Ecology and high-durability injection locked laser with flexible power for double-patterning ArF immersion lithography

Hiroshi Umeda*, Hiroaki Tsushima, Hidenori Watanabe, Satoshi Tanaka,
Masaya Yoshino, Shinich Matsumoto, Hiroshi Tanaka, Akihiko Kurosu
Yasufumi Kawasuji, Takashi Matsunaga, Junichi Fujimoto and Hakaru Mizoguchi

Gigaphoton Inc., 400 Yokokura-Shinden, Oyama-shi, Tochigi, JAPAN 323-8558

ABSTRACT

ArF immersion technology has been used widely in volume production for 45nm node. For 32nm node and beyond, double patterning technology with ArF immersion lithography is considered to be the main stream solution until EUV is ready.
Our target is to reduce CoO(Cost of ownership) and we aim to develop for ecology and high durability laser. We will introduce the latest performance data of the laser built for ArF immersion lithography under the EcoPhoton concept.
Eco-photon concept:

-CoC (Cost of Consumable)
-CoD (Cost of Downtime)
-CoE(Cost of Energy & Environment)

We have developed flexible and high power injection-lock ArF excimer laser for double patterning, GT62A-1SxE (Max90W/6000Hz/Flexible power with 10-15mJ/0.30pm (E95)) based on the GigaTwin platform[5]. A number of innovative and unique technologies are implemented on GT62A-1SxE. In addition, GT62A-1SxE is the laser matching the enhancement technology of advanced illumination systems. For example, in order to provide illumination power optimum for resist sensitivity, it has extendable power from 60W to 90W.
We have confirmed durability under these concept with the regulated operation condition with flexible power 60-90W.
We show the high durability data of GT62A-1SxE with Eco-Photon concept. In addition to the results the field reliability and availability of our Giga Twin series (GT6XA). We also show technologies which made these performances and its actual data. A number of innovative and unique technologies are implemented on GT62A.

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

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 32nm node and beyond. In addition, double patterning is considered to be the 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)
We paid attention to ecology and confirmed the durability of the latest model : GT62A-1SxE. This paper shows eco-friendly and high durability data results of GT62A-1SxE in addition to the results the field reliability and availability of our Giga Twin series (GT6XA).
*hiroshi_umeda@gigaphoton.com; phone +81-285-28-8413; fax +81-285-28-8439; http://gigaphoton.com.

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. TOWARD ECO-FRIENDLY ARF EXCIMER LASER

2.1 ArF Excimer Laser and Its Relationship with Ecology

In order to fulfill the needs of the semi-conductor industry, we also develop our lithography lasers considering ecology throughout our development process. As a matter of fact, eco-friendly attitudes eventually lead to reduction of the total CoO (Cost of Ownership). The below table 2 shows that Gigaphoton target with regard to eco-friendliness. Now, with the latest laser GT62A-1SxE, based on the EcoPhoton concept, we executed substantive verification for the terms shown in Table 2.

Aim	Ecology : Eco-Friendly Lithography Tools		
Benefit	Total CoO (Cost of Ownership) reduction		
Factor	CoE	CoC	CoD
Terms	Electric power consumption Gas consumption	Reliability (Durability test)	Availability
	Durability		
Technologies	60-90W Flexible output power		GT Platform
	Injection Lock	Long lifetime modules	
	TGM	GRYCOS, MPL	TGM

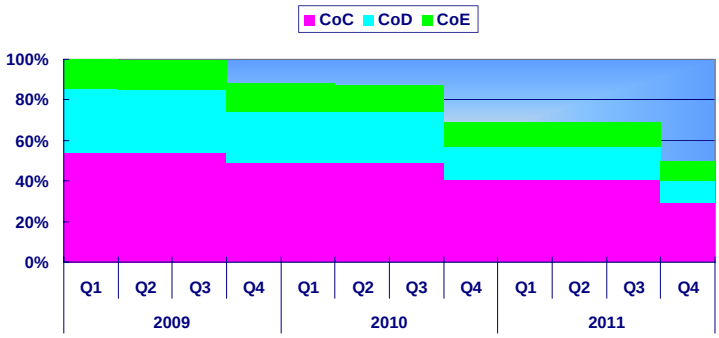
Table2. EcoPhoton concept and Gigaphoton target

2.2 Eco-friendly and "EcoPhoton" concept

Gigaphoton's target is to achieve over 50 % cost reduction before Y2012*. Fig.1 shows cost reduction achievement and plan of EcoPhoton.

