High durable 4-kHz ArF excimer laser G42A for sub-90-nm lithography

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ABSTRACT

Mass production in 193 nm lithography is now starting and its target node is moving from 90 nm to 65 nm. The main performance requirement of ArF excimer laser in this situation is high power with ultra narrow spectrum for higher throughput. The other hand, higher reliability and lower cost of ownership (CoO) are strongly hoped in mass production because CoO of ArF excimer laser is still higher than that of KrF excimer laser. We have already reported the 4 kHz ArF excimer laser for mass production, model G42A, which has an 20 W of average power, spectral bandwidth less than 0.3 pm (FWHM) and a spectral purity less than 0.75 pm (E95). We applied some technologies to G42A for achieving the high reliability and long lifetime. As a result, G42A showed the stable performance during the lifetime of over 10 billion pulses. In this paper, we report the long-term stability of G42A. And also, we introduce the reliability data of G40A series, which is the previous 4 kHz ArF excimer laser model.

Keywords: excimer laser, ArF, 193-nm, microlithography, line-narrowing, high repetition rate

1. INTRODUCTION

Recently, the high power with ultra narrow bandwidth is required for higher throughput in mass production for 193-nm lithography. In this situation, 40 W ArF excimer laser is introducing to the semiconductor market [1]. Gigaphoton has already started to develop the high power ArF excimer laser, which is the model GT40A [2]. This laser is based on the twin chamber technology, which is an injection lock laser configuration. The target specifications are 60 W, spectral bandwidth less than 0.18 pm (FWHM) and a spectral purity less tan 0.5 pm. This specification will cover the next generation lithography of below 65 nm node.

The other hand, the 20 W ArF laser is now operating and still hoped for the process development and 200 mm line. The 20W laser is based on the single chamber technology. This means that the performance is very stable and initial cost is very low, compared with twin chamber laser configuration. In last year, we introduced a 20 W ArF laser, model G42A to semiconductor markets as a light source for sub-90 nm lithography generation [3]. G42A is based on the single chamber technology, which is inherited from KrF excimer laser. And also, the following technologies are applied to G42A to achieve high reliability and low cost of ownership (CoO).

(1) G-electrode technology
(2) Magnetic bearing technology
(3) High durable optics technology

In this paper, we describe the long term stability of over 10 billion pulses in G42A, which has the following specifications: a repetition rate of 4 kHz, output power of 20 W, FWHM spectral bandwidth below 0.30 pm, and spectral purity below 0.75 pm. And also, we show the reliability data of G40A series, which is the previous 4 kHz ArF excimer laser model.

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2. FEATURES AND SPECIFICATINS

Table 1 lists the main performance characteristics of the Gigaphoton ArF excimer laser. The main differences between them are spectrum performance and power. The following technologies are used in G42A to achieve long lifetime and high reliability.

Table 1 Performance of ArF excimer laser

Items	G41A	G42A	GT40A
Repetition rate	4000 Hz	4000 Hz	4000 Hz
Output power	20 W	20 W	60 W
Pulse energy	5 mJ	5 mJ	15 mJ
Energy dose stability	<±0.3%	<±0.3%	<±0.3%
Spectral bandwidth (FWHM)	<0.35 pm	<0.3 pm	<0.18 pm
Spectral purity	<1.0 pm	<0.75 pm	<0.5 pm
Average wavelength stability	<±0.03 pm	<±0.03 pm	<±0.03 pm

2.1 G electrode technology

Chamber lifetime is the main factor to decide the CoO because the chamber cost is the most expensive, compared with other main module such as line narrowing module (LNM) and monitor module (MM). And also, the chamber lifetime of ArF excimer laser is half of KrF excimer laser. So, the longer chamber lifetime is most important issue and is strongly hoped in production phase. One of the main factors limiting chamber lifetime is electrode ablation by the discharge [4]. Electrode ablation degrades laser performance characteristics such as laser efficiency and energy stability. This improvement is a main countermeasure to extend the chamber lifetime. Conventional electrode consists of only metals. This means that it is difficult to prevent the ablation. The other hand, G-electrode has protection films. This film protects the electrode from the ablation by discharge. The electrode ablation rate can be predicted by F2 consumption rate because the F2 reacts the metal by discharge. Figure 1 shows the F2 consumption rate per operation in conventional electrode and G electrode chamber. F2 consumption is drastically improved by G- electrode chamber. This means that the ablation rate is improved and the chamber lifetime drastically extends.

