High-NA high-throughput scanner compatible 2 kHz KrF excimer laser for DUV lithography

Hiroaki Nakarai, Naoto Hisanaga, Natsushi Suzuki, Takashi Matsunaga, Takeshi Asayama, Jun Akita, Toru Igarashi, Tatsuya Ariga, Satoru Bushida, Tatsuo Enami, Ryoichi Nodomi, Yuichi Takabayashi, Shoichi Sakanishi, Takashi Suzuki, Hitoshi Tomaru, Kiyoharu Nakao

Excimer Laser Dept., Electronics Div.,Komatsu Ltd.,
400 Yokokura-shinden, Oyama, Tochigi 323-8559, Japan

ABSTRACT

We have succeeded in the development of an excimer laser with ultra narrow bandwidth applicable to high N.A. scanners targeting on the 0.13μm-design rule. Key word of our solution for 0.13μm-design rule was "extended technologies of currently available KrF excimer laser unit (model G20K)". As the result we could shorten development time remarkably. The narrower the laser spectrum, the less the influence of chromatic aberration on exposure projection lens; this is a well-known fact. We have developed the technologies to achieve spectral bandwidth less than 0.5pm, 20% narrower than our current model G20K. In order to attain this number, the major design change was made on line narrowing module, which was redesigned to minimize the dispersion of wavelength element. In addition gas condition was fine-tuned for the new line narrowing module. Integrated energy stability has been improved within +/-0.35% with 35pulses window by the introduction of a high efficiency pulse power module and a faster gas circulation system.

The rest of oscillation performances and durability equate with the base model G20K. The intelligent gas control system extended gas exchange interval up to 200 million pulses or 7 days. The G20K already passed through 10 billion-pulse test. Total energy loss was within 4mJ which is small enough to be compensated by gas injection and voltage change; it is a unique compensation system of Komatsu.

Keywords: KrF, excimer laser, line narrowing, pulse power module, gas circulation system, gas control

1. INTRODUCTION

In the semiconductor industry, the lithography technology, like higher N.A lens and high speed scanning system, has alternately made progress for more microscopic pattern and higher throughput. Of course we, the excimer laser supplier, have corresponded to them by making wavelength bandwidth narrower and increasing repetition rate, too.

Table 1 shows the course of the laser specification. Recently this cycle has accelerated, so we have to design the new machine fitting to at least two phases in order to shorten developing term. Komatsu's KrF excimer laser, named G20K[1] , is the base machine for 2kHz operation, with spectral bandwidth less than 0.6pm and integrated energy stability within +/-0.4%. The G20K has already been working on the mass production lines of the world.

Figure 1 shows the construction of the laser. Krypton gas and Fluorine gas is introduced to the laser chamber through the gas delivery module. And used gas is exhausted to the external ventilation system through the fluorine trap. The high voltage is supplied to the electrode by the pulse power module (PPM). Enclosed gas is excited between electrodes at discharge, then the excimer light is generated. This light makes a round trip between the front mirror and the line narrowing module (LNM). The LNM reflects selected wavelength, but it has a width. We redesigned the LNM to narrow this width. A part of the beam goes out, another part of the beam returns back at the front mirror. Residual particles after discharge are circulated with the cross flow fan (CFF). We added the improvement to the gas circulation system. The energy, the wavelength, and the spectral bandwidth are measured at the monitor module (MM). This sends the data to the controller, which orders each module to keep good performance. Now, we have developed the upper grade machine "G21K" which has higher performance. The spectral bandwidth is less than 0.5pm, and the spectral purity (95% energy concentration) less than

1.4pm. The integrated energy stability is within +/-0.35%, this value is achieved with only 35pulses. These performances are obtained by upgrade kits designed compatible with the base machine.

Here we introduce about the recent technical progress, line narrowing technology in the second section, discharge technology in the third section. By using these technologies, we could reach the target performance. We report about short term (about one week) and long term system performance in the fourth section. Lastly we refer to the CoO.

