High Power Injection Lock Laser Platform for ArF Dry/Wet Lithography

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1. INTRODUCTION

193-nm lithography is moving from the pre-production to the mass production phase and its target node is shifting from 90 nm to 65 nm. And now the ArF-immersion technology is spotlighted as the enabling technology for below 45nm node[1]. 157nm lithography is still important for next generation node below 45 nm as backup technology[2].

Gigaphoton has already released G40A (20W, 0.35pm) in 2001, G41A (20W, 0.30pm)[3] in 2002, G42A (20W, 0.25pm)[4] in 2003 to the advanced lithography market. On the other hand, since 1998 we have been developing high power 157nm light source for micro lithography with injection lock technology in research phase[5][6]. We have demonstrated a 30W, 0.12pm, @157nm line narrowed light source for microlithography with "Injection lock technology"[1][2]. Based on this injection lock technology, we have successfully developed "GigaTwin", a high power injection lock laser platform for 193nm lithography system. We have already released a high power ultra narrowed ArF laser "GT40A" (45W, 4000Hz, 11.25mJ, 0.18pm), with the GigaTwin platform.

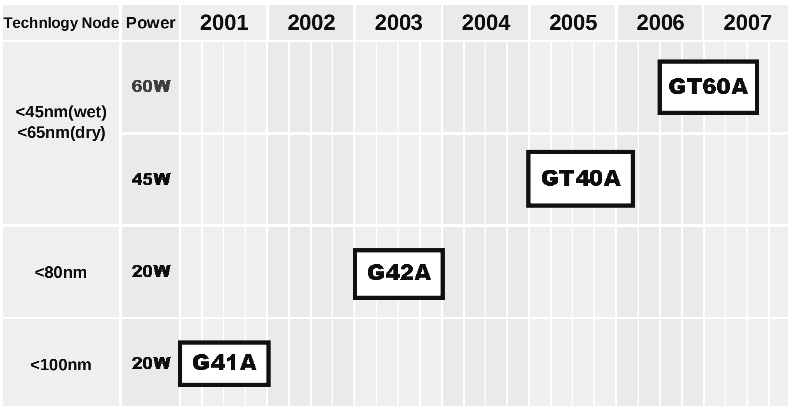

Figure 1. Technology node and product roadmap of Gigaphoton

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2. High Power Injection Lock Laser "GigaTwin" GT40A

(1) Concept

New injection lock system

In the past, injection lock laser system has been thought to be unsuitable for lithography because of its high coherence, which causes speckle patterns on an exposure image. However we could break this popular belief, by employing a unique injection lock scheme. We proposed a new incoherent cavity* which realizes incoherent oscillation even in such an injection lock system[8]. This incoherent cavity is the very breakthrough that realized the GigaTwin, injection lock system for lithography.
 * Patent pending

Figure 2. "GigaTwin" GT40A

Schematic advantage

We discussed technical merits of injection lock in our last paper[9]. We put the following merits of injection lock technology to account. These merits allowed us to utilize several benefits.

Merits	Benefits
1) High efficiency	Easy to get higher power
2) Narrow spectral bandwidth	Easy to get better FWHM and E95
3) Wide tolerance of timing	Better stability and 2-charger system
4) Very small seed light is needed for operation	Low CoO from low optical load
5) Long pulse duration	Low CoO from low optical load

The new injection lock system commits a lot of benefits, dramatically high performance, high stability and lower CoO.

Design advantage

The GigaTwin platform has been designed flexible to easily introduce higher performance - such as 60W throughput and finer spectrum control - through several product generations.

On the other hand, the dual chamber system is more complex than the single chamber system, because the number of components in the dual chamber system is larger than the single. However we planned that the time of troubleshooting and repair of the dual chamber system should be the same level as, or lower than that of the single chamber system. Therefore we employed new design concepts in the GigaTwin platform as follows:

1) Self check function
2) Easy replace module design
3) Remote maintenance (REDeeM)

With these designs, the GigaTwin has extremely smaller downtime, high availability and higher reliability even in such a large system.

