High-power and high-energy stability injection lock laser light source for double exposure or double patterning ArF immersion lithography

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ABSTRACT

ArF immersion technology is spotlighted as the enabling technology for below 45nm node. Recently, double exposure technology is also considered for below 32nm node. We have already released an injection lock ArF excimer laser with ultra-line narrowed and stabilized spectrum performance: GT61A (60W/6kHz/ 10mJ/0.35pm) to ArF immersion market in Q4 2006. The requirements are: i) higher power ii) lower cost of downtime for higher throughput iii) greater wavelength stability for improved overlay and iv) increased lifetimes for lower operation costs.

We have developed high power and high energy stability injection lock ArF excimer laser for double patterning: GT62A (90W/6000Hz/15mJ/0.35pm) based on the technology of GT61A and the reliability of GigaTwin (GT) platform. A high power operation of 90W is realized by development of high durability optical elements. Durability of the new optics is at least 3 times as long as that of the conventional optics used in the GT61A. The energy stability is improved more than 1.5 times of performance in the GT61A by optimizing laser operational conditions of the power oscillator. This improvement is accomplished by extracting potential efficiency of injection lock characteristic. The lifetime of power oscillator, which is one of the major parts in cost of ownership, is maintained by using higher output of the power supply.

Keywords: 32nm node, ArF excimer laser, Injection Lock, line narrow, 193nm lithography, Immersion, spectrum bandwidth, high power

1. INTRODUCTION

193nm ArF light sources are widely used from below 90nm node in semiconductor mass production1). And ArF immersion lithography technology is ready to begin volume production at the 45nm node. Beyond that, double patterning is considered to be the most promising technology to meet the requirement associated with the next-generation 32nm node. To achieve this, market demands for ArF light source are getting more severe, for example on power and spectral bandwidth. Higher laser power is needed for higher throughput and stable narrower spectral bandwidth is needed for higher NA. In addition, maximize uptime of ArF light source is demanded for higher throughput.

With these background, Gigaphoton released reliable 4kHz/45W/0.5pm (E95) ArF light source for 65nm node in 2005, model GT40A2), based on injection lock technology developed in corporation with ASET3) in 2002. This injection lock technology was originally targeted for high power 5kHz/30W/0.5pm (E95) fluorine laser as a 157nm lithography light source. Since then we adopt this injection lock technology for reliable higher power, narrower spectral bandwidth laser systems.

After the first generation model GT40A, we succeeded in releasing second generation model GT60A of higher output power 6kHz/60W/0.5pm (E95) for higher throughput and higher NA 1st immersion tool in 2006 and third generation of narrower spectral bandwidth 6kHz/60W/0.35pm (E95) model GT61A for higher NA 45nm node in 2007. In addition, this year fourth generation of higher power for higher throughput model GT62A (6kHz/90W/0.35pm) is developed for double patterning 32nm node (Table 1). All these laser systems are integrated on a common and already proven reliable GT platform.

In this paper, we report key technologies of higher output power and performance test results during 15days gaslife of the GT62A.

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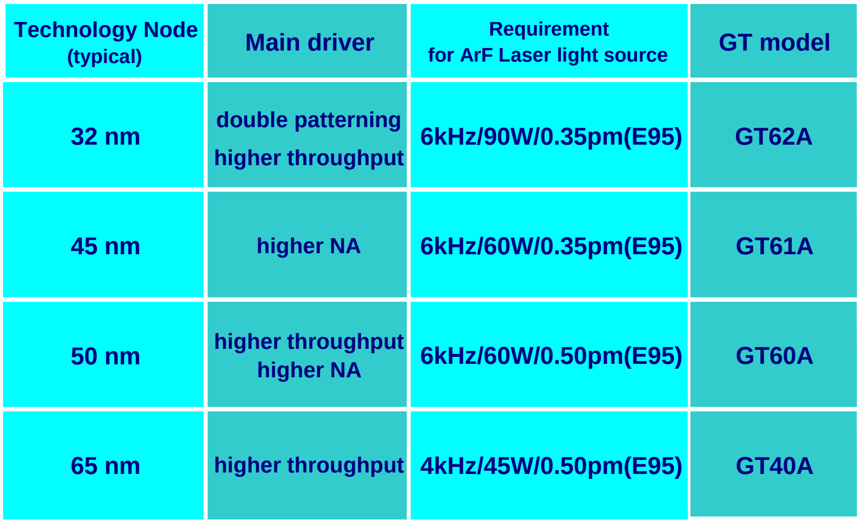
Table 1. Technology nodes and required performance for ArF light sources