2.2 Magnetic bearing technology

One of major factors to decide the chamber reliability is the bearing, which is only a moving part in the chamber. Mechanical bearing system has physical contacts. This has lifetime limitation by ball deterioration inside the mechanical bearing. This deterioration induces the mechanical vibration and directly affects the wavelength stability. The other hands, magnetic bearing technology is applied to G42A, which was already applied to 2 kHz KrF laser. Magnetic bearing has no physical contacts. This assures trouble free by bearing.

2.3 High durable optics technology

The LNM is a main module to decide the spectrum performance and wavelength stability. The optics in LNM consists of a high–dispersion, high-efficiency grating and high-transmittance prisms. These optics are the another main factors to decide the CoO because high optical intensity in LNM deteriorates the optics efficiency. This optics deterioration determines the LNM lifetime. From this point, we developed the high durable optics optimized to 193-nm wavelength. Figure 2 shows the optics deterioration rate in conventional and new optics. The rate in new optics is below half in conventional optics. This performance drastically improves the CoO.

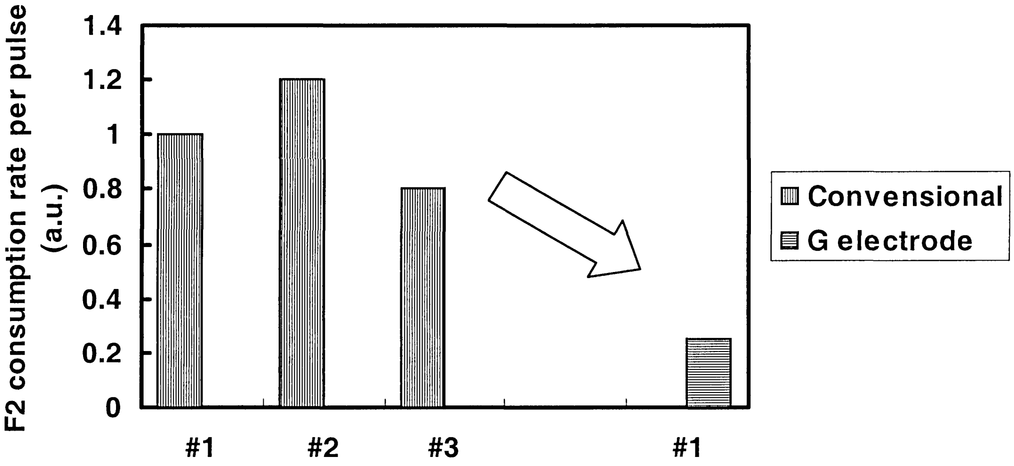

Fig. 1 F2 consumption rate per pulse in conventional electrode and G-electrode chamber

