Study on Photo-chemical Analysis System (VLES) for EUV Lithography

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Abstract

A system for photo-chemical analysis of EUV lithography processes has been developed. This system has consists of 3 units: (1) an exposure that uses the Z-Pinch (Energetiq Tech.) EUV Light source (DPP) to carry out a flood exposure, (2) a measurement system RDA (Litho Tech Japan) for the development rate of photo-resists, and (3) a simulation unit that utilizes PROLITH (KLA-Tencor) to calculate the resist profiles and process latitude using the measured development rate data. With this system, preliminary evaluation of the performance of EUV lithography can be performed without any lithography tool (Stepper and Scanner system) that is capable of imaging and alignment. Profiles for 32 nm line and space pattern are simulated for the EUV resist (Posi-2 resist by TOK) by using VLES that hat has sensitivity at the 13.5nm wavelength. The simulation successfully predicts the resist behavior. Thus it is confirmed that the system enables efficient evaluation of the performance of EUV lithography processes.

Keywords

EUV lithography, Resist sensitivity, Open frame exposure, Lithography simulation

Introduction

EUV lithography is a type of reduction projection exposure lithography that uses EUV (Extreme Ultra-Violet) rays at a wavelength of 13.5 nm. EUV lithography is under development toward achieving 90 nm designs with ArF dry exposure and 65-45 nm designs with ArF immersion exposure for mass production of semiconductor devices[1-2]. Additionally, EUV lithography is considered the most promising candidate for next-next-generation lithography tools for the 32 nm technology node[3]. An emerging consensus suggests that use of EUV exposure technology for mass production will commence in 2009[4]. Table 1 shows the relationship among the technology node, numerical apertures (NA) of the exposure equipment, and process factor (k1)[5]. Enabling 32 nm design based on exposure technologies using an ArF laser light source will require developing an optical system with NA increased to 1.55 and k1 factor reduced to 0.26. In contrast, an exposure technology using EUV as a light source would allow the use of an optical system with NA of 0.25 for mass production of the 32 nm node. It would also require a relatively permissive k1 factor of 0.59. These are the primary reasons for the growing movement to develop EUV exposure technology.

The technical obstacles hampering development of EUV exposure equipment will not necessarily be easier to solve than those affecting ArF immersion exposure equipment. The 13.5 nm wavelength requires a catoptrics system that combines several multilayer-film reflecting mirrors[6]. It is not possible to use a refractive lens, since no lens material exists for wavelengths near 13.5 nm. This means the development of EUV exposure equipment will require a reexamination of fundamental technologies for light sources, illumination optical systems, projection optical systems, masks, and so on. Various exposure equipment manufacturers are working to develop EUV reduction projection exposure systems[7-8], but for practical applications, the development of resist materials for EUV lithography must precede the development of exposure equipment. For these reasons, we have developed a new virtual lithography evaluation system that takes a completely different tack from conventional resist evaluation technologies (direct evaluation method), which require actual patterning to assess resists. This new evaluation system focuses on open-frame exposures using an EUV light source, measurement of development rate at various exposure doses, and lithography simulation using development rate data. Evaluations of the new system are discussed below.

Table 1 Relationships among technology node, numerical aperture (NA), and process factor (k1)

Wavelength (nm)	Tech. Node	65nm	45nm	32nm	22nm	16nm
	NA	k1	k1	k1	K1	k1
193	0.93	0.31				
	1	0.4				
	1.2		0.28			
	1.35		0.31	0.22	0.15	
	1.55			0.26	0.18	
13.5	0.25			0.59	0.41	
	0.35				0.57	0.41
	0.45					0.53

System configuration

The virtual lithography evaluation system (VLES) developed consists of an EUV open-frame exposure system, a resist development analyzer (RDA), and a lithography simulator (Prolith/ KLA-Tencor). Figure 1 is a schematic diagram of the VLES.

