Ultra line-narrowed ArF excimer laser G42A for sub-90-nm lithography generation

Takashi Saito, Toru Suzuki, Masaya Yoshino, Osamu Wakabayashi*, Takashi Matsunaga, Junichi Fujimoto, Kouji Kakizaki, Taku Yamazaki, Toyoharu Inoue, Katsutomo Terashima, Tatsuo Enami, Hirotoshi Inoue, Akira Sumitani*, Hitoshi Tomaru, Hakaru Mizoguch

Gigaphoton Inc.
400 Yokokurashinden, Oyama-shi, Tochigi 323-8558, Japan
*Komatsu Ltd,
1200, Manda, Hiratsuka-shi, Kanagawa 254-8567, Japan

ABSTRACT

193-nm lithography is going to move from pre-production phase to mass production phase and its target node become narrowing from 90 nm to 65 nm. In these situations, the laser manufacture needs to provide the high durable ArF excimer laser, which has superior spectrum performance. Gigaphoton has already introduced 4 kHz ArF laser (model G41A) to 193-nm lithography market, which produce 20 W and spectrum bandwidth of 0.35 pm (FWHM). G41A has showed high reliability and long lifetime over 5 billion pulses. In this paper, we report on the 4 kHz ArF excimer laser for mass production, model G42A, which has 20 W, spectral bandwidth less than 0.3 pm (FWHM) and a spectral purity less than 0.75 pm (E95).

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

1. INTRODUCTION

In 2000, we have reported the development of a high reliable, 2 kHz ArF excimer laser, the model G20A, which has an output power of 10 W, a spectral bandwidth less than 0.5 pm (FWHM), and a chamber lifetime of 5 billion pulses [1]. Moreover, we introduced a 4 kHz ArF excimer laser, model G41A to semiconductor market as a light source for sub-100 nm lithography generation [2]. G41A applies the high repetition rate technology as well as a long lifetime technology inherited from G20A [3]. G41A is now showing the sufficient performance in the field.

The other hand, semiconductor market for 193-nm lithography is moving from pre-production phase to mass production phase. In this situation, the laser manufacture is requested to develop the laser, which has more high reliability and lower cost of ownership (CoO). And also, the target node in mass production phase goes from 90 nm to 65 nm. It is important to achieve the narrower spectrum and precise wavelength control to meet this target node. In order to meet these strict requirements of next generation 193-nm lithography, we developed G42A, based on the data of G41A. Main difference between G41A and G42A are a line narrowing module (LNM), discharge chamber and monitor module (MM). As we all know, these are main modules to decide the laser performance, such as lifetime and spectrum. We concentrated to improve these modules in G42A.

In this paper, we describe the performance of this laser, 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 describe the key performance to decide a lifetime.

2. FEATURES AND SPECIFICATINS

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Table 1 lists the main performance characteristics of the G41A and G42A, and the following technologies are used in the G42A to achieve the narrower spectral bandwidth and high reliability.

Table 1 Performance of ArF excimer laser

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

2.1 Line Narrowing Module (LNM)

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. Its configuration is almost same as G41A. However, to achieve narrower spectrum, the LNM for G42A uses 25 % higher dispersion optics, compared with that for G41A. This higher resolution optics assures the narrower spectrum during module lifetime. And also, coating of all optics is optimized to 193-nm wavelength because damage to the optics coating determines the LNM lifetime.
Wavelength stability is most important for high NA scanners as well as spectrum performance, in order to achieve high resolution and good CD control. High-speed actuator is applied to LNM in both G41A and G42A to achieve the fast and precise wavelength control. Wavelength is controlled in pulse-to-pulse level speed by this actuator.

