Flexible and reliable high power injection locked laser for double exposure and double patterning ArF immersion lithography

Masaya Yoshino*, Hiroshi Umeda, Hiroaki Tsushima, Hidenori Watanabe,
Satoshi Tanaka, Shinich Matsumoto, Takashi Onose, Hiroyuki Nogawa,
Yasufumi Kawasuji, Takashi Matsunaga, Junichi Fujimoto and Hakaru Mizoguchi
Gigaphoton Inc., 400 Yokokura-Shinden, Oyama-shi, Tochigi, JAPAN 323-8558

ABSTRACT

ArF immersion technology is spotlighted as the enabling technology for the 45nm node and beyond. Recently, double exposure technology is also considered as a possible candidate for the 32nm node and beyond. We have already released an injection lock ArF excimer laser, the GT61A (60W/6kHz/10mJ/0.30pm) with ultra line-narrowed spectrum and stabilized spectrum performance for immersion lithography tools with N.A.>1.3, and we have been monitoring the field reliability data of our lasers used in the ArF immersion segment since Q4 2006.
In this report we show field reliability data of our GigaTwin series – twin chamber ArF laser products. GigaTwin series have high reliability. The availability that exceeds 99.5% proves the reliability of the GigaTwin series.
We have developed tunable and high power injection-lock ArF excimer laser for double patterning, GT62A (Max90W/6000Hz/Tunable power with 10-15mJ/0.30pm (E95)) based on the GigaTwin platform. A number of innovative and unique technologies are implemented on GT62A.

- Support the latest illumination optical system
- Support E95 stability and adjustability
- Reduce total cost (Cost of Consumables, Cost of Downtime and Cost of Energy & Environment)

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 in semiconductor mass production from the 90 nm node and beyond. And the ArF immersion technology is even spotlighted as the enabling technology for the 45nm node and beyond. In addition, double patterning is considered to be most promising technology to meet the requirement of the next generation 32nm node. To achieve this, market demands for ArF light source are getting more severe, for example, higher power and narrower spectral bandwidth are required for higher throughput and higher NA lithography respectively.
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)]. In addition, the latest generation model GT62A-1SxE 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)

*masaya_yoshino@gigaphoton.com; phone +81-285-28-8416; fax +81-285-28-8439; http://gigaphoton.com.

In this paper, we report on the innovative technology of GT62A-1SxE and reliability data of the GigaTwin series in the field.

Technology Node (typical)	Main driver	Requirement for ArF Laser light source	Power	GT model
32 nm	double patterning higher throughput (advenced system)	6kHz//0.3pm(E95)	60 - 90W	GT62A-1SxE
32 nm	double patterning higher throughput	6kHz/0.3pm(E95)	60W	GT62A-1S
45 nm	higher NA	6kHz//0.3pm(E95)	60W	GT61A
50 nm	higher throughput higher NA	6kHz//<0.5pm(E95)	60W	GT60A
65 nm	higher throughput	4kHz//<0.5pm(E95)	45W	GT40A

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

2. FEATURES AND MAJOR SPECIFICATIONS OF THE GT SERIES

2.1 Gigaphoton injection lock system

Gigaphoton's injection lock (MOPO) system consists of a Master Oscillator (MO) and a Power Oscillator (PO). 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 changed tunably from 60W to 90W without having negative impacts on major laser performances, including spectrum and wavelength stability

2.2 GigaTwin series major 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 GigaTwin series are shown in table 2.
The latest generation model GT62A-1SxE has extendable power from 60W to 90W tunably without upgrading. In MOPO, extension power is achieved easily. The MO condition does not necessarily change, because PO has higher gain. Therefore spectrum and wavelength stabilities stay unaffected. In addition, the GT62A-1SxE has inherited proven high reliability and low running cost on GigaTwin platform.

