Ultra line narrowed injection lock laser light source for higher NA ArF immersion lithography tool

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ABSTRUCT

The GT61A ArF laser light source with ultra line narrowed spectrum, which meets the demand of hyper NA (NA > 1.3) immersion tool, is introduced. The GT61A aims at improving spectrum performance from value E95 0.5pm of GT60A. The spectrum performance 0.3pm or less was achieved by developing an ultra line narrowing module newly.

Moreover, in 45nm node, since it indispensably requires OPC (optical proximity correction) and a narrower process window, improved stabilization of spectrum performances was performed by bandwidth control technology. Newly designed Bandwidth Control Module (BCM) includes high accuracy measurement module which support the narrower bandwidth range and active bandwidth control module. It also contributes to the reduction of the tool-to-tool differences of the spectrum for every light source.

Keywords:
45nm node, ArF excimer laser, Injection Lock, line narrow, 193nm lithography, Immersion, spectrum bandwidth, high power

1. INTRODUCTION

The 193-nm lithography has moved to the 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/ E95) to ArF immersion market in Q1 2006.

In the technology below 45nm node, a light source will be required narrower spectrum and the high average laser power.

The GT61A ArF laser light source of the ultra line narrowed spectrum is developed. GT61A is based on the production proven GT (GigaTwin) platform, which has advanced Injection Lock system.

Improving on the GT60A, which achieved a spectral bandwidth (E95) of 0.5 pm, the GT61A reaches a spectral bandwidth of 0.35 pm. In addition, a newly developed high-precision measuring instrument and stabilization mechanism are provided as a standard feature, allowing highly stable spectrum performance throughout the entire lifetime. The GT61A represents a great contribution to the stability of the lithography process.

2. SPECTRUM PERFORMANCE REQUIREMENT FOR HYPER NA IMMERSION LITHOGRAPHY

Wide spectrum bandwidth of light source produce focus blur by the effect of chromatic aberration of projection lens. Narrower bandwidth is required for smaller design rule.

Until now the full width at half maximum (FWHM) metric is widely used to describe the spectrum bandwidth. However bandwidth of 95% energy concentration (E95) metric has better correlation to the lithographic performance parameters.6) In this paper E95 is mainly used as a principal metric of spectrum bandwidth.

Fig. 1 describes the spectrum specification for different NA of ArF scanners. The slopes below NA = 1 and beyond NA = 1 are different. The reason is that chromatic aberration of projection lens is reduced by the refractive-reflective optics design used for the immersion lithography scanners. As a result E95 less than 0.35pm specification is required for the design rule below 45nm.

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Generally, the influence of the focus shift on the CD becomes larger in isolated patterns than in dense patterns. Therefore isolated patterns are easy to be influenced by E95 variations. For better understanding of the E95 effect to the CD, CD sensitivity to E95 change for different pattern size is useful.[6)] Fig.2 shows the simulation results for the hole patterns. The sensitivity increases as the pattern becomes smaller. To reduce the CD error for smaller design rule, E95 deviation must be suppressed.

E95 changes will also impact upon OPE (Optical Proximity Effect). Laser-to-Laser difference and fluctuation through the laser lifetime could cause variation in OPE tool matching and its stability.

To answer these requirements the new laser whose E95 is less than 0.35pm and more stable E95 is developed. At the same time accurate E95 on board metrology is a must for very small E95 such as 0.35pm. New high accuracy E95 on board measurement module is developed