2.2 Discharge chamber

In high repetition rate operation, acoustic wave strongly affect the laser performance, such as spectrum, wavelength stability and energy stability. Acoustic wave generates by discharge and spreads to various direction. Then it reflects from various structures inside laser chamber and it returns to discharge area. It induces the fluctuation of gas density and instability of discharge at specific frequency range of over 2 kHz. This gives impact to various laser performance at this range. We applied the acoustic wave damper to reduce the acoustic wave. Figure 1 shows gas density fluctuation with/without the damper, which was calculated from the acoustic wave simulation. Gas density variation becomes half level with acoustic wave damper. This technology is applied to both G41A and G42A to achieve stable operation in high repetition rate over 2 kHz.
Chamber lifetime is main factor to decide the cost of ownership (CoO) and low CoO is strongly hoped in production phase. G42A applies two technologies to achieve longer lifetime and high reliability. One is a magnetic bearing, which was already applied to 2 kHz KrF lasers, model G20K/G21K. We developed a high power magnetic bearing to apply a 4 kHz ArF excimer laser. Magnetic bearing has no physical contacts. This assures trouble free by bearing and high reliable operation during chamber lifetime. Two is G-electrodes, which was newly developed in Gigaphoton. 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 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 electrode ablation by discharge.

2.3 Monitor module

Bandwidth of a laser spectrum is generally specified in terms of FWHM. Moreover, almost all lasers use on-board monitoring system of FWHM to check the spectrum performance. The other hand, it was showed that the E95 metric is more suitable for bandwidth specification because imaging performance is very sensitive to spectral background intensity [5]. From this point of view, we developed the E95 on-board monitoring system. The etalon spectrometer has been used in various excimer lasers as on-board FWHM monitor. It is found that the bandwidth measured by the etalon spectrometer has a strong relationship with spectral purity, E95 by optimizing the etalon. Figure 2 shows the relationship between spectral purity and calculated bandwidth of MM after optimization. This figure includes 3000 data point. These data were calculated by convoluting actual spectrum with etalon's instrumental function. As shown in this figure, a MM bandwidth shows a strong relationship with a spectral purity E95. We can monitor the spectral purity E95 by using this relationship. This method is very simple and it is easy to apply the current system. G42A applies this technology.

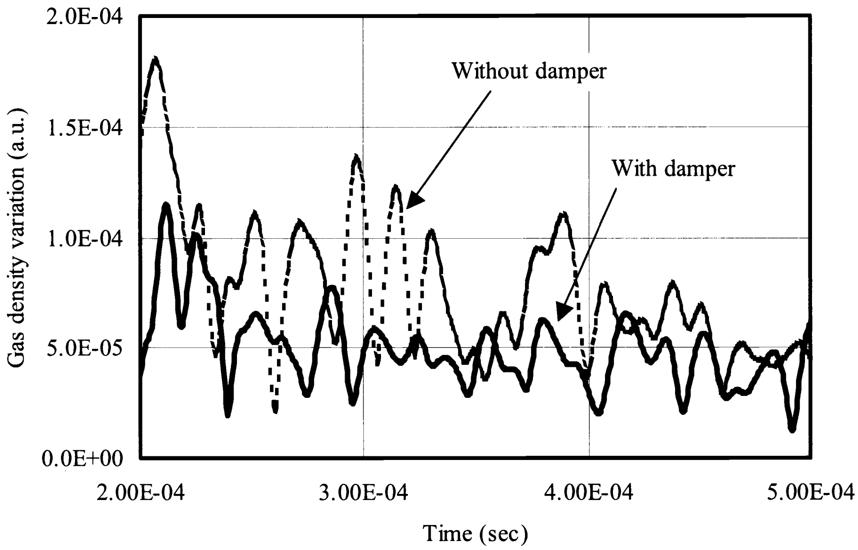

Fig. 1 Calculated gas density variation in the discharge region with and without acoustic wave damper.

