The ArF laser for the next-generation multiple-patterning immersion lithography supporting green operations

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ABSTRACT

Multiple patterning ArF immersion lithography has been expected as the promising technology to satisfy tighter leading edge device requirements. One of the most important features of the next generation lasers will be the ability to support green operations while further improving cost of ownership and performance. Especially, the dependence on rare gases, such as Neon and Helium, is becoming a critical issue for high volume manufacturing process.

The new ArF excimer laser, GT64A has been developed to cope with the reduction of operational costs, the prevention against rare resource shortage and the improvement of device yield in multiple-patterning lithography. GT64A has advantages in efficiency and stability based on the field-proven injection-lock twin-chamber platform (GigaTwin platform). By the combination of GigaTwin platform and the advanced gas control algorithm, the consumption of rare gases such as Neon is reduced to a half. And newly designed Line Narrowing Module can realize completely Helium free operation. For the device yield improvement, spectral bandwidth stability is important to increase image contrast and contribute to the further reduction of CD variation. The new spectral bandwidth control algorithm and high response actuator has been developed to compensate the offset due to thermal change during the interval such as the period of wafer exchange operation. And REDeeM Cloud™, new monitoring system for managing light source performance and operations, is on-board and provides detailed light source information such as wavelength, energy, E95, etc.

Keywords: ArF excimer laser, multiple patterning, injection-lock, green operations, reduction of neon usage, helium free

1. INTRODUCTION

Multiple patterning ArF immersion lithography has been expected as the promising technology to satisfy tighter leading edge device requirements. One of the most important features of the next generation lasers will be the ability to support green operations while further improving cost of ownership and performance. As semiconductor manufacturing fabs are going to expand, their cost and impact to the environment cannot be negligible. Total operating cost including gas, electricity, coolant and exhaust are estimated as much as $200k/year/laser. Recently Neon and Helium gas supplies are going to be unstable and become a threat to the operation of high volume manufacturing. In laser system, Neon is used as laser gas in the chamber. Regarding 193nm-ArF laser, the key elements is Argon and Fluorine. But, more than 96% of the laser gas is Neon as a buffer. And Helium is used as purge gas in Line Narrowing Module because its low refraction index is convenient to keep the bandwidth of laser stable. To keep high volume manufacturing sustainable, we need to support greener fab operations. On the other hand, both overlay and CD errors must be minimized to shrink CD nodes of the next generation multiple-pattering. To enhance the resolution and productivity for the next generation multiple-patterning application, various laser performances such as stable E95 control and tighten wavelength stability are required. And performance monitoring system for managing light source performance and operations becomes

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important to improve the yield rate.

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. (Fig.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 lithography with multiple-patterning is tighter wavelength and bandwidth stabilities. Especially bandwidth stability is becoming more important. To support the next generation multiple-patterning process, a new ArF excimer Laser, GT64A has been developed [7].

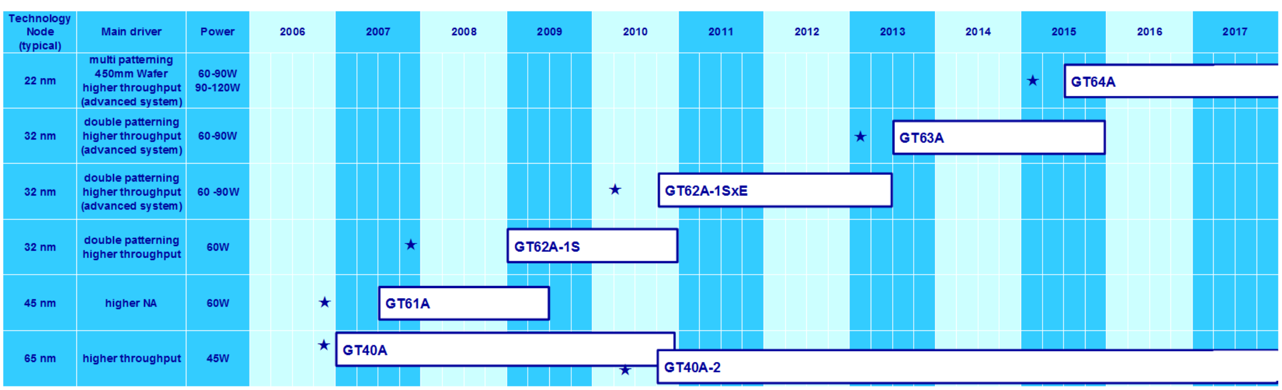

Fig.1 Technology nodes and the GigaTwin platform based on injection-lock technology

2. FEATURE OF NEW ArF IMMERSION LASER GT64A

The new ArF Excimer Laser, GT64A has been developed to support the next generation multiple-patterning process. Features of the GT64A are the ability to support green operations and productivity enhancement.