ArF model		GT40A	GT60A	GT61A	GT62A-1S	GT62A-1N	GT62A-1SxE
Wavelength	nm	193	193	193	193	193	193
Power	W	45	60	60	60	90	60 - 90
Pulse energy	mJ	11.25	10	10	10	15	10 - 15
Max. rep rate	Hz	4000	6000	6000	6000	6000	6000
FWHM	pm	0.2	0.2	N.A	N.A	N.A	N.A
E95	pm	<0.5	<0.5	0.3	0.3	0.3	0.3
Durability (Expected)							
MO Chamber	Bpls	40*	40*	40*	40*	40*	>40***
PO Chamber	Bpls	40*	40*	40*	40*	40*	>40***
LNM / MO LNM	Bpls	60**	60**	60**	60**	60**	60**
MM	Bpls	30	30	30	30	30	30
FM / PO FM	Bpls	30	30	30	30	30	30
PO RM	Bpls	30	30	30	30	30	30

* GRYCOS technology
** MPL (Multi Positioning LNM)
*** Durability can be extendable @ <90W

Table 2. Major specifications of the GigaTwin series.

3. MAJOR PERFORMANCE OF THE GT62A-1SxE

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 60W to 90W to 60W
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: three minutes each time

The results are described below.

3.1 Output pulse energy and output power

Tunable output power provides illumination power optimum for resist sensitivity. Fig.1 shows the pulse train of output energy at 60W, 70W, 80W and 90W. We have confirmed that the tunable range of output power is from 60W to 90W.

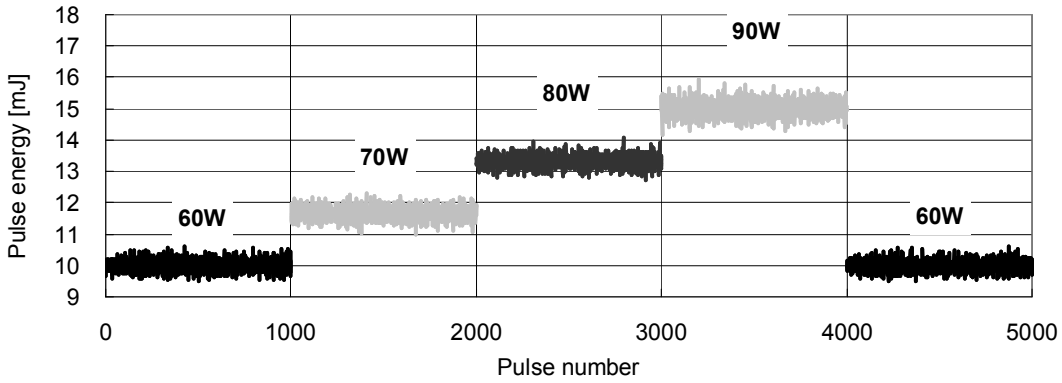

Figure1. Pulse energy and output power

3.2 Dose stability

Dose stability is an important property of laser output because it affects CD control. Fig.2 shows the trend of energy dose stability at 60W, 70W, 80W and 90W. These data was calculated by integrating the energy over the specified moving window. We have confirmed that there is no difference from 60W to 90W operation.

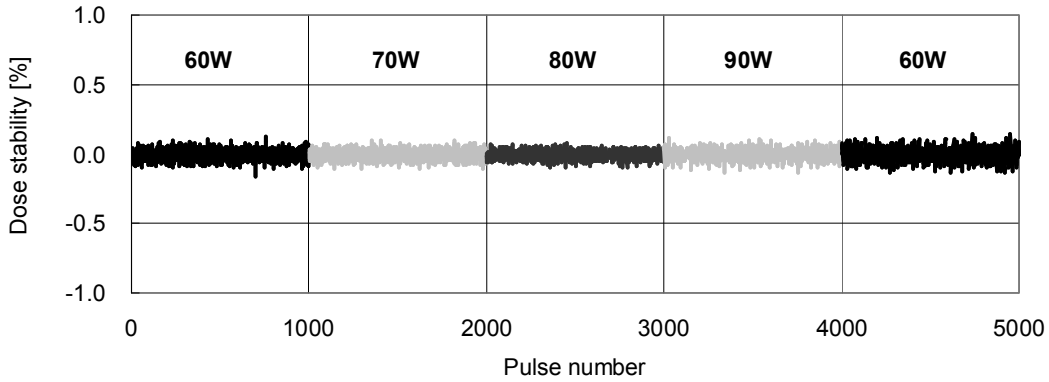

Figure 2. Dose stability from 60 to 90W

3.3 Wavelength stability

Changes of wavelength cause defocus, so the stability of the wavelength is important. Fig.3 and Fig.4 show the dependency of wavelength error and wavelength stability sigma with wavelength control on output power levels at 60W, 70W, 80W and 90W. 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.

