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ABSTRACT

193nm ArF excimer lasers are widely used as light sources for the lithography process of semiconductor production. At first, ArF excimer lasers have been used in semiconductor productions at the 90nm node and recently ArF excimer lasers have begun to be used for the 32nm node, by the progress in the immersion technology and the double-patterning technology. Furthermore, considering current status of development of the lithography technology using a next-generation light source, or extreme ultraviolet (EUV) light source, the start of mass production with the next-generation light source is estimated to start from 2015. Therefore, there is a need for extension of 193nm immersion lithography technology. By using the multi-patterning and double-patterning technology, design rules below limit at single exposure is possible. However, throughput is reduced due to increased lithography processes. In order to improve a decrease in throughput, a high power ArF excimer laser and larger size wafer (450mm in diameter) is needed. We have developed a new high power laser with the concept of eco-friendly. In this paper, we will introduce technologies used for our latest ArF excimer laser having tunable output power between 90W and 120W and report its performance data.

Keywords: 32nm node, 450mm wafer, ArF excimer laser, Injection Lock, Line narrow, 193nm lithography, Immersion, Spectral bandwidth, High power, Double-patterning, Multi-patterning, Ecology

1. INTRODUCTION

ArF immersion technology has been used widely in volume production for 45nm node. For 32nm node and beyond, double-patterning technology with ArF immersion lithography is considered to be the main stream solution until EUV is ready. We have continued to release our GT6xA series lasers to meet the demands of the industry, that is, to realize high throughput and high NA. GT60A (60W/6000Hz/0.50pm (E95)) was released in the first quarter of 2006 in order to provide a light source for immersion lithography at the 45nm node.[1] This model achieved improved energy stability and narrow spectral at 60W. GT61A (60W/6000Hz/0.35pm (E95)) was released in 2007 to meet the high-NA lithography.[2] This model realized highly accurate E95 by a stabilization control system provided as standard. GT62A (90W/6000Hz/0.35pm (E95)) was released in order to satisfy the double-patterning lithography.[3] This model realized output power of 90W. GT62A-1SxE (60-90W/6000Hz/0.35pm (E95)) was released in order to satisfy the enhancement technology of advanced illumination systems.[4] This model achieved tunable output power between 60W and 90W. We have finished the development of GT63A which inherits the performance of GT62A, realizes Reliability, Availability and Maintainability and also meets a latest illumination enhancement technology. GT63A is the most up-to-date light source for lithography process.[4]

Today, 193nm ArF excimer lasers are used not only for immersion lithography but also for advanced lithography technologies such as multi-patterning and larger size wafer (450mm in diameter). However, these tend to increase the number of lithography processes, which directly decrease throughput. In order to improve throughput, it is required to improve the speed stage of the scanner as well as the higher power laser. Now we are going to release a new laser GT64A. The new laser inherits the performance of GT63A, realizes Reliability, Availability and Maintainability and also meets the demands to further improve throughput. The maximum output of this laser is 120W. This laser system as with other all laser systems are built on the GigaTwin platform, a common and reliability-proven platform. (Table 1) In this paper, we report the technologies used for the laser and also some properties such as beam profiles, divergence and stabilities of output power at 120W.

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Table 1. Technology nodes and required performance for ArF light sources

Technology Node (typical)	Main driver	Requirement for ArF Laser light source	Power	GT model
22 nm	multi patterning 450mm Wafer higher throughput (advenced system)	6kHz//0.30pm(E95)	90 - 120W	GT64A
32 nm	double patterning higher throughput (advenced system)	6kHz//0.30pm(E95)	60 - 90W	GT63A
32 nm	double patterning higher throughput (advenced system)	6kHz//0.30pm(E95)	60 - 90W	GT62A-1SxE
32 nm	double patterning higher throughput	6kHz/0.30pm(E95)	60W	GT62A-1S
45 nm	higher NA	6kHz//0.30pm(E95)	60W	GT61A
65 nm	higher throughput	4kHz//<0.50pm(E95)	45W	GT40A

2. LASER SYSTEM AND POWER UP

2.1 Gigaphoton injection lock system

Gigaphoton's injection lock system consists of a Master Oscillator (MO) and a Power Oscillator (PO). Low energy and highly narrow bandwidth seed light is produced by the MO and is amplified by the PO. We adopt injection lock system for the following reasons.