2.1 Green technology

Recently Neon and Helium supplies are unstable and become more critical to the operation of high volume manufacturing. To cope with the unstable supply of Neon and Helium, green technologies such as reduction of gas consumption are implemented to the GT64A (Fig.2). Advanced gas control algorithm reduces the consumption of Neon to a half. And completely Helium free operation can be realized by newly developed Line Narrowing Module.

2.2 Productivity enhancement

Overlay and CD errors must be minimized to shrink CD nodes of the next generation multiple-pattering. To enhance the resolution and productivity for multiple-patterning application, various laser performances such as stable E95 control and tighten wavelength stability are required (Table 1). Especially E95 stability is becoming more important. GT64A has enough E95 stability performance to meet tighten stability requirement. And performance monitoring system for managing light source performance and operations becomes important to improve the yield rate. New application software called REDeeM Cloud™ will enable high-precision and customizable monitoring. (Fig.2)

Green ready

	GT63A	GT64A
Neon consumption	200kL/year	100kL/year
Helium Consumption	80kL/year	0kL/year

Productivity Enhancement

	GT63A	GT64A
E95 Stability		
Wafer Average	300fm±30fm	300fm±5fm
Shot Average	-	300fm±5fm
On-board Beam Performance Monitor	Option	sMonitoring by shot & REDeeM Cloud

Fig. 2 Feature of new ArF immersion laser GT64A

Process Requirements	Laser Requirements
Precise CD Control	Stable E95 control
Accurate Focus, Overlay	Improved Wavelength Stability
High Yield rate	Performance monitor

Table 1 Performances required to lasers to meet process requirements

3. GREEN TECHNOLOGIES

To cope with unstable supply of Neon and Helium, green technologies are implemented to the GT64A. By applying new gas control algorithm called “eTGM”, Neon gas consumption can be reduced by 50%. For further Neon reduction, gas recycling system called “hTGM” has been developed and laser performance using recycled gas is confirmed. And newly developed Line Narrowing Module enables completely Helium free operation.

3.1 Neon reduction technology

During laser operation, the laser gases in chambers are degraded gradually. To avoid the downtime due to gas-exchange, a certain degree of fresh gas is introduced to chamber and then almost same amount of the degraded existing gas is exhausted at fixed intervals. At traditional method, amount of injection and exhaust (gas rinse) is fixed anytime (Fig.3 (a)). By new gas control algorism, parameters such as input power, gas pressure and energy of laser are closely monitored during operation and fed back to the gas controller system. The amount of gas rinse can be optimized according to the laser condition (Fig.3 (b)). Fig.4 shows comparison of the gas consumption trend between current gas control and new gas control over 500 Million pulses operation. By applying new algorithm, the laser gas consumption can be reduced by 50%.