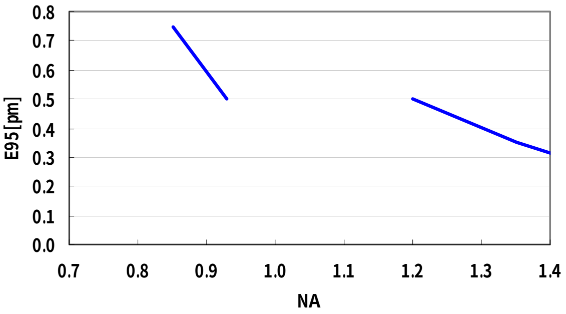

Figure 1. Laser E95 specification vs NA

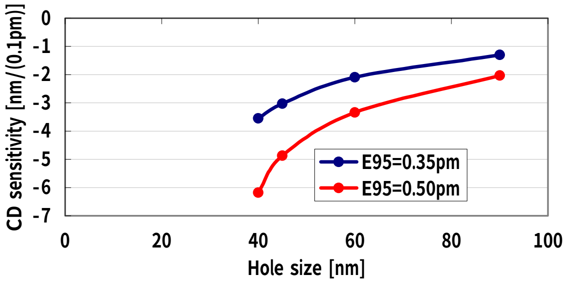

Figure 2.
Simulation results of CD sensitivity for the hole pattern

3. HIGH RESOLUTION LINE NARROWING MODULE

In the lithography excimer laser, the module which makes narrow band spectrum is called line narrowing module (LNM). LNM consists of littrow mounted Echelle grating and beam expansion prisms. It is a kind of high-resolution monocrometer and works as a rear mirror of laser cavity. For the conventional ArF excimer laser the resolution, ratio between wavelength to bandwidth, of LNM is required about one million. Because GT61A needs to increase the resolution by 30%, new LNM is designed to achieve the less than 0.35pm bandwidth. Such a high resolution LNM is very sensitive to the change of internal parts and atmosphere in the LNM. Therefore change of laser’s operating condition, such as heat or vibration, can easily affect the spectrum performances. To suppress these changes careful heat design of LNM and systematic design of laser system were performed. When spectrum performance is increased, the efficiency to output the optical energy from the laser is decreased. As a result laser chamber lifetime becomes shorter. To prevent this, the improvement of injection lock efficiency and laser power supply without changing the size of laser were performed. Finally longer life time than GT60A laser is achieved

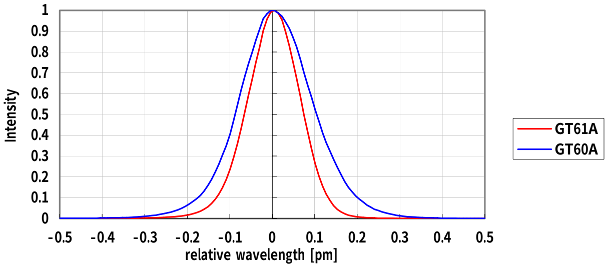

Fig. 3 shows the typical spectrum profile of GT61A. Newly designed LNM achieved the E95 of 0.25pm. As a comparison, GT60A’s profile is also plotted. Both profiles have good symmetry. The ratio between E95 and FWHM is about 2 for both lasers.

Figure 3. Spectrum profile
GT61A: E95 0.25pm
GT60A: E95 0.35pm

Fig. 4 shows the effectiveness of heat design of new LNM. This test is performed by the 75% duty cycle operation with 60W (10mJ 6KHz), which is highest duty cycle for the laser. Start from the laser's cold condition, firing is started and continued about two hours. Upper blue line is the case of not good design for the heat. E95 became broader about 0.07pm. New design LNM (lower red line) suppresses long-term drift of the E95. It should be noted that this experiment is done without the E95 feedback control loop.
Fig. 5 shows short-term drift of E95. It corresponds first two hundreds seconds of Fig. 4. Even with the short-term which correspond to the time scale within wafer exposure, new LNM has good stability.

Fig. 6 shows the repetition rate dependency of E95. This performance is mainly affected by the acoustic wave intensity in the laser chamber. New chamber design since GT60A have very good performance.