Table 1. The coarse of laser specification

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Model name	G6			G7		G10K		G20K	G21K
Repetition.rate	600Hz					1000Hz		2000Hz	
Bandwidth	1.2pm								
			0.8pm						
							0.6pm		
									0.5pm

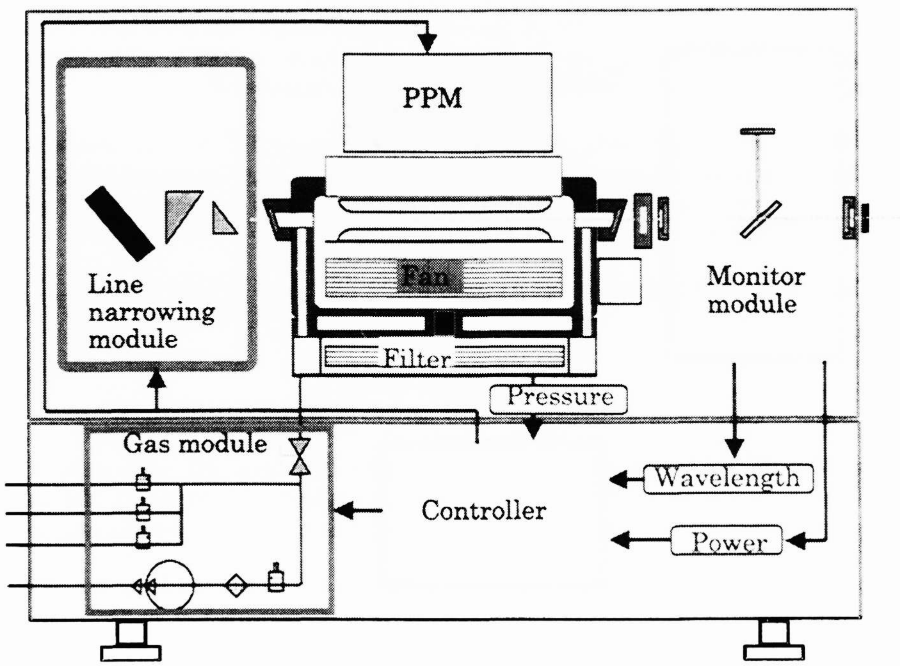

Figure 1. The construction of Komatsu's excimer laser

2. ULTRA LINE NARROWING TECHNOLOGY

In order to correspond to the 0.13μm design rule, it is necessary that the spectral bandwidth is narrowed less than 0.5pm. For the excimer laser in lithography, it is the popular method that the partial mirror and the LNM are assembled into the resonator. Using the LNM, a wide band incident ray is reflected to the different direction according to the wavelength. Only the ray whose direction agrees with incident direction is able to resonate with front mirror, so its wavelength is determined. Its bandwidth depends on a light and dark interference condition, defined as the resolution. The higher resolution of LNM can restrict the resonance wavelength, so the spectral bandwidth becomes narrower. We tried to make the resolution as high as possible in a limited space. Though the spectral bandwidth depends on not only the module resolution but also the aperture size or divergence and the number of round trips, increasing the module resolution is the only way without changing the other beam dimension. In addition the spectral purity seriously depends on the resolution of the LNM. We improved the resolution to 1.4 times as high as the conventional type.

Figure 2 shows the spectral profile after de-convolution processing, comparing it with the conventional type. We attain to 0.27pm spectral bandwidth and 1.11pm spectral purity. It is obvious that the far components from center wavelength on the bottom are remarkably reduced. So we could prove that newly designed LNM contributed to the improvement of the spectral purity. And we confirmed that beam dimension, except for spectral quality, beam profile and beam divergence, has little change. These data, measured by photo diode array, are shown in Figure 3 and Figure 4. The compatibility also could be confirmed by these results. It is only negative but unimportant point that the output energy was less about 1mJ than conventional type.

Figure 5 shows the relationship between the spectral bandwidth and purity. This data is acquired by changing the fluorine concentration. Very good correlation is obtained. Though it is difficult to calculate the spectral purity every pulse at real time, by controlling the spectral bandwidth the laser system can keep spectral purity fixed, too. The durability of the optical elements in the LNM had already been evaluated during 15 Billion pulses. Total transmittance loss was less than 6.7% as compared with initial.

