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

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ABSTRACT

The Argon Fluoride (ArF) immersion lithography is now shifting to mass production phase for below 45nm node. For a laser light source in this node, narrower and more stable spectrum performance is required. We have introduced GT61A ArF laser light source (60W/6kHz/10mJ/0.35pm) with spectrum E95 stabilization system which meets these requirements. The narrow and stabilized spectrum performance was achieved by developing an ultra line narrowing module and Bandwidth Control Module (BCM). It contributes to the reduction of differences of the spectrum during exposure over a wafer, wafer to wafer, during machine lifetime and machine to machine for every light source. Stable laser performance is obtained for mass production. The GT61A integrated on a common and already reliability-proven GigaTwin (GT) platform, and its inherited reliability is proved with the availability over 99.5% in the field.

Keywords: excimer laser, injection lock, ArF, 193nm, immersion, spectrum bandwidth, 45nm node, high power

1. INTRODUCTION

The 193nm lithography has moved to mass production phase and its target node is shifting from 65 nm to 45 nm. And the ArF-immersion technology is even spotlighted as the enabling technology for below 45nm node. We have already released an injection lock ArF excimer laser with high power and high repetition rate: GT60A (60W, 6000Hz, 10mJ, 0.5pm). The GT61A ArF laser light source with ultra line narrowed and stabilized spectrum (E95 <0.35pm) is developed for hyper NA. A newly developed high-precision E95 measuring module and stabilization control system are provided as a standard feature, allowing highly stable spectrum performance throughout the entire product lifetime. We have already shipped over hundred units of GT lasers and nearly twenty units of GT61A lasers in the field. The GT61A with superior performance of E95 stability and field-proven high availability represents a great contribution to the stability of higher Numerical Aperture (NA) ArF immersion lithography process.

2. RELIABLE GIGATWIN PLATFORM

Higher laser power is needed for higher throughput and stable narrower spectral bandwidth is needed for higher NA. But high laser power and narrow spectrum are in the relation of the trade-off in a single chamber system. We solved this trade-off with the schematic of injection lock system[1)]. This twin-chamber GigaTwin(GT) platform is based on injection lock technology developed in ASET fluorine laser lithography project [2)]. A schematic of GT system is shown in Fig. 1.

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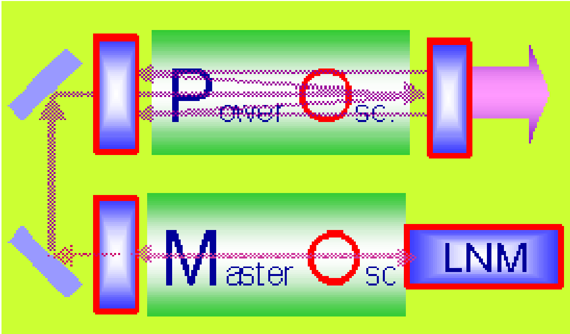

Figure 1. A schematic of the injection lock (MOPO) system

Low energy but narrow bandwidth seed light is produced in Master Oscillator (MO) and is amplified by Power Oscillator (PO). Line Narrowing Module (LNM) that consists of diffraction grating and beam expander prisms is mounted adjacent to the laser chamber and comprises the optical resonator with the front mirror. The LNM functions as a wavelength narrow pass filter and narrowed spectrum E95 is obtained. Here MO could be optimized to deliver the narrow spectral bandwidth, while the PO could be designed for optimal power with maintaining complete hardware compatibility between MO and PO. Therefore the system can easily get higher power with very small seed light energy, and it has wider tolerance of synchronization timing of injection lock compared with MOPA system[1)]. Moreover long laser pulse duration which is important to reduce optical load is easily obtained. On the other hand, the dual chamber system is more complex than the single one, because the number of components in the dual chamber system is much larger than the single. However the GigaTwin(GT) laser system employs easy replacement design, so replacement time of each module is shorter than that of conventional laser. Therefore all GT laser system has high availability and low Cost of Ownership (CoO).

