120W ArF laser with high-wavelength stability and efficiency for the next-generation multiple-patterning immersion lithography

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ABSTRACT

The new ArF Immersion Laser, GT64A has been developed to support the next generation multiple-patterning process. It offers the industry's highest output power of 120W with high stability and efficiency. 120W output power with auto-adjusting function enables to meet the requirements of various processes and makes higher-throughput possible even at 450mm-wafers. The increased wavelength stability and bandwidth stability can further improve overlay accuracy and CD error required for the next generation multiple-patterning lithography. Advanced gas control algorithm reduces the consumption of rare gases such as neon to a half. Helium-free operation is also under development to cope with the unstable supply of helium gases worldwide.

New advanced wavelength control and bandwidth control algorithm has been developed to meet tighter stability requirement for the next generation multiple-patterning lithography.

Keywords: DUV, KrF, ArF, photo-lithography, injection-lock laser, line narrow, 193nm lithography, Immersion, spectrum bandwidth, high power

1. INTRODUCTION

ArF excimer lasers are expected to be the main solution in the next generation photolithography using multiple-patterning due to the difficulty in developing EUV lithography system. We have already released an injection lock ArF excimer laser with high output power and high repetition rate for higher throughput and higher NA first immersion tool: GT60A (60W/6000Hz/0.5pm (E95)) to the ArF immersion market in Q1 2006 [1]. In the technology for 45nm and beyond, a light source is required to offer a narrower spectrum and high average laser power. We succeeded in releasing the next generation model, GT61A (6kHz/60W/0.30pm (E95)) with narrower spectral bandwidth used for high-NA lithography at the 45nm node in 2007 [2]. Both a newly developed high-precision E95 measuring module and a stabilization control system are provided as standard features, allowing a highly stable spectrum performance throughout the entire product lifetime. The higher throughput model, GT62A (6kHz/90W/0.30pm (E95)) with the higher power was developed for double patterning lithography at the 32nm node [3]. For the GT62A, a variety of technologies to reduce the running cost of laser is introduced, which is applicable backward for the previous GigaTwin series lasers [4][5]. In addition, the GT63A is the laser matching the enhancement technology of advanced exposure systems. For example, in order to provide illumination power optimum for resist sensitivity, it has extendable power from 60W to 90W. All laser systems are built on the GigaTwin platform, a common and reliability-proven platform. (Table 1) In order to fulfill the needs of the semi-conductor industry, we also develop our lithography lasers considering ecology throughout our development process. As a matter of fact, eco-friendly attitudes eventually lead to reduction of the total Cost of Ownership (CoO)[6].

For the next generation lithography, smaller CD with reduced cost and the potential extension to large size wafers (450mm) introduce difficult performance challenges. The requirement on the laser source to support the next generation

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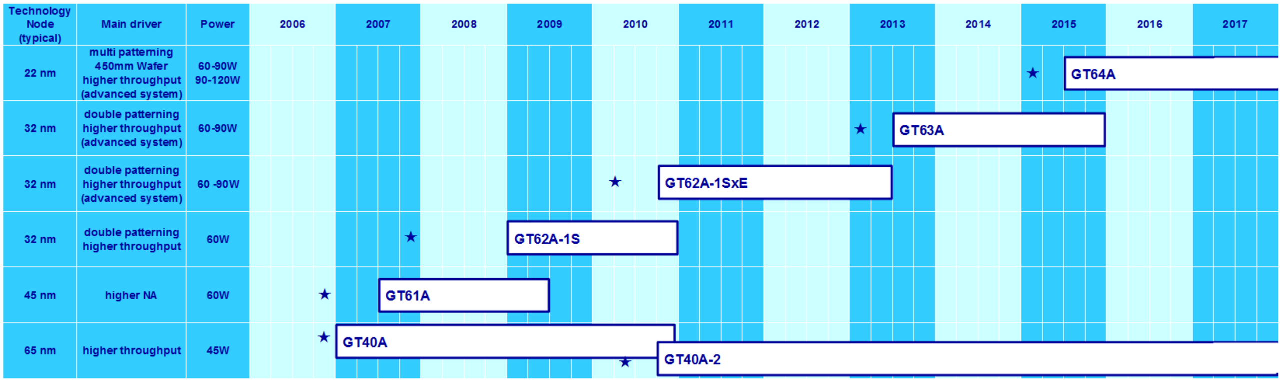
lithography with multiple-pattering is higher output power of DUV 193nm and tighter wavelength and bandwidth stabilities. The enhancement in output power from conventional 60W to 120W is necessary to achieve wafer throughput more than 200 wafers by hour. Also Wavelength stability and bandwidth stability are becoming more important. The requirement of wavelength stability has become 40% in 10 years as shown in Fig.1. To support the next generation multiple-patterning process, a new ArF excimer Laser, GT64A has been developed. It offers the industry's highest output power of 120W with high wavelength and bandwidth stability.