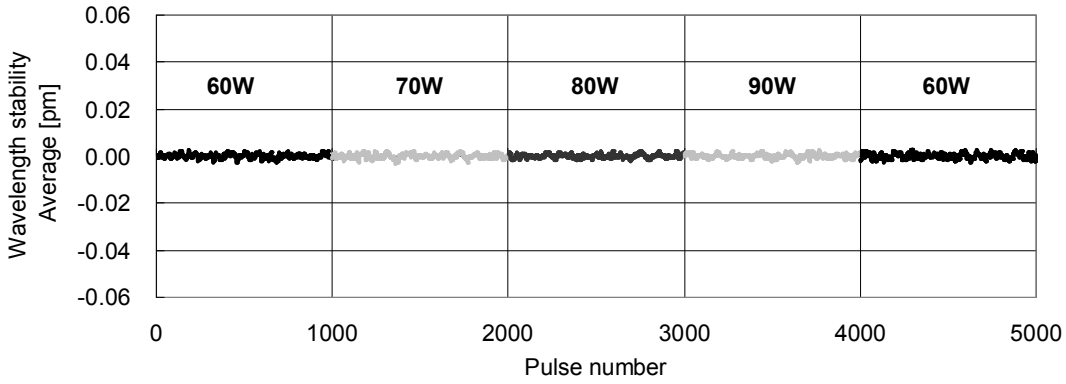

Figure 3. Wavelength stability error from 60 to 90W

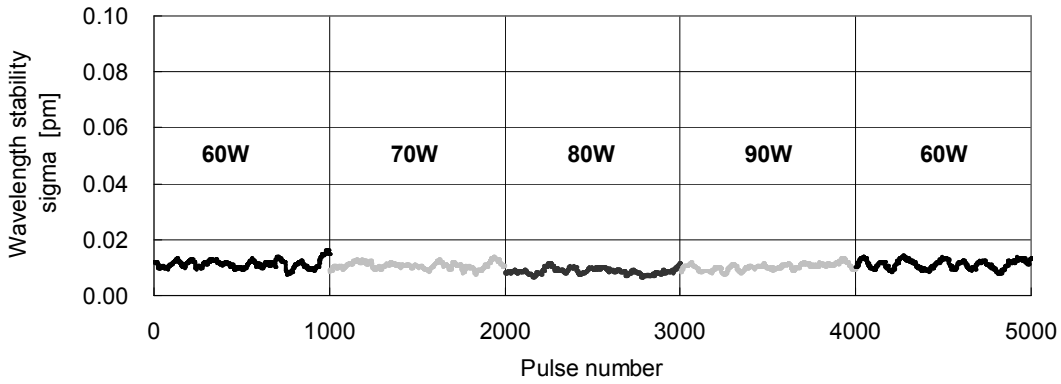

Figure 4. Wavelength stability sigma from 60 to 90W

3.4 Spectral bandwidth

The spectral bandwidth of laser is an important factor for imaging ability and CD control. Fig. 5 shows the data of spectral bandwidth of 95% energy concentration (E95) with spectral bandwidth control with E95 set point 0.3pm at 60W, 70W, 80W and 90W. Fig. 6 shows the spectral profile shape at 60W, 70W, 80W and 90W. We have confirmed that spectral bandwidth control accuracy and spectral profile shape are independent of output power.