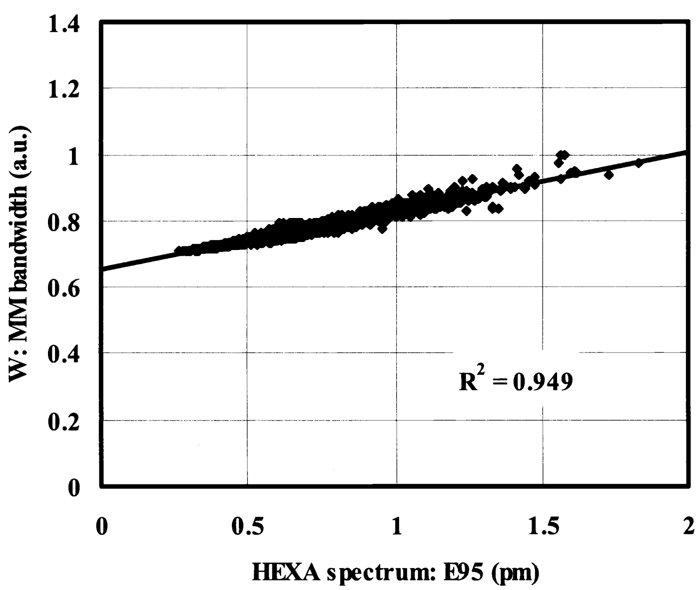

Fig. 2 The relationship between HEXA E95 and MM bandwidth.

3. PERFORMANCE

3.1. Spectral characteristics

Figure 3 shows initial spectral profile for the G42A, as measured by the HEXA (holographic and echelle grating expander arrangement) spectrometer developed by Gigaphoton. The slit function was 0.1 pm for FWHM, and this was measured by using a 193-nm coherent light source [6]. The spectral bandwidth (FWHM) was measured as 0.17 pm with convolution and 0.12 pm with de-convolution. The spectral purity for 95% energy was measured as 0.95 pm with convolution and 0.20 pm with de-convolution. The initial spectrum is sufficiently narrow for next 193-nm lithography. Figure 4 shows spectrum dependency on repetition rates. Spectrum was measure at every 50 Hz step in over 2 kHz. Spectrum performance has a spike structure at around 3400 Hz. This is due to build-up of the acoustic wave [7]. However, spectrum purity is below 0.3 pm in almost all repetition rate and initial condition. This is due to the newly developed high-resolution LNM and acoustic wave damper.