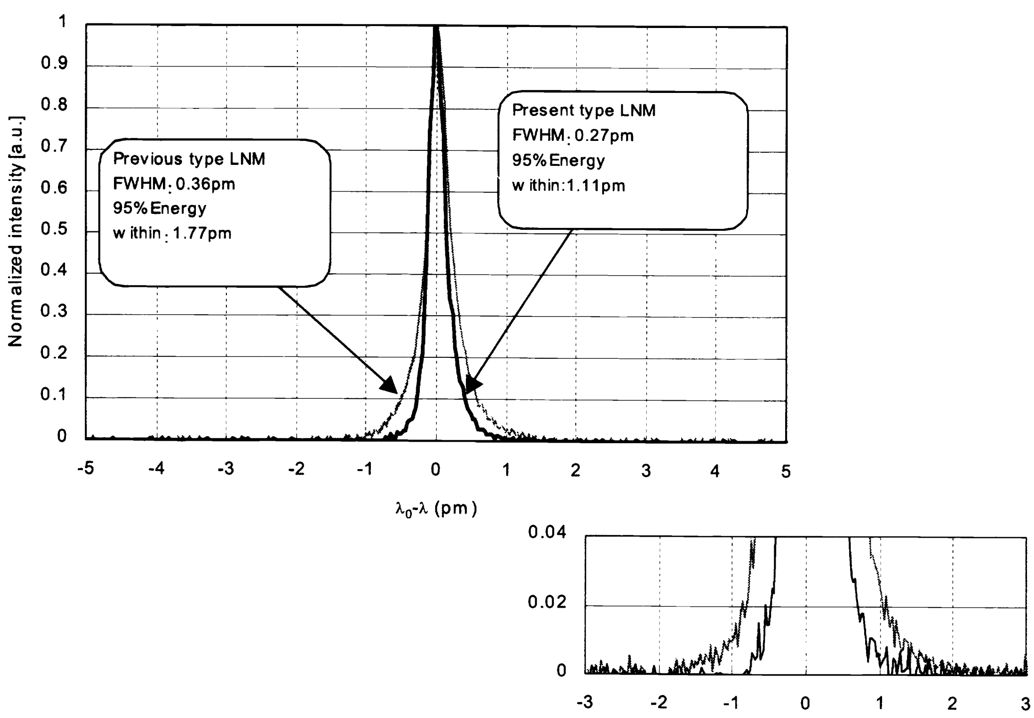

Figure 2. Spectral profile with new line narrowing module

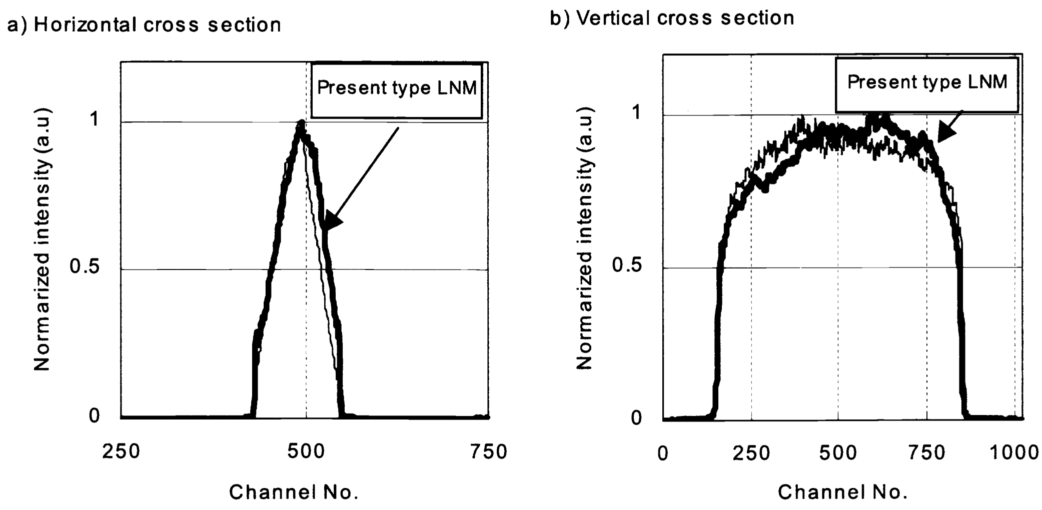

Figure 3. Beam profile: a) horizontal cross section, b) vertical cross section

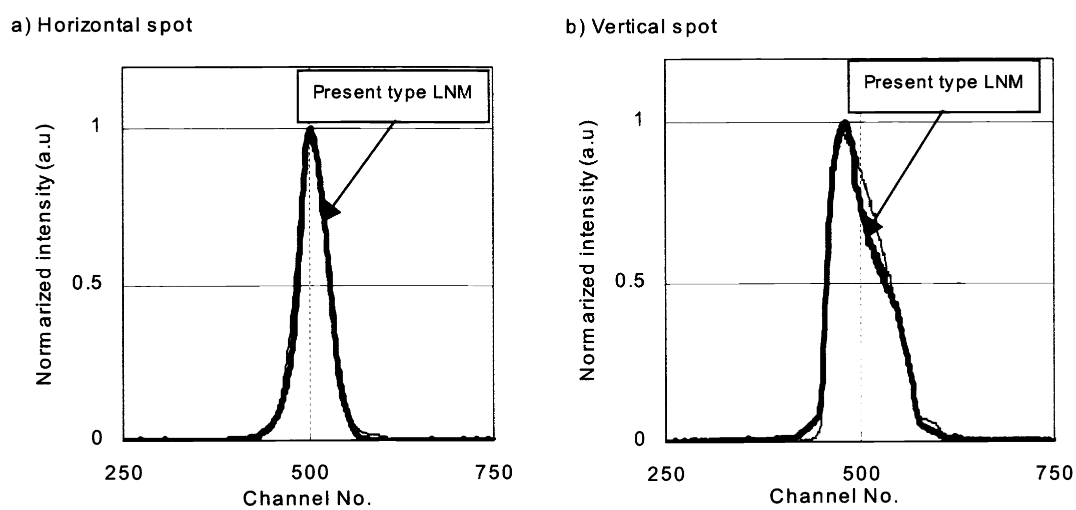

Figure 4. Beam divergence : a) horizontal cross section, b) vertical cross section

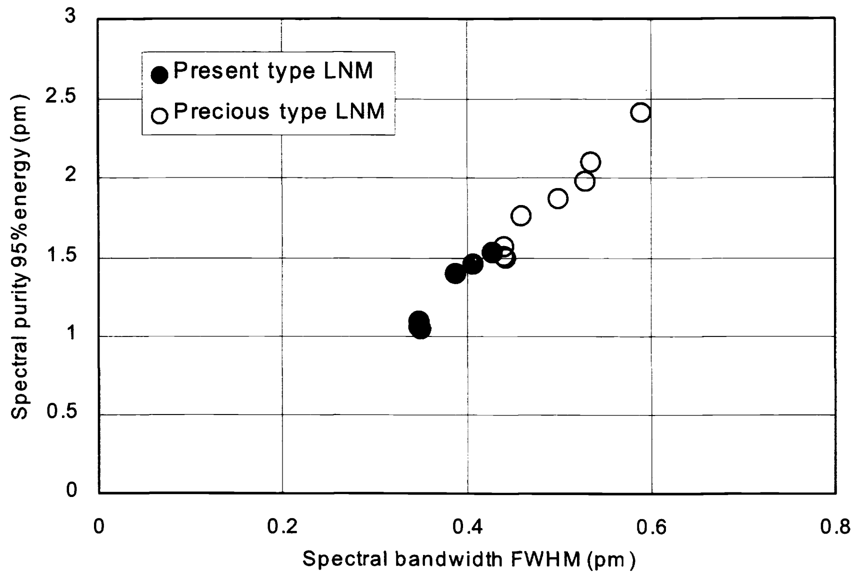

Figure 5. The relationship between spectral bandwidth and purity

3. DISCHARGE TECHNOLOGY

Not only increasing the repetition rate of oscillation but also an improvement of energy stability contributes to high throughput. Because it is possible to decrease the necessary pulses for averaging dosage on the wafer. For the scanner in particular it is important to evaluate the integrated energy with running window. We had attained this performance by improvement of the gas circulation system that removes the residual particle after discharge. We have had two approaches.