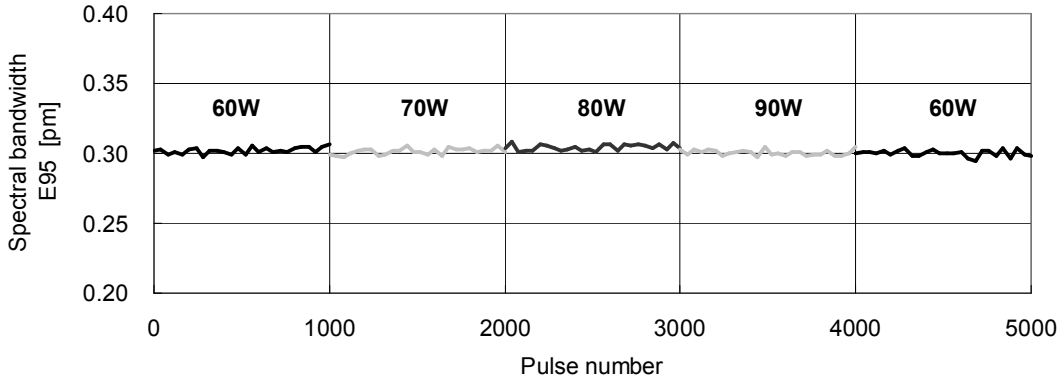

Figure 5. Spectral bandwidth from 60 to 90W

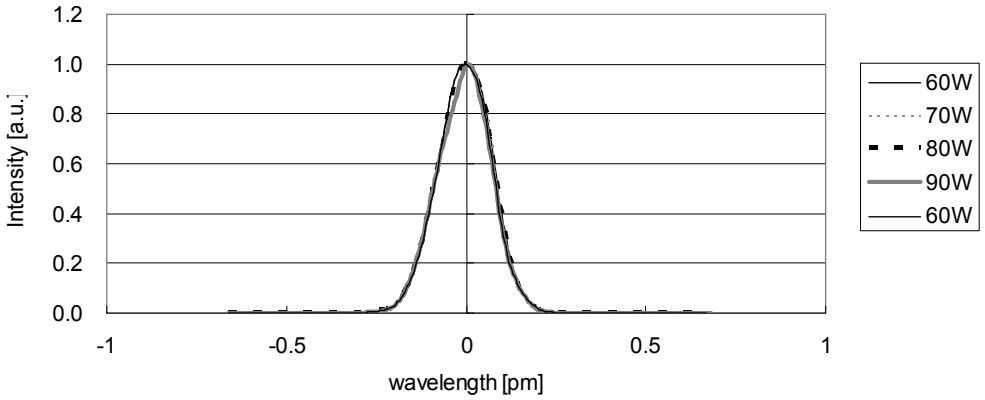

Figure 6. Spectral profile shape from 60 to 90W

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[5]. Fig.7 shows the laser pulse shape and the pulse duration T_{IS} (Time Integrated Square) at 60W, 70W, 80W and 90W. We have confirmed that pulse duration keeps more than 150 nsec under output power from 60W to 90W

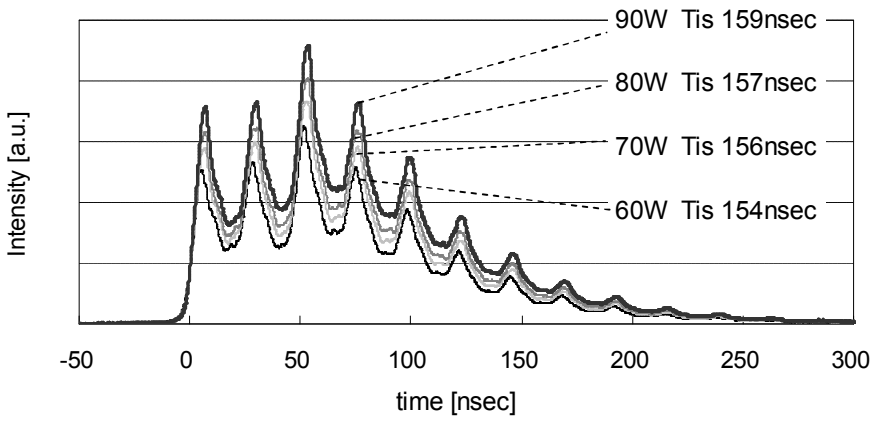

Figure 7. Laser pulse shape and the pulse duration

3. 6 Beam profile and divergence

New illumination system like a double patterning lithography requires ArF laser with more stable optical performances. Fig. 8 and 9 show the dependency of the fluctuation of beam profile and divergence on output power levels of 60W, 70W, 80W and 90W, respectively. These data were normalized at 60W data. We have confirmed that beam profile and divergence are stable from 60W to 90W.