Gigaphoton develops and releases its products in consideration for the ecology under EcoPhoton concept. Ecophoton is based upon three factors: CoC (Cost of Consumable), CoD (Cost of Downtime), CoE(Cost of Energy & Environment). Our focus is not only to reduce CoC and CoD but also to effectively offer eco-friendly applications and performances to reduce CoE, as in electric power or gas consumption.

In order to improve the tree factors (CoC、CoD、CoE) that EcoPhoton concept is found on, it is necessary to realize high durability at the fundamental level, and this paper shows the results of high durability, based on the durability tests.



Based on EcoPhoton policy

Fig.1 cost reduction achievement and plan

EcoPhoton offers a total cost reduction roadmap with a more comprehensive scope, including the impact it can have on the environment.

2.3 Approach to EcoPhoton

- CoC: Focus on the durability test

We have developed and introduced into the market our own lifetime extension technologies: GRYCOS (Gigaphoton Recycle Chamber Operating System) and MPL (Multi Positioning LNM).

GT62A-1SxE is able to optimize the laser output according to the user's demand and is also able to reduce the load of optics, extending their lifetime.

-CoE: Focus on the reduction of Gas and Electric consumption

We developed an ArF excimer laser "GT62A-1SxE" with a highly efficient injection locked system and flexible output power, and we also installed TGM in GT6XA ArF laser. Thus, we have achieved the reduction of Gas and Electric power consumption.

- CoD: Focus on the availability

In order to improve the availability, we adopted the time-proven GT Platform for our latest laser; GT62A-1SxE, thus keeping the conventional level of maintenance efficiency. Furthermore, using the lifetime extension technologies mentioned above, we made it possible to reduce the total CoD.

Thanks to these technologies, we have improved CoC, CoD, and CoE.

3. DURABILITY OF GT62A-1SxE

We verified the durability for the latest, eco-friendly ArF excimer laser, GT62A-1SxE. Furthermore, we confirmed that the latest laser is eco-friendly, considering CoE, CoC, and CoD in Table3. Regarding the availability of GT series, we confirmed with the field data.

Verification terms

-High durability
-Flexible output power (Major performance)
-Electric power consumption
-Gas consumption

3.1 Target Durability

In this verification, we evaluated the quality and reliability based on the durability test. That is to say, EcoPhoton concept also reflects that eco-friendly lasers are not complete without the durability. Good result from the durability test is one of the indicators for the long availability.

The durability test supplies CoE, CoC, and CoD of GT62A-1SxE with a quantitative underpinning. Table 3 shows the target durability for the modules of GT62A-1SxE. The latest generation model GT62A-1SxE has extendable power from 60W to 90W as the standard.

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

Table 3. Major specifications and the module life time target.

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

We tested the major durability performances in GT62A-1SxE and they were confirmed to meet design targets.
Its conditions are as follows:

Output power: 90W (It is most severe condition for optics)
It confirmed the condition of tuned power in the step of 10W from 60W to 90W
Repetition rate: 6kHz

We also confirmed the durability up to at least 30Billon pulses. The point of this durability test is

- To confirm a shortest module lifetime and reliability of the laser.
- To confirm the performance GRYCOS and MPL.
  There is a possiblity that GRYCOS execution may influence the dose stability performance and MPL execution may influence the spectrum performance.
  We have confirmed these performances do not change after GRYCOS and MPL execution.

We think that the durbility test up to 30Billiion pulses can show enough data to confirm the durability.

3.2 Durability test result

We confirmed the durability test under 90W condition. We checked the major output specifications and flexible power from 60W to 90W periodically.

Output power: set the power in the step of 10W from 60W to 90W.
Major output specification: output pulse energy, energy dose stability, wavelength stability, spectral bandwidth, beam profile, beam divergence at the same time at each power
We executed GRYCOS and MPL at 20Billion pulses. After these demonstrations are done, it is operating without trouble.

Fig.2 shows the pulse train of the output energy during the durability test over 30Billion pulses(Bpls).