(2) Specification

Major specifications of GT40A are indicated in table 1. The output power is 45W and the repetition rate is 4kHz. The technology of 60W with 4kHz has already been established in the GigaTwin platform, as it was developed in parallel with 45W.Bandwidth is very narrow, which is corresponding to high NA ArF lenses. Impact on diffractive index (compaction / rarefaction) is minimized by longer pulse duration by using optical pulse stretching technology. The numbers of consumable parts are six (6) by reducing the load of optical components.

Tuning range	193.330 – 193.450 nm
Power	45W
Bandwidth (FWHM, E95)	0.20 pm, 0.50 pm
Repetition Rate	4000 Hz
Pulse duration	>70ns
Maintenance requirement	6 consumable modules
Size	2800W x 820D x 2050 H

Table 1. Specification of GT40A

(3) Outline of system

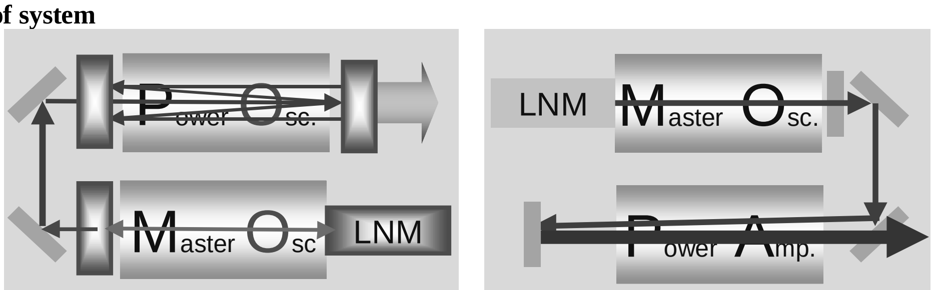


Figure 3. Diagram of injection lock system compared with MOPA

In fig.3 a schematic diagram of injection lock system is shown. Injection lock system consists of dual lasers; master oscillator laser (MO) and power oscillator laser (PO). Also optical cavities of the PO confine an optical pulse of the MO inside the cavity. Optical property of the PO laser is controlled with spontaneous emission induced by the MO laser light. For controlling the PO almost one order less energy than MOPA system is required to the MO. And the timing range of two lasers is much wider than MOPA system. These two unique properties realize a lot of benefits for laser system design. Very low energy of the MO pulse can extend the lifetime of line narrowing module and front mirror of the MO. Very wide timing allows timing error caused by charging error between the MO and the PO. In contrast, MOPA system allows very small allowance that's why the MOPA system chose single charging system.

A sketch of GT40A is shown in fig.4. Mechanical dimension is 2800W x 820D x 2050 H, which is compatible with that of conventional dual chamber lasers in the market. All of the components and modules are built in one package. The system consists of several modules. The modules are categorized into only six (6) consumables, which include master oscillator chamber, power oscillator chamber, power oscillator mirrors, monitor module and fluorine trap. To maintain the performance of the laser, only six (6) consumable parts need periodical replacement. Non-consumable parts don't need to be replaced in usual operation.