3. MAIN SPECIFICATIONS OF THE GT LASER SERIES AND THEIR IMPROVEMENT

Table 1. Main specifications of GT series

	Model	GT40A	GT60A	GT61A	GT62A
	typical technology node [nm]	65	50	45	32
Specifications	Wavelength [nm]	193	193	193	193
	Power [W]	45	60	60	60/90
	Pulse energy [mJ]	11.25	10	10	10/15
	Rep. rate [Hz]	4000	6000	6000	6000
	E95 [pm]	0.5	0.5	0.35	0.35
	E95 stabilization	(option)	(option)	standard	standard
Durability (Expected)	MO chamber [Bpls]	20	20	20	20
	PO chamber [Bpls]	30	30	30	30
	Monitor Module [Bpls]	30	30	30	30
	Amp Front Mirror [Bpls]	12	12	12	12
	Amp Rear Mirror [Bpls]	12	12	12	12

Main specifications of GT laser series are shown in Table 1. 1st generation of GT series was shipped as model GT40A, and its main specifications are 4kHz/45W/0.5pm (E95). System durability was confirmed to be very stable up to 20 billion pulses[3)].

Development of new chamber and power supply module associated with increase in repetition rate (4->6kHz) enabled higher laser power (45->60W) for higher throughput. This 2nd generation of GT series, model GT60A[4], had also confirmed to be very stable up to 20 billion pulses and proven to be reliable.[5]

The 3rd generation model GT61A[6] for hyper NA(>1.3) immersion lithography tools has improved spectral bandwidth performance from 0.5 pm (E95%) down to 0.35 pm, and E95 stabilization system – BCM – is introduced as a standard feature. Long chamber lifetime same as GT60A is attained by improved pulse power module despite of efficiency loss due to spectrum improvement. Major module developments of the GT61A are as follows.

1) high resolution and high thermal stable Line Narrowing Module (LNM)
2) high resolution E95 measurement module
3) E95 stabilization control module
4) Power-upped pulse power module

For 4th generation model, 90W upgradeable GT62A is developed for double patterning or double exposure 32nm node[7].

All these laser systems are integrated on a common and already proven reliable GT platform, there are advantages below:

(1) Only the major modules need to be developed for every new model, thus allowing timely and speedy new model releases

(2) The reliability achieved by the current model will be inherited by the next-generation model

(3) New technologies developed for the next-generation model can be smoothly introduced backwards into the current model

4. HIGH STABILITY PERFORMANCE OF THE GT61A

After its release in Q4 2006, the GT61A is now reaching over 20 units of shipment within one year. The following performances of the GT61A confirm high reliability and high stability.

4.1 Intrinsic repeatability of BCM metrology

Repeatability of E95 measured by BCM metrology compared to E95 measured by the external high resolution grating type spectrometer[8] simultaneously is evaluated. Even this measurement includes the intrinsic deviation of external spectrometer, E95 error sigma is almost below 0.01pm for all laser system (see Fig. 2).

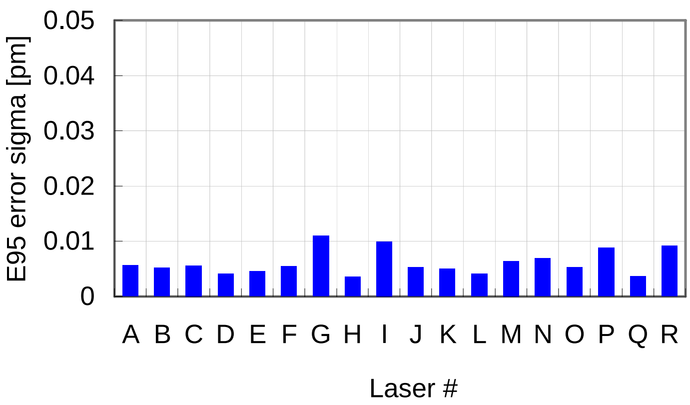

Figure 2. E95 error sigma between external spectrometer and BCM metrology

4.2 Linearity of BCM metrology

Linearity of BCM metrology is confirmed below. Spectrum E95 of laser is changed from 0.2pm to 0.5pm by BCM. Maximum and minimum E95 error compared with the external high resolution spectrometer is shown in Fig. 3. Using this high linearity and reliability BCM metrology, each laser can measure its E95 precisely.