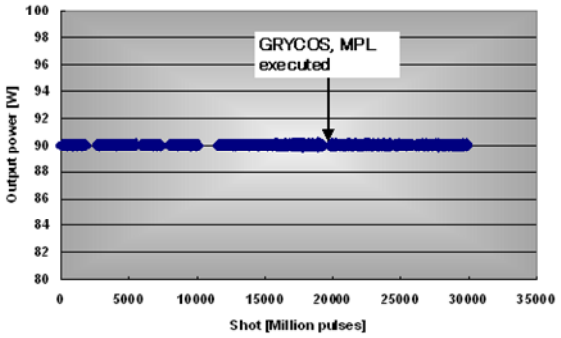


Fig.2. Pulse energy trend

3.3 Dose stability

Dose stability is an important property of laser output because it affects CD control. Fig.3 shows the trend of energy dose stability during durability test. These data was calculated by integrating the energy over the specified moving window. Fig.4 shows the trend of energy dose stability from 60W to 90W operation. We have confirmed that there is no problem from 60W to 90W operation over the entire 30billion pulses.

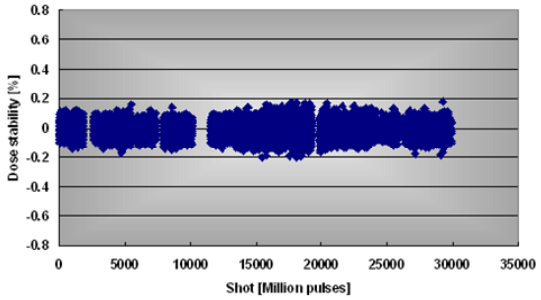


Fig.3 Dose stability trend in the durability test

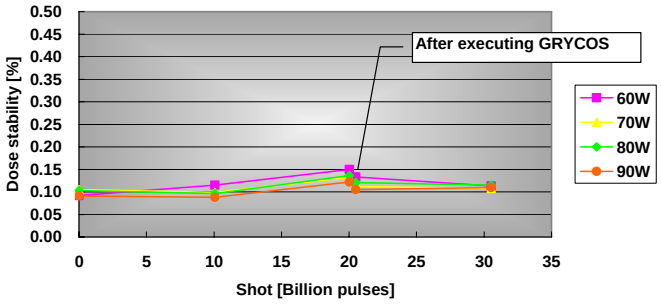


Fig.4. Dose stability trend from 60W to 90W

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. We confirmed stability by 30 billion pulses of the whole.

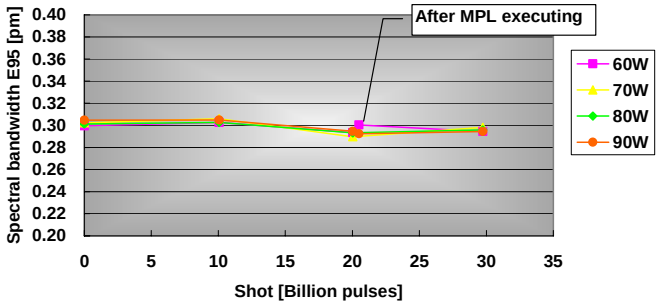


Fig.5. Spectral bandwidth from 60 to 90W

3.5 Wavelength stability

Changes of wavelength cause defocus, so the stability of the wavelength is important. Fig.6 shows the dependency of 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. We confirmed stability by 30 billion pulses of the whole.

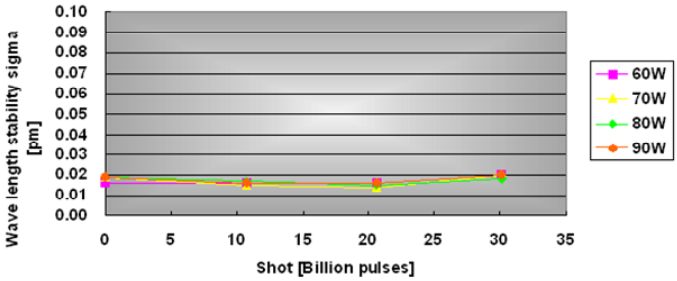


Fig.6 . Wavelength stability error from 60 to 90W

3. 6 Beam profile and divergence

Fig.7 and 8 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 the spec. We have confirmed that beam profile and beam divergence are stable from 60W to 90W.