Technology Node (typical)	Main driver	Requirement for ArF Laser light source	GT model
32 nm	double patterning higher throughput	6kHz/90W/0.35pm(E95)	GT62A
45 nm	higher NA	6kHz/60W/0.35pm(E95)	GT61A
50 nm	higher throughput higher NA	6kHz/60W/0.50pm(E95)	GT60A
65 nm	higher throughput	4kHz/45W/0.50pm(E95)	GT40A

2. FEATURES AND MAIN SPECIFICATIONS OF THE GT SERIES

2.1 Gigaphoton injection lock system

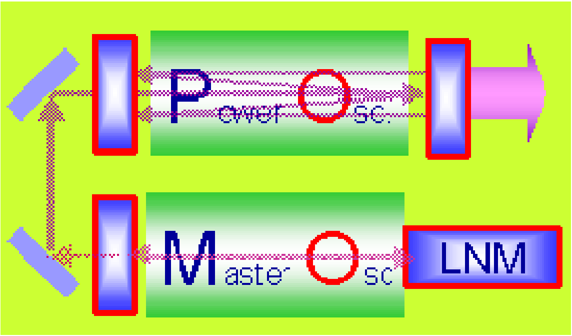


Fig. 1. A schematic of the injection lock (MOPO) system

Gigaphoton's injection lock (MOPO) system consists of a Master Oscillator (MO) and a Power Oscillator (PO). A schematic of this system is shown in Fig.1. Low energy and highly spectrally narrowed bandwidth seed light is produced by the MO and is amplified by the PO. We adopt injection lock system for the following reasons[3)].

Merits	Benefits
1) Higher efficiency	Easy to get higher power
2) Narrow spectral bandwidth	Easy to get 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 characteristic, output power has been increased from 60W to 90W without deteriorating spectrum and energy stability. Lifetime of the power oscillator is maintained by using higher output of the power supply.

2.2 GT series main specifications

Gigaphoton’s technological advance allows semiconductor industry to challenge not only for higher throughput but for the shrinking of IC design geometry. Major specifications of the GT series are shown in table 2.

1st generation of the GT series was shipped as model GT40A[4)], and its main specifications are 4kHz/45W/0.5pm (E95). To extract higher laser power (45->60W), 2nd generation of GT series, model GT60A, introduced advanced technology as follows for higher repetition rate operation (4->6kHz)[5)].

1) More efficient acoustic wave damper compared with the GT40A (chamber)
2) Improved gas flow (chamber)
3) Higher power supply with high stability in addition to heat load countermeasure

3rd generation model GT61A for narrower spectral bandwidth (0.5->0.35pm) was equipped with high resolution line narrowing module (LNM)[6)]. All these laser systems are integrated on a common and already proven reliable GT platform[7)].

4th generation model GT62A was improved as follows.

1) Higher output of the power supply for higher output power (10mJ/60W->15mJ/90W)
2) Higher accuracy gas control module and new gas control algorithm for gaslife extension (3days/100Mpulse->15days)
3) Anti-vibration function in the chamber for improvement of wavelength stability
4) Extremely durable optics compared with the GT61A (at least 3 times)
5) Upgradeability from 60W to 90W

Table 2. Major specifications of the GT series.

ArF model		GT40A	GT60A	GT61A	GT62A
Wavelength	**nm**	**193**	**193**	**193**	**193**
Power	**W**	**45**	**60**	**60**	**60/90**
Pulse energy	**mJ**	**11.25**	**10**	**10**	**10/15**
Max. rep rate	**Hz**	**4000**	**6000**	**6000**	**6000**
E95	**pm**	**0.5**	**0.5**	**0.35**	**0.35**
Durability (Expected)					
MO Chamber	**Bpls**	**20**	**20**	**20**	**20**
PO Chamber	**Bpls**	**30**	**30**	**30**	**30**
FM*	**Bpls**	**12**	**12**	**12**	**12**
MM*	**Bpls**	**30**	**30**	**30**	**30**

*FM：Front Mirror, MM: Monitor Module

3. TECHNOLOGY OF THE GT62A

3.1 Higher output power

A higher power ArF excimer laser is necessary for higher throughput. Injection lock technology is more efficient by design than other dual chamber configurations. Therefore it is easy to get higher power. The power increase from 60W to 90W is accomplished by making use of the injection lock characteristic. For higher output power we have changed the operation gas pressure and high voltage of chamber. And the GT62A is equipped with new power supply which has higher maximum power to maintain chamber lifetime. As a result, high power operation of 90W was achieved. Moreover the GT62A PO chamber lifetime is 30Billion pulses that is same as the GT61A4 (60W).