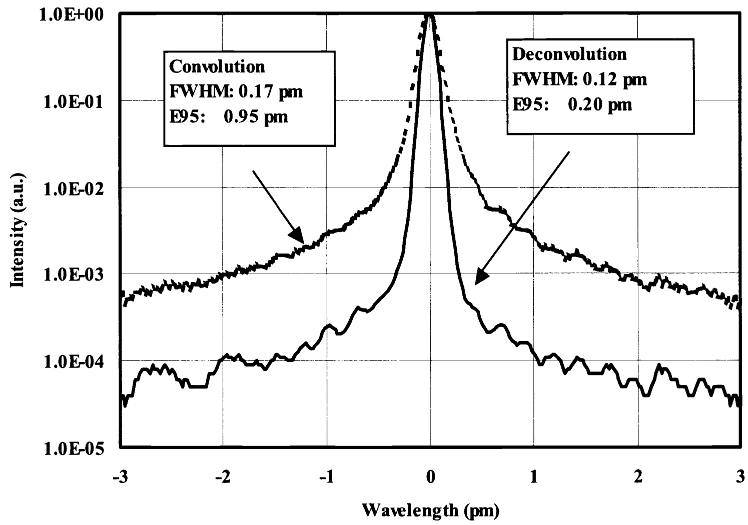

Fig. 3 Spectra for the whole laser beams measured by a HEXA spectrometer

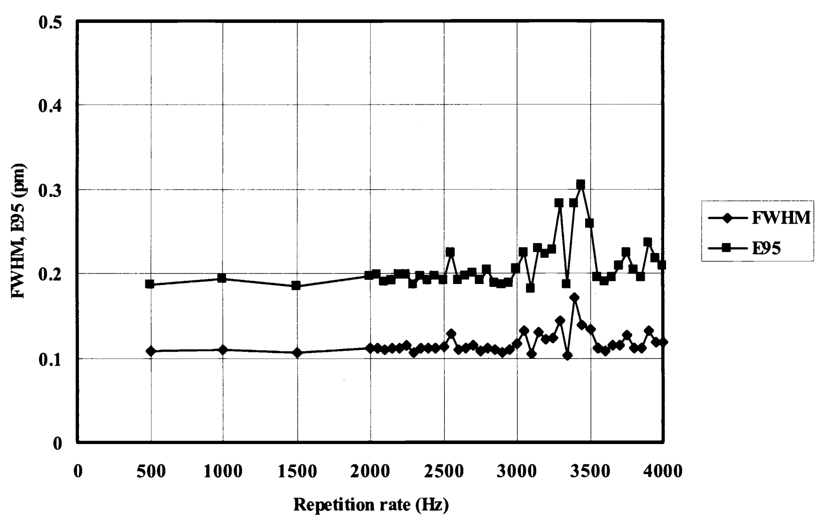

Fig. 4 Spectrum dependency on repetition rate.

3.2. Wavelength stability

Figure 5 shows average wavelength error dependency on repetition rate in short term operation. The data was measured at 20 Hz step. Figure 6 shows maximum and minimum values of the averaged wavelength error (50-pulse window) and wavelength stability sigma. Average wavelength error is below +/- 0.01 pm and wavelength stability sigma is below 0.03 pm in all range. Acoustic wave slightly affects the wavelength performance. However this influence to wavelength stability is small by acoustic wave damper and high seed actuator can compensate sufficiently its influence.

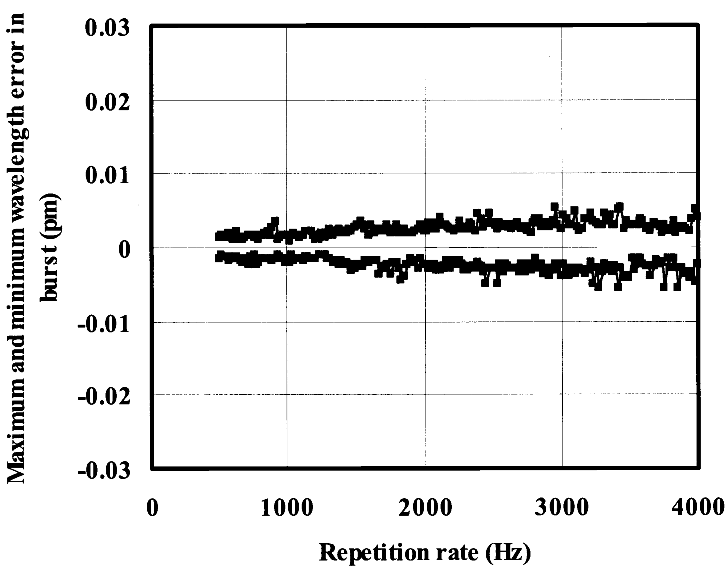

Fig. 5 Average wavelength stability dependency on repetition rate (50 pulse window)

