Optical performance of laser light source for ArF immersion double patterning lithography tool

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ABSTRACT

In advanced lithography processes, immersion lithography technology is beginning to be used in volume production at the 45-nm technology node. Beyond that, double-patterning immersion lithography is considered to be one of the promising technologies -meeting the requirements of the next-generation 32-nm technology node. Light source requirements for double patterning lithography tool are high power and high uptime to enhance economic efficiency, as well as extremely stable optical performances for high resolution capabilities.
In this paper, the GT62A, Argon Fluoride (ArF) excimer laser light source which meets these requirements is introduced. The GT62A has an emission wavelength of 193-nm, a power output of 90 W and a repetition rate of 6,000 Hz. The dose uniformity of the GT62A was improved for reduction of Critical Dimension (CD) variation and better Critical Dimension Uniformity (CDU). A stable wavelength and a spectrum bandwidth of the GT62A satisfy the requirements of the high resolution lithography tools which need the steady focus stability. In addition, we verified by simulation that the spectrum bandwidth control in the GT62A contributes to Depth of Focus (DOF) enhancement. The new technology for the light source and detailed optical performance data are presented.

Keywords: 32nm node, ArF excimer laser, 193nm, Injection Lock, line narrow, immersion, double patterning lithography, spectrum bandwidth, high power, optical performance, CD control, DOF enhancement

1. INTRODUCTION

193nm ArF light sources are widely used in semiconductor mass production of the 90 nm node and beyond. And the ArF immersion technology is even spotlighted as the enabling technology for the 45nm node and beyond. In addition, double-patterning immersion lithography is scheduled as the most promising technology to meet the requirement of the next-generation 32nm node. Therefore, high- throughput and high-resolution exposure tools for the 193nm lithography require ArF light sources with high output power and stable narrow spectrum bandwidth.
We have already released an injection lock ArF excimer laser with high output power and high repetition rate: 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/0.35pm (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/0.35pm (E95)) with the higher power was developed for double patterning lithography at the 32nm node (Table 1) [3)]. All these laser systems are built on the Giga Twin (GT) platform, a common and reliability-proven platform.
In this paper, we report on the optical performance data of the GT62A.

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Technology Node (typical)	Main driver	Requirement For ArF Laser light source	GT model
32 nm	double patterning higher throughput	6kHz / 90W / 0.35pm (E95)	GT62A
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

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

2. GT62A FEATURES

Compared with the previous models of the GT series, improvements for GT62A are listed as follows (The (1) - (4) were reported in the previous paper [3]).

1) Higher output of the power supply for higher output power (15mJ / 90W, increased from 10mJ / 60W).
2) Improved gas control module and new gas control algorithm for gas lifetime extension (from 3days / 100 Mpulses extended to 15days / unlimited pulses). This technology is called Total Gas Management (TGM). [4]
3) Extremely durable optics compared with the GT61A (more than 3 times improvement).
4) Field upgradeability from 60W to 90W.
5) Enhancement in energy stability by TGM.
6) New Optical Pulse Stretcher (OPS) designed to provide longer pulse duration and lower special coherence.
7) Anti-vibration structure in the Line Narrow Module (LNM) for the improvement of the wavelength stability.
8) Beam Profile (BP) stabilizer for the improvement of BP size stability.

3. IMPROVED DOSE UNIFORMITY

The performances to improve dose uniformity are as follows.

- Improved Dose Stability
- Reduced spatial coherence and temporal coherence

3.1 Dose Error

It is crucial issue for double patterning lithography tools to reduce the variations in CD. The energy stability of the laser gives an impact to CD variation.

Figure 1 indicates the dose error during a gas lifetime at 90W. The dose error is decreased by 40 % compared with the conventional data (the repeat of 100 Million pulses gas lifetime) by use of the TGM technology. Moreover, the dose error remains stable during 15 days (>2 Billion pulses).