Firstly, we tried to decrease the amount of residual particles. After the main discharge, a lot of surplus energy caused discharges like ark again. This type discharge caused big damage to the electrodes because of partial constriction. In order to avoid this, it is effective to absorb the surplus energy into the pulse power circuit, not to release it into the discharge space.

Secondly, we tried to restrain the gas flow velocity disturbance between the electrodes. In order to average the dosage with small pulses, it is necessary to avoid the instantaneous energy down, even if only 10%. It is well known that this is caused by instantaneous gas flow velocity down between the electrodes. A primary factor is whirl behind the obstruction in gas flow course. We practiced the gas flow simulation and examination and succeeded in reducing the disturbance of the gas flow velocity without unbalance of the electrical parameter for discharge circuit. Figure 6 shows the comparison of gas flow velocity at the center of discharge space and disturbance between before and after improvement. It is obvious that there is no instantaneous circulation velocity down after improvement.

By these improvements, we could reach a target, integrated energy stability within +/- 0.35% with 35pulses. The result is shown in Figure 7. This figure shows the distribution of the integrated energy stability, maximum and minimum plots of 2000 burst. The worst data was +/- 0.27% with 35pulse running window.

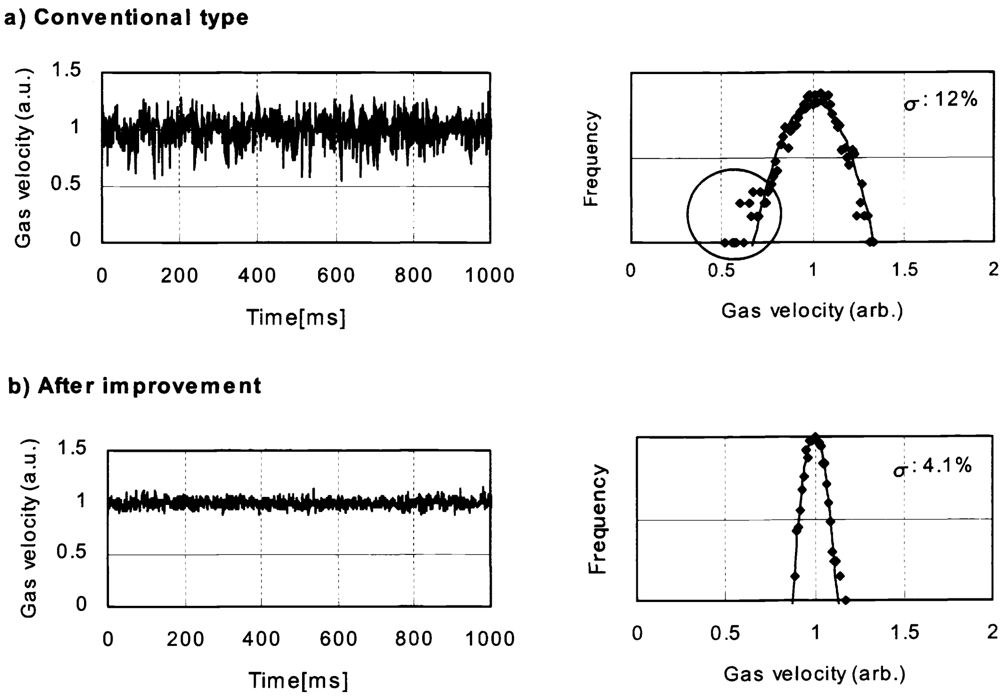

Figure 6. The effect of reducing gas flow disturbance;