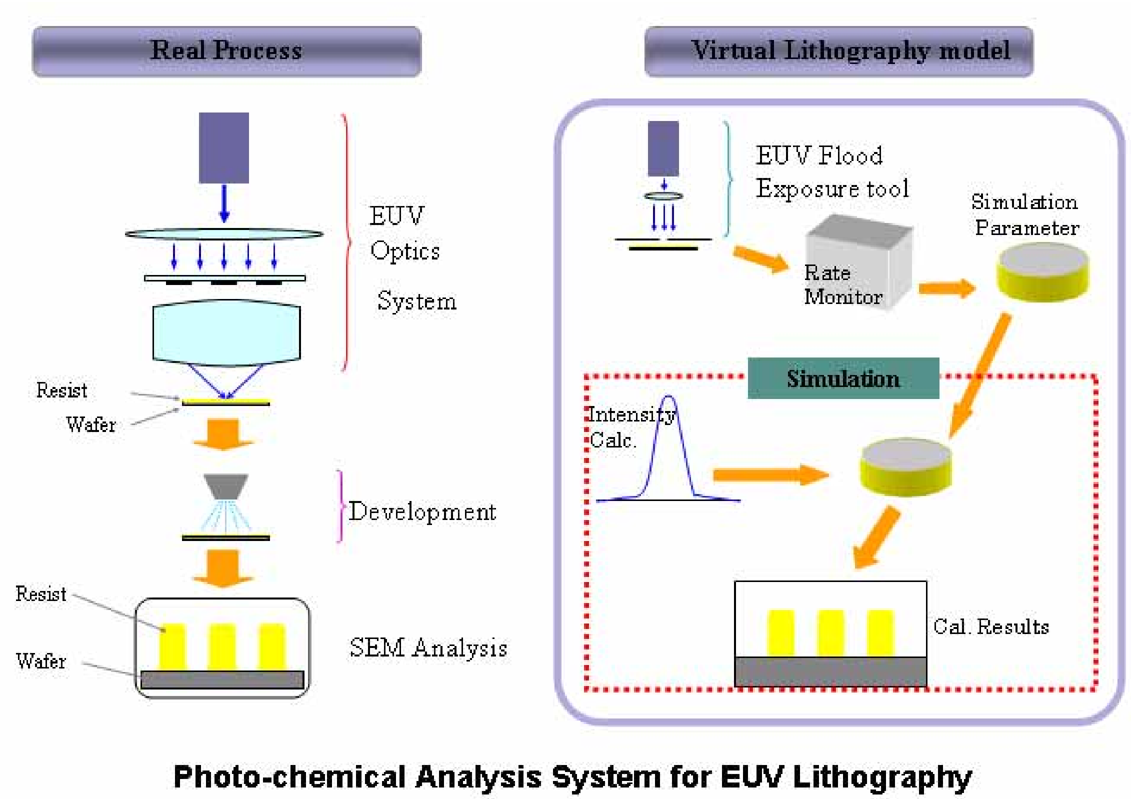


Figure 1 Schematic diagram of the VLES

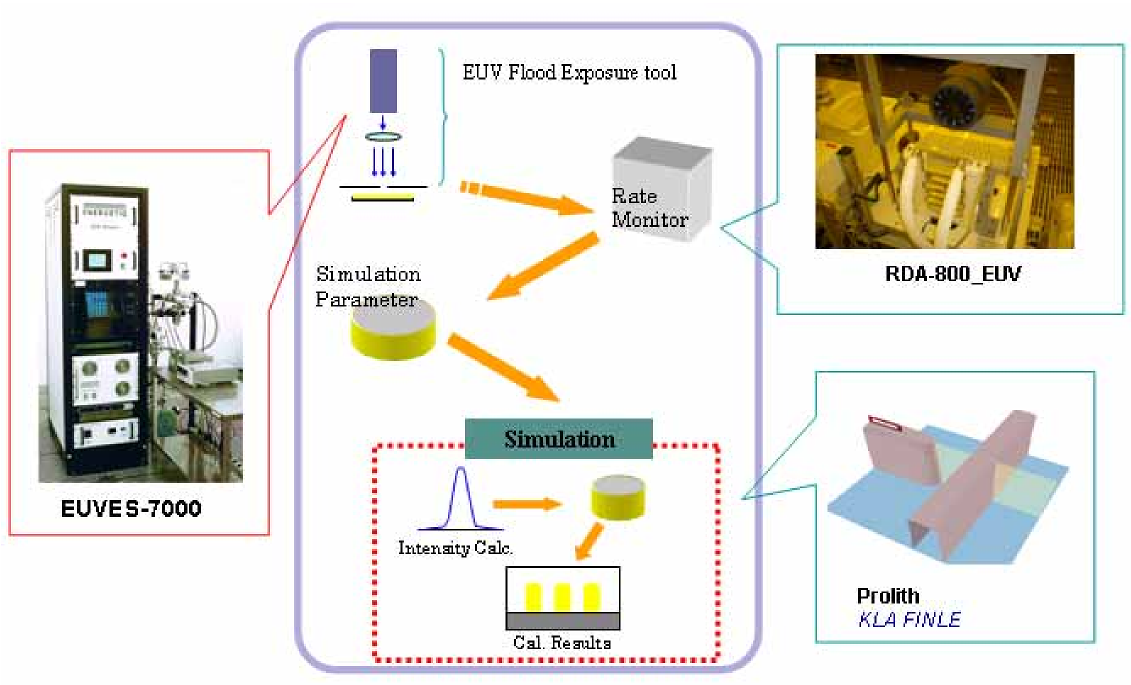


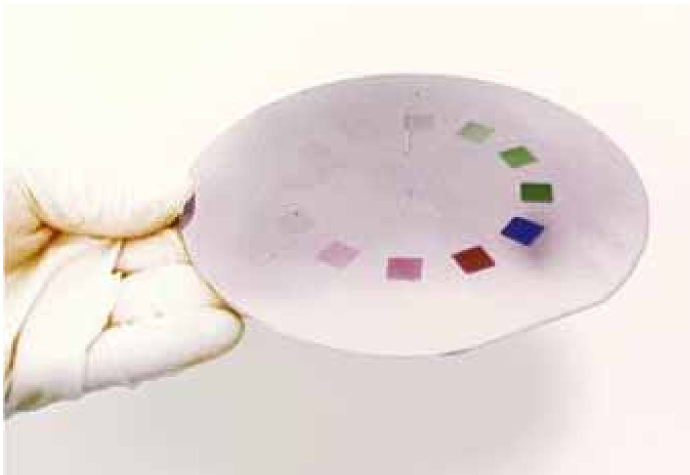
Figure 2 Analyzers used in the VLES

Figure 2 shows the analyzers comprising the VLES.

(1) EUV open-frame exposure system (EUVES-7000)

This equipment uses an electrodeless Z-pinch discharge-excitation plasma light source[9] manufactured by Energetiq Technology Inc. and extracts 13.5 nm light using a Zr filter and multilayer reflecting mirrors. The exposure pattern is a 10 mm x 10 mm open frame, and 12 exposures can be achieved per wafer at varying exposure doses. Figure 3 shows an external view of this equipment and a photo of an exposure pattern (After exposure, PEB, and development by using SAL-601).

(a)



(b)

Figure 3 (a) External view of EUVES-7000 and (b) exposure pattern

Figure 4 is a photo of the beam line.