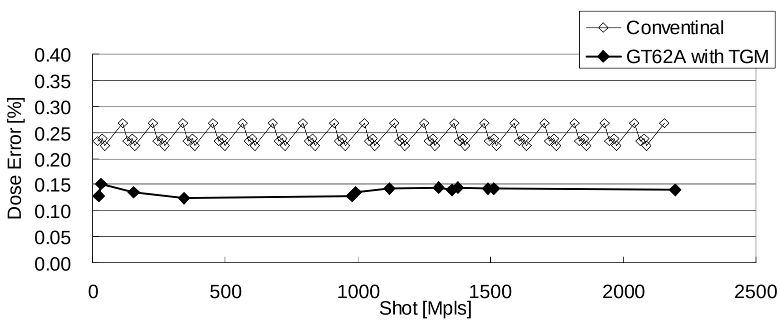

Figure 1. Trend of dose error during a gas lifetime. The dose error is decreased by 40% compared to the conventional data (the repeat of 100 Million pulses gas lifetime).

3.2 Performance to reduce Spatial and Temporal coherence

The contribution of Line Edge Roughness (LER) to CDU is an increasing concern. Since the speckle contrast gives impact to LER, the suppression of the speckle contrast contributes to reduce LER. Therefore, we need to reduce the speckle contrast to improve CDU.

There are two types of coherence as the factors inducing the speckle pattern formed on wafers: the spatial coherence and the temporal coherence. So, it is important for the suppression of the speckle contrast to reduce the two kinds of coherence. Table 2 summarizes some parameters affecting the coherence and some methods of speckle contrast reduction.

We adopted “Longer Tis (Total Integrated Square)” to reduce the temporal coherence, and “New optical system” to reduce spatial coherence. Therefore, a new OPS was designed for both approaches.

On the other hand, “Increasing Nslit” limits throughput. “Large spectrum bandwidth” goes against the respect of smaller line-space structure. So, those methods were not chosen to reduce the temporal coherence.

Tis is a temporal pulse width defined by the following equation.

$$Tis = \frac{\left(\int P(t)\, dt\right)^2}{\int P(t)^2\, dt}$$

Where P(t) is a function of temporal laser pulse profile.

Factors inducing the speckle pattern	Parameters	To reduce speckle contrast (small LER)
Spatial coherence	Optical axis	**New optical system to reduce spatial coherence**
Temporal coherence	Number of pulses to exposure: Nslit	Increase Nslit
	Temporal pulse width: Tis	**Longer Tis**
	Spectrum bandwidth: BW	Large BW

Table 2. Some parameters affecting the coherence and some methods of speckle contrast reduction.

The spatial coherence is measured with the shearing interferometer. Figure 2 shows the results of the spatial coherences of both the conventional and new OPS. The spatial coherence was improved by using the new OPS.

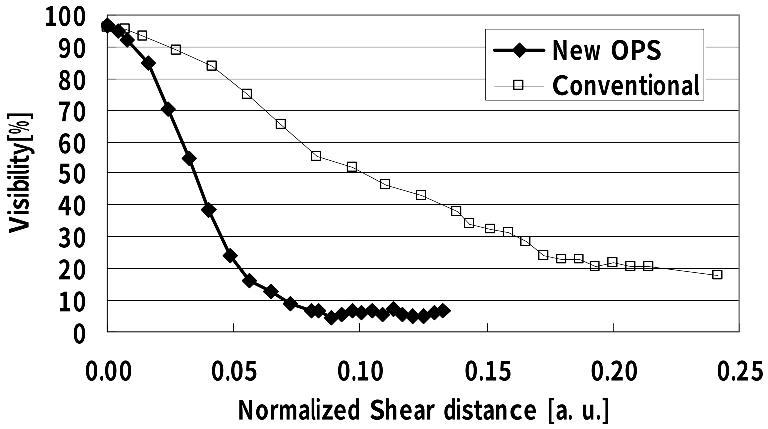

Figure 2. The results of the spatial coherences of the conventional and the new OPS measured by using the Shearing interferometer

The visibility is given by

$$\text{Visibility} = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

Where I_{max} and I_{min} are respectively the maximum and minimum intensity of the fringe pattern at the Shearing interferometer.