Merits	Benefits
1) Higher efficiency	Easy to obtain higher power
2) Narrow spectral bandwidth	Easy to obtain narrower spectrum
3) Wide tolerance of synchronization timing	Better stability and 2-charger system
4) Very small seed light energy	Low Cost of Ownership (CoO) from low optical load
5) Long pulse duration	Low CoO from low optical load

By making use of these injection lock characteristics, output power has become tunable from 90W to 120W without having negative impacts on major laser performances, including spectrum and wavelength stability.

2.2 High power laser with the concept of eco-friendly

The easiest way to increase output power is to increase the input power. However, the increase in input power is not eco-friend because it is accompanied by increase in power consumption, in the apparatus size and in cost. Therefore, Gigaphoton chose to increase the output power efficiency under eco-friendly concept.

Figure 1 shows the laser output power for the electric input power. Here, the electric input is the power that is input to the laser chamber. The solid line shows the relationship between the actual electric input and the laser output. Dashed line with square dots shows the result of estimating the relation between electric input and laser output power while maintaining the relationship between the electric input and laser output power in a single chamber laser that does not adopt the injection locking system. Dashed line with circle dots shows the result of estimating the relation between electric input and laser output power while maintaining the relationship between the electric input and laser output power in a twin chamber laser that adopt the injection locking system for the first time. This figure show that the next two matters.

- 120W laser system is to save about 60% of the electrical energy than a laser system with a single chamber.
- 120W laser system is to save about 20% of the electrical energy than a laser system with an initial twin chamber.

Gigaphoton has been paying attention to ecology for the past years, and has been successful to develop lasers efficient in output power. Among these, there are two major efficiency improvement points, that is, times when progresses are made toward high power from 20W to 45W and from 90W to 120W. We have carried out the following two methods to increase the lasing efficiency.

1) Adoption of the injection lock system

2) Increase the gain of the amplifier chamber

Regarding 2), it is easily possible by the injection lock technology of Gigaphoton.

Figure 2 shows major utilities for the laser output power. Although laser output power is increased from 90W to 120W, there is no change in utilities. This could be achieved by improving the lasing efficiency.