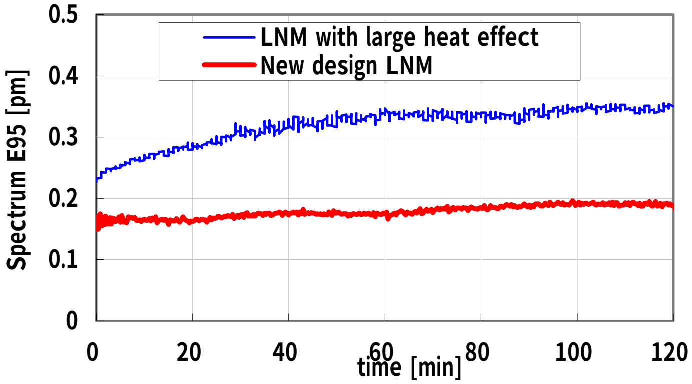

Figure 4. **Long-term drift of E95**

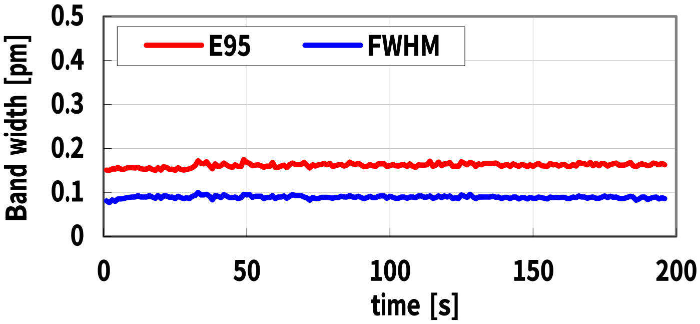

Figure 5. **Short-term drift of E95**

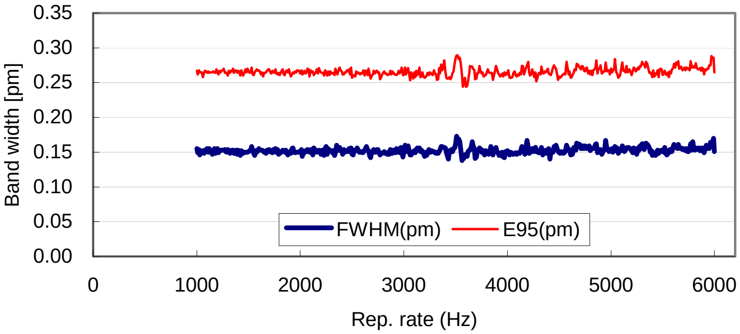

Figure 6. **Repetition rate dependency of E95 and FWHM**

4. HIGH RESOLUTION E95 MEASUREMENT MODULE

The measurement of E95 is more difficult than that of FWHM because it is sensitive to the background light information. Even the state of art spectrometer, which has large size Echelle grating with multi pass arrangement, approaches to its limit to measure the E95 required for less than 45nm design rule. On the other hand high resolution on board spectrometer is required to monitor and check the stability of E95. The on board spectrometer must be small enough to fit in the laser frame and stable over the lifetime of laser. To meet those requirements, new high resolution E95 measurement module is developed.

To ensure the enough signal to noise level, sensor, light intensity and exposure time design are carefully performed. Also for the longer stability, sensor and optical part's degradation are considered to keep the accuracy over the lifetime.

To push the measurement performance to the limit of the instruments, intrinsic error factor must be removed. The deconvolution method, which is same algorithm as the external spectrometer, is used to remove error factor$^{1)}$. The method is that measure the instrument function by the standard light source, which has very narrow bandwidth, before the installation of the E95 measurement module. When real E95 measurements are performed, measured data are deconvolved by the instrument function. Normally this calculation need long time and it is not fast enough to the evaluation of real laser at real time. All the E95 measurement module install in the GT series lasers have the special calculation hardware to accelerate the deconvolution process.

Fig. 7 shows the repeatability performance of new E95 measurement module. The same laser pulse is measured by both external spectrometer and on board E95 measurement module at the same time. After the measurements difference between two tools are plotted. Even this measurement include the intrinsic deviation of external spectrometer, the deviation is below 10fm.

Fig. 8 shows the linearity performance. This measurement is also taken by the same procedure as Fig. 7. Only difference is E95 of laser are changed from 0.2pm to 0.5pm. This graph shows very good linearity performance.

With these evaluations, total measurement accuracy is less than 25fm which is about 37% better than the conventional E95 measurement module.