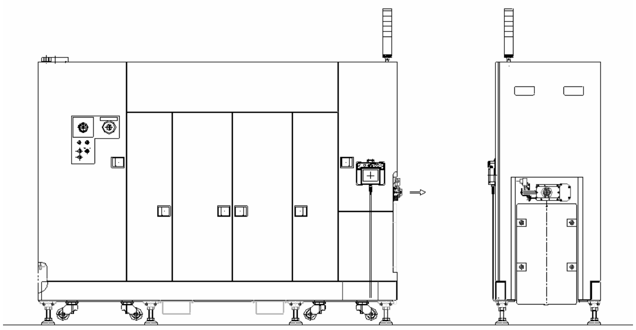


Figure 4. Sketch of GT40A

3. Technical Key Point

(1) Stability of Laser Performance

We verified the advantage in the laser performance of the injection lock scheme, in comparison with MOPA, through experimental data. The result was clear - the injection lock scheme has much higher performance and is extremely more stable than MOPA. Fig5 (a) (b) show the maps of energy stability (+-%), which depending on the repetition rate through 2000 – 4000Hz and the timing jitter in the dual chamber synchronization. Fig.5 (a) is the injection lock, (b) is MOPA. These two maps show clearly that the injection lock has extremely wider margin for fine energy stability than MOPA.

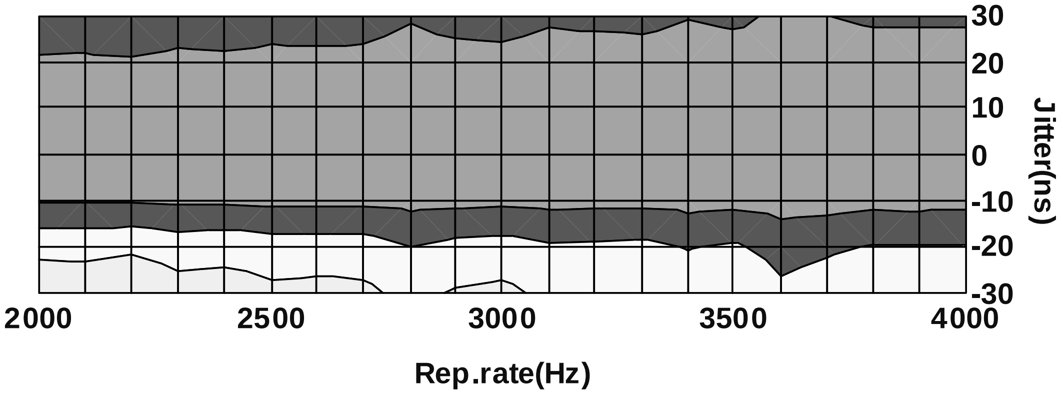


Figure 5. (a) Map of energy stability of Injection Lock scheme

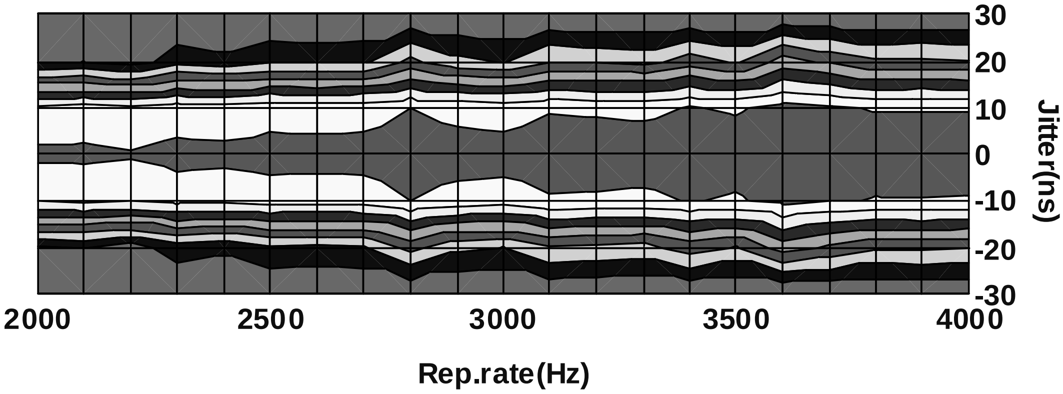
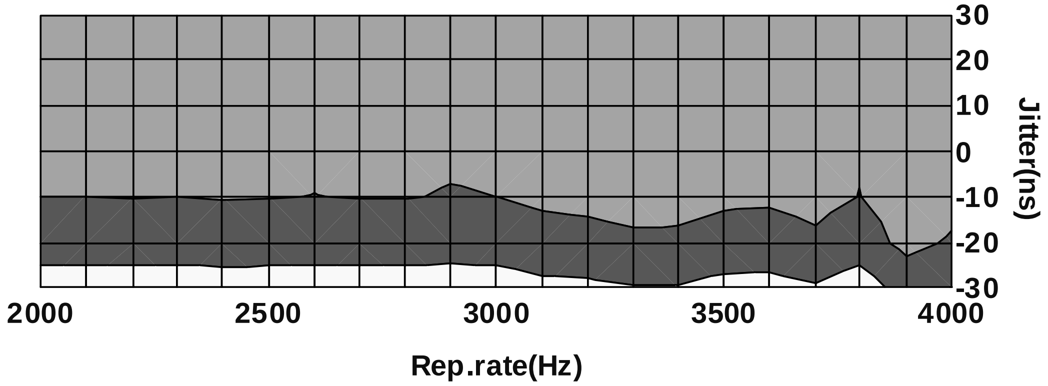