3.2 Extension gaslife to 15days

To extend gaslife is one of market demands for ArF light source. The longer the gaslife becomes, the lower the gas exchange frequency. As a result, wafer productivity is improved. To satisfy the demand, we have improved hardware and software needed for gas control.

In general, the causes of the deterioration of the gas are consumption of fluorine and generation of impurities. Therefore addition of fluorine and control of the amounts of impurities by exhaust and injection were already performed for extending gaslife. But higher accuracy gas control is necessary for a further gaslife extension. The GT62A has new hardware and software as following for extending gaslife.

1) New gas supply module for improvement of injection and exhaust accuracy
2) New gas control algorithm for adapting to a change of operating condition

These improvements allow to maintain a stable fluorine concentration with less than 1kPa error. As a result, gas refill interval increases from 3 days to 15 days, the resulting downtime is then only 24 times / year – down from 150-300 times / year under typical operation at volume manufacturing fabs.

3.3 Anti vibration function

To improve wavelength stability, the chamber of the GT62A has had an anti-vibration function. In general the chamber of high repetition frequency excimer laser has the cross flow fan (CFF) for replacing gas deteriorated by electrical discharge. When the vibration by CFF propagates to optical modules, it causes deterioration of wavelength stability. Wavelength stability of the GT62A is greatly improved by the anti-vibration function.

3.4 Extremely durable optics

We have developed high durability optics for 90W output. The developed optics elements are mirrors.

Durability of the developed mirrors is at least 3 times as long as that of the conventional mirrors used in GT61A laser.

4. MAIN PERFORMANCE OF THE GT62A

We tested the main initial performances and they were confirmed to meet design targets.

The results are described as follows

4.1 Output power

Fig.2 shows output pulse energy characteristic for input energy of power supply at 6kHz. These data were taken typical gas pressure of PO chamber for GT62A (90W) and GT61A (60W) respectively. The maximum power of the GT62A has increased by a newly developed higher output power supply. As a result, The GT62A PO chamber lifetime is 30Billion pulse that is same as the GT61A (60W)

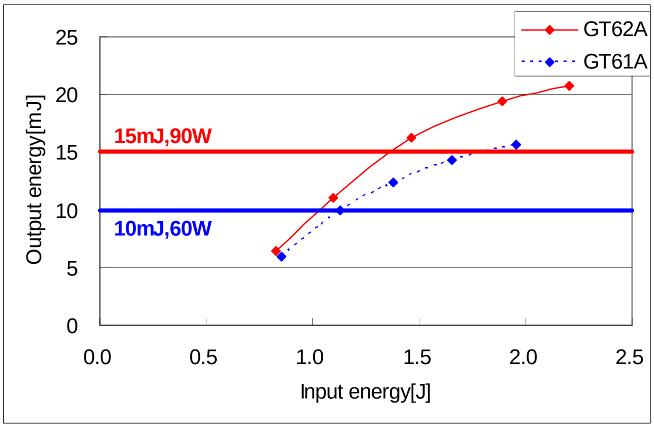


Fig. 2. Typical output pulse energy characteristic

4.2 Resonance characteristic

Fig.3 and Fig.4 show the repetition rate dependency of spectrum E95 and energy dose stability. Data points were taken from 1500Hz to 6000Hz with steps of 20Hz. Spectrum data were taken with the spectral bandwidth control turned OFF. Energy dose stability data was calculated by integrating the energy error over a moving window. This performance is mainly affected by the acoustic wave intensity in the laser chamber. The repetition rate characteristic was very good over whole operating range. This results from the optimized laser chamber design for acoustic wave in the GT60A. We have confirmed that spectrum and energy stability performance are very good in spite of higher power 90W.