Figure 3 shows the comparison of the pulse duration obtained by using the configuration of the new OPS and the conventional data. The new OPS achieved Tis of longer than 130nsec, which is substantially longer than conventional OPS (Tis = 70nsec). It is expected that LER may reduce to 73% (= SQRT (70/130)) by the new OPS because it is known that the relation between LER and Tis is formulated as follows.

$$LER \propto \frac{1}{\sqrt{Tis}}$$

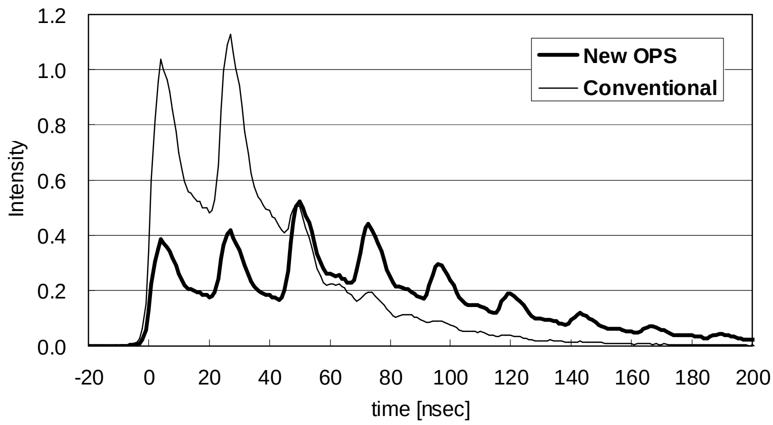

Figure 3. Pulse duration of the conventional and the new OPS

The peak energy of new OPS is decreased by 55 % compared with the conventional data as shown in Figure 3. This improvement will contribute to the lifetime of optics inside scanners.

4. ENHANCED FOCUS CAPABILITY

The performances to enhanced focus capability are as follows.

- Wavelength stability (Short-term and Middle-term performance)
- Spectrum bandwidth stability
- Spectrum E95 changed by a Bandwidth Control Module (BCM) [2] for the improvement of DOF

The focus stability is evaluated in CD. The better the focus stability is, the smaller CD value becomes. As semiconductor devices are becoming increasingly highly-integrated, the higher focus stability is required. Thus, because double patterning lithography demands the higher focus stability, it is necessary to precisely control CD.
The wavelength stability and spectrum E95 stability are measured as the laser performance which impacts CD control [5].

4.1 Wavelength stability (Short-term performance)

The anti-vibration structure in the LNM was developed to enhance the wavelength stability. Thanks to the successful introduction of this structure into the LNM, we are able to offer enhanced wavelength stability with GT62A.
Figure 4 and Figure 5 show the repetition rate dependency of wavelength error and wavelength stability sigma with wavelength control by the anti-vibration structure in the LNM. These data were averaged over typical moving window as a part of standard statistical treatment. Wavelength error and stability sigma have been halved by the new LNM.

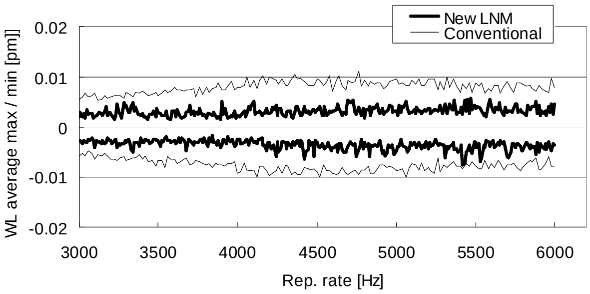

Figure 4. The repetition rate dependency of wavelength error

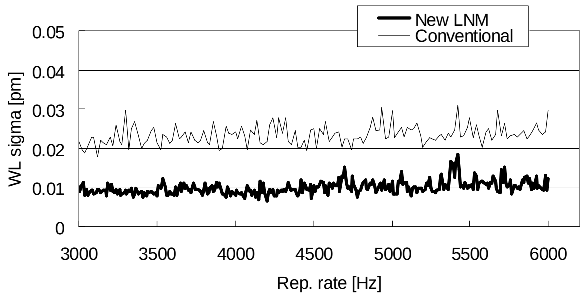

Figure 5. The repetition rate dependency of wavelength sigma

4.2 Wavelength stability (Middle-term performance)

Figure 6 shows the trend of wavelength error during 15 day gas lifetime (>2 Billion pulses). These data were averaged over typical moving window. No deterioration of wavelength stability is observed during 15 days (>2 Billion pulses). The wavelength error is improved by the new LNM.