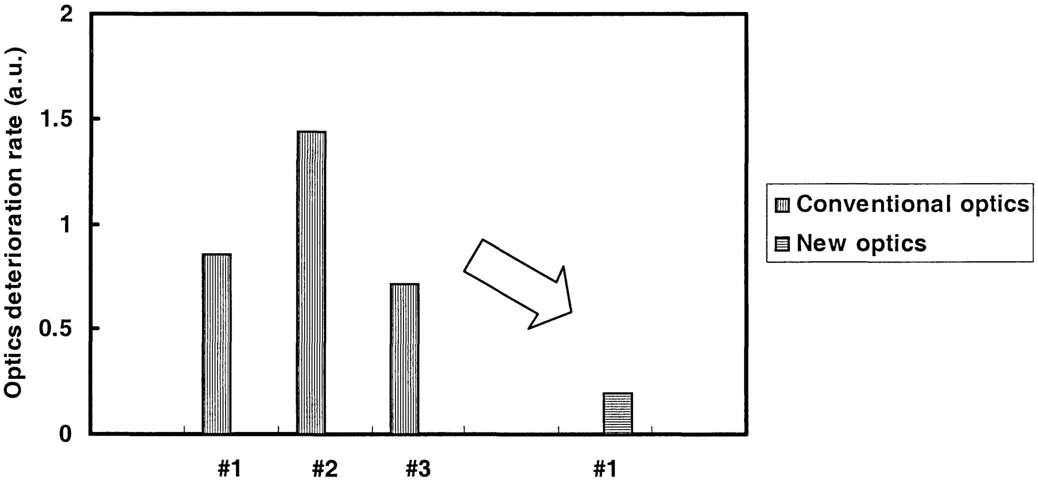

Fig. 2 Optics deterioration rate in conventional and new optics

3. LONG TERM STABILITY

3.1. Gas pressure and energy

We previously reported that our energy consumption method during the gas and module lifetime is to increase the gas pressure [5]. This is because the laser pulse energy increases with increasing the gas pressure. In addition, the gas-pressure operating range is wider than the high voltage operating range. In that sense, energy behavior dependency on gas pressure is very important for our energy gas control system. Figure 3 shows the gas pressure and operating voltage during the lifetime test. The operating pulse energy is 5 mJ at 4 kHz of about 70 % duty. The drastic gas pressure change is due to gas exchange. As shown in this figure, the gas pressure after gas exchange increased from below 2500 hPa to over 3000 hPa by 13 billion pulse operation. This is due to the module deterioration, such as chamber and line narrowing module. However, the operating gas pressure is still 3600 hPa in 13 billion pulses and it dose not reach the gas pressure limitation, which is 4000 hPa. Figure 4 shows the pulse energy dependency on gas pressure in initial, 6 and 13 billion pulses at constant high voltage. This pulse energy behavior is another expression of module deterioration and it was drastically reduced by a 13 billion operation. However, the pulse energy at 4000 hPa is still 11 mJ . This has the sufficient margin to 5 mJ operation.