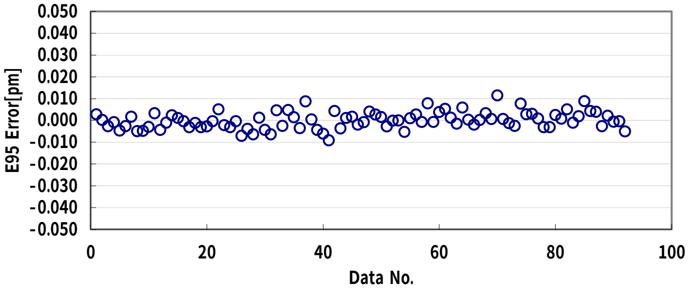

Figure 7. Repeatability of E95 measurement module

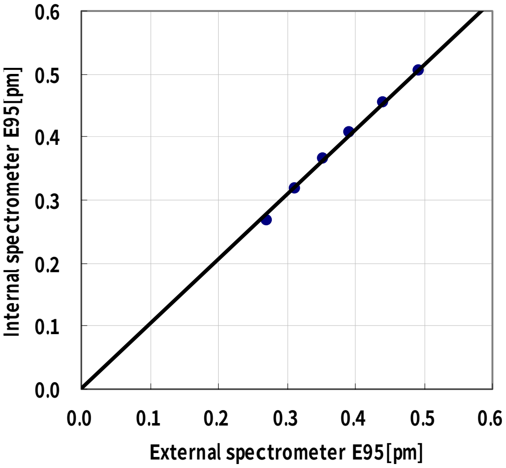

Figure 8. Linearity of E95 measurement module

5. ADVANCED BANDWIDTH CONTROL MODULE

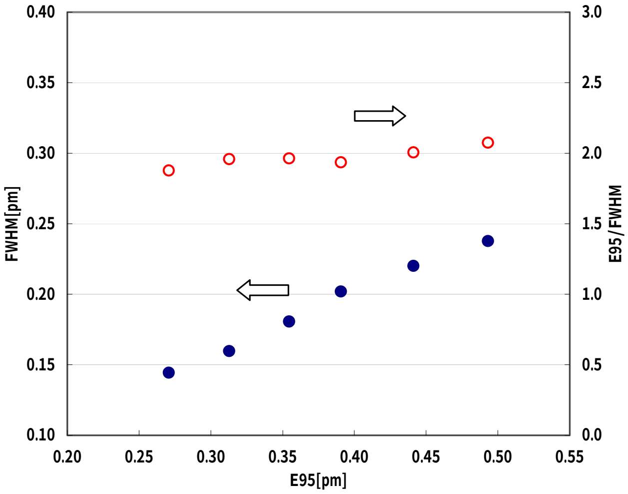

Figure 9.
E95 and FWHM relationship for different set points

Even the new LNM has good stability of E95, there are small drift over the lifetime. Also there are laser-to-laser differences for the E95. To keep the same E95 value for every laser, E95 tuning function is required. The advanced bandwidth control module (BCM) can also work with the new LNM for the narrower bandwidth.

The fluorine concentration in the gas mixture and trigger timing are well known parameters as the method to change the E95. However, these parameters are basic parameter for the excimer laser and laser performance will also change at the same time. For example, fluorine concentration in the gas mixture parameter will change the optical output energy and temporal pulse shape. The trigger timing will also change the spectral shape and dose stability. These changes are not desirable for the tuning of E95 with the lithography process. GT61A's BCM neither change the fluorine concentration in the gas mixture nor trigger timing. BCM can change the E95 for wide range without changing laser's important parameters. Fig. 9 shows the BCM performance of GT61A. It describes the E95 changes from 0.25pm to 0.5pm. Filled dot (left axis) shows the FWHM of the spectrum and blanked dot (right axis) shows ratio between E95 and FWHM. This graph shows that the spectrum shape is always same for different E95.

Fig. 10 shows the performance of BCM for different time span, short term (four seconds), middle term (thirty minutes), and 3 day gas-life. All graphs show that BCM can keep the same E95 at any time scale.