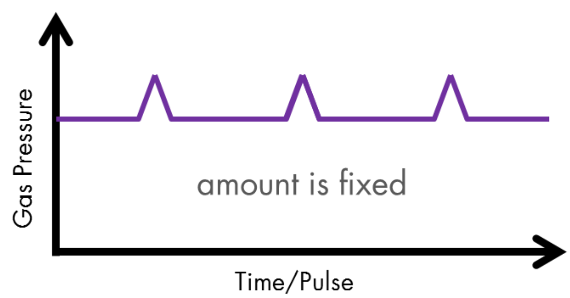

Fig.3 (a) Current gas control algorithm

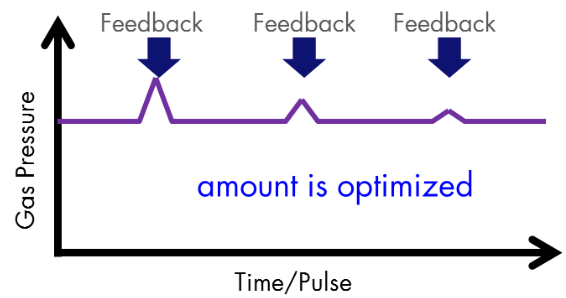

Fig.3 (b) New gas control algorithm

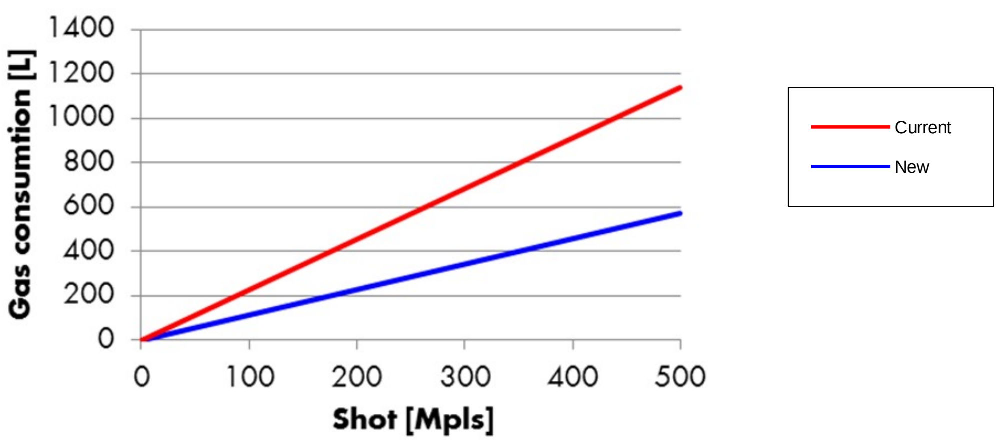

Fig.4 Comparison of gas consumption trend between current and new gas control algorithm

3.2 Neon gas recycling system

As the need for reducing the consumption of Neon gas becomes demanding, new innovations such as Neon recycling systems for lasers are needed. Our next step in the roadmap is to recycling or reusing resources. Fig.5 shows concept design of gas recycling system called hTGM (h-series TGM). The gas inside excimer laser chambers is replaced regularly by continuous gas exhaust and fresh gas injection to remove impurities generated during the electrical discharge. By this mechanism, the rare gases such as Argon, Krypton, and Neon are continuously released into air. To avoid this loss, hTGM system purifies used gas into fresh gas so that laser can use it repeatedly.

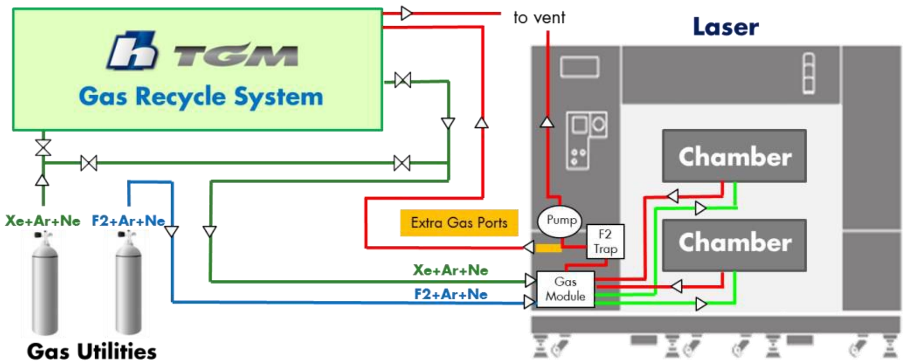

Fig.5 hTGM; gas recycling concept

We have confirmed KrF laser performance using recycled gas from hTGM system (Fig.6). Based on gas capacity of hTGM system, the laser has started to use recycled gas after vertical green dot line. Fig.7 shows pulse count and laser key performance data of energy stability and wavelength error. Each laser performance shows no significant difference before and after using recycled gas.