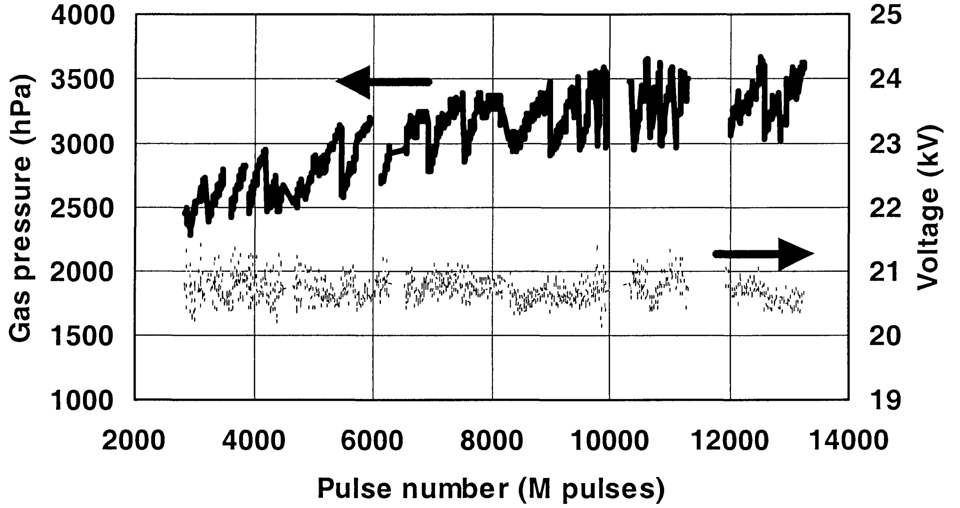

Fig. 3 Operational gas pressure and voltage during the lifetime test

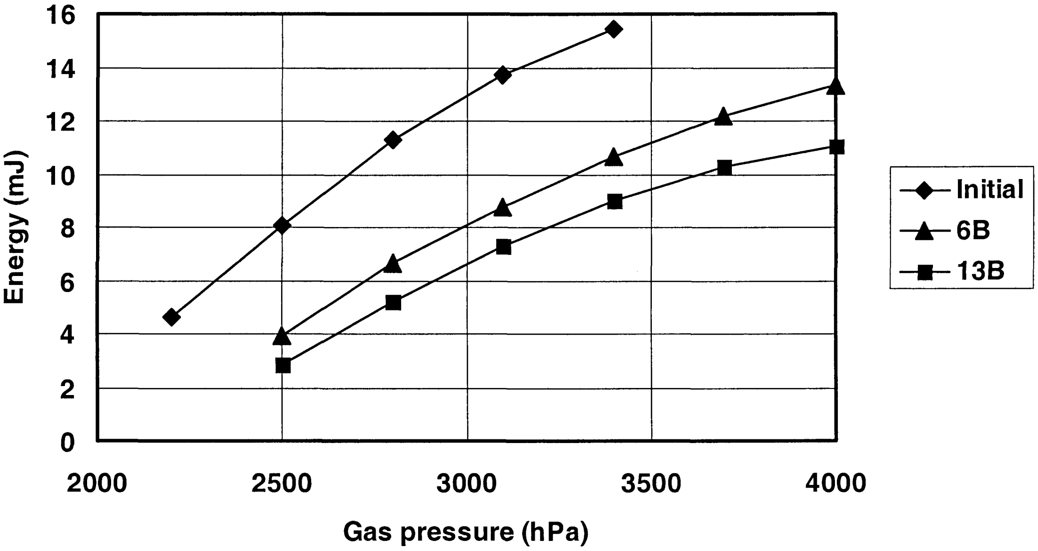

Fig. 4 Pulse energy dependency on gas pressure at initial, 6 and 13 billion pulses at constant voltage.

3.2. Spectrum

Figure 5 shows spectral profile at initial, 6 and 13 billion pulses, which were measured in fresh gas condition. This was measured with the HEXA (Holographic and echelle grating expander arrangement) spectrometer made by Gigaphoton [6]. The spectral FWHM and E95 increased from 0.11 and 0.19 pm to 0.15 pm and 0.30 pm by the lifetime. These are mainly due to the gas pressure increase. High gas pressure reduces the pulse duration and affects the spectrum performance. However, the spectrum performance has still large margin to the specification and there is no spectrum deterioration by line narrowing module deterioration.

Figure 6 shows spectral E95 dependency on repetition rates. Spectrum was measured at 50 Hz step. Spectrum performance to repetition rates has a spike structure at around 3400 Hz. This is due to build-up of the acoustic wave [7]. However there is no drastic change about this spike structure by a long-term operation.