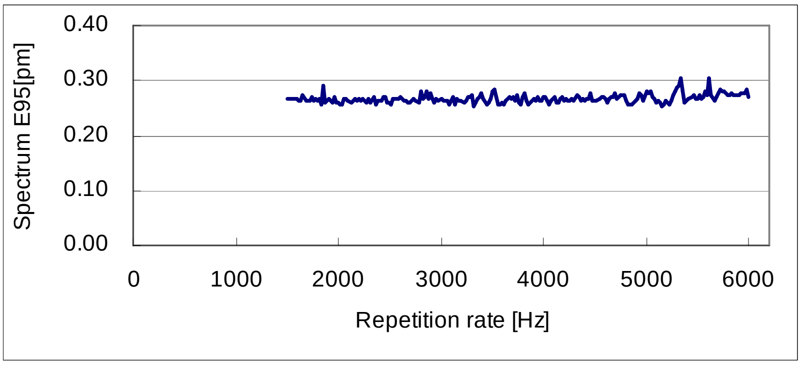


Figure 3. Repetition rate dependency of spectrum with spectral bandwidth control turned OFF

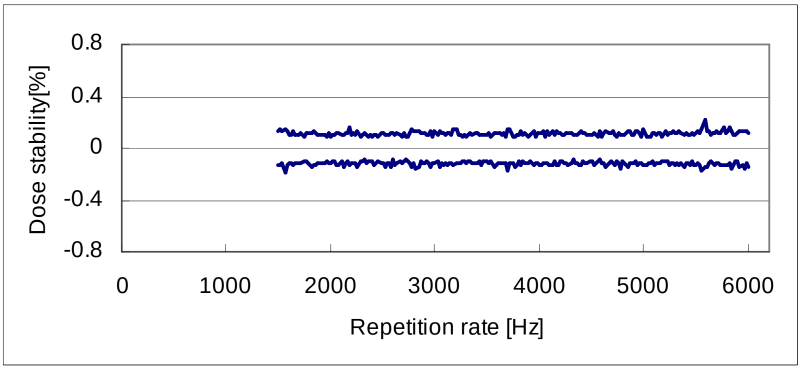


Figure 4. Repetition rate dependency of Dose stability

4.3 Wavelength stability

Changes of wavelength cause defocus, so the stability of the wavelength is important. Fig.5 and Fig.6 show the repetition rate dependency of wavelength error and wavelength stability sigma with wavelength control. These data were calculated by statistically treating the wavelength error averaged over the typical moving window. Wavelength error has been halved by anti-vibration function

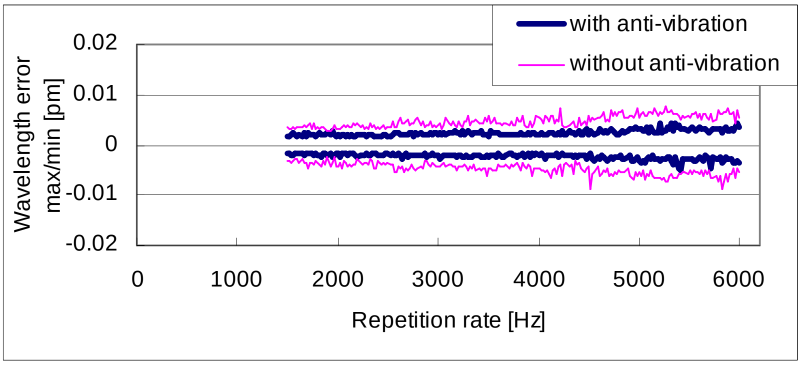


Figure 5. Wavelength error max/min

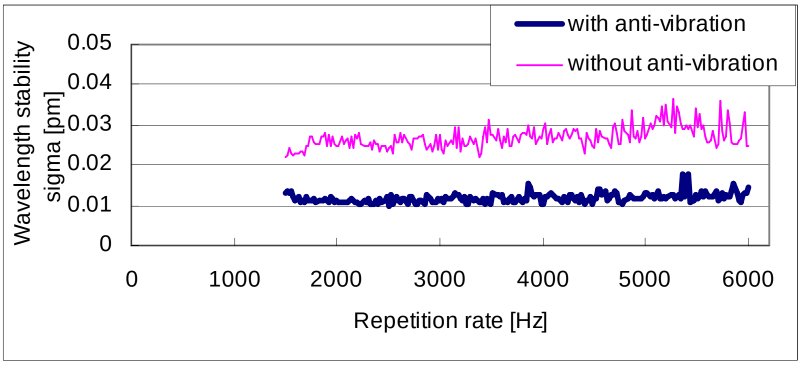


Figure 6. Wavelength stability sigma

4.4 Active controlled E95 spectral bandwidth performance

Bandwidth control module (BCM) is inherited to the GT62A. BCM can actively control spectral bandwidth of 95% energy concentration (E95). Fig.7 shows (a) operation duty dependency, (b) pulse energy dependency and (c) repetition rate dependency of spectrum E95 respectively. These data were taken with spectral bandwidth control with E95 set at 0.3pm. We have confirmed that spectrum E95 is very stable over various operation duties, pulse energy and repetition rate at 90W operation.

