Reliable High Power Injection Locked 6kHz 60W Laser for ArF Immersion Lithography

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ABSTRACT

Reliable high power 193nm ArF light source is desired for the successive growth of ArF–immersion technology for 45nm node generation. In 2006, Gigaphoton released GT60A, high power injection locked 6kHz/60W/0.5pm (E95) laser system, to meet the demands of semiconductor markets. In this paper, we report key technologies for reliable mass production GT laser systems and GT60A high durability performance test results up to 20 billion pulses.

Keywords: excimer laser, injection lock, ArF, 193nm, immersion

1. INTRODUCTION

193nm ArF light sources are widely used from below 90nm node semiconductor mass production. And also ArF-immersion technology is growing to reach 45nm 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.

Technology Node (typical)	Main driver	Requirement for ArF Laser lihgt source	GT model
32 nm	double patterning double exposure higher throughput	6kHz/90W/0.35pm(E95)	GT61A-1H
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

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

From these background, Gigaphoton released reliable 4kHz/45W/0.5pm(E95) ArF light source for 65nm node in 2005, model GT40A[1], based on injection lock technology developed in ASET. This injection lock technology was originally targeted for high power 5kHz/30W/0.5pm(E95) fluorine laser as a 157nm lithography light source [2]. 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 to release second generation model GT60A of higher output power 6kHz/60W/0.5pm(E95) for higher throughput and higher NA 50nm node 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, next year fourth generation of higher power and narrower spectral bandwidth for higher throughput model GT61A-1H(6kHz/90W/0.35pm) is scheduled for double patterning or double exposure 32nm node(Fig.1). All these laser systems are integrated on a common and already proven reliable GT platform.

In this paper, we report key technologies of reliable mass production GT laser systems and GT60A high durability performance test results up to 20 billion pulses.

2. FEATURES AND MAIN SPECIFICATIONS OF GT SERIES

2-1. Gigaphoton Injection lock system(MOPO)

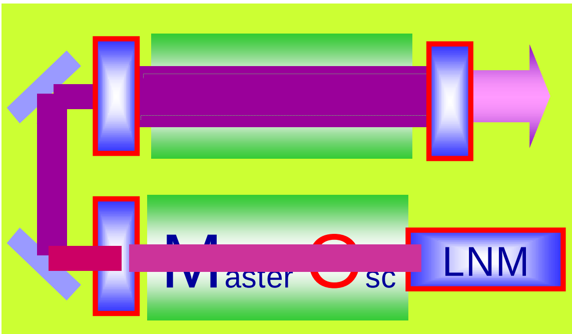

Fig.2 A schematic of the injection lock (MOPO)system

A schematic of the Gigaphoton's injection lock system (MOPO) is shown in Fig.2. Low energy but very spectrally narrow bandwidth seed light is produced in Master Oscillator (MO) and amplified by Power Oscillator (PO). We adopt injection lock system for reliable higher power, narrower spectral bandwidth laser systems for the following reasons[2].

Merits	Benefits
1) High 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 CoO from low optical load
5) Long pulse duration	Low CoO from low optical load

2-2. G-electrodes

Chamber lifetime is mainly limited by degradation of electrodes inside. Fluorine molecules react with electrodes materials by getting discharge energy and make gradual electrodes deterioration. In order to resolve this issue, GT60A install G-electrodes, which are already installed such model as G40/41K(4kHz-KrF laser), G40/41/42A(4kHz-ArF laser) and GT40A. Its durability is already proven to be reliable in the field. G-electrodes, which are metal electrodes with specially treated surfaces, make discharge very stable and decrease electrode deterioration.

2-3. GT series main specifications

Gigaphoton's technological advances help semiconductor markets to challenge not only for higher throughput but for the shrinking of IC design geometry. Major specifications of GT series are shown in table 3.

1-st generation of GT series is shipped as model GT40A [3], and its main specifications are 4kHz/45W/0.5pm(E95). To get higher laser power (45->60W), 2-nd generation of GT series, model GT60A, introduced advanced technology as follows for higher repetition rate operation (4->6kHz).

1) Strong acoustic wave damper compared with GT40A (chamber)
2) Improvement of gas flow (chamber)
3) Higher power supply with high stability in addition to heat load countermeasure

3-rd generation model GT61A for narrower spectral bandwidth(0.5pmE95->0.35pmE95) is equipped with high resolution LNM (line narrowing module). All these laser systems are integrated on a common and already proven reliable GT platform.