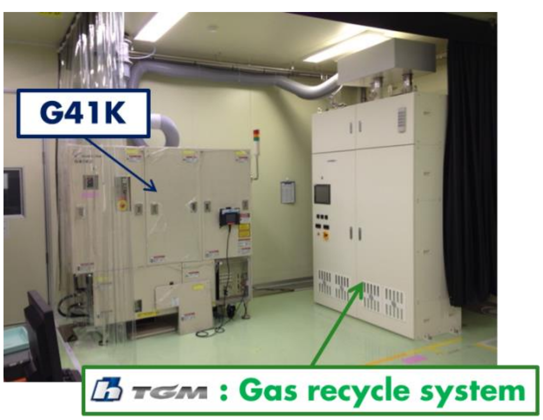

Fig.6 hTGM system

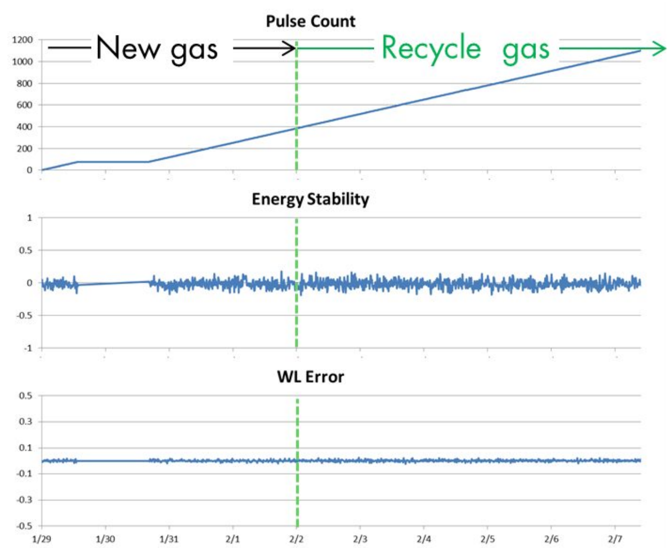

Fig.7 Laser performance using recycled gas

3.3 Helium free technology

Helium is used as purge gas in Line Narrowing Module. Merit is its low refractive index. About an order of magnitude lower temperature dependence of refractive index provides less wavefront change due to refractive index distribution in the module. Typical E95 fluctuation without E95 control is shown in Fig.8 (a). While the laser is operated with high duty cycle mode, increasing heat effect causes E95 broaden. This impact is relatively smaller when Helium is used as purge gas. It is suitable for precise E95 control. To conquer Helium supply risk, new Line Narrowing Module (LNM) has been developed. Fig.8 (b) shows E95 fluctuation of new LNM without E95 control. New module enables completely Helium free operation by compensating this thermal effect.

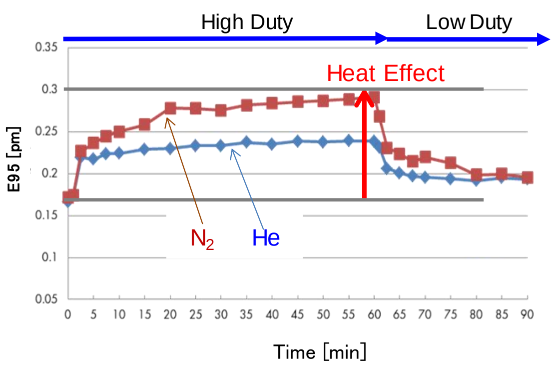

Fig.8 (a) E95 fluctuation of current LNM without control

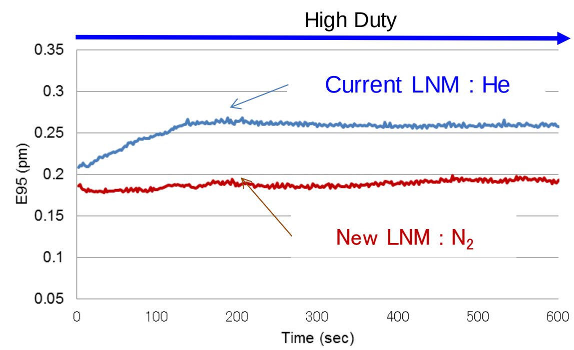

Fig.8 (b) E95 fluctuation of new LNM without control

4. PRODUCTIVITY ENHANCEMENT

Thermal change during the period of wafer exchange operation affects bandwidth stability. New advanced bandwidth control algorithm and faster actuator to adjust E95 have been developed to meet tighter bandwidth stability requirement for the next generation multiple-patterning lithography. The newly developed feedback control has improved bandwidth stability and less than +/- 3fm wafer averaged bandwidth stability has been achieved. And newly developed actuator has improved shot averaged bandwidth stability and achieved less than +/- 5fm.

