, K. Sato, T. Harada, and H. Kinoshita, *J. Photopolym. Sci. Technol.*, 27 (2014) 631.

6. S. Nagata, S. Niihara, T. Harada, and T. Watanabe, *J. Photopolym. Sci. Technol.*, 30 (2017) 583.

7. A. Sekiguchi, *Electr. Commun. Jpn.*, 81 (1998) 542.

8. A. Sekiguchi, C. A. Mack, Y. Minami, and T. Matsuzawa, *Proc. SPIE*, 2725 (1996) 49.

9. A. Sekiguchi and Y. Sensu, *Proc. SPIE*, 8682 (2013) 55.

10. F. H. Dill, W. P. Hornberger, P. S. Hauge, and J. M. Shaw, *IEEE Trans. Electron Devices*, 22 (1975) 445.

11. F. H. Dill, *IEEE Trans. Electron Devices*, 22 (1975) 440.

12. B. Meliorisz, U. Hofmann, N. Unal, and J. Sachen, *Proc. IDW '10 17th International Display Workshops*, (2010) FMC3-4.