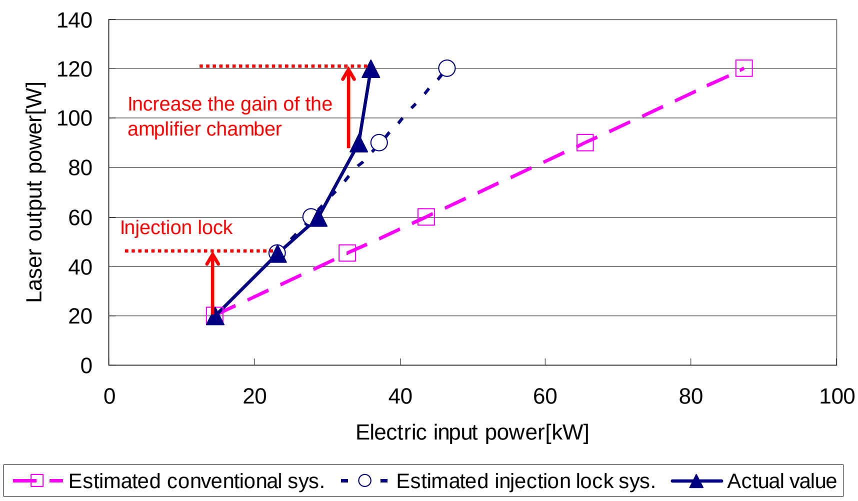

Figure1. Laser output power

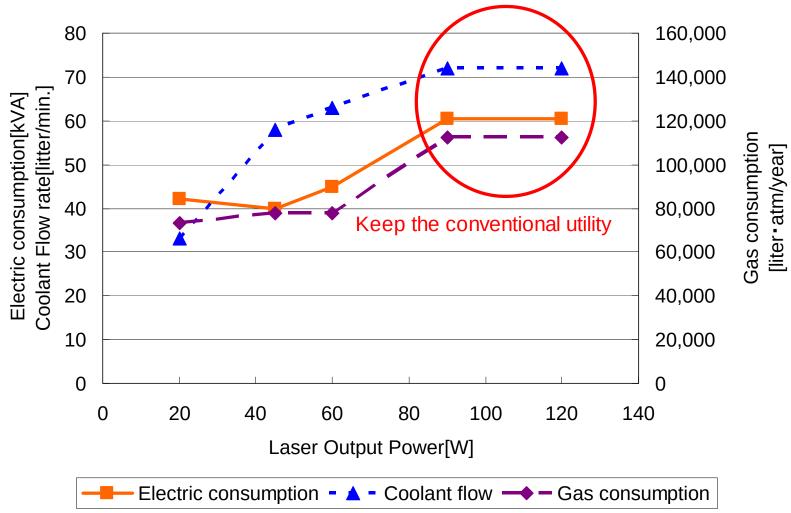

Figure2. Major utilities for the laser output power

3. MAJOR INITIAL PERFORMANCE OF THE GT64A

We tested the major performances and they were confirmed to meet design targets.
Its conditions are as follows:

Output power: tuned power in the step of 10W from 90W to 120W to 90W
Repetition rate: 6kHz
Measured performances: output pulse energy, energy dose stability, wavelength stability, spectral bandwidth, pulse duration, beam profile, beam divergence, beam position and beam pointing at the same time at each power
Time for changing target power: five seconds each time

The results are described below.

3.1 Output pulse energy and output power

Tunable output power provides optimum illumination power for resist sensitivity. Figure 3 shows the pulse train of output energy at 90W, 100W, 110W and 120W. We have confirmed that the tunable range of output power is from 90W to 120W. When change of energy is required, the laser optimizes the control parameters automatically. Then, the output is changed automatically within 5 seconds.

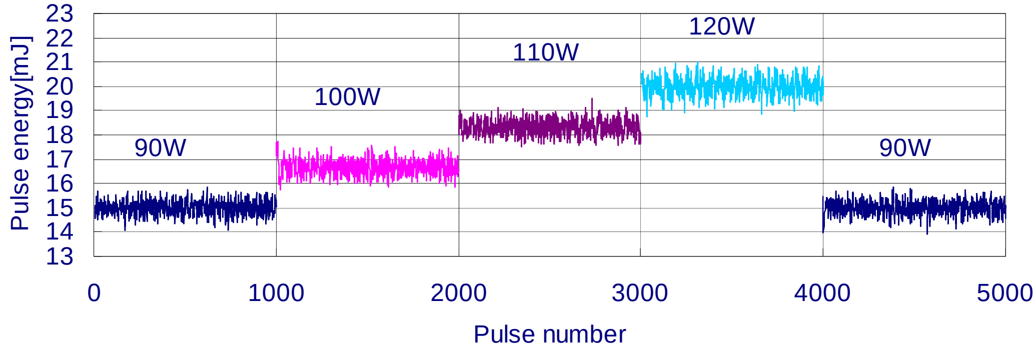

Figure3. Pulse energy and output power

3.2 Dose stability

Dose stability is an important property of laser output because it affects CD control. Figure 4 shows the trend of energy dose stability at 90W, 100W, 110W and 120W. These data was calculated by integrating the energy over the specified moving window. We have confirmed that there is no difference in 90W through 120W operation.