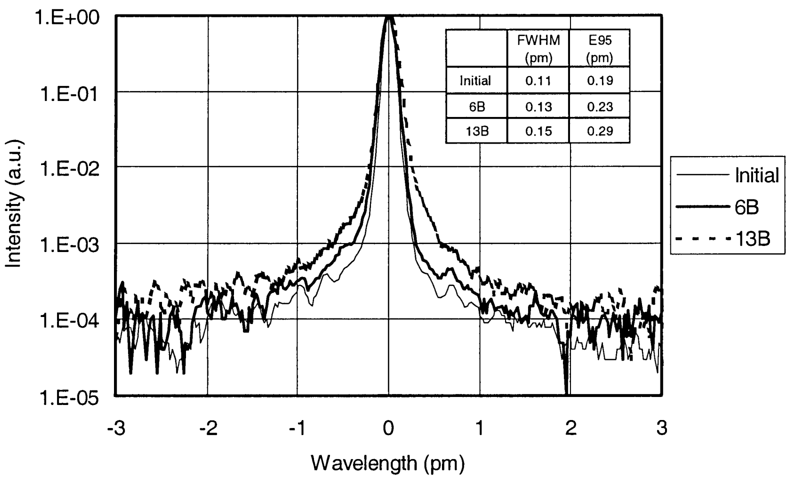

Fig. 5 Spectral profile at initial, 6 and 13 billion pulses

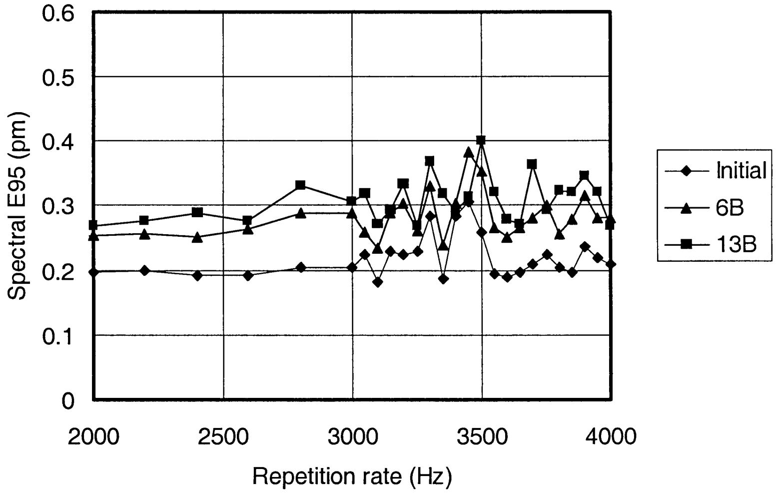

Fig. 6 Spectral E95 dependency on repetition rate at initial, 6 and 13 billion pulses

3.3 Wavelength stability

Wavelength stability is most important for high NA scanner as well as spectrum performance, in order to achieve high resolution and good CD control. High-speed actuator is applied to G42A to achieve fast and precise wavelength control. Figure 7 shows maximum and minimum values of the average wavelength error (50-pulse sliding window) during the lifetime test. Average wavelength error is at around +/- 0.01 pm and shows the very stable performance during over 10 billion pulses. It is well known that mechanical vibration affects the wavelength stability. From this result, there is no problem about mechanical vibration and this is mainly due to the magnetic bearing technology, which has no physical contacts.

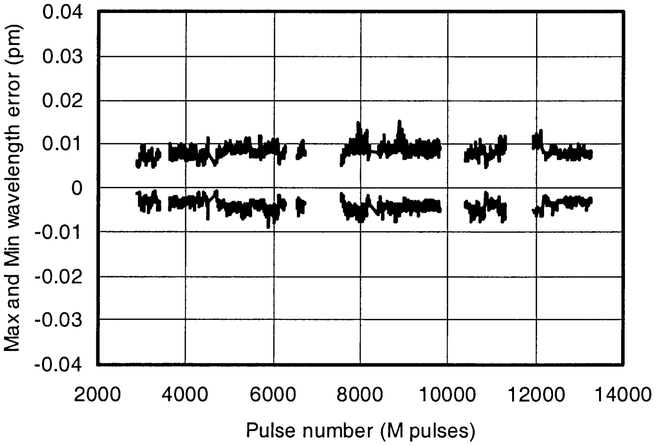

Fig. 7 Maximum and minimum wavelength error during the lifetime test

3. 4 Dose stability

Dose stability performance has a great impact for CD error. Figure 8 shows the maximum and minimum dose stability. Dose stability is below +/- 0.3 % (99.7% criteria) shows the very stable performance during over 10 billion pulses. Electrode ablation by discharge affects the dose stability performance. This stable performance is mainly achieved by G electrode technology.

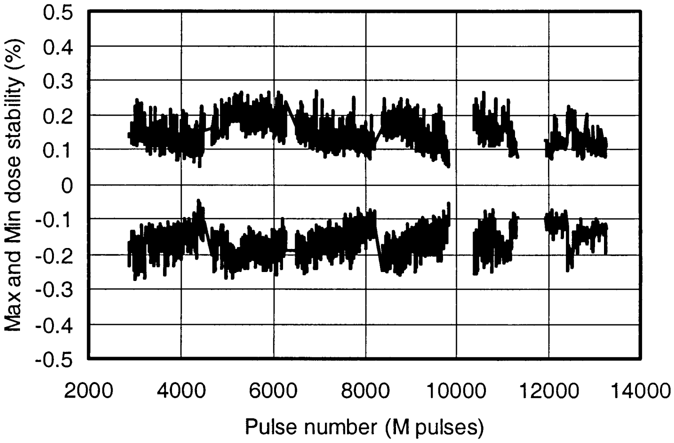

Fig. 8 Energy dose stability during the lifetime test

3. 5 Pulse duration

Pulse duration affects the lifetime of projection lens in scanner system. This means that long pulse operation is very important for total CoO in 193 nm lithography. In G42A, the long pulse technology is applied, which is based on only the discharge technology. Figure 9 shows pulse duration performance during the lifetime. Average pulse duration is about 40 ns during the lifetime. This performance is very useful to extends the lifetime of projection lens.