Technology Node (typical)	Main driver	Power	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
22 nm	multi patterning 450mm Wafer higher throughput (advanced system)	60-90W 90-120W										★ GT64A		
32 nm	double patterning higher throughput (advanced system)	60-90W								★ GT63A				
32 nm	double patterning higher throughput (advanced system)	60 -90W					★ GT62A-1SxE							
32 nm	double patterning higher throughput	60W		★		GT62A-1S								
45 nm	higher NA	60W	★	GT61A										
65 nm	higher throughput	45W	★	GT40A			★ GT40A-2							

Table 1 Technology nodes and the GigaTwin platform based on injection-lock technology

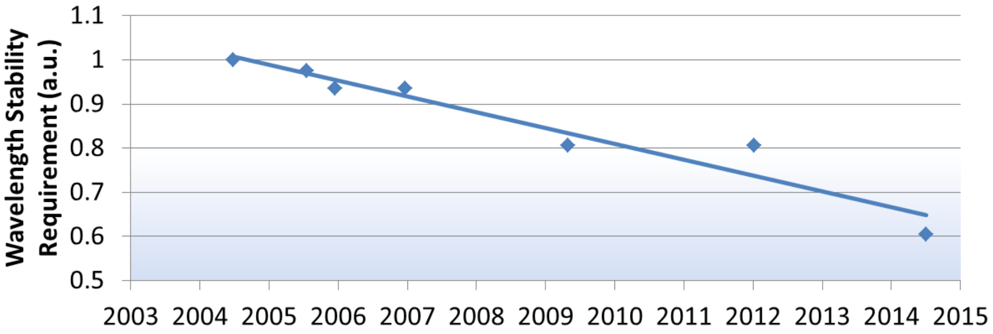


Fig.1 Wavelength stability requirement

2. FEATURE OF NEW ArF IMMERSION LASER GT64A

Basic improvements applied to the GT64A are high output power with high wavelength and bandwidth stability to meet the requirements for the next generation multiple-patterning lithography and 450mm wafers. Fig.2 shows the feature of new immersion laser GT64A. The increased wavelength stability and bandwidth stability of the GT64A can further improve overlay accuracy and CD error required for the next generation multiple-patterning lithography. And the GT64A can deliver up to 120W of output power. The industry's highest lasing efficiency is achieved through the proven Injection Lock technology. No additional utilities are required by this 120W light source, and the ingenious optical configuration makes it possible to maintain stable beam qualities. The automatic output adjustment function enables the output power to be dynamically optimized to meet the specific requirements of customers' processes. Furthermore, this function can also prevent the generation of unneeded power, thus contributing to the reduction of the operational cost and environmental impact. Advanced gas control algorithm reduces the consumption of rare gases such as neon to a half.

Helium-free operation is also under development to cope with the unstable supply of helium gases worldwide.

- Improved Stability Control
    - Wavelength Stability
    - E95 stability +/-3fm Wafer Averaged
- Flexible Power 90W to120W
- On-Board Beam Performance Monitor

Fig.2 Feature of new ArF immersion laser GT64A

3. IMPROVED STABILITY CONTROL

Thermal change during the period of wafer exchange operation affects wavelength and bandwidth stability. This thermal change results large error of wavelength and bandwidth from the target at the beginning of wafer exposure. To reduce this error, new advanced wavelength control and bandwidth control have been developed.

3.1 Compensation of thermal drift

Thermal change during the period of wafer exchange operation affects wavelength and bandwidth stability. The irradiation of a laser beam causes the temperature rise of optical elements and the wavefront deformation in the Line Narrowing Module (LNM) (Fig.3). This wavefront deformation results large wavelength error and bandwidth error at the beginning of wafer exposure after few seconds interval for wafer exchange operation. Fig.4 and Fig.5 show the wavelength error and bandwidth error after interval of wafer exchange operation respectively. At the beginning of wafer exposure, large errors have been seen. These errors are due to thermal change of optical elements during the period of wafer exchange operation. To reduce these errors, new control algorithms have been developed (Table 2).