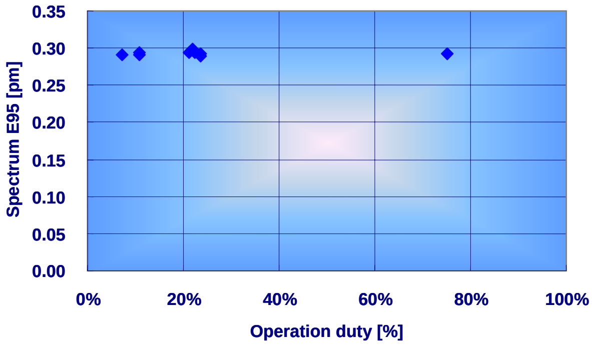


Fig. 7(a). Operation duty dependency of E95

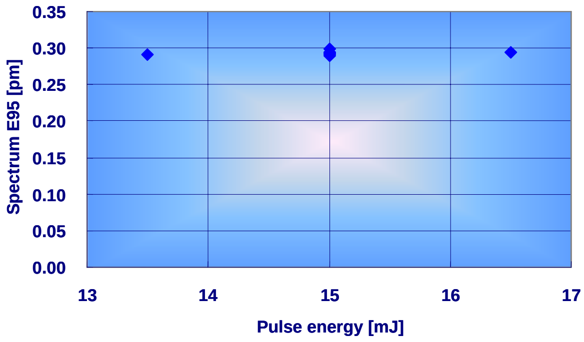


Fig. 7(b). Pulse energy dependency of E95

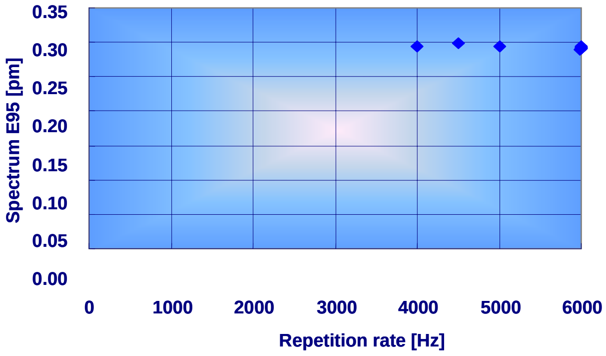


Fig. 7(c). Repetition rate dependency of E95

5. MID TERM PERFORMANCE OF THE GT62A

We tested the 15days gaslife. And mid term performances were confirmed to be very stable for 15days without gas refill. Its condition is as follows.

Pulse energy: 15mJ
Repetition rate: 6kHz
Duty cycle: 25% and 75% (changed alternately)
Total shot: 1billion pulses

The results are described as follows.

5.1 Spectral bandwidth

The spectral bandwidth of laser is an important factor for imaging ability and CD control. Fig.8 and Fig.9 show the trends of spectrum E95 of 15day gaslife with spectral bandwidth control with E95 set point 0.3pm. E95 measured by the BCM is shown in Fig.5 and E95 measured by the external high resolution spectrometer is shown in Fig.9. Spectral bandwidth control accuracy was less than 0.04pm and no drift of spectrum was for 15 days