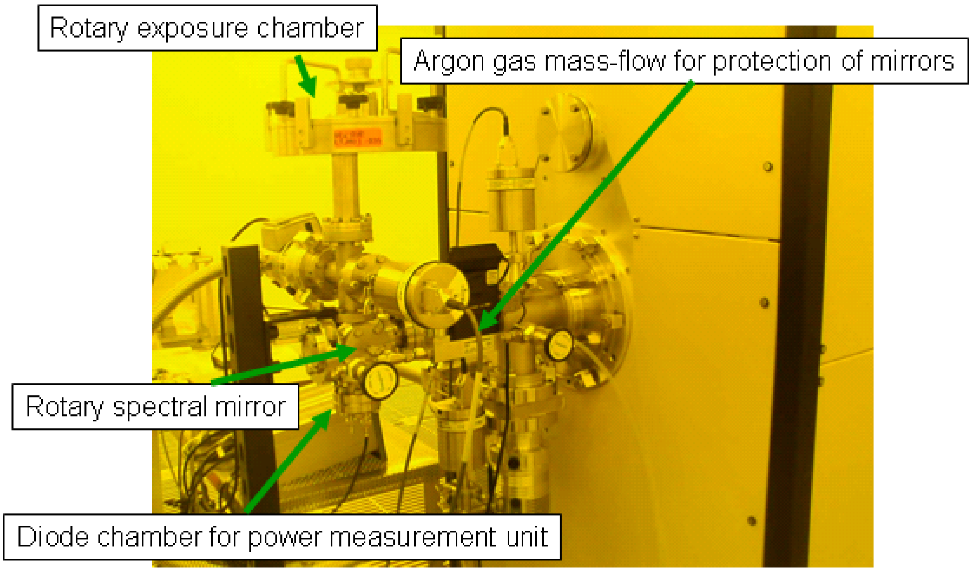


Figure 4 Beam line for EUV exposure

The plasma emissions produced by the EQ-10M pass through the Zr filter to remove UV-region rays. Next, the Mo-Si multilayer reflector selectively reflects only 13.5 nm rays, which are shaped by the aperture into a 10 mm x 10 mm exposure region. The rotary Mo-Si multilayer reflector directs the light with a reflection angle of 45° toward the exposure chamber at the upper section of the equipment during the exposure of a substrate. For power measurement, it rotates and directs the light to the power measurement diode chamber at the lower section of the equipment. Exposures are performed while the wafer rotates. A total of 12 exposures are possible per wafer at varying exposure doses.

(2) Resist development analyzer (RDA-800EUV)

Following the exposure, a wafer is processed for PEB. Then, following measurement the film thickness, the development rate of a resist corresponding to each corresponding exposure dose is measured using this resist development analyzer[10].

(3) EUV lithography simulator (Prolith Ver. 9.3)

The obtained development rate data file is imported into the Prolith lithography simulator[11] (manufactured by KLA-Tencor/ Finle division) for EUV lithography simulation.

Experiment and results

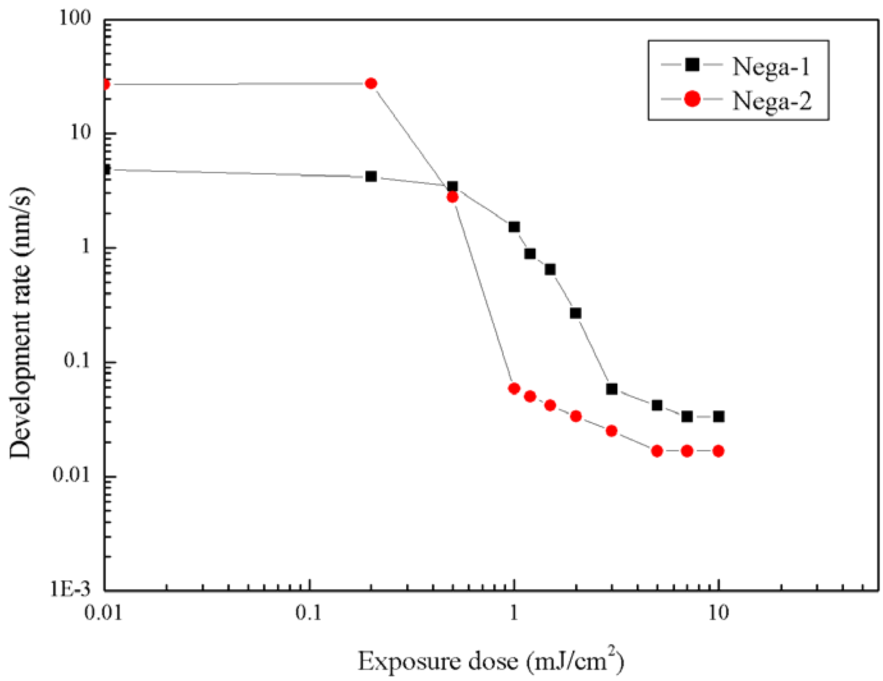
We investigated the sensitivity of positive-type and negative type resists in EUV exposure by the system described above, then performed simulations using the development rate data obtained. Table 2 indicates the conditions of the resists in our experiment.