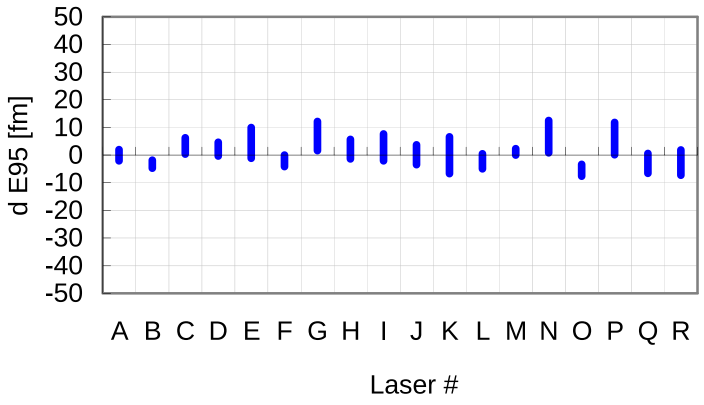

Figure 3. Linearity Error of BCM

4.3 Middle term spectrum E95 stability

Spectrum E95 is very important spectral parameter for Optical Proximity Effect (OPE) [9]. With spectral bandwidth control, middle term spectrum E95 stability is evaluated. Averaged E95 over 30 seconds (correspond to wafer) while running the laser at a typical duty cycle is measured by the external spectrometer. Variation of wafer average E95 wafer to wafer is shown in Fig. 4. Middle term E95 is stable enough for all lasers.

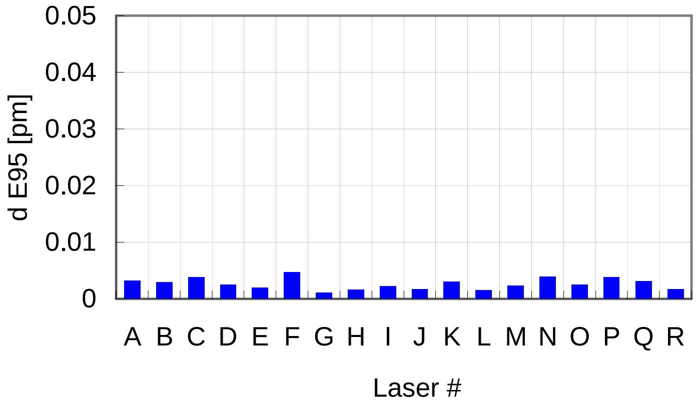

Figure 4. Variation of wafer average E95 wafer to wafer

4.4 E95 stability over gas life

Periodic performance check during gas life (3days/100Mshots) including gas-life-start and gas-life-end are performed. Test performance condition has several operation duty and repetition rate. Fig. 5 shows the maximum and minimum variation E95 measured by the external high resolution spectrometer. Laser to laser E95 differences are removed and well-controlled to its set point (0.3pm).

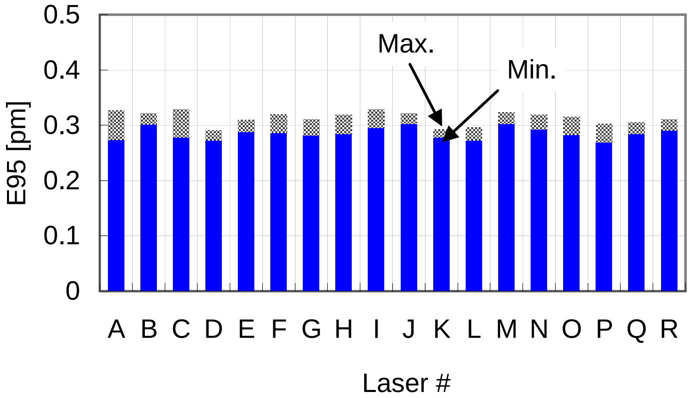

Figure 5. Spectrum E95 variation over gas life

4.5 Long term E95 stability over module life

Fig. 6 shows the reliable E95 performance measured by internal BCM metrology of the GT61A in the field. Spectrum E95 is controlled to 0.30pm for long time stably.