4.1 Bandwidth stability improvement

Gigaphoton originally developed the control method using optical components for the variable bandwidth. Fig.9 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.9 (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 λ_1. The diffracted beam is resonated to output a fine spectrum. On the other hand, Fig.9 (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 λ_1, λ_2, and λ_3 to output a thicker spectrum. Fig.10 shows the bandwidth control system diagram of GT64A. Bandwidth control system consists of LNM, Bandwidth Control Module (BCM) and controller. 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.

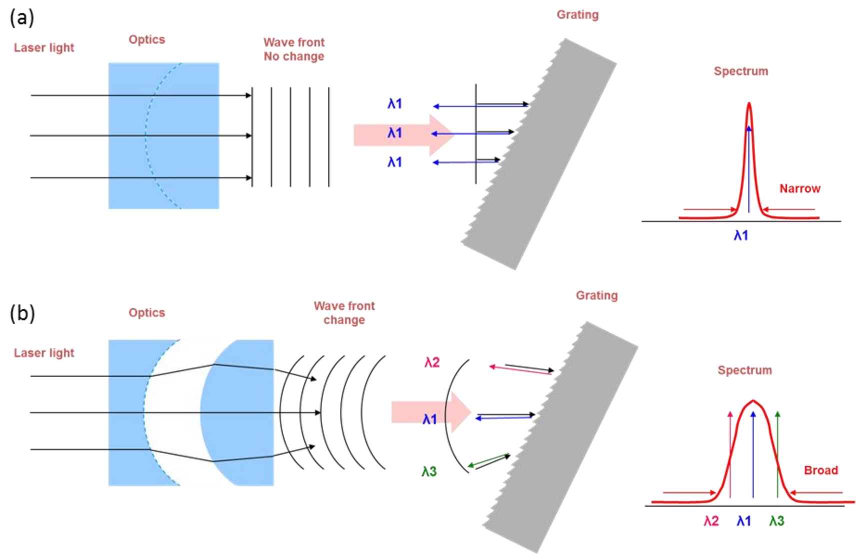

Fig.9 Theory of the spectrum variable mechanism

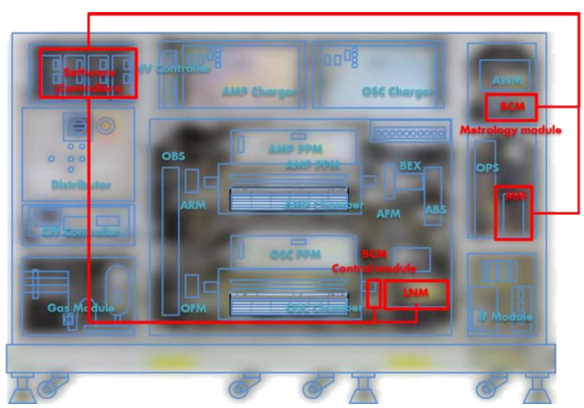

Fig.10 System diagram of GT64A

New advanced bandwidth control has been developed to meet tighter bandwidth stability requirement for the next generation multiple-patterning lithography. New software controls BCM and there is no changes in the current hardware design of the laser. Fig.11 shows the test result of current and new bandwidth control. In Fig.11 (a), E95 at the timing just after the period of wafer exchange operation tends to be thinner than control target with current control. On the other hand, new algorithm is implemented to minimize this negative effect. Faster feedback loop can minimize the delay time of control. Bandwidth offset at the beginning of wafer exposure can be significantly decreased and highly precise E95 control is realized (Fig.11 (b)). Fig.12 shows histogram of wafer averaged bandwidth over 2,000 wafers simulated operation. Less than +/- 3fm wafer averaged bandwidth stability has been achieved.