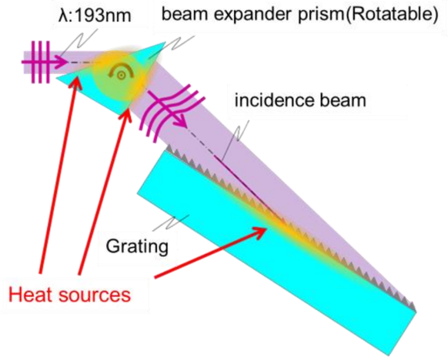


Fig.3 Deterioration factor in LNM

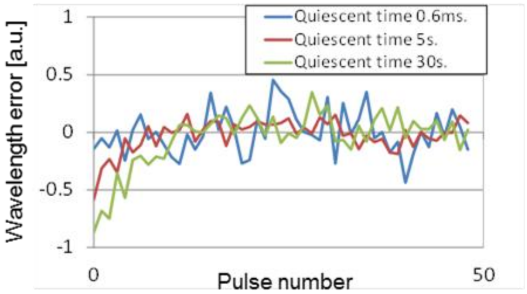


Fig.4 Example of wavelength error

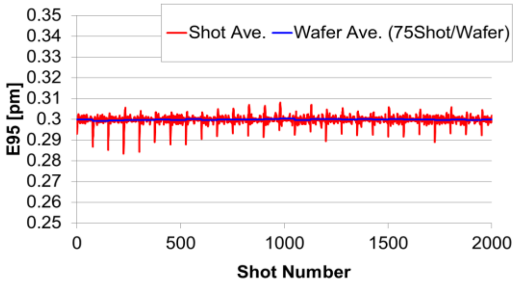


Fig.5 Example of bandwidth error

Deterioration factor	Phenomena	Improvement
Thermal drift	Wavelength stability : WL error offset after few seconds interval for wafer exchange operation	Introduce feed-forward control during interval of wafer exchange operation
	E95 stability : E95 error offset after few seconds interval for wafer exchange operation	Introduce new feed-back control

Table 2 Phenomena and improvement point

3.2 Improved stability control

Fig.6 shows the system diagram of GT64A. Wavelength control system consists of LNM, Monitor module (MM) and controller. And Bandwidth Control Module (BCM) is the system to control bandwidth. The BCM consists of two sub-modules: BCM Metrology, which allows high-precision measurement of bandwidth, and BCM Control, which allows the spectrum to be made variable.

New advanced wavelength control and bandwidth control have been developed to meet tighter stability requirement for the next generation multiple-patterning lithography. New software controls LNM and BCM and there is no changes in the current hardware design of the laser

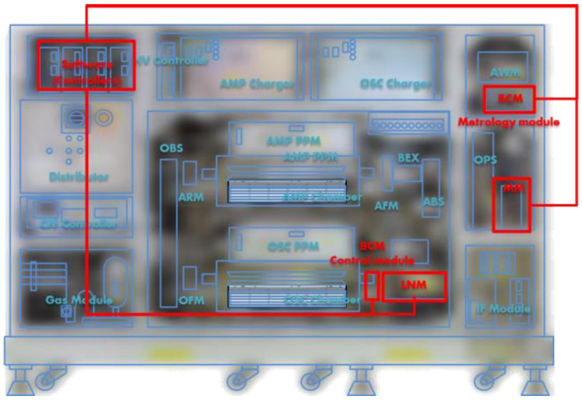


Fig.6 System diagram of GT64A

4. WAVELENGTH STABILITY

Thermal change during the period of wafer exchange operation affects wavelength stability. Its behavior is modelled and new advanced wavelength control algorithm has been developed to meet tighter stability requirement for the next generation multiple-patterning lithography. The newly developed feed forward control has reduced the wavelength error by 40%.