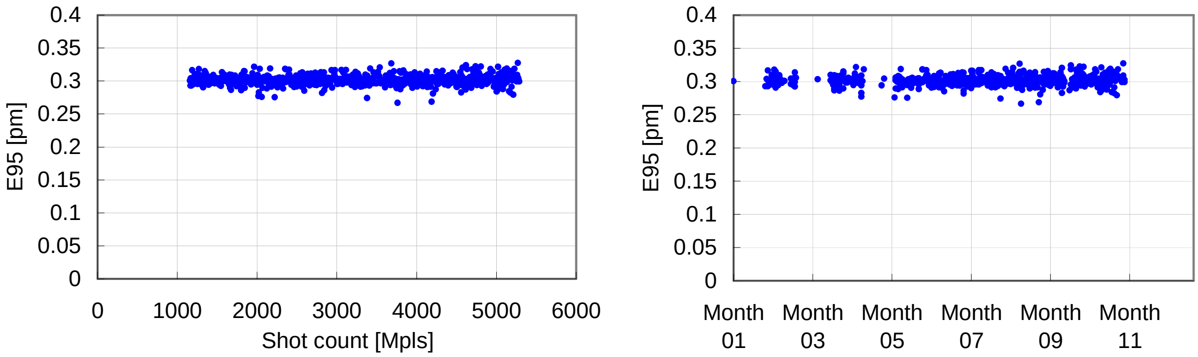

Figure 6. Long term E95 stability [Laser # B]

4.6 Temporal pulse width

The193nm photon energy may cause damage in projection lenses and other optical elements in exposure tools. Longer temporal pulse width with lower peak power intensity of the laser pulses lowers CoO. Total Integrated Square pulse width (TIS) was defined as[10)]

$$T_{IS} = \frac{\left(\int T(t)dt\right)^2}{\int T^2(t)dt},$$

Where t: time, T(t): the temporal profile intensity as a function of time.

Fig. 7 shows variation of the temporal pulse width over a 100M shots run.

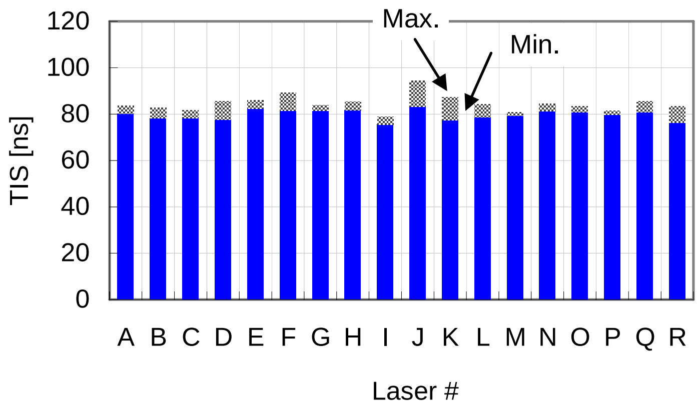

Figure 7. TIS variation over gas life

4.7 Energy stability

Dose stability that is calculated by integrating the energy over the typical moving window is also important property because it affects CD control. Fig. 8 shows worst dose stability and worst energy sigma in several patterns after gas life respectively and energy well-controlled.