Figure 5. (b) Map of energy stability of MOPA scheme

Fig6 (a) (b) show the maps of spectral E95 stability (pm), which depending on the repetition rate through 2000 – 4000Hz and the timing jitter in the dual chamber synchronization. Fig.6 (a) is the injection lock, (b) is MOPA. These two maps show clearly that the injection lock has extremely wider margin for the fine spectrum than MOPA.



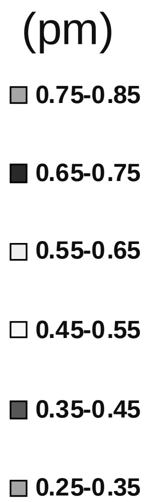


Figure 6. (a) Map of E95 stability in Injection Lock scheme

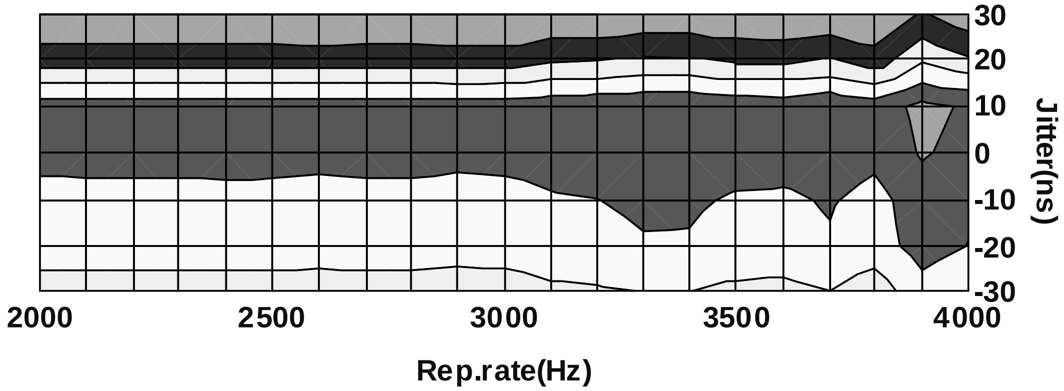


Figure 6. (b) Map of E95 stability in MOPA scheme

(2) Durability

Chamber

The new injection lock system is equipped with the dual power supply system (fig.7), which permits the control of the synchronization timing in wide allowance. The dual power supply system controls each chamber separately, that maximizes the durability of each chamber.