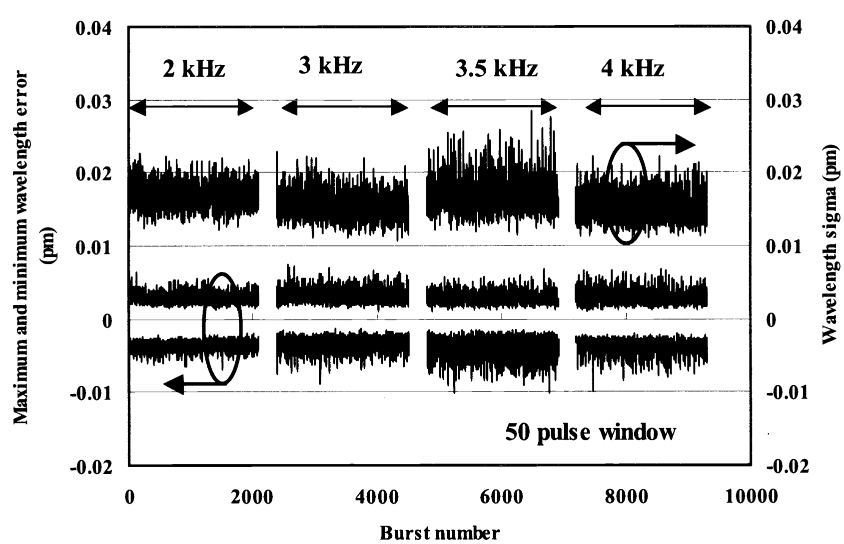

Fig. 6 Average wavelength stability and wavelength stability sigma in middle term operation (50 pulse window)

3.3 Energy stability

Figure 7 shows energy stability as a function of repetition rate at 5-mJ constant energy. Data was measured at 20 Hz step. Figure 8 shows the energy dose error in middle term operation. Energy stability sigma is very stable in all repetition range. This performance is very important for lithography applications. And also, high-energy dose stability is required to good CD control. G42A can meet the specification of below 0.3 % (99.7% criteria) in all repetition range.