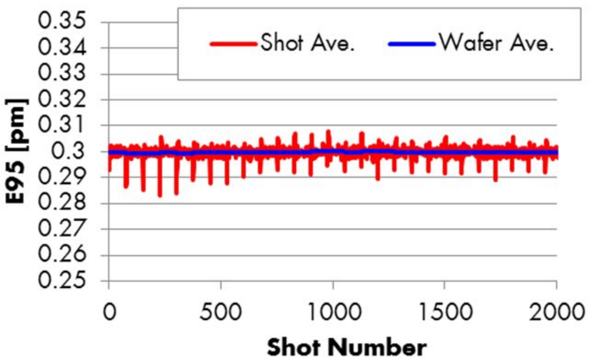

Fig.11 (a) E95 stability with current control

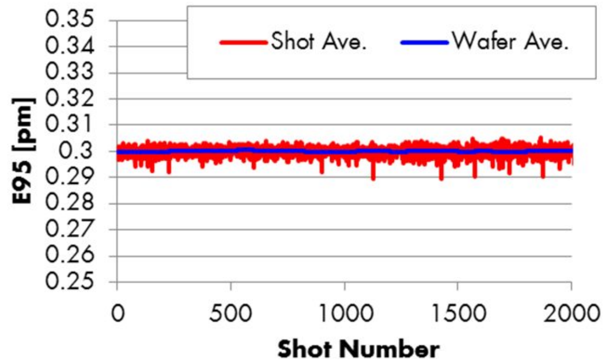

Fig.11 (b) E95 stability with new control

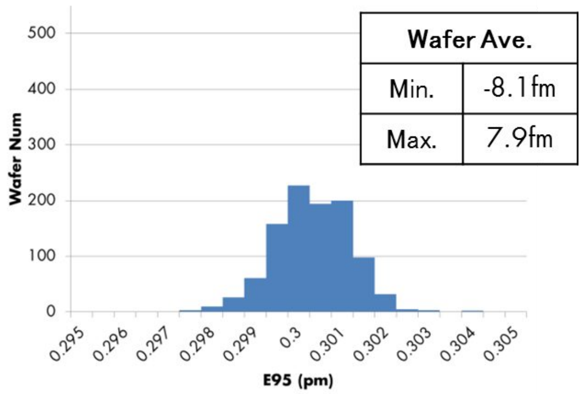

Fig.12 (a) Histogram of E95 stability with current control

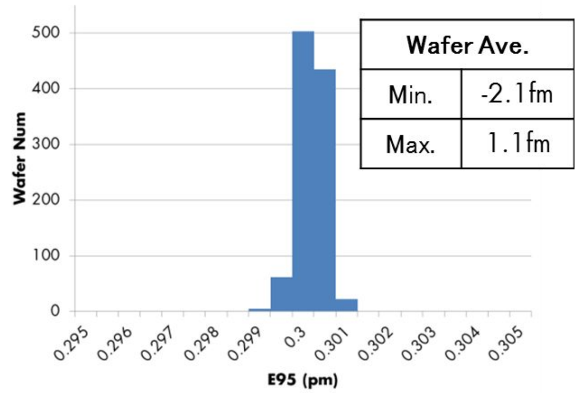

Fig.12 (b) Histogram of E95 stability with new control

For further improvement of E95 stability, new actuator to control E95 has been developed. Fig.13 shows step response of E95 with current actuator and new actuator. In Fig.13 (a), current actuator takes 2seconds to stabilize 100fm gap from target. On the other hand, new actuator can stabilize more than 30 times faster than current actuator (Fig.13 (b)). We think that the new actuator has enough speed to keep E95 stable not only in a wafer level but also in each shot level. Fig.14 shows short term E95 stability comparison between current and new actuator. We simulated about 30 wafers operation in our test bench. Fig.14 (a) shows histogram of E95 shot average with current actuator. Fig.14 (b) shows histogram with new actuator. As shown in Fig.14 (b), shot average can be achieved less than +/-5fm with this new actuator. This improvement will contribute to the productivity.