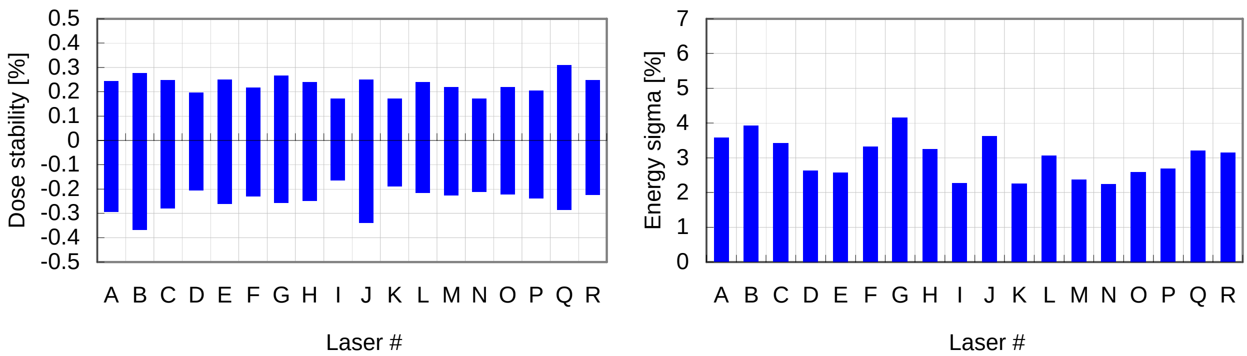

Figure 8. Worst Dose stability and energy sigma

4.8 Wavelength stability

Change of wavelength cause defocus, so the stability of the wavelength is important. Average wavelength stability is calculated by integrating the center of wavelengths over the typical moving window. Fig. 9 shows worst wavelength stability in several patterns after gas life respectively and wavelength is well-controlled.

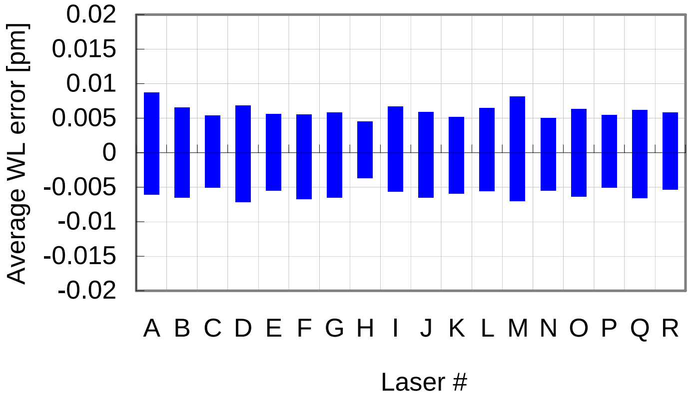

Figure 9. Worst wavelength error

4.9 Energy dynamic range

During gas life, maximum and minimum laser energy is measured (See Fig. 10). It is verified that the laser has enough latitude of energy range with the allowed voltage range over gas life.

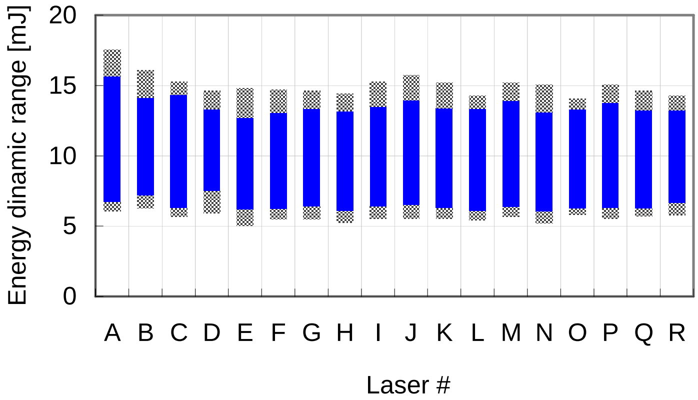

Figure 10. Energy dynamic range over gas life

4.10 Gas pressure and operation voltage

Fluctuation of gas pressure and high voltage during gas life are shown in Fig.11A and Fig. 11B. There is enough margin for system lifetime because operational upper limit of the system is 420kPa and 25kV, respectively.

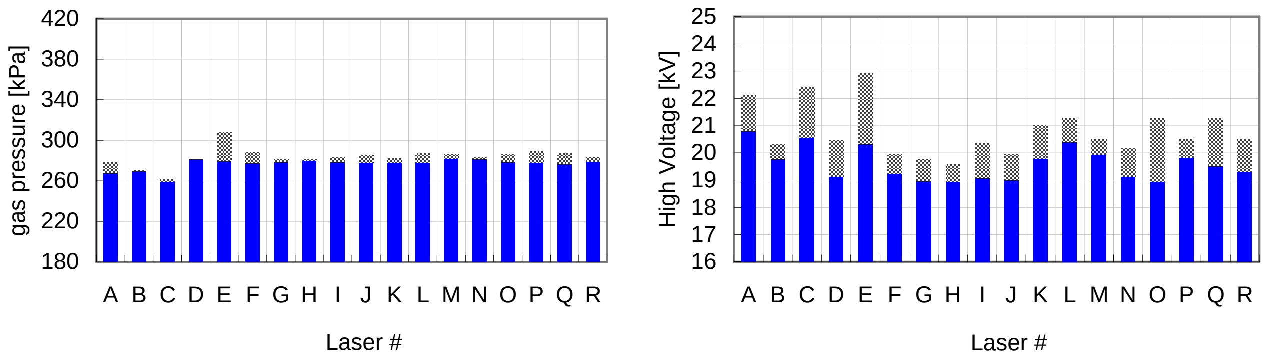

Figure 11A. Fluctuation of gas pressure and high voltage during gas life (MO)