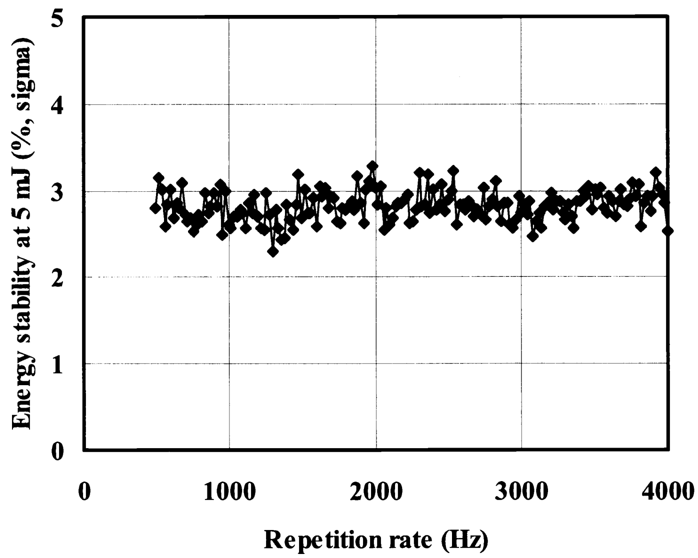

Fig. 7 Energy stability (sigma) as a function of repetition rate

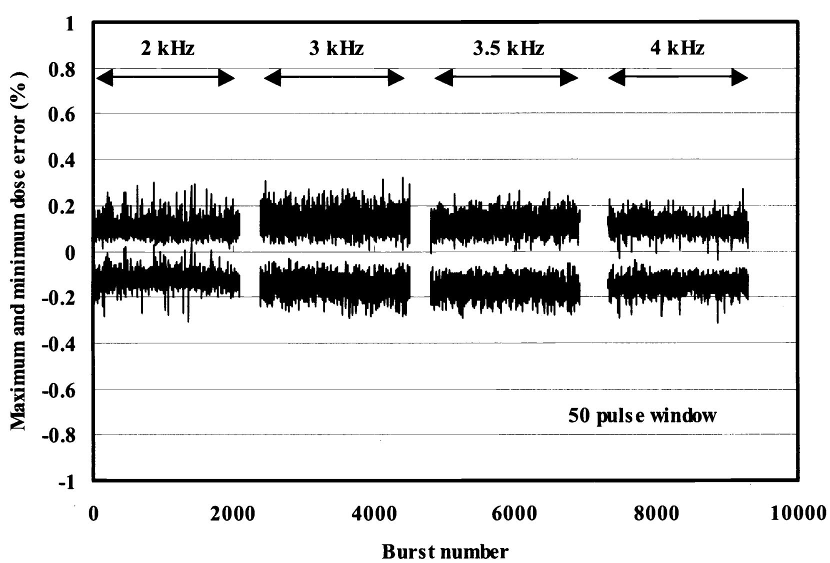

Fig. 8 Energy dose stability in middle term operation

3. 4 Gas pressure performance

We previously reported that our energy consumption method during the chamber lifetime was to increase the gas pressure [8]. This is because the laser pulse energy increases with increasing 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. And, spectrum performance dependency on gas pressure is also important because spectrum increases with increasing the gas pressure. Figure 8 shows the energy and spectrum dependency on gas pressure at a 4 kHz operation. As shown in this figure, G42A produces over 15 mJ, which is 3 times larger than that of target energy of 5 mJ. The energy decrease per billion is sufficiently lower than 1 mJ. This means that G42A has sufficient performance to achieve the module lifetime of over 8 billion pulses. And also, the spectrum performance strongly depends on gas pressure. However, G42A shows sufficient spectrum performance even in high gas pressure of over 3000 hPa and high energy of over 15 mJ.

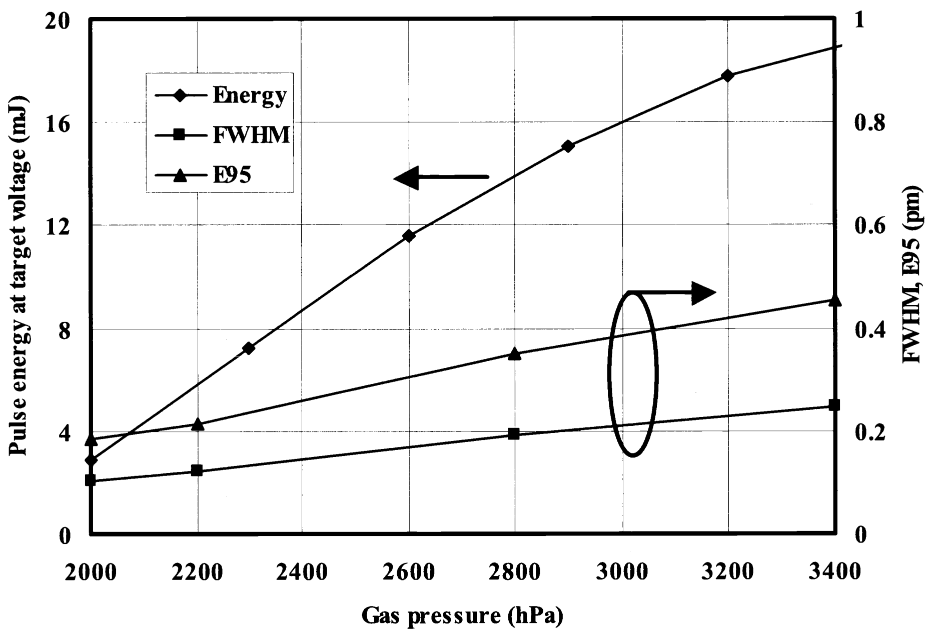

Fig. 9 Gas pressure performance

4. COST OF OPERATION

As noted previously, ArF excimer lasers for mass production are required to operate under high–performance conditions, such as high repetition rate and narrow spectral bandwidth, and with reduced CoO. In KrF excimer laser technology, a 30% reduction in operation cost has been achieved every year. The G42A core technologies show the possibility of a drastic reduction in ArF excimer laser operation cost. Target maintenance intervals for the G42A are listed in Table 2.

Table 2 Target maintenance intervals for core modules of the ArF laser

Items	Target maintenance interval	
	2003/1Q	2004/1Q
Gas lifetime	>100 million	>100 million
Laser chamber module	>8 billion	>10 billion
Line narrowing module	>8 billion	>10 billion
Monitor module	>10 billion	>10 billion
Front mirror	>10 billion	>10 billion

5. SUMMARY

We have introduced a mass-production type 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 reported about the new technologies, which are applied to G42A. These are as follows.
- Ultra high-resolution technology
- Acoustic wave damper technology
- G-electrode and magnetic bearing technology
- E95 monitoring technology

These technologies will assure the high reliable operation during the module lifetime.

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