Table.3 Major specification of GT series.

ArF model		GT40A	GT60A	GT61A
Wavelength	nm	193	193	193
Power	W	45	60	60
Pulse energy	mJ	11.25	10	10
Max. rep rate	Hz	4000	6000	6000
FWHM	pm	0.2	0.2	N.A
E95	pm	0.5	0.5	0.35
Durability (Expected)				
MO Chamber	Bpls	13	13	20
PO Chamber	Bpls	19	19	30
LNM / MO LNM	Bpls	-	-	-
MM	Bpls	30	30	30
FM / PO FM	Bpls	12	12	12
PO RM	Bpls	12	12	12

3. DURABILITY AND LONG-TERM PERFORMANCE

We tested the various performances and module durability of GT60A up to 20 billion pulses. The main durability test conditions were as follows.

Pulse energy	10mJ
Repetition	6kHz
Duty cycle	75% (maximum duty of GT60A)

The results are described below.

3-1. Spectral bandwidth

The spectral bandwidth of laser is an important factor for imaging ability and CD control. The trends of spectral integral of 95%(E95) at several repetition rates and duties are shown in Fig.4 These data were taken without spectral bandwidth control [4]. Until 20 billion pulses E95 remained stable and under the specification with large margin. Gigaphoton's injection lock technology contributes to not only narrower but stable spectral bandwidth throughout various operational conditions. In case of single chamber configurations, spectral bandwidth is integral value of whole laser pulse and is easily influenced by operating conditions such as input energy and gas pressure. But Gigaphoton's injection lock technology is from its concept, able to stabilize spectral bandwidth. These reasons are as follows[2]. MO time-resolved spectral bandwidth is correlated with oscillating times, tend to be narrowed and finally saturated as oscillating times are increased. The synchronization timing between MO and PO is highly regulated so that spectrally stable narrower part of the MO seed laser pulse is injected into PO laser. PO laser inherits time-resolved spectral property of MO at the synchronization timing and amplifies its energy.

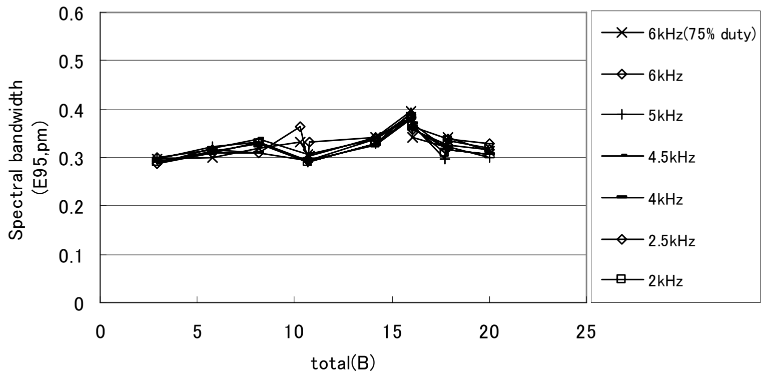

Fig.4 The trend of spectral bandwidth

3-2. Wavelength stability

Change of wavelength cause defocus, so the stability of the wavelength is important. The trends of wavelength stability at 6kHz operation is shown in Fig.5. The values were calculated by statistically treating the difference between the target and actual wavelength averaged over the typical moving window. No deleterious change was seen until 20 billion pulses. This stable result comes from highly accurate and very stable control of the wavelength and the low vibration of the discharge chamber even at 6kHz operation.