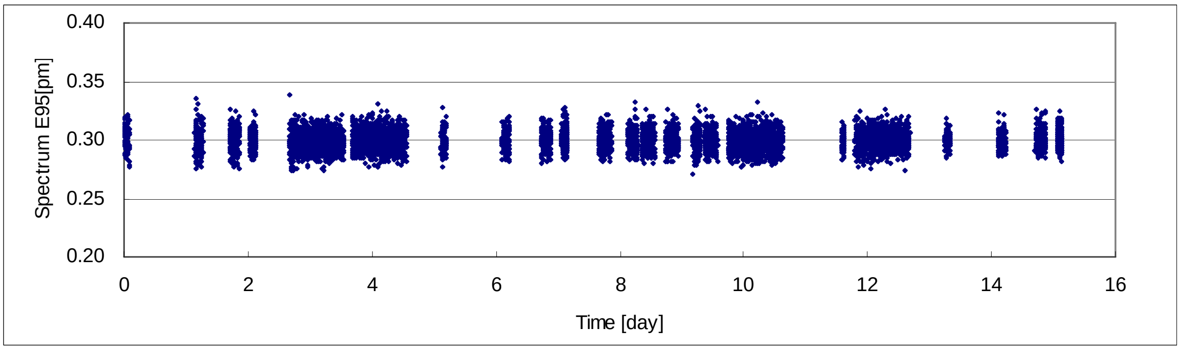


Figure 8. Trend spectrum in gaslife with spectral bandwidth control

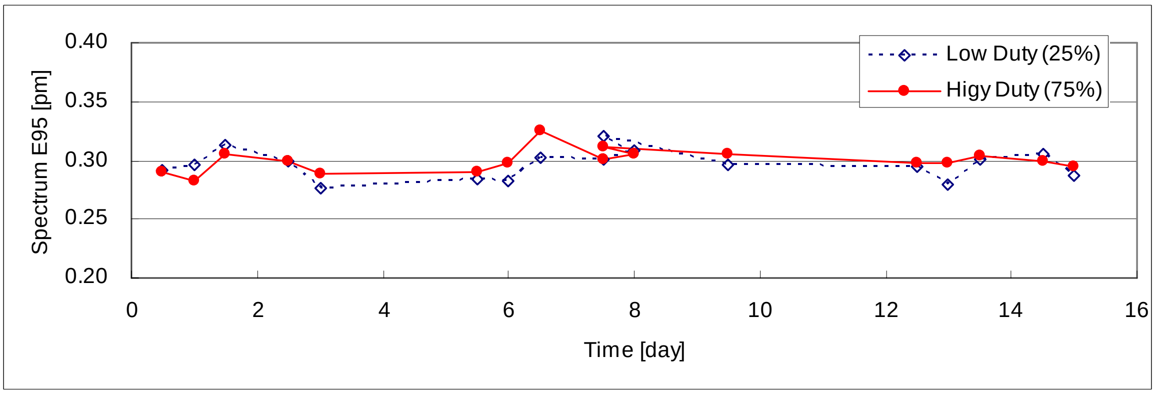


Figure 9. Trend spectrum E95 measured with external spectrometer in gaslife

5.2 Wavelength stability

Fig.10 shows the trend of wavelength error of 15day gaslife. These data were calculated by statistically treating the wavelength error averaged over the typical moving window. No deterioration of wavelength stability is observed over 15 days.

All GT model have an internal absolute wavelength meter (AWM) for calibration. And this calibration is executed during gas refill operation automatically. Fig.11 shows the trend of wavelength error measured with external absolute wavelength meter. No wavelength drift was observed during 15 day and absolute wavelength error was less than 0.03pm. We have confirmed the calibration of absolute wavelength is not needed for 15 days, resulting in no additional downtime by this calibration.