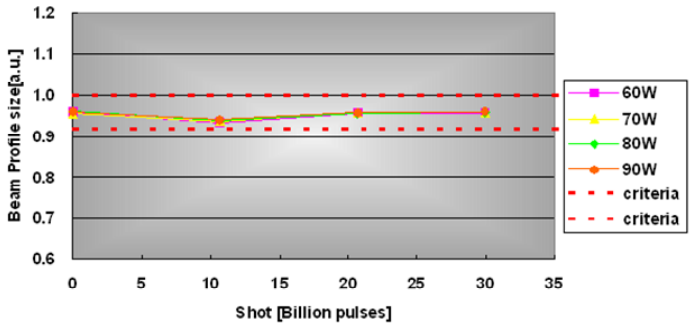


Fig.7 Output power dependency of beam profile size

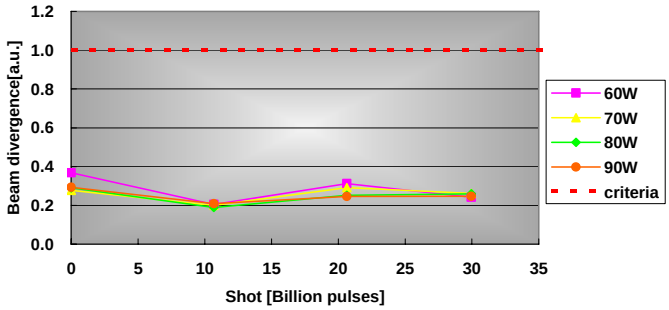
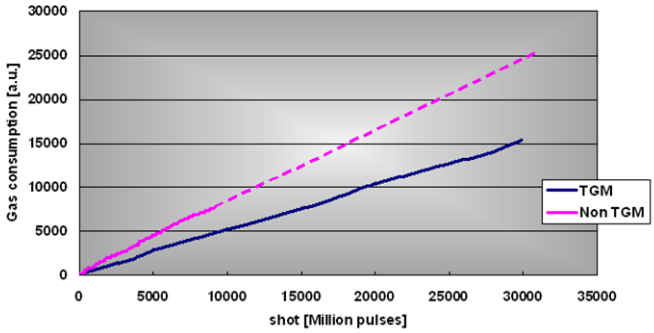


Fig.8 Output power dependency of beam divergence

4. UTILITY CONSUMPTION OF GT62A4-1SXE

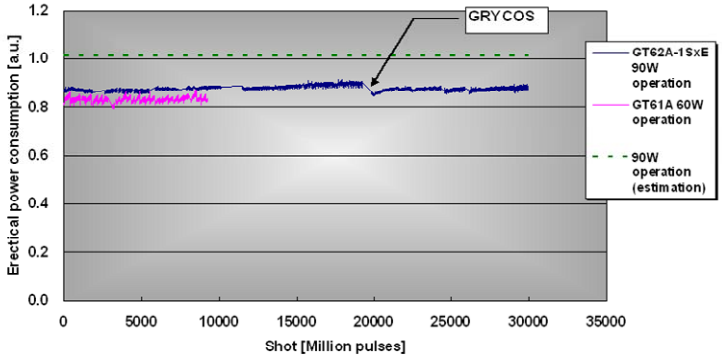
Fig.9 shows the trend of the gas consumption on TGM and on Non TGM. We confirmed reduction in gas consumption with new gas control technology TGM in durability test.
The gas consumption rating achieves over -30% compared with the conventional ratio without TGM.



*Condition : Result of durability test in Gigaphoton
Non TGM 60W operation in GT61A
TGM 90W operation in GT62A-1SxE

Fig.9 Gas consumption trend with TGM to Non TGM

Fig.10 shows the trend of the electric consumption with Injection lock system. We confirmed reduction in electric power consumption on 90W operation to 60W operation in durability test.

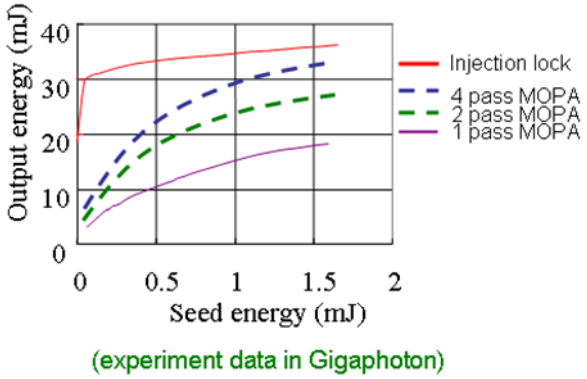


*Condition : Result of durability test in Gigaphoton

Fig.10 Electric power consumption under 90W operation to 60W

90W operation is usually thought to consume more electric power than 60W operation by 20 percent; however, GT laser

with the injection-lock system achieved 90W operation within less than 5% percent increase in electric power consumption. Fig 10 shows that electrical power consumption is steady over the durability test.
Because the efficiency of the Injection lock system is good as shown in figure 11. We estimated that at least 20 percent was necessary from the result of Figure 11 the electric power of 90W operation. And we confirmed that electrical power consumption was returned to an initial value after having executed GRYCOS execution.