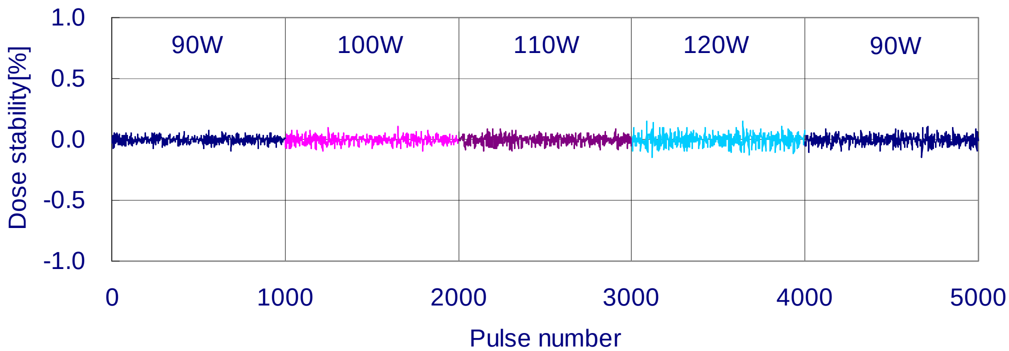

Figure4. Dose stability from 90 to 120W

3.3 Wavelength stability

Changes of wavelength cause defocus, so the stability of the wavelength is important. Figure 5 and Figure 6 show the dependency of wavelength error and wavelength stability sigma with wavelength control on output power levels at 90W, 100W, 110W and 120W. These data were calculated by statistically treating the wavelength error averaged over the specified moving window. We have confirmed that wavelength control accuracy is independent of output power.