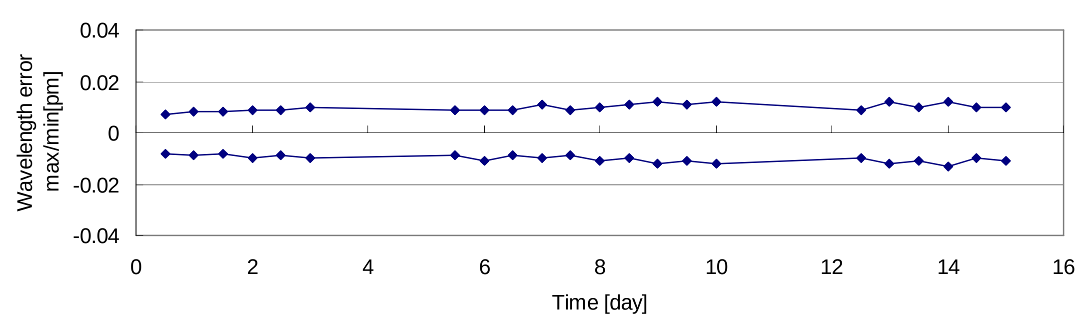


Figure 10. Trend of wavelength error in gaslife

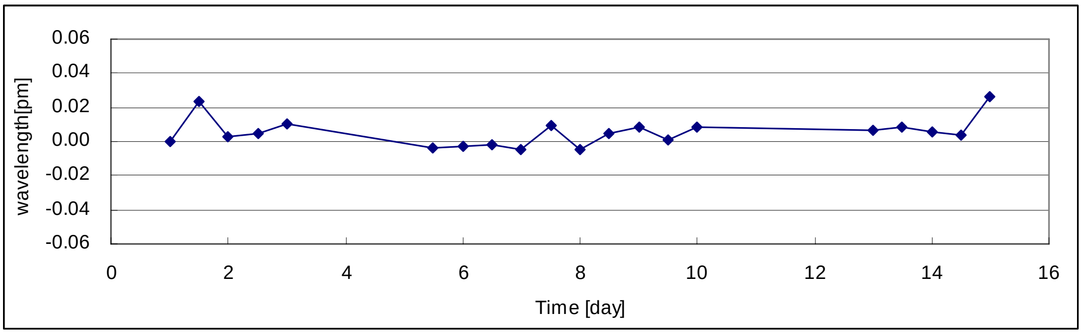


Figure 11. Trend of wavelength error measured with external AWM

5.3 Energy stability

Dose stability is an important property of laser output because it affects CD control. Fig.12 shows the trend of energy dose stability of 15day gaslife. This data was calculated by integrating the energy over the specified moving window. No deterioration of energy stability is observed.

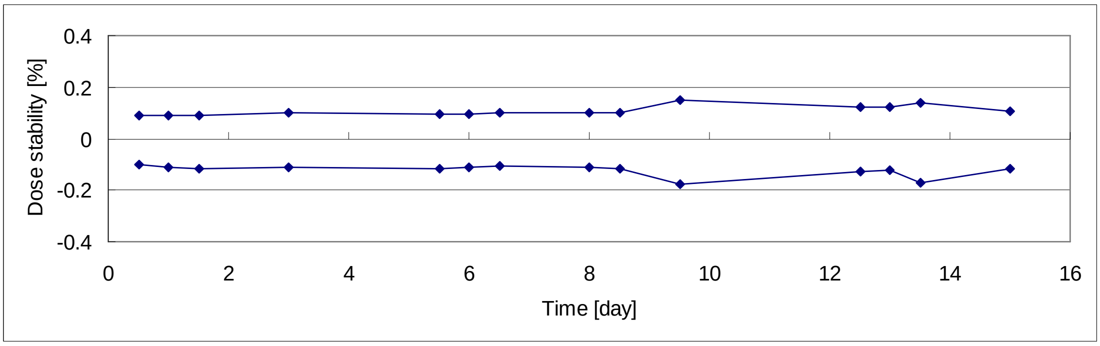


Figure 12. Trend of energy dose stability in gaslife

5.4 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. Fig.13 shows the trend of the pulse duration T_{IS} (Time Integrated Square) of 15days gaslife. Fig.14 shows the laser pulse shape at initial and 15th day in gaslife. A change of fluorine concentration influences the laser pulse shape. But it is controlled precisely by new gas supply module and new gas control algorithm. The laser pulse shape hardly changes over 15days.