All the GT models have an internal Absolute Wavelength Meter (AWM) for calibration. And this calibration is automatically executed during gas refill operation. Figure 7 shows the trend of wavelength error measured with an external absolute wavelength meter. No wavelength drift was observed during 15 days (>2 Billion pulses) and absolute wavelength error was less than ±0.03pm. We have confirmed that the calibration of absolute wavelength is not needed during 15 days (>2 Billion pulses), which results in elimination of additional downtime.

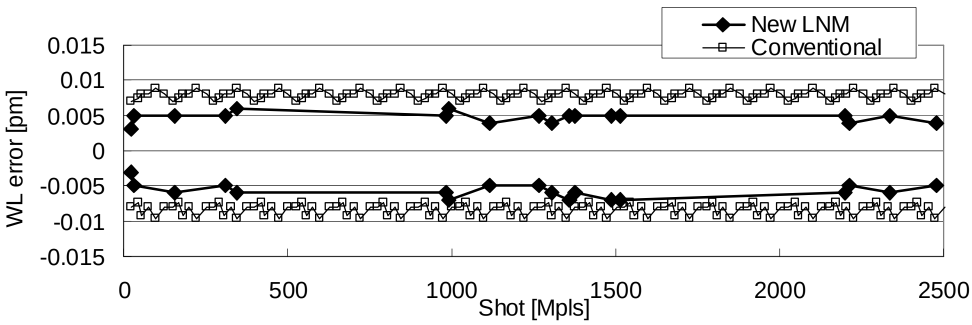

Figure 6. Trend of wavelength error in gas lifetime. The data of “New LNM” is a TGM gas lifetime. The data of “Conventional” is the repeat of 100 Million pulses gas lifetime.

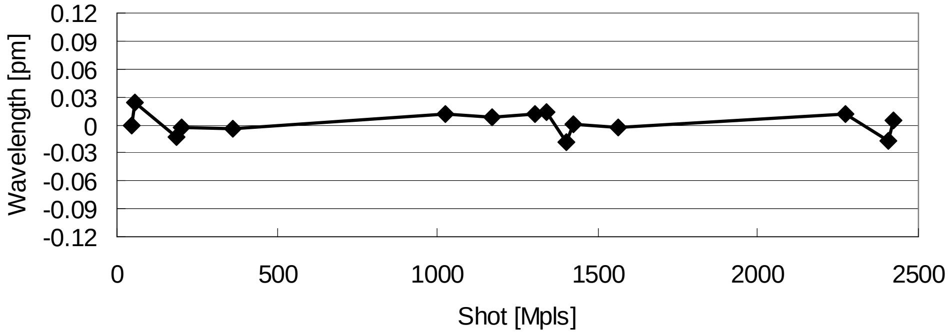

Figure 7. Trend of wavelength error measured with external AWM in gas lifetime

4.3 Spectrum bandwidth stability

Figure 8 shows the trends of spectrum E95, which is measured with an external high resolution spectrometer, during 15day gas lifetime (>2 Billion pulses). The spectrum E95 is precisely controlled around 0.30 pm by BCM. The spectral bandwidth control accuracy was less than ±0.02pm and no drift of spectrum occurred during 15 days (>2 Billion pulses).