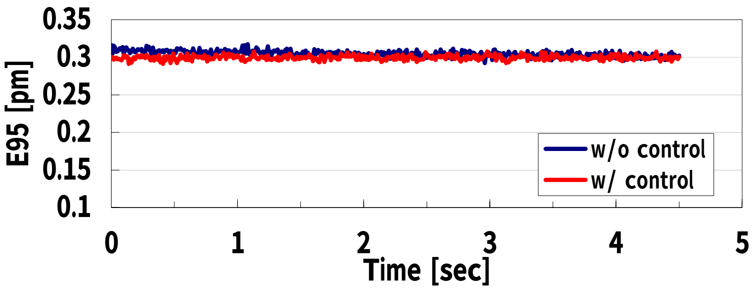

Figure 10-a.
Short term (4sec)
Target E95 = 0.3pm

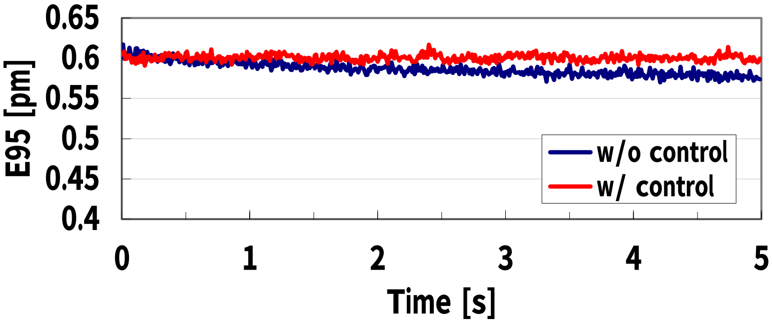

Figure 10-b.
Short term (4sec)
Target E95 = 0.6pm

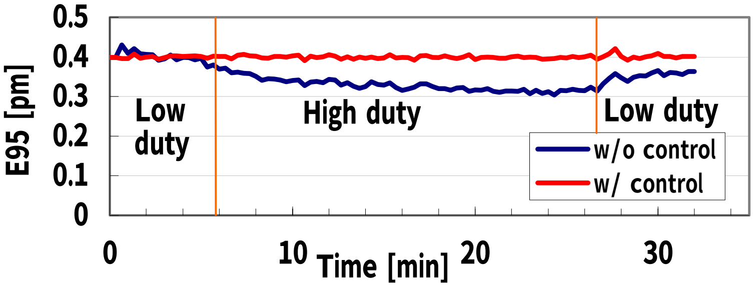

Figure 10-c. Middle term (30 min) stability of E95. Target E95 = 0.4pm

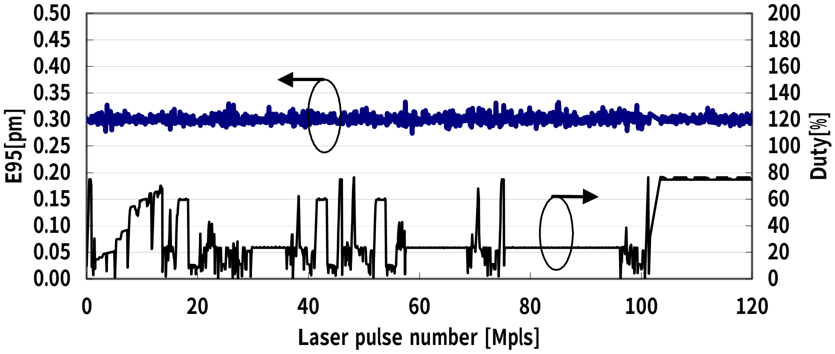

Figure 10-d. Long term (3days) stability of E95

Time scale	objective	Variation of PV [pm]	
		w/ control	w/o control
Short Term (5sec)	within chip	0.03	0.05
Middle Term (30min)	wafer to wafer	0.03	0.13
Long Term (12-24hours)	lot to lot	0.07	0.13

Table 1. Variation of E95 for different time scale

To confirm the laser performance change due to the E95 value, wavelength stability and dose stability were checked with different E95 set point, 0.30pm and 0.45pm, by the BCM. Fig. 11 shows the wavelength stability for and Fig. 12 shows the dose stability. Both graph shows that both performances are not affected by the change of E95 set point.

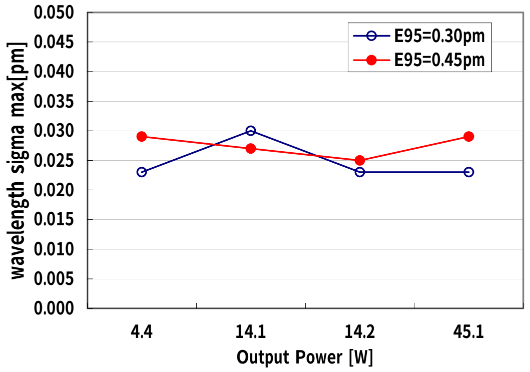

Figure 11. Wavelength stability for two E95 target.

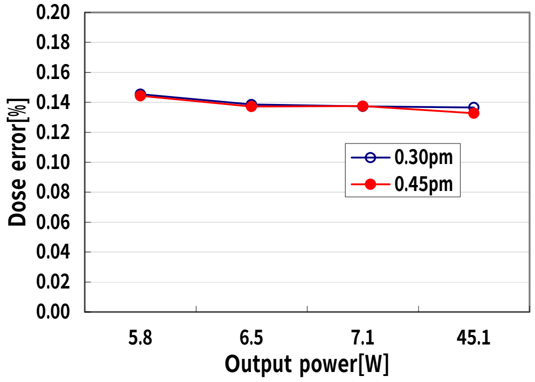

Figure 12. Dose error for two E95 target

6. LASER SPECIFICATION OF GT61A

Tables 2 summarize the specification of GT series ArF lasers. For the next generation high throughput scanner or double patterning scanner, the development of GT61A-1H which has higher power and high dose stability is planned.

ArF model		GT40A	GT60A	GT61A
Wavelength	nm	193.4	193.4	**193.4**
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**

Table 2. Major specification of GT series.
*** Spectrum specification has some differences in each scanner model**

7. CONCLUSION

The GT61A ArF laser light source of the ultra line narrowed spectrum, which meets the demand of hyper NA (NA > 1.3) immersion tool, is introduced. The spectrum performance 0.3pm or less was achieved by a newly developed an ultra line narrowing module.

Moreover, in 45nm node, since it indispensably requires OPC (optical proximity correction) and a narrower process window, improved stabilization of spectrum performances was performed by bandwidth control technology. Newly designed Bandwidth Control Module (BCM) includes high accuracy measurement module which support the narrower bandwidth range and active bandwidth control module. It also contributes to the reduction of the tool-to-tool differences of the spectrum for every light source.

8. ACKNOWLEDGEMENT

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