Table 2 Conditions of resists in the experiment

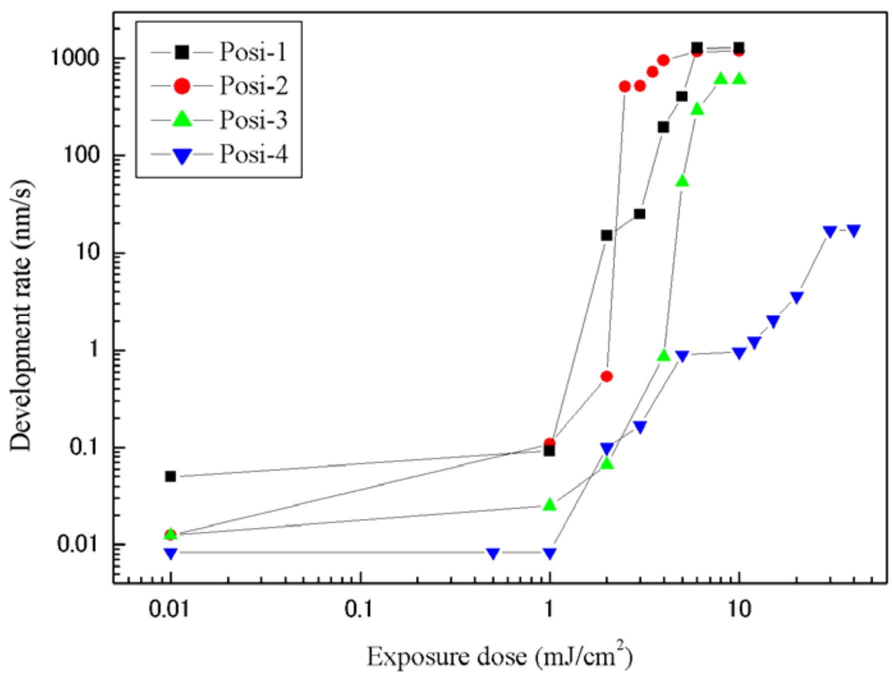
Negative-type						
Resist	maker	Pre-bake		PEB		Thickness
		Temp.	Time	Temp.	Time	
Nega-1	Rohm & Haas E.	105	60	115	60	100
Nega-2	Nippon Kayaku	90	90	95	100	100

Positive-type						
Resist	maker	Pre-bake		PEB		Thickness
		Temp.	Time	Temp.	Time	
Posi-1	TOK	120	90	120	90	100
Posi-2	TOK	100	90	110	90	100
Posi-3	TOK	110	90	100	90	100
Posi-4	Nippon Zeon	90	90	95	100	100

The negative-type resists examined were the Nega-1 electron beam resist (Rohm and Haas) and Nega-2 epoxy-resin-base chemically amplified resist (Nippon Kayaku). The positive-type resists used in our experiment were Posi-1 and Posi-2 acrylic-resin-base resists, and Posi-3 low-molecular-weight resist and the Posi-4 non-chemically amplified electron beam resist (Nippon Zeon),. Figure 5 (a) shows the discrimination curves for negative-type resists, while Figure 5 (b) indicates the discrimination curves for positive-type resists.