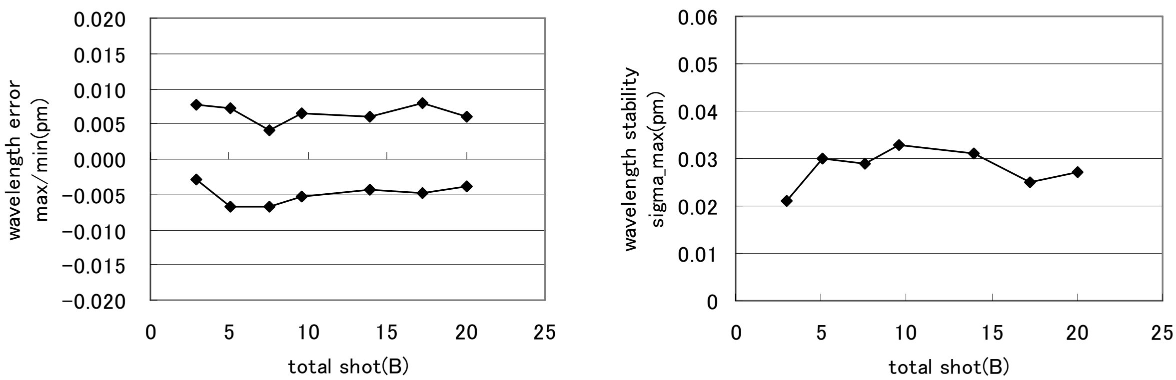

Fig.5 The trend of wavelength stability(left) and sigma(right) at 6kHz operation

3-3. Does stability

Dose stability is an important property of laser output because it affects CD control. The trends of energy dose error at 6kHz operation are shown in Fig.6. No deleterious changes were seen until 20 billion pulses. This result shows stability of not only electric discharge but injection lock system over the long term.

The repetition rate characteristics of dose stability are shown in Fig.7. Data was taken from 1kHz to 6kHz with steps of 10Hz, and the dose error was calculated by integrating the energy over a moving window. The dose error was stable over whole operating range. This results from the optimized laser chamber design for both acoustic wave and gas flow in addition described above.

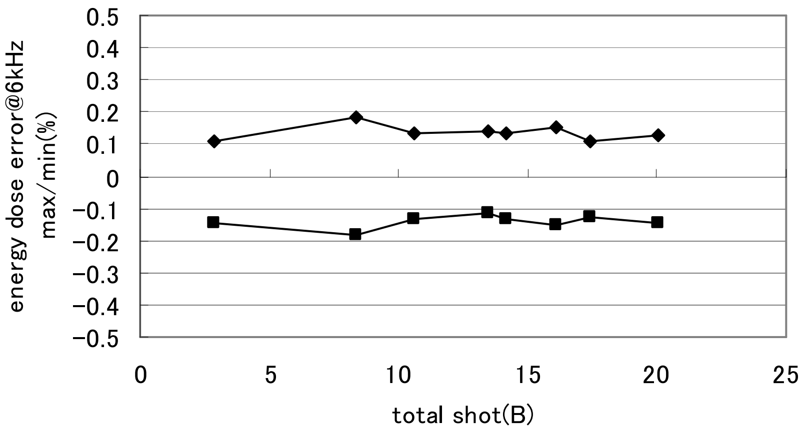

Fig.6　The trend of dose stability at 6kHz operation

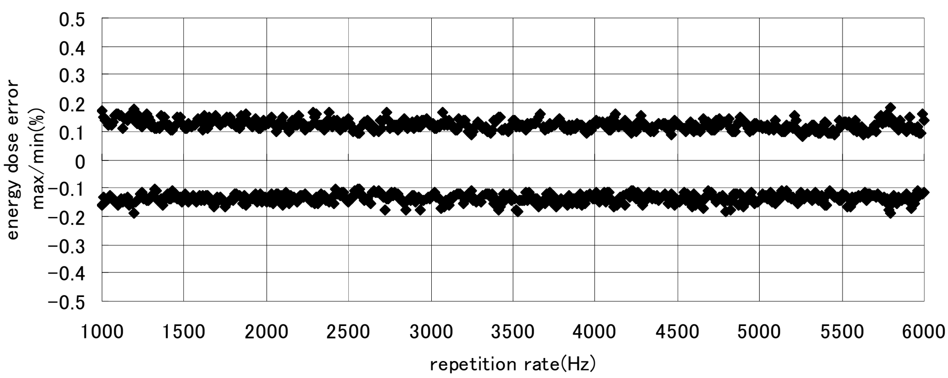

Fig.7　Repetition rate characteristics of dose stability at 13.5 billion total pulses.

3-4. Pulse duration

Long pulse duration over the long term is important because it lowers CoO. This is because the peak power intensity of laser pulses affects the lifetime of optical components inside scanners. The pulse duration Tis (Time Integrated Square) of GT60A stayed above 85ns until 20 billion pulses, as shown in Fig.8.