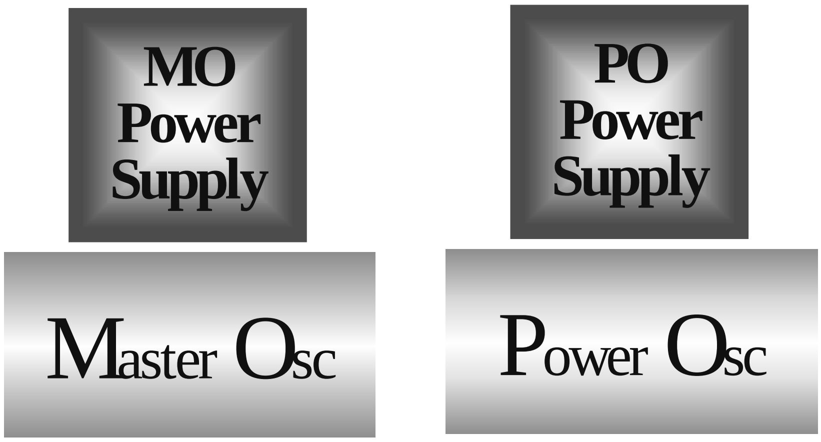


Figure 7. Dual Power Supply System

Optics in MO

The injection lock system require very small energy for MO, and the pulse energy of MO in the injection lock system is quite smaller than that of MO in MOPA. This small pulse energy reduces the DUV load to the optical parts of MO laser. Therefore the durability of expensive optical components in MO laser are extended dramatically.

Optics after PO

Durability of optics strongly depends on peak intensity of laser pulse. Peak intensity of injection lock system is around 40% lower than that of MOPA system. This comes from theoretical difference between the injection lock and MOPA. Laser system uses a lot of optical components after PO laser. This low peak energy of the injection lock also extends the lifetime of the optical components after PO laser.

Control system

GT40A employs the same architecture of the reliable controller system of G42A - a single chamber system, only extending the number of module controllers. This extendable design of the controller system guarantees the reliability of the laser control.

(3) Maintainability

In the dual chamber system, the number of components is larger than the single chamber system that may make maintainability worse. So, a drastic study of high maintainability design was done in the concept design of GT40A. The results are easy trouble shooting and easy replacement of modules and parts.

Automatic troubleshooting

For troubleshooting we developed an automatic troubleshooting function. Laser control system finds out the troubled components after operation of self-check function key in laser controller paddle. The laser controller can determine the source of troubles, by collecting and analyzing several signals of sensors, which are equipped on components in the laser system. This function will dramatically shorten the time of troubleshooting.

Easy replacement

The GT40A design employs easy replacement design. Replacement time of each module is shorter than that of single chamber laser. This design minimizes the time of maintenance. And also the time of optical axis-alignment is shortened by a sophisticated mechanical design.

REDeeM

Since 2001, Gigaphoton developed "REDeeM"- the remote data acquisition system through Internet - and has utilized it as a strong field service tool, for preventive maintenance. The GT40A employs upgraded REDeeM function "Remote Paddle", which enables the tuning of operational parameters, configurations of the laser system, through the network.

(4) CoO merit

Low cost of ownership (CoO) of DUV light source is quite important to mass production lithography. So it was necessary for us to give a cost-optimized design to GT40A. Even though the dual chamber system is much more complex than the single chamber system, we could make CoO remarkably low in GT40A, by lowering the DUV optical load and by reducing the number of the laser components. For example, in the MO laser part, the DUV optical load was lowered approximately 30% than single chamber laser that drove the both of the line-narrowing module (LNM) and the front mirror into non-consumable elements. We also decreased the number of consumable parts by studying optimized equipment design. As shown in Table 2, GT40A has only six (6) consumable parts, which is only one more than five (5), the single chamber system.

GT40A (dual chamber)

	Module
1	MO chamber
2	PO chamber
3	PO front module
4	PO rear module
5	Monitor module
6	F2 trap

single chamber system

	Module
1	Chamber
2	Line narrowing module
3	Monitor module
4	Front mirror
5	F2 trap

Table 2. Consumable parts in GT40A in comparison with single chamber system

3. Performance Data

(1) Spectral stability

E95 is very important spectral parameter for OPE control. Stability of E95 spectral data during over one month is shown in fig.8. E95 stability is 0.33+/-0.07. This data proves excellent long-term stability of spectral performance of GT40A.