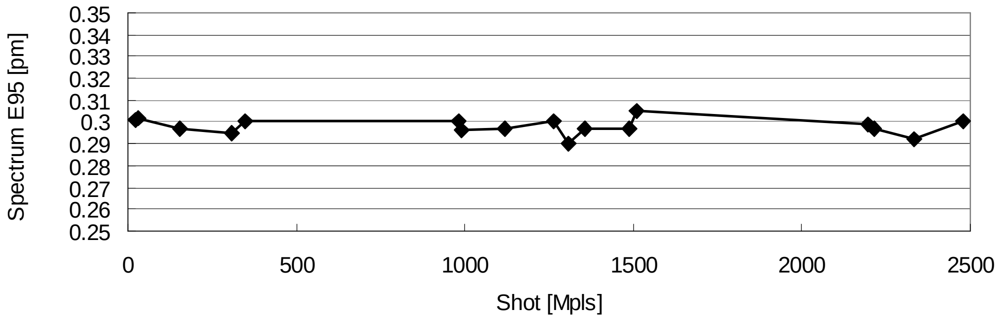

Figure 8. Trend spectrum E95 measured with the external spectrometer in the gas lifetime

4.4 Spectrum E95 changed by BCM and the simulation of DOF

The BCM is adopted to the GT62A. BCM can flexibly control spectral bandwidth (E95) by changing the wave front of laser light.

Several typical spectrum profiles are shown in Figure 9 while spectrum E95 is changed by BCM control. Usually, the spectrum E95 of GT62A is precisely controlled around 0.30 pm by BCM, however, the spectrum E95 can easily be tuned from narrow value to broad one. We have successfully developed the optical solution for BCM to provide both highly stable spectrum performance and E95 tuning function.

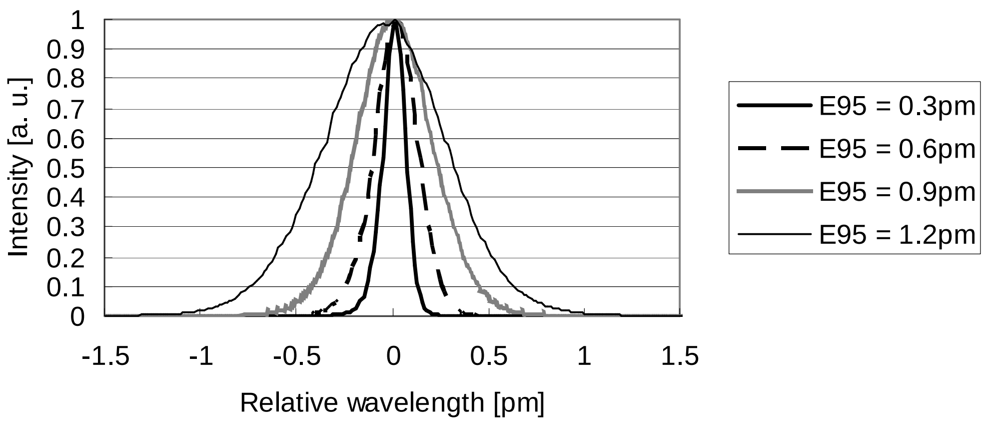

Figure 9. The typical spectrum profiles when BCM control parameter is changed. The tuning speed is within a few seconds when spectrum bandwidth is tuned from narrow to broad E95.

DOF is one of the projection lithography performances which the spectrum bandwidth affects. DOF can generally be thought of as the range of focus errors that a process can tolerate and still give acceptable lithographic results (in detail, the range of focus that keeps the resulting printed feature within a variety of specification such as line width, sidewall angle, resist loss, and exposure latitude). The effect of focus on a projection lithography system is a critical part of understanding and controlling a lithographic process [6].

Therefore, we investigated the impact on DOF at the contact-hole pattern in the simulator (PROLITH^{TM} v.9.3). The Exposure Latitude (EL) versus DOF as simulation results is shown in Figure 10. We found that DOF at 8% EL was enhanced 1.45 times by changing the spectrum E95 from 0.3pm to 1.2pm (for example, increase from >0.20µm DOF to >0.29µm DOF at 8% EL). Here, we can see DOF can be expanded by tuning spectrum bandwidth.