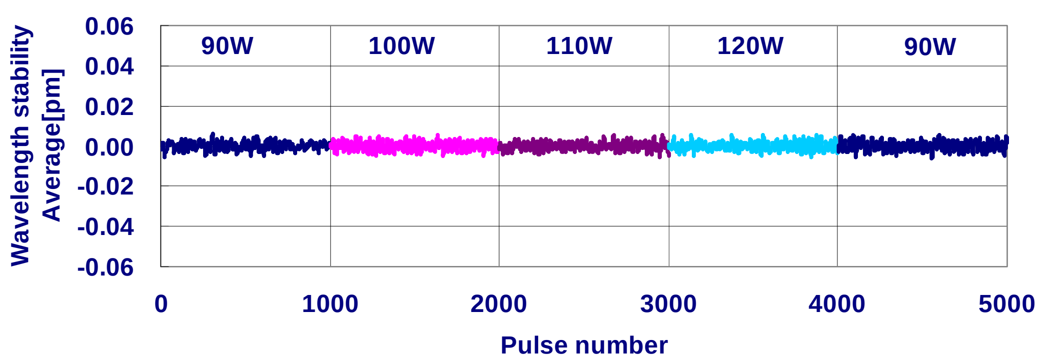

Figure5. Wavelength stability error from 90 to 120W

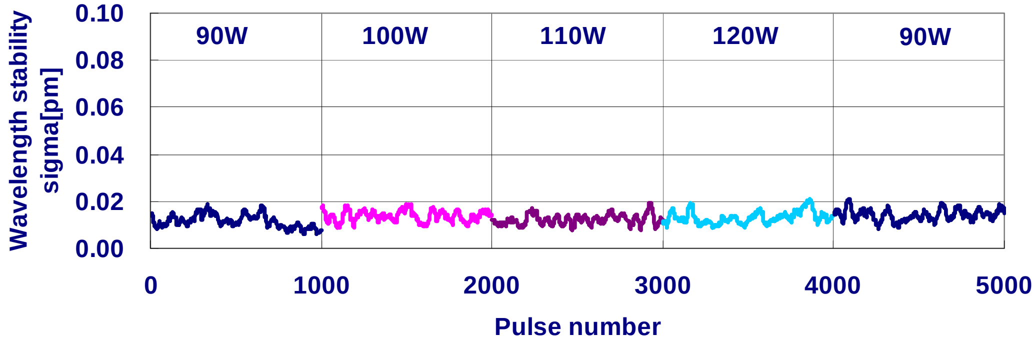

Figure6. Wavelength stability sigma from 90 to 120W

3.4 Spectral bandwidth

The spectral bandwidth of a laser is an important factor for imaging ability and CD control. Figure 7 shows the data of spectral bandwidth of 95% energy concentration (E95) with spectral bandwidth control with E95 set point 0.3pm at 90W, 100W, 110W and 120W. Figure 8 shows the spectral profile shape at 90W, 100W, 110W and 120W. We have confirmed that spectral bandwidth control accuracy and spectral profile shape are independent of output power.

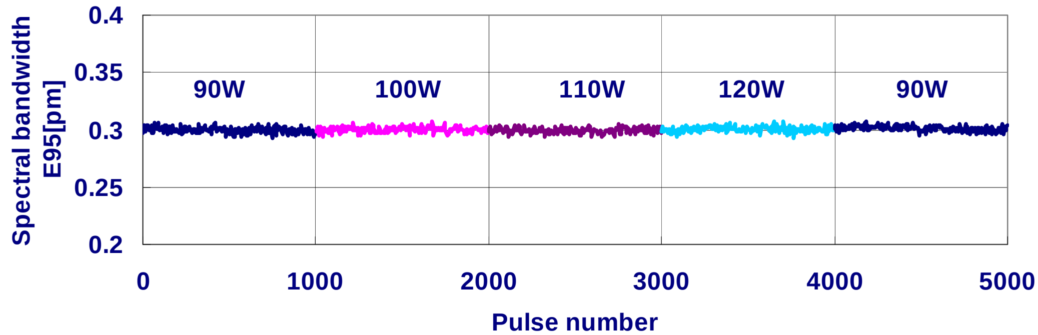

Figure7. Spectral bandwidth from 90 to 120W

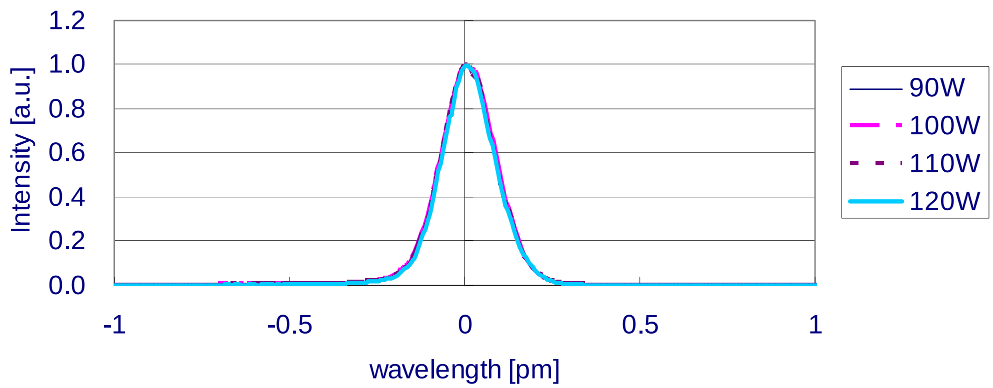

Figure8. Spectral profile shape from 90 to 120W

3.5 Pulse duration

Long pulse duration is important because it lowers CoO. This is because the peak power intensity of laser pulses affects the lifetime of optical components inside scanners. In additional, long pulse duration is able to reduce the line edge roughness. Figure 9 shows the laser pulse shape and the pulse duration TIS (Time Integrated Square) at 90W, 100W, 110W and 120W. We have confirmed that pulse duration keeps more than 160 nsec under output power from 90W to 120W.