(a) Discrimination curves for negative-type resist



(b) Discrimination curves for positive-type resists

Figure 5 Relationship between development rate and exposure dose

Table 3 shows the results of development characteristic evaluations.

Table 3 Development characteristics

Negative-Type	Eth(60) mJ/cm2	γ60	tanθ
Nega-1	0.928	-1.445	-2.23
Nega-2	0.478	-3.023	-3.73

Positive-Type	Eth(60) mJ/cm2	γ60	tanθ
Posi-1	2.562	2.325	5.06
Posi-2	8.574	3.997	30.75
Posi-3	8.497	1.528	14.53
Posi-4	14.710	1.669	1.90

The results indicated that Posi-2 provides the highest contrast.

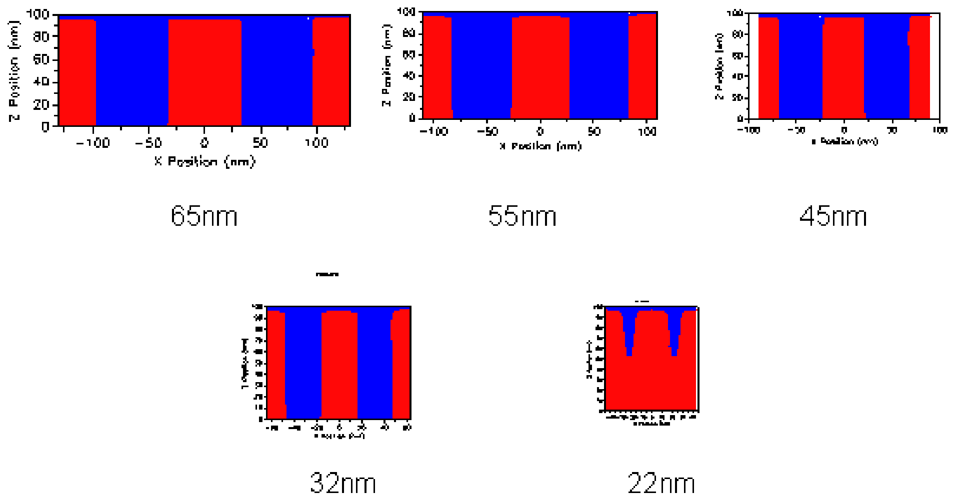
Simulation

We performed a simulation using the Posi-2 development data. Table 4 gives the simulation conditions.

Table 4 Simulation conditions (with Nikon HiNA-3)

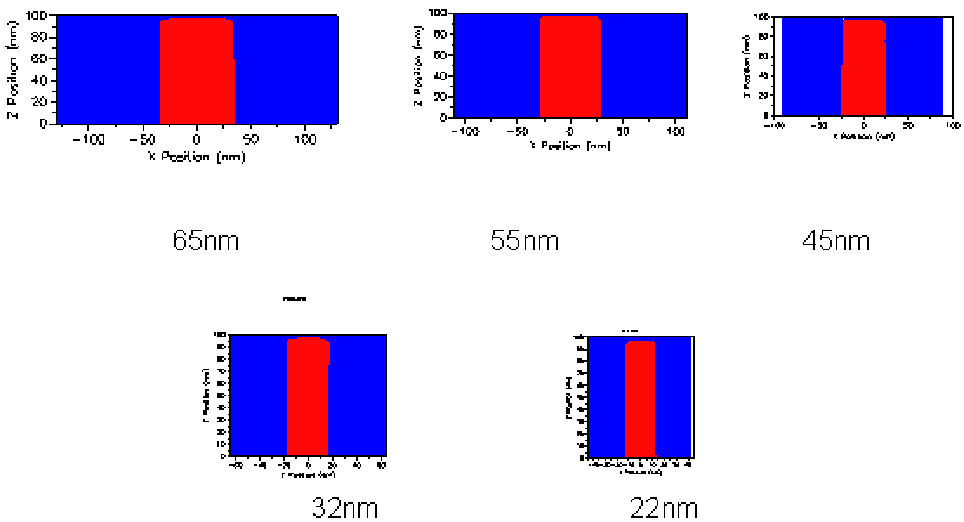
Wavelength (nm)	13.5
NA	0.3
Σ	0.8
Reduction	1/5