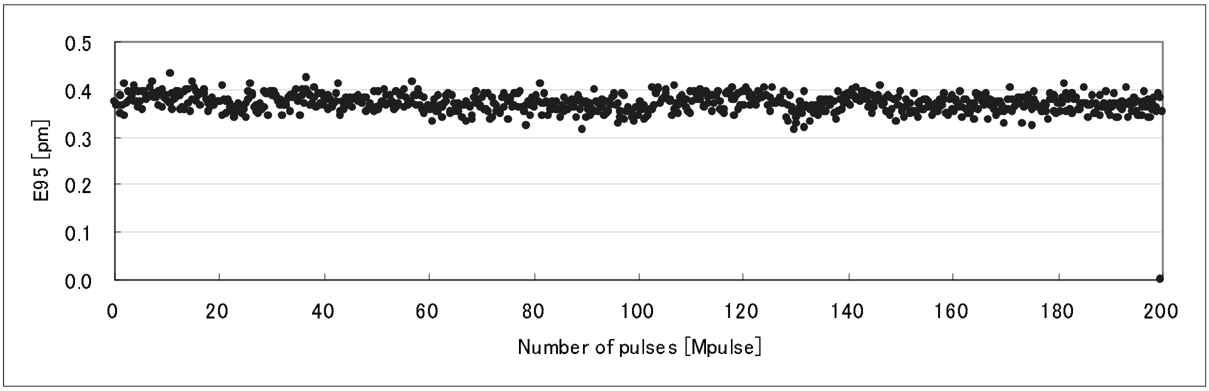


Figure 8. E95 stability of GT40A

(2) Energy stability

Energy stability is the dominant parameter for dose uniformity of exposure. GT40A has very high energy stability over wide repetition rate (from 1kHz to 4kHz). In general, the energy stability depends on discharge stability in chamber. Discharge stability is affected by gas density fluctuation, which comes from shockwave interaction of former discharge. Fig.8 shows a fine energy stability of GT40A in each burst (exposure shot mode). This performance is enabled by sophisticated anti-acoustic wave chamber design.