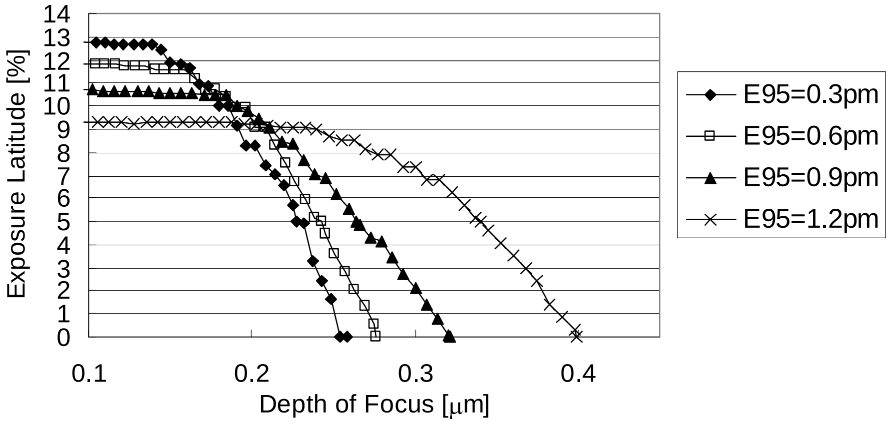

Figure 10. The results of EL vs. DOF in the simulation (@ NA: 1.35 immersion / Illumination: Quasar / Blade Angle: 20 deg / Sigma Outer: 0.9 / Sigma Inner: 0.7 / Pattern: 1D Binary – Contact hole / Hole size: 60nm / Pitch: 120nm)

5. BETTER BEAM PROPERTIES

The BP stabilization is necessary for the steady illumination in a scanner system. Therefore, BP stabilizer was equipped on the GT62A.

Figure 11 shows the trend of BP size during 15day gas lifetime (>2 Billion pulses). The BP size of the laser with this stabilizer is very stable compared to that without the stabilizer. The stabilizer is very effective to enhance the BP size stability.

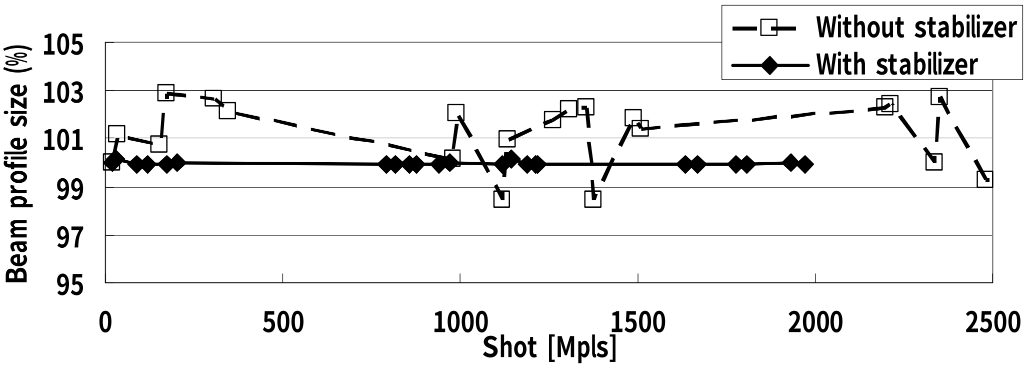

Figure 11. Trend of Beam profile size in the gas lifetime

6. CONCLUTION

Gigaphoton has developed the GT62A laser for immersion double patterning lithography. The summary is as follows.

1. Compared with conventional data, the dose error is decreased by 40% thanks to TGM technology.
2. The LER could be improved to less than 73 % by the new OPS. (The lower peak energy by the new OPS will contribute to extend the optics lifetime of scanners.)
3. GT62A can provide stable wavelength required for double patterning process by the anti-vibration structure in the LNM. The wavelength error and stability sigma have been halved compared with the conventional design. And actively controlled spectrum E95 bandwidth with BCM is very stable at 90W operation.
4. We verified by simulation that DOF at 8% EL was enhanced 1.45 times by changing the spectrum E95 from 0.3pm to 1.2pm.
5. The spectrum bandwidth can be tuned in one broad actuation range and at high tuning speed by BCM.
6. The stable BP size of GT62A delivers the steady illumination needed for scanner systems.

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