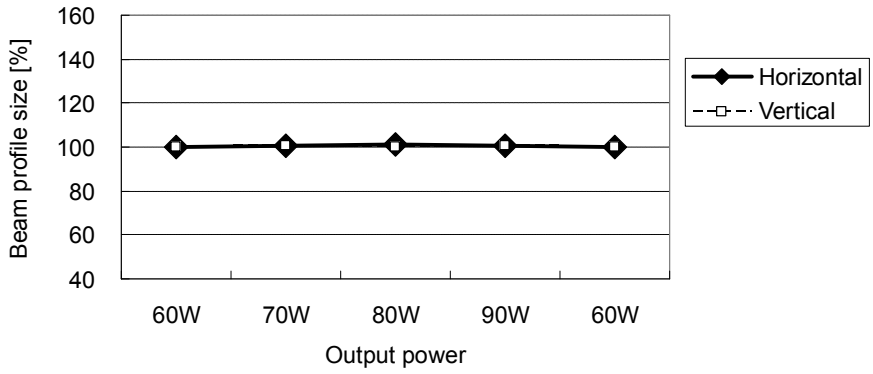

Figure 8. Output power dependency of beam profile size

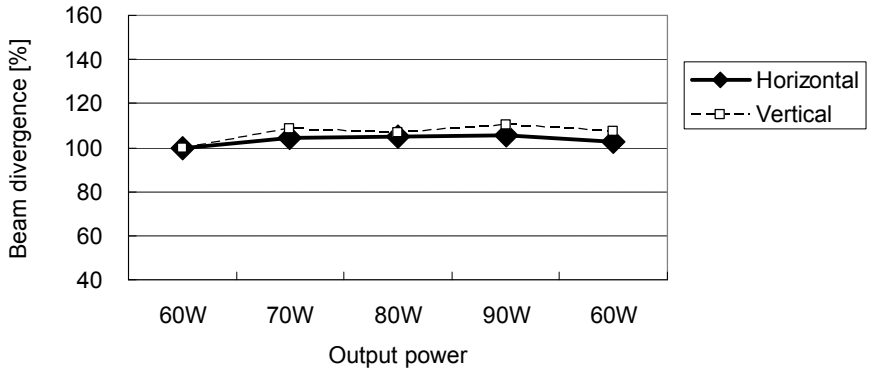

Figure 9. Output power dependency of beam divergence

3.7 Beam position and pointing

As in preceding section, new illumination system like a double patterning lithography requires ArF laser with more stable optical performance. Fig. 10 and 11 show the output power dependency of beam position and pointing at 60W, 70W, 80W and 90W, respectively. These data were calculated to initial 60W data. We have confirmed that beam position and pointing are stable from 60W to 90W.