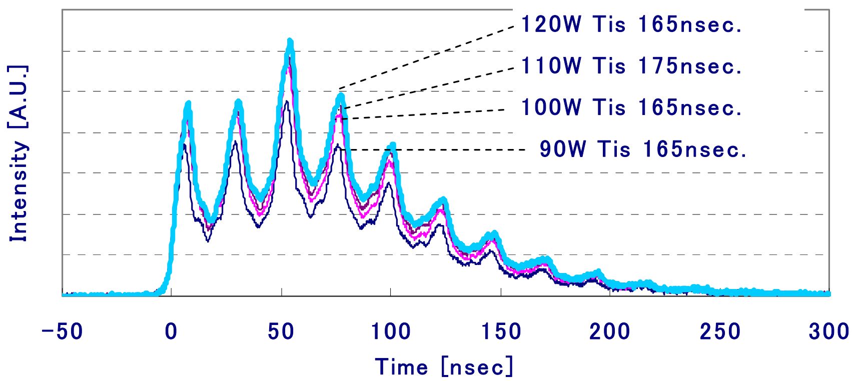

Figure9. Laser pulse shape and the pulse duration

3.6 Beam profile and divergence

New illumination system like multi-patterning lithography requires ArF laser with more stable optical performances. Figure 10 and 11 show the dependency of the fluctuation of beam profile and divergence on output power levels of 90W, 100W, 110W and 120W, respectively. These data were normalized at 90W data. We have confirmed that beam profile and divergence are stable in 90W through 120W.

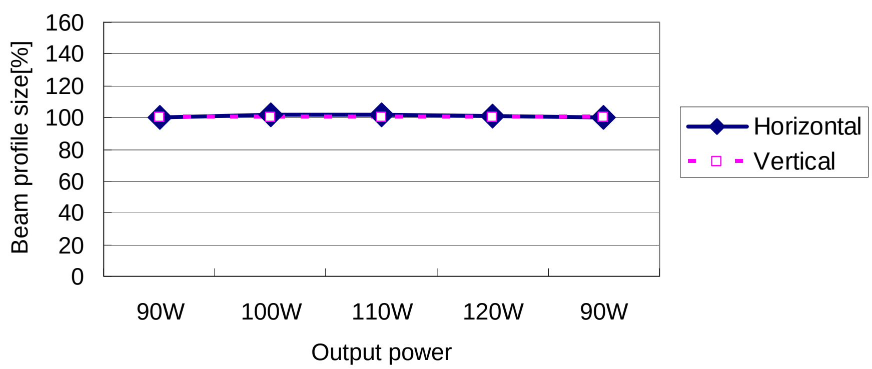

Figure10. Output power dependency of beam profile size

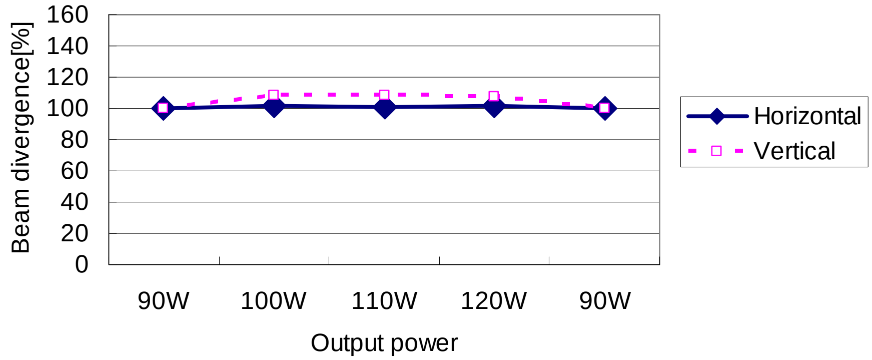

Figure11. Output power dependency of beam divergence

3.7 Beam position and pointing

As in preceding section, new illumination system like a multi-patterning lithography requires ArF laser with more stable optical performance. Figure 12 and 13 show the output power dependency of beam position and pointing at 90W, 100W, 110W and 120W, respectively. These data were calculated to initial 90W data. We have confirmed that beam position and pointing are stable in 90W through 120W.