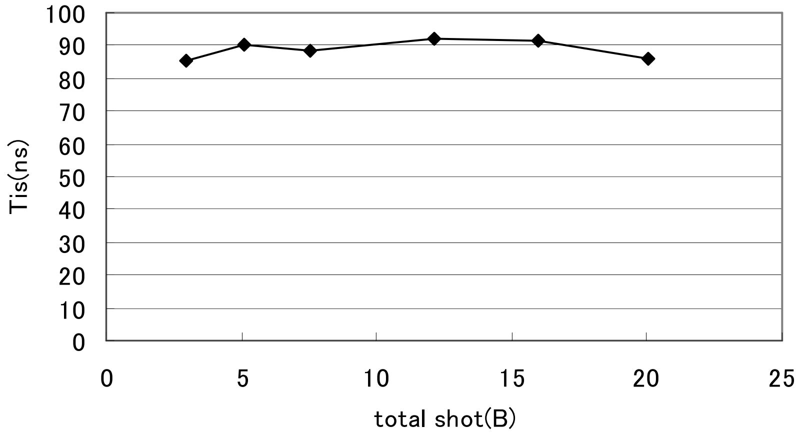

Fig.8 The trend of pulse duration at 6kHz operation

3-5. Gas pressure and operation voltage

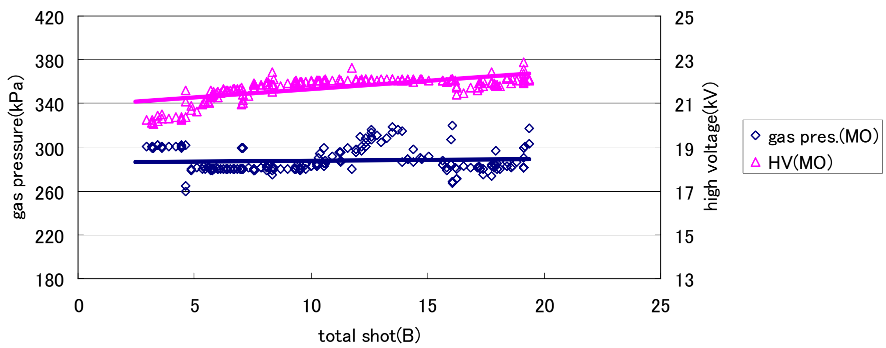

Fig.9 Trends of HV and gas pressure of MO chamber

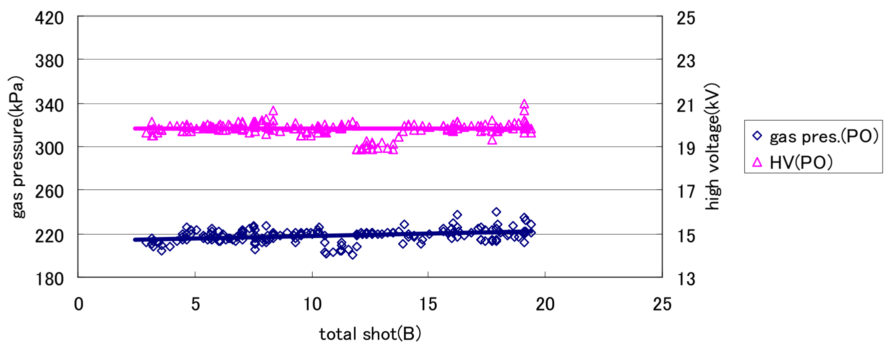

Fig.10 Trends of HV and gas pressure of PO chamber

GT60A has the same energy control as other Gigaphoton laser models. Drops in efficiency are compensated by combination of increasing the laser gas pressure and the electrical energy input, which is controlled by changing the high voltage (HV). The trends of the gas pressure and HV of the MO and PO chamber under fresh gas conditions are shown in Fig.9 (MO) and Fig.10 (PO). For the MO chamber, initial gas pressure and HV were 300kPa and 20kV, and at 20 billion pulses, they were 300kPa and 22kV. For the PO chamber, the gas pressure and HV remained around 210kPa and 20kV until 20 billion pulses. We could not see any change. So we can safely say that the MO and PO chamber can be used for 13 and 19 billion pulses respectively.

4. SUMMARY

Gigaphoton released GT60A, high power injection locked 6kHz/60W/0.5pm(E95) laser system, to meet the demands of semiconductor markets for 50nm node generation. Performances including spectral bandwidth, wavelength stability, dose stability, pulse duration etc. and module durability were confirmed to be very stable up to 20 billion pulses and proven to be reliable. This highly reliable performance and durability will also be inherited by next generation GT series.

5. ACKNOWLEDGEMENT

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