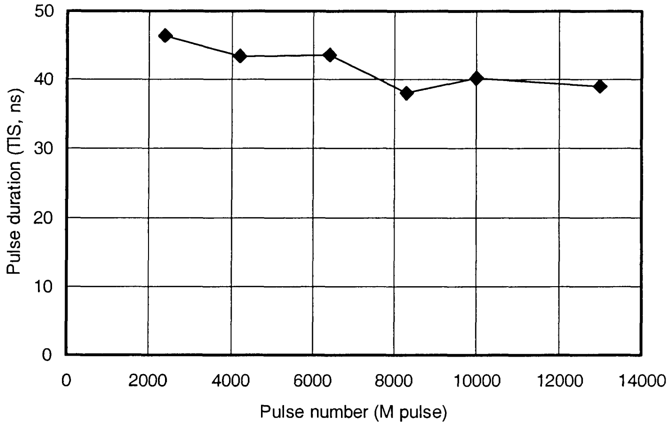

Fig. 9 Pulse duration during the lifetime test

4. RELIABILITY

The high reliable operation is very important and strongly required in mass production. Currently, a few tens of Gigaphoton 4 kHz ArF laser are operating in semiconductor manufactures. These lasers are showing the high reliable performance. Figure 10 shows the MTBF (mean time between failure and availability) in ten G41A. Average MTBF 4683 hours and availability is 99.7%. These performances are still improving and these high reliable performance are inherited to G42A. And also, G42A has some new technologies such as magnetic bearing and high durable optics. G42A will show the higher reliability in near future.

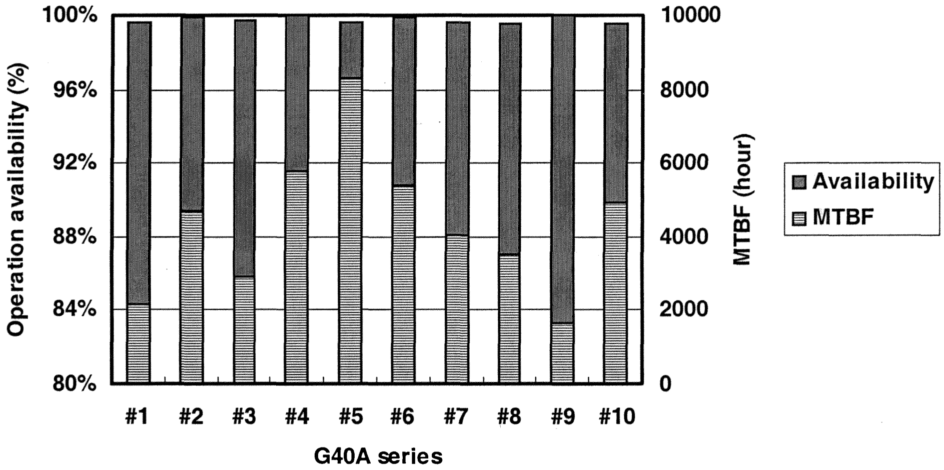

Fig. 10 MTBF and availability in G41A

5. SUMMARY

We have showed the long term stability of over 10 billion pulses in G42A, which is a 4-kHz ArF excimer laser with ultra-narrow bandwidth applicable to high-NA scanners. This laser produces an output power of 20 W at 4 kHz, with a dose stability of less than +/- 0.3 %, WL stability of less than +/- 0.03 pm, 0.30 pm (FWHM), and spectral purity of less than 0.75 pm (95%). We have also introduced the technologies for high reliability, which are applied to G42A. These are as follows.

- G-electrode technology
- Magnetic bearing technology
- High durable optics technology

These technologies will assure the high reliable operation during the module lifetime. And also, this high reliable performance will be inherited to the next generation ArF laser, model GT40A.

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