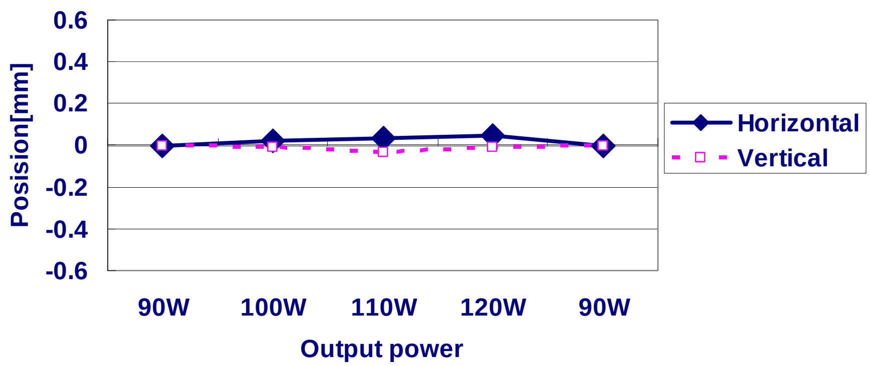

Figure12. Output power dependency of beam position

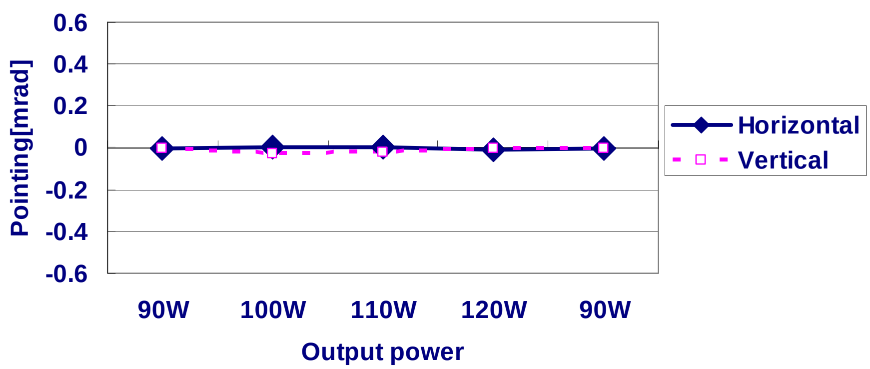

Figure13. Output power dependency of beam pointing

4. DURABILITY OF GT64A

We are going to confirm the durability test under 120W condition. We are going to check the major output specifications.

Output power: 120W (It is most severe condition for optics)
Repetition rate: 6 kHz
Major output specification: output pulse energy, wavelength, spectral bandwidth
We executed GRYCOS (The Gigaphoton Recycled Chamber Operation System) at 21Billion pulses. GRYCOS is the technology that a laser chamber can be used up to 40Bpls by using the chamber as an oscillator and then an amplifier. This is a unique technology of Gigaphoton that can be realized by commonalized amplifier and oscillator chambers. After these demonstrations are done, the chamber is operating without trouble.

Figure 14 shows the pulse train of the output energy during the durability test over 26Billion pulses (Bpls).

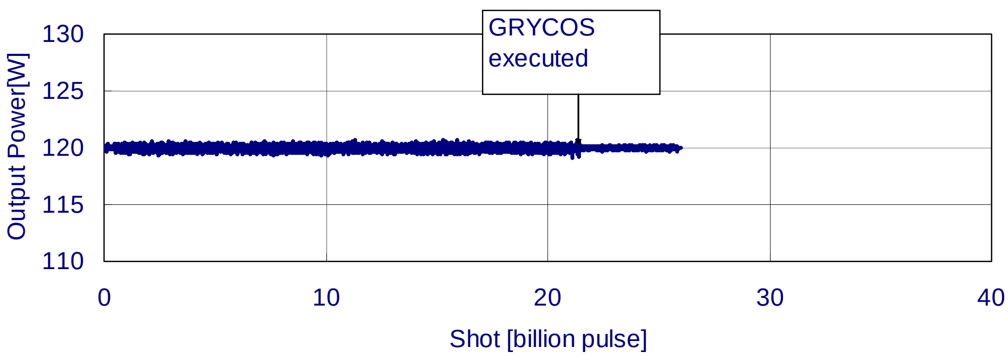

Figure14. Pulse energy trend

4.1 Wavelength

Changes of wavelength cause defocus, so the stability of the wavelength is important. Figure.15 shows the dependency of wavelength during durability test. We confirmed stability by 26 billion pulses of the whole.