(experiment data in Gigaphoton)

Fig.11 Result of output power in Injection lock and MOPA system

5. AVAILABILITY

Now ArF lithography is used in 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 2010 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.

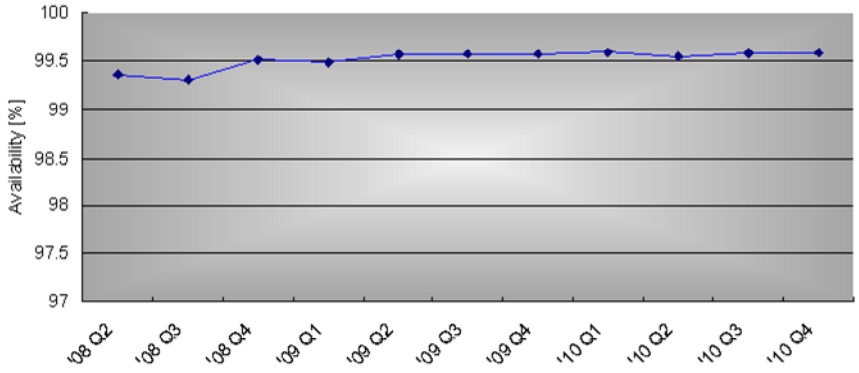


Figure 12. Availability of GT lasers up to Q4 2010

6. CONCLUSION

Gigaphoton has developed lasers in consideration for the eco-friendly and match the lithography tool of the double patterning.
It not only reduces CoC and CoD; it also contributes to the environment in the point of CoE such as reduction in electric power consumption and gas consumption under EcoPhoton concept.
We have confirmed that the latest laser:GT62A-1SxE has high durability for our target. We have confirmed there was no problem in the severest condition at least 30Bpls.
GT62A-1SxE is adaptable to the latest lithography tools. And it is also designed to support the requirement of process parameter flexibility of exposure tool and end customer.

-CoE: Gas consumption and electrical power consumption improved.
-CoC: High durability was proved with durability test.
-CoD: The availability was proven in the field with GT Platform.

7. REFERENCES

1. H. Mizoguchi, T.Inoue, J. Fujimoto, T. Suzuki, T. Matsunaga, S. Sakanishi, M. Kaminishi, Y. Watanabe, T. Nakaike, M. Shinbori, M. Yoshino, T. Kawasuji, H.Nogawa, H. Umeda, H. Taniguchi, Y. Sasaki, J. Kinoshita, T. Abe, H. Tanaka, H. Hayashi, K. Miyao, M. Niwano, A. Kurosu, M. Yashiro, H. Nagano, T igarashi, T. Mimura, K. Kakizaki: "High Power Injection Lock 6kHz 60W Laser for ArF Dry/Wet Lithography", Proc. SPIE Vol. 6154, 615425(2006)
2. T. Suzuki, K. Kakizaki, T. Matsunaga, S. Tanaka, Y. Kawasuji, M. Shimbori, M. Yoshino, T. Kumazaki, H. Umeda, H. Nagano, S. Nagai, Y. Sasaki, H. Mizoguchi: "Ultra line narrowed injection lock laser light source for higher NA ArF immersion lithography tool", Proc. SPIE Vol. 6520, 652024(2007)
3. M. Yoshino, H. Nakarai, T. Ohta, H. Nagano, H. Umeda, Y. Kawasuji, T. Abe, R. Nohdomi, T. Suzuki, S. Tanaka, Y. Watanabe, T. Yamazaki, S. Nagai, O. Wakabayashi, T. Matsunaga, K. Kakizaki, J. Fujimoto, H. Mizoguchi: "High-power and high-energy stability injection lock laser light source for double exposure or double pattering ArF immersion lithography", Proc. SPIE Vol. 6924, 6924-199 (2008)
4. Hiroaki Tsushima, Masaya Yoshino, Takeshi Ohta, Takahito Kumazaki, Hidenori Watanabe, Shinichi Matsumoto, Hiroaki Nakarai, Hiroshi Umeda, Yasufumi Kawasuji, Toru Suzuki, Satoshi Tanaka, Akihiko Kurosu, Takashi Matsunaga, Junichi Fujimoto and Hakaru Mizoguchi: "Reliability report of high power injection lock laser light source for double exposure and double patterning ArF immersion lithography", Proc. SPIE Vol. 7274, 7274-156 (2009)
5. 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: "Flexible and reliable high power injection locked laser for double exposure and double patterning ArF immersion lithography" , Proc. SPIE Vol. , 7640, 7640-80 (2010)