a) before improvement and distribution, b) after improvement

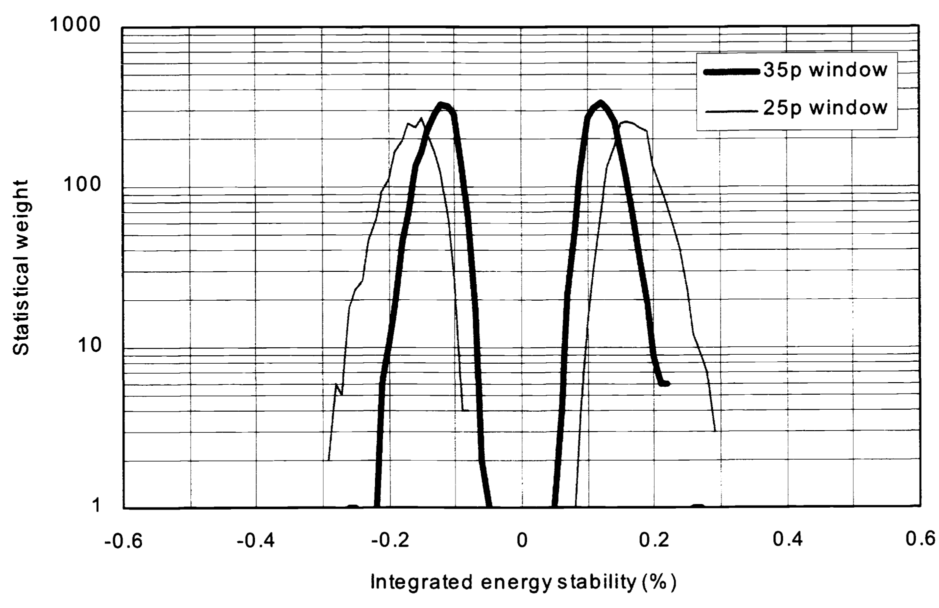

Figure 7. Integrated energy stability distribution

4. SYSTEM PERFORMANCE

The target performances of G20K and G21K are shown in Table 2. In order to maintain the laser's performance for a long time, our laser has some control systems. One of them is the gas control system. This is designed with two concepts; 1) automatic (except for total gas replacement every week) without interrupting the wafer exposure process, 2) energy compensation method to elongate chamber life as long as possible. Energy decline factors are degradation of electrodes and optics elements, impurities generation in the laser chamber, and fluorine consumption by reaction with electrode at discharge. Against these, energy can be compensated by fresh gas injection or high voltage rise. Figure 8 shows contour lines of energy, according to gas pressure and high voltage.

For a week's operation we have to be careful with impurities rather than the degradation. In order to keep the impurity concentration low enough, partial gas replacement is available. The conventional way is that when the energy efficiency decreases, usually indicated by high voltage rise, a part of the used gas is replaced by fresh gas, then the efficiency recovers to halfway. However, as we expressed at the head of this section, we have to execute this without interrupting the exposure process. Our new way is that when energy efficiency increases by continuous micro injection of Krypton and Fluorine gas against a bad influence of impurities, usually indicated by high voltage drop, a small part of the used gas is exhausted. As exhaustion is needed only when the efficiency is high enough, we don't have to interrupt the wafer exposure process. Figure10 shows the trend data of gas pressure and high voltage and other performances through 7days, with 200Million pulses. It is understood that micro-injection and a small amount exhaust are well-balanced.

On the other hand, it is necessary to reduce the degradation of electrodes to elongate the chamber life. In addition the dynamic range by gas pressure is wider than by high voltage. So we decided to use gas pressure rise without high voltage rise for energy compensation. Of course, for quick and fine energy tuning each pulse, high voltage adjustment is used. Every total gas replacement, the chamber gas pressure increases higher and higher by automatic pre-oscillation, against high voltage is nearly constant. Therefore chamber gas pressure indicates the extent of the degradation. We had already completed the durability test for 11Billion pulses on G20K, and analyzed the consumable parts. We show the result in figure 10, trend of chamber gas pressure and high voltage and other performances at total gas replacement.