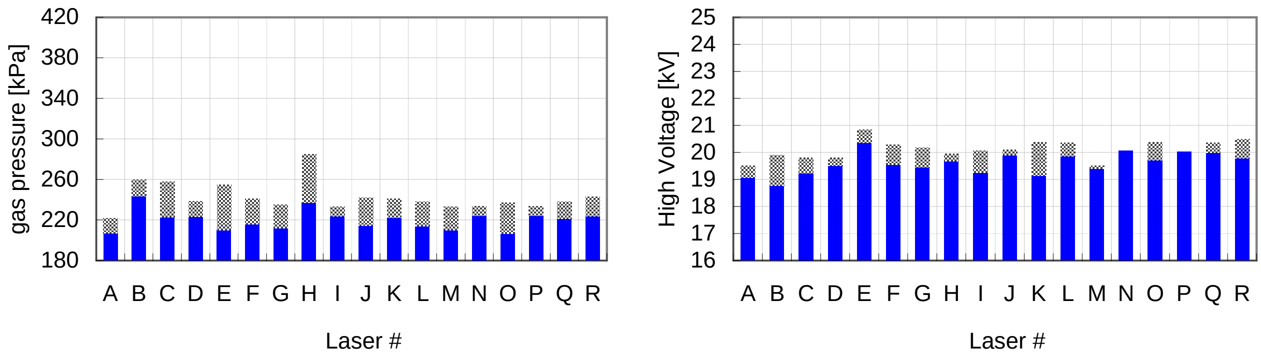

Figure 11B. Fluctuation of gas pressure and high voltage during gas life (PO)

5. HIGH AVAILABILITY OF THE GT60A/61A

Now ArF lithography moves into high volume production, and reliability of the laser is industry's common request. We show availability data of GT lasers.

5-1. Definitions

Availability:

"Availability" shows percentage of the system can be available. Higher availability is preferred.

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

Each data is calculated over 3 months window.

5-2. Laser Availability

Availability of Gigaphoton lasers up to Q4 2007 is shown at Figure 12. The GT60A and GT61A have high reliability performance -- same as matured KrF lasers. The common platform for Gigaphoton's twin-chamber system contributes this high reliability. Over 99.5% availability is achieved in all quarters.

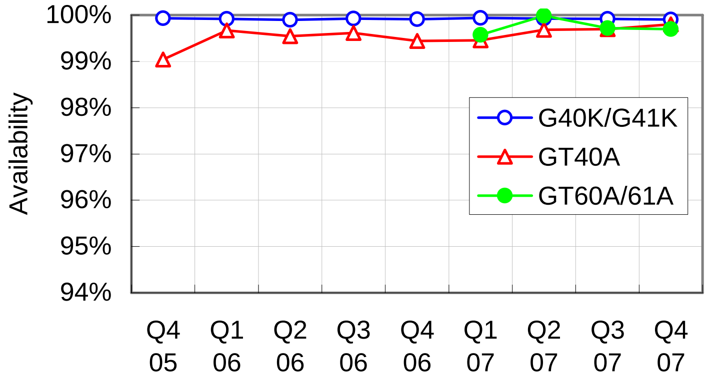

Figure 12. Availability of GT60A/GT61A

6. SUMMARY

The GT61A ArF laser light source with an ultra line narrowed and stabilized spectrum, which meets the demand of hyper NA immersion tool, is proved to be highly reliable and stable. The stabilized spectrum performance below 0.35pm was achieved. Availability that exceeds 99.5% proves the reliability of the GT61A.

7. ACKNOWLEDGEMENT

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