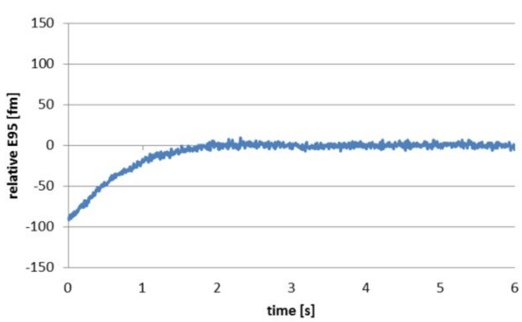

Fig.13 (a) Step response of E95 with current actuator

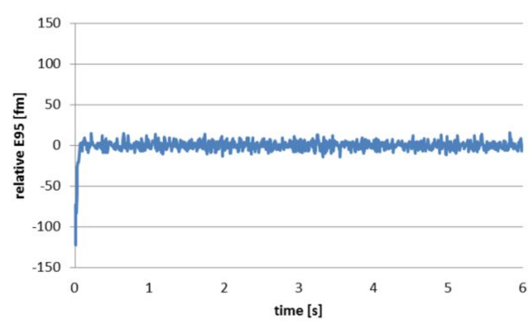

Fig.13 (b) Step response of E95 with new actuator

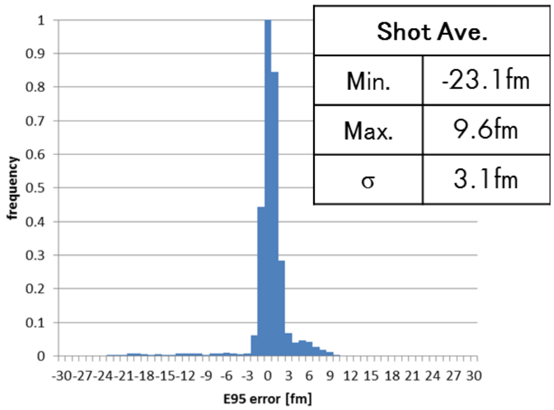

Fig.14 (a) Histogram of E95 stability with current actuator

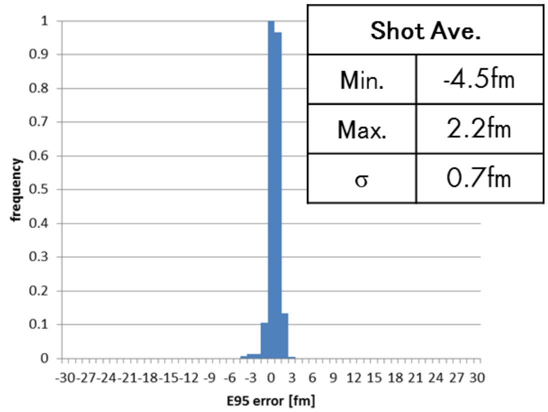

Fig.14 (b) Histogram of E95 stability with new actuator

4.2 Open innovation platform

Process technologies begin to shrink below 10 nm and multi-patterning at this level is very challenging. Tool performance becomes more critical and customizable monitoring will also be needed. We need to work closely with customers, scanner makers, and other third parties to understand the needs of the next generation lithography. As first step of our new software strategy, we created new application software called REDeeM Cloud™. On-board Beam Performance Monitor and REDeeM Cloud™ will enable high-precision and customizable monitoring. Collaboration with external partners enables us further green operations or new improvement.

Fig.15 shows an example of wafer analysis, E95 behavior in one wafer exposure. Horizontal axis is shot (scan) number. Laser performance on wafer level can be easily checked with this monitoring system.

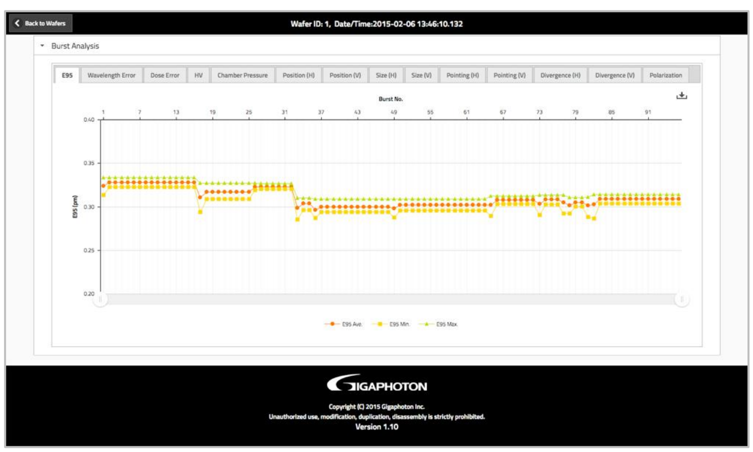

Fig.15 An example of wafer analysis

5. SUMMARY

Gigaphoton has developed the new ArF excimer laser GT64A which supports the next generation multiple-patterning process. Based on the field-proven twin-chamber platform, it offers cost-effective green operations while improving performance. Consumption of Neon is reduced to a half by new gas control called eTGM and completely Helium free operation can be realized by newly developed Line Narrowing Module. New advanced bandwidth control has improved the bandwidth stability. Less than +/- 3fm wafer averaged bandwidth stability has been achieved. And newly developed actuator to control E95 has improved shot averaged bandwidth stability and shot average can be achieved less than +/- 5fm. REDeeM Cloud™ will enable high-precision and customizable monitoring. Collaboration with external partners enables us further green operations or new improvement.

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