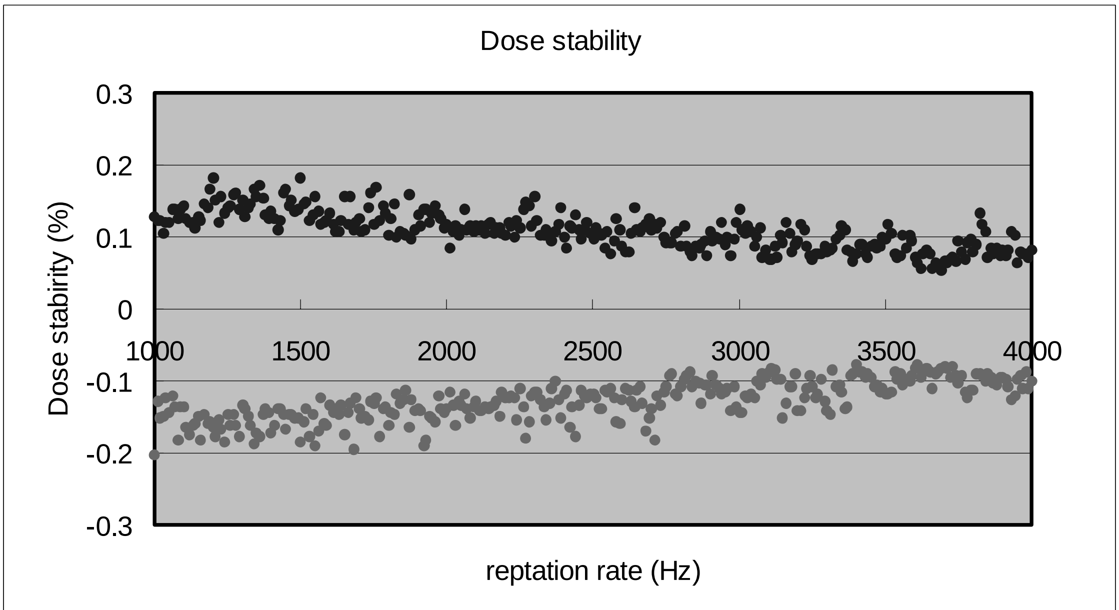


Figure 9. Energy stability of GT40A

(3) Pulse duration

Peak energy in each laser pulse affects on damage of optical components. Therefore optical pulse duration should be longer and stable. Fig.10 shows that the pulse duration of GT40A is very long. And this characteristic is kept during whole gas lifetime.

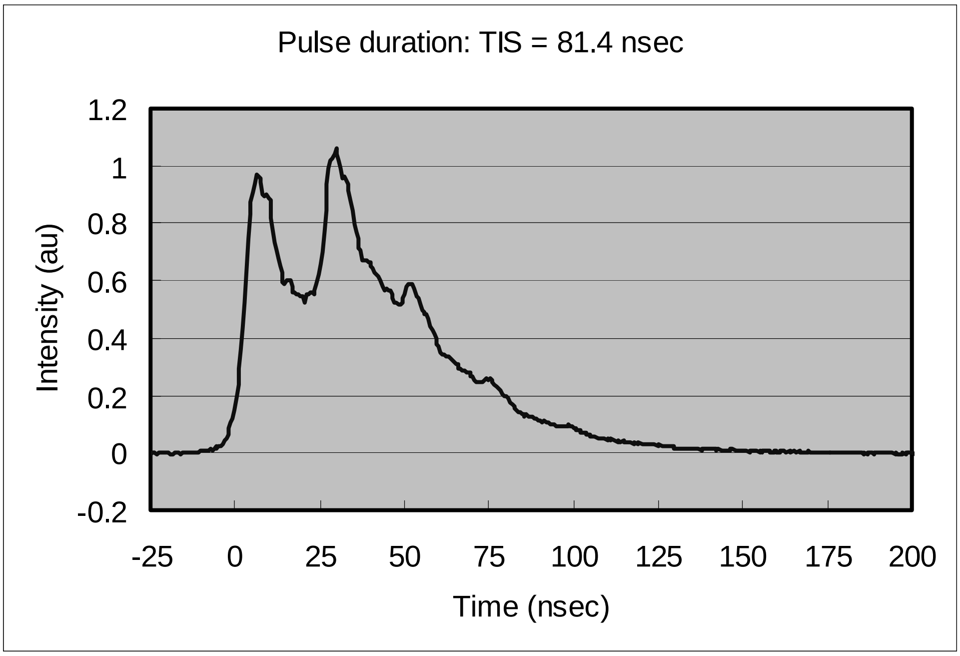


Figure 10. Pulse duration of GT40A

4. Conclusion

The 193-nm immersion lithography is moving from the pre-production to the mass production phase and its target node is expanding from 90 nm to 65 nm. And now the ArF-immersion technology is spotlighted as the enabling technology of below 45nm node[1)].

Since 1998 we have demonstrated 30W, 0.12pm, @157nm line narrowed light source for microlithography with "Injection lock technology"[1)2)]. Based on this injection lock technology, we have successfully developed "GigaTwin", a high power injection lock laser platform for 193nm lithography system. The new injection lock technology has advanced performances in comparison with MOPA (Master Oscillator Power Amplifier) laser system, in efficiency, stability and spectral property[3)]. The new high power ultra narrowed ArF laser GT40A (45W, 4000Hz, 11.25mJ, 0.18pm) is equipped with the "GigaTwin" injection lock system, whose latest development data is presented in this paper. And GigaTwin platform has a lot of flexibility to introduce higher performances and functions.

We are convinced that Gigaphoton's art of technology "GigaTwin" series, introduced with GT40A, will surely increase its lineup to lead the semiconductor industry below 65nm node era.

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