We examined L&S patterns and isolated patterns with pattern dimensions of 65, 55, 45, 32, and 22 nm. The defocus was examined using a 32 nm L&S pattern. Resist thickness was 100nm. Substrate was Si. Figures 6 through 8 show our simulation results. With L&S patterns, resolution can be maintained up to 32 nm. For isolated patterns, the results suggested that 22 nm resolution was within reach. In the depth of focus (DOF) simulation, the results indicated a resolution range of -0.1 to +0.1 μm from simulation result.



L&S Pattern simulation, Exposure dose= 17.2mJ/cm^2

Figure 6 Simulation results (65-22 nm Line and space patterns)



Iso Pattern simulation, Exposure dose= 17.2mJ/cm^2

Figure 7 Simulation results (65-22 nm Isolated patterns)

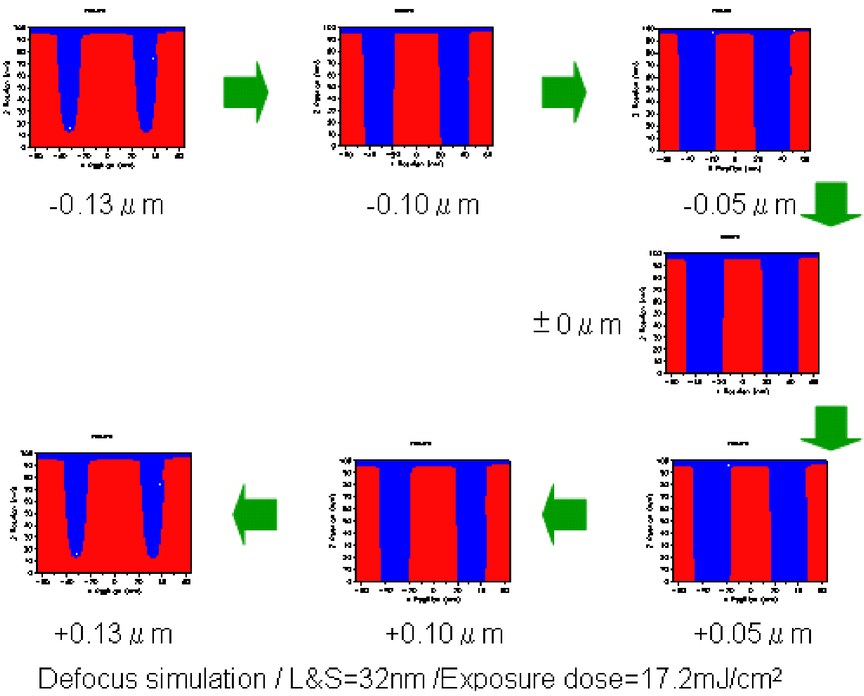


Figure 8 Simulation results (32 nm L&S, defocus -0.13 to +0.13 μm)

Conclusion

The VLES is comprised of the EUVES-7000 EUV open-frame exposure system, RDA-800EUV development rate analyzer, and Prolith lithography simulator. We used the VLES to compare the sensitivity and development contrast of negative-type and positive-type resists with EUV exposure. We also simulated EUV exposure using development rate data for the Posi-2, which showed the highest development contrast of all resists tested. The results of the experiment indicated a resolution of 32 nm with L&S patterns and a resolution of 22 nm with isolated patterns from simulation result. We also calculated defocus characteristics with a 32 nm L&S pattern. According to calculations, we estimate a focus margin of approximately 0.2 μm in depth of focus. We believe that using the system as described in this paper will permit the development of photoresist materials for EUV and expedite process development without requiring the purchase of costly EUV exposure equipment.

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