4.1 Control method and block diagram

To compensate thermal drift during the period of wafer exchange operation, newly developed feed-forward control is introduced. Fig.7 shows the configuration of a LNM. The wavelength is controlled by changing the rotation of a beam expander prism using a piezo actuator and a stepper motor. Fig.8 shows block diagram of wavelength control. Fig.8 (a) shows the block diagram of current wavelength control. And Fig.8 (b) shows the block diagram of newly developed wavelength control. To compensate thermal drift during the period of wafer exchange operation, newly developed feed-forward control is introduced. The command for the offset reduction is calculated according to the quiescent time and the beam expander prism is rotated using a stepper motor in the period of wafer exchange operation.

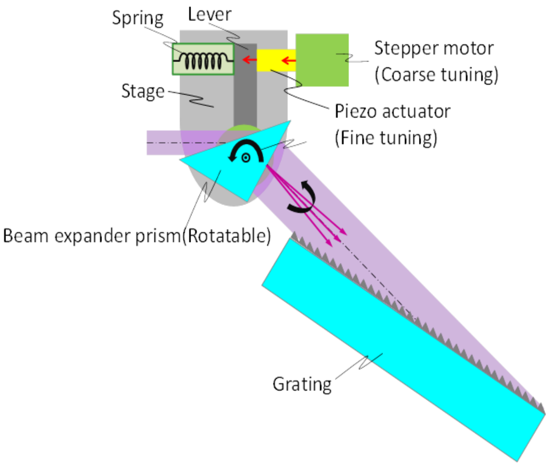
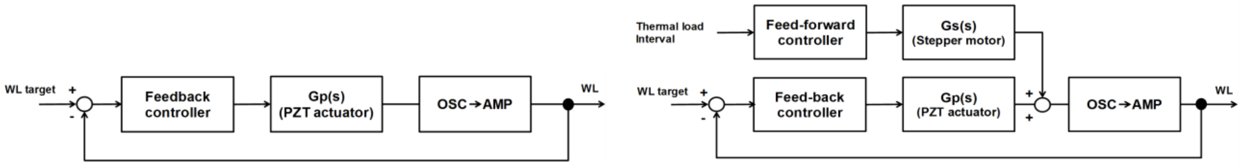


Fig.7 Wavelength control mechanism



(a) Current (without feed-forward control)

(b) Newly developed (with feed-forward control)

Fig.8 Block diagram of wavelength control

4.2 Test results of new wavelength control

The wavelength stability of the GT64A has been improved by approximately 40% with newly developed wavelength control algorithm. This enables very high overlay accuracy, CD control, and small LER required by the next generation multiple-patterning process technologies. Fig.9 shows the test result and the result of new algorithm (with feedforward control) has reduced the wavelength error by 40%. This enables very high overlay accuracy, CD control, and small Line Edge Roughness (LER) required for the next generation multiple-patterning process technologies.

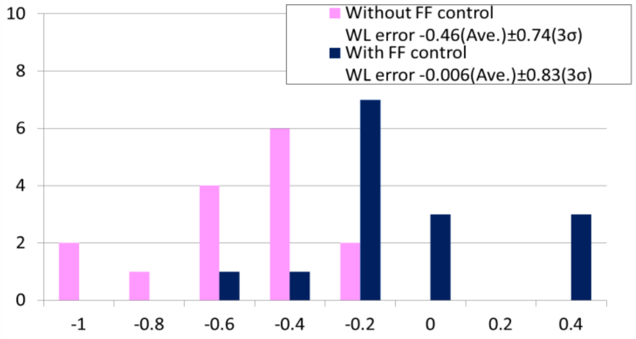


Fig.9 Wavelength error comparison (histogram of 15 samples)

5. BANDWIDTH STABILITY

Thermal change during the period of wafer exchange operation affects bandwidth stability. Its behavior is modelled and new advanced bandwidth control algorithm has been developed to meet tighter bandwidth stability requirement for the next generation multiple-patterning lithography. The newly developed feedback control has improved the bandwidth stability and less than +/- 3fm wafer averaged bandwidth stability has been achieved.

5.1 Control method and block diagram

Gigaphoton originally developed the control method using optical components for the variable bandwidth. Fig.10 shows the theory of the spectrum variable mechanism. The combination of optical components and actuator allows control of laser spectrum. The spacing between these two optical components can be adjusted to make the spectrum variable. Optical components are arranged in a resonator to make the spectrum variable. Fig.10 (a) shows the case in which the spectrum control is not conducted. If parallel-plate optics are arranged in the resonator for laser, the laser beam incident to an optical component is transmitted through the optical component just as if it is a plane wave. The plane wave is incident to the grating in the resonator to diffract wavelength λ1. The diffracted beam is resonated to output a fine spectrum. On the other hand, Fig.10 (b) shows the case in which the optical components are arranged separately to transmit the laser beam. The laser beam changes from a plane wave to a spherical wave and is incident to the grating to diffract different wavelengths λ1, λ2, and λ3 to output a thicker spectrum.