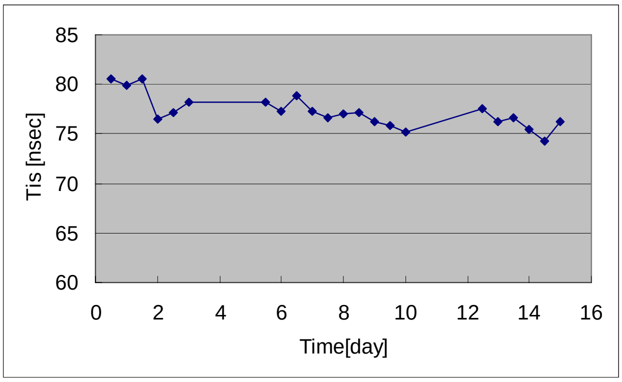


Figure 13. Trend of the pulse duration

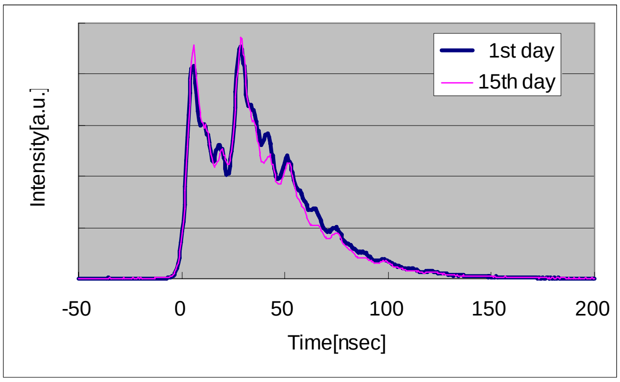


Figure 14. Laser pulse shape in gaslife

5.5 Gas pressure and operation voltage

The GT62A has the same energy control as other GT models. The trends of the HV and gas pressure of MO and PO chamber in 15days gaslife are shown in Fig.15 (MO) and Fig.16 (PO). For the MO chamber, the initial gas pressure was 260kPa, and it became 290kPa after 15days (1 billion pulses). For the PO chamber, the initial gas pressure was 280kPa, and it became 320kPa after 15days. The maximum gas pressure and HV are 420kPa and 28kV, respectively. The GT62A has enough output power margin.

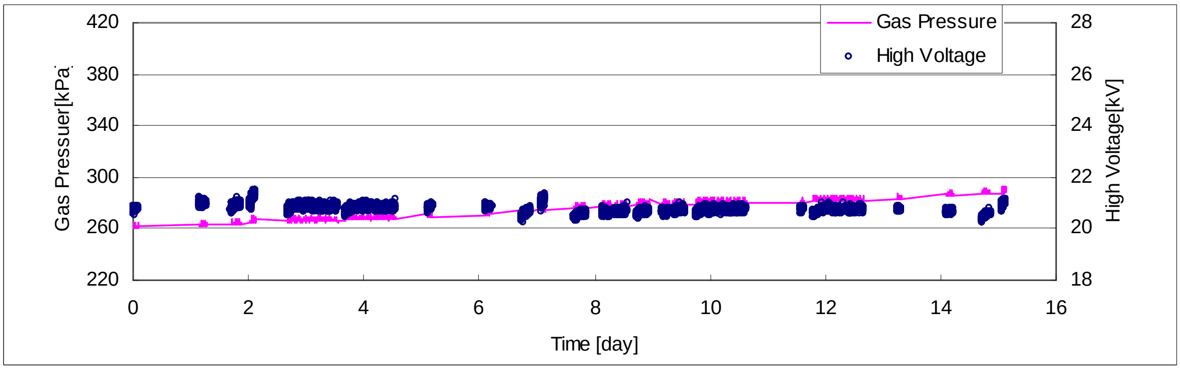


Figure 15. Trend of HV and gas pressure of MO chamber

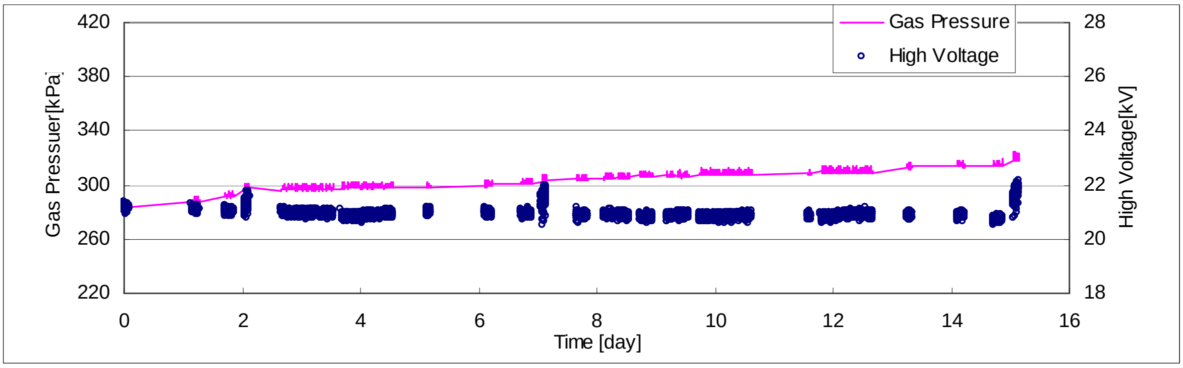


Figure 16. Trend of HV and gas pressure of PO chamber

6. CONCLUSION

Gigaphoton has developed the GT62A, a high power (90W) laser for immersion double patterning lithography. The performances of GT62A have been improved over the previous models: Dose stability by optimizing laser operating conditions, low CoO by long lifetime oscillator enabled by a newly developed higher output power supply and high durability with newly developed optics. And actively controlled spectrum E95 bandwidth with BCM is very stable at 90W operation. Gas refill interval has been increased to 15days (24 times / year), yielding to a dramatic reduction of cost of downtime.

7. ACKNOWLEDGEMENT

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