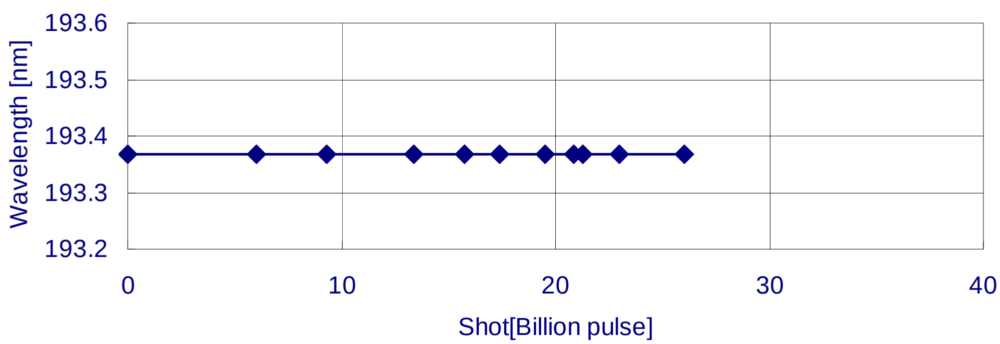

Figure15. Wavelength trend in the durability test

4.2 Spectral bandwidth

The spectral bandwidth of laser is an important factor for imaging ability and CD control. Figure 16 shows the data of spectral bandwidth of 95% energy concentration (E95) with spectral bandwidth control with E95 set point 0.3pm at 120W. We confirmed stability by 26 billion pulses of the whole.

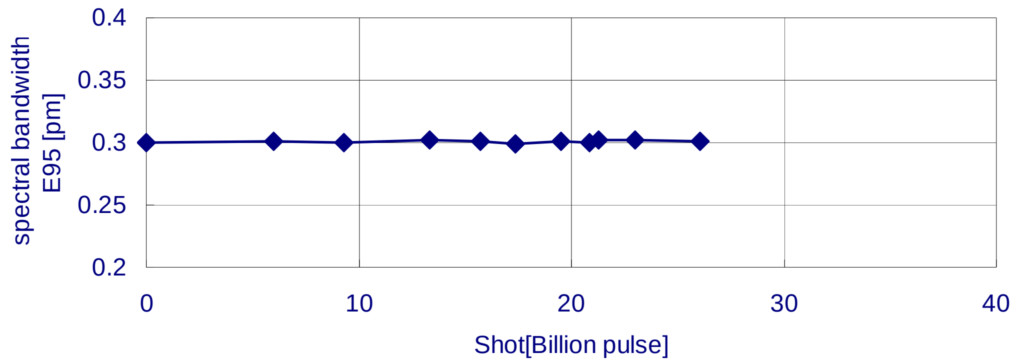

Figure.16 Spectral bandwidth E95 trend in the durability test

5. CONCLUSION

Gigaphoton has developed the tunable output power (90W - 120W) laser GT64A.

It is designed to support the requirement of both multi-patterning and 450 mm wafer lithography and has the following characteristics.

- Power up: 120W for high throughput.

-Optimized illumination power for various resist sensitivities.

-High stability and beam quality for overlay accuracy.

-Contribution to reduce optics deterioration.

Now, we are carrying out the durability test under 120W condition. We do not find degradation as of 26Bpls in major specification of laser. We continue to carry out the durability test to demonstrate the reliability until 40Bpls.

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