Fig.11 shows block diagram of bandwidth control. New feedback controller has been developed to improve bandwidth stability to meet tighter bandwidth stability requirement.

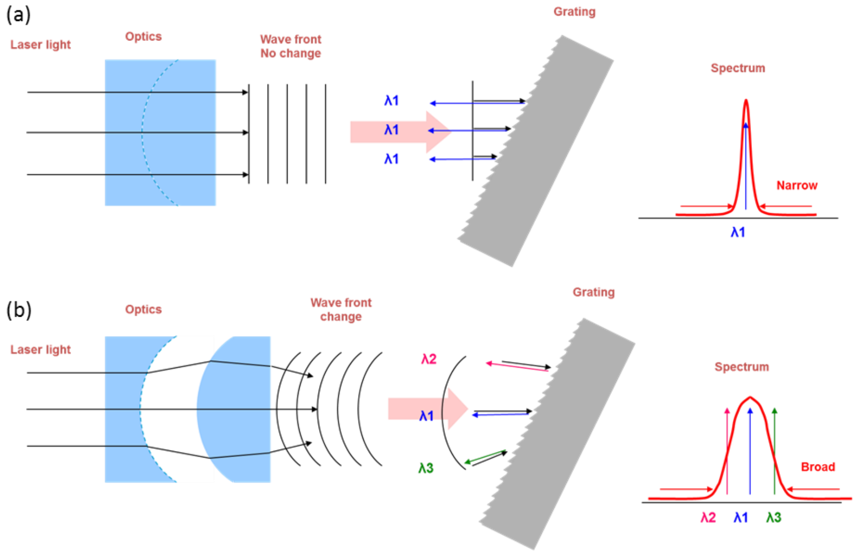


Fig.10 Theory of the spectrum variable mechanism

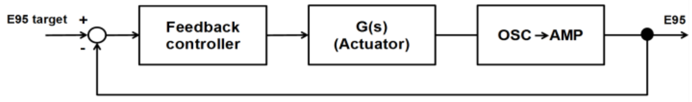


Fig.11 Block diagram of bandwidth control

5.2 Test results of new bandwidth control

Fig.12 and table 3 show the test result of advanced bandwidth control. This new control has improved the bandwidth stability. Less than +/- 3fm wafer averaged and +/- 10fm shot averaged bandwidth stability has been achieved.

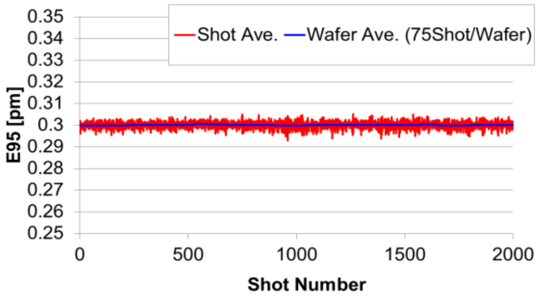


Fig.12 Advanced bandwidth control test results of helium free operation

		Current	Advanced
E95 stab.	Min. [fm]	-16.68	-6.96
Shot Ave.	Max. [fm]	8.00	5.06

		Current	Advanced
E95 stab.	Min. [fm]	-0.75	-0.20
Wafer Ave.	Max. [fm]	0.35	0.41
	max-min	1.10	0.62

Table 3 Advanced bandwidth control test results of helium free operation

6. SUMMARY

Gigaphoton has developed the new ArF excimer laser GT64A which supports the next generation multiple-patterning process and offers the industry's highest output power of 120W with high wavelength and bandwidth stability. New advanced wavelength control algorithm and bandwidth control algorithm have been developed to compensate thermal drift during the period of wafer exchange operation. The new advanced wavelength control has reduced the wavelength error by 40%. New advanced bandwidth control has improved the bandwidth stability. Less than +/- 3fm wafer averaged and +/- 10fm shot averaged bandwidth stability has been achieved. The wavelength and bandwidth stability of the GT64A meet tighter stability requirement for the next generation multiple-patterning photolithography.

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