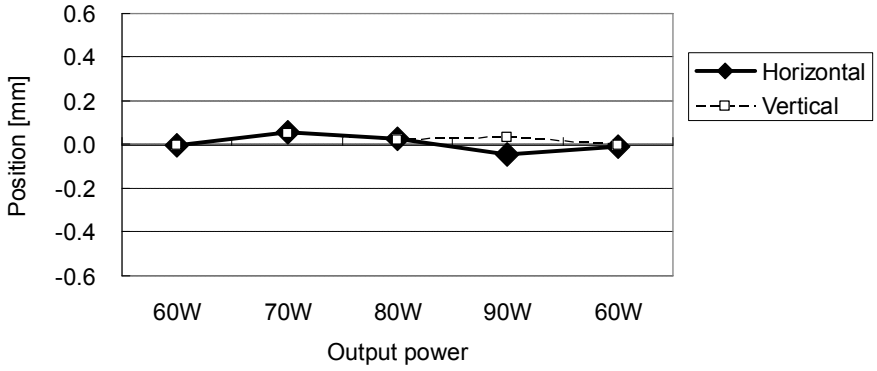

Figure 10. Output power dependency of beam position

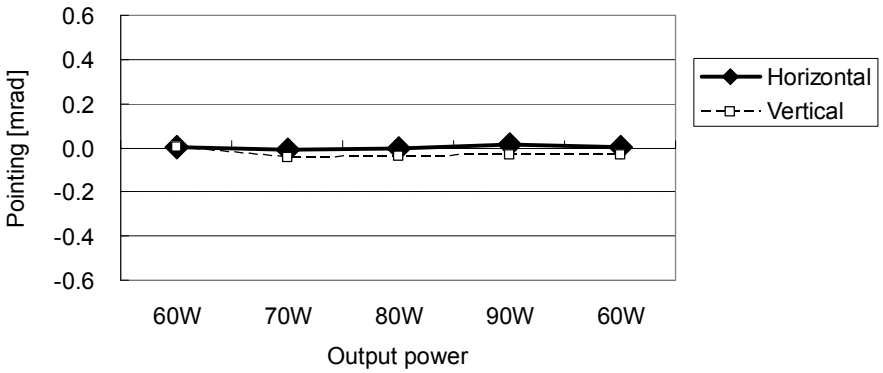

Figure 11. Output power dependency of beam pointing

4. OTHER FEATURES OF THE GT SERIES

4.1 Reliability

Now ArF lithography moves into high volume production, and reliability of the laser is industry's common request. We evaluated reliability by "Availability" as reliability indicators. "Availability" shows system available time by percentage of total time. The definition of Availability in this report is shown as follows.

Availability = [Total Hour – (Scheduled Downtime + Unscheduled Downtime)] / [Total Hour]

Availability of GigaTwin series up to Q4 2009 is shown at Fig.12. GigaTwin series have high reliability performance. Various technologies used for GigaTwin series are contributing high reliability. The availability that exceeds 99.5% proves the reliability of the GigaTwin series.
GT62A-1SxE has proven reliability by inheriting the GigaTwin platform.

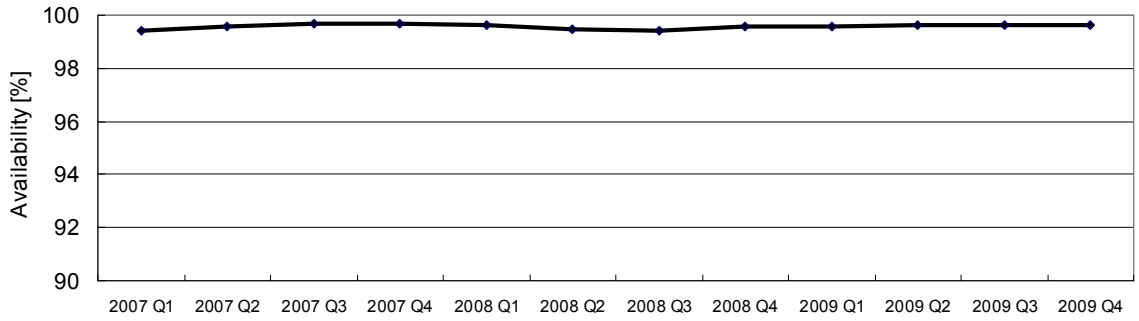

Figure 12. Availability of GT lasers up to Q4 2009

4.2 Reduction of running cost

In the semiconductor industry, price competition has become more intense than ever. The reduction of the equipment running cost, therefore, is one of the major concerns. We have developed a variety of technologies to reduce the laser running cost, or the cost of operation (CoO). A Number of innovative and unique technologies are implemented on the GigaTwin series in order to reduce the running cost of laser. The improvements are:

1) Chamber lifetime extension: The Gigaphoton Recycled Chamber Operation System (GRYCOS)
   20 billion pulses → 40 billion pulses
2) LNM lifetime extension: Multi Positioning LNM (MPL)
   30 billion pulses → 60 billion pulses
3) Gas lifetime extension: Total Gas Manager (TGM)
   3days → 15days: 24times/year

These three technologies can be applied to all the laser types built on GigaTwin platform. The details of the technologies were reported in the previous paper[4)]
Inheriting the GigaTwin platform, GT62A-1SxE features the reduced running costs.

5. CONCLUSION

Gigaphoton has developed the tunable output power (60W - 90W) laser GT62A-1SxE.
It is designed to support the requirement of process parameter flexibility of exposure tool and end customer.

-Optimized illumination power for various resist sensitivities.
-Meeting the advanced illumination system.
-Contribution to reduce optics deterioration and the line edge roughness.
-Well maintained CD variation at all power range.

Inheriting the GigaTwin platform, it features proven reliability and the reduced running costs by GRYCOS, MPL and TGM.

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