Table 2. Target performance of G20K and G21K

Item	**Performance**	
	G20K	**G21K**
Repetition rate	**1-2000Hz**	**1-2000Hz**
Average power	**20W**	**20W**
Pulse energy	**10mJ**	**10mJ**
Integrated energy stability	**<+/-0.4% (40pulse)**	**<+/-0.35% (35pulse)**
Central wavelength	**248nm**	**248nm**
Wavelength stability	**<+/-0.1pm**	**<+/-0.1pm**
Spectral bandwidth	**<0.6pm(FWHM)**	**<0.5pm(FWHM)**
Spectral purity	**<2.0pm (95% energy concentration)**	**<1.4pm (95% energy concentration)**

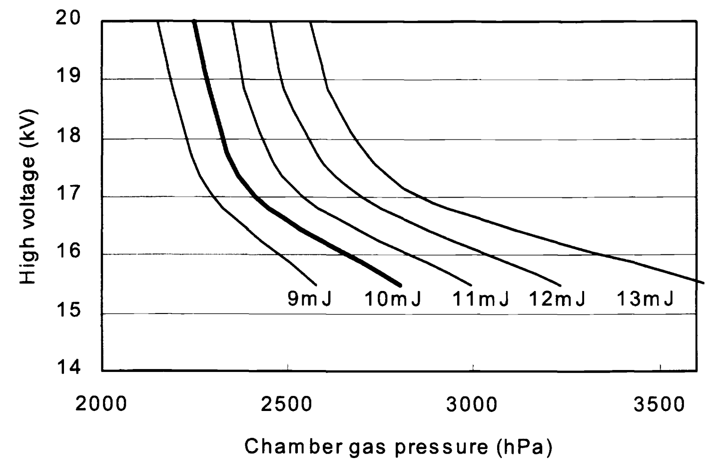

Figure 8. Energy contour lines

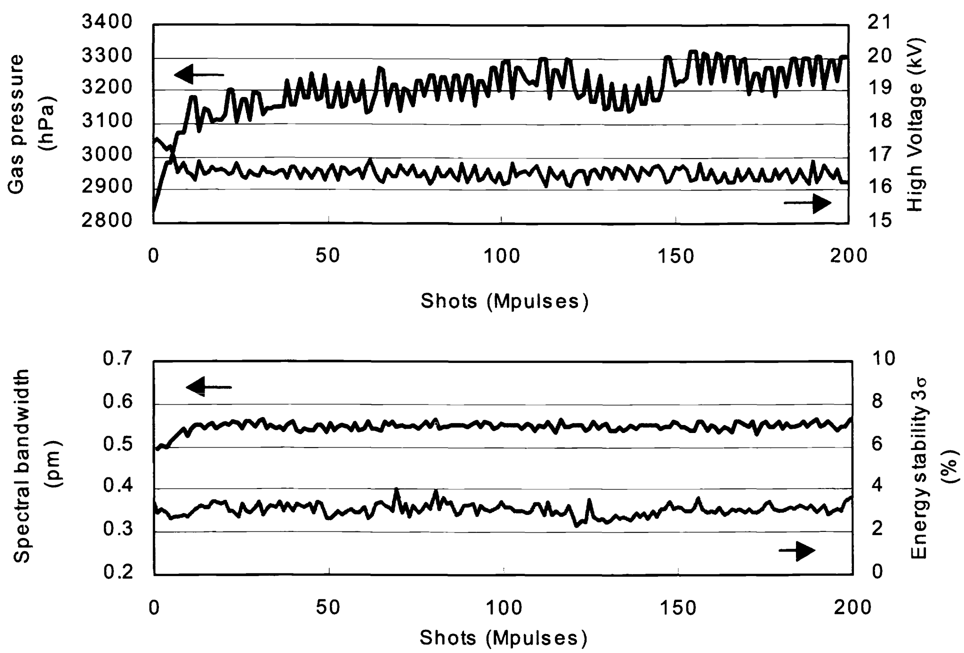

Figure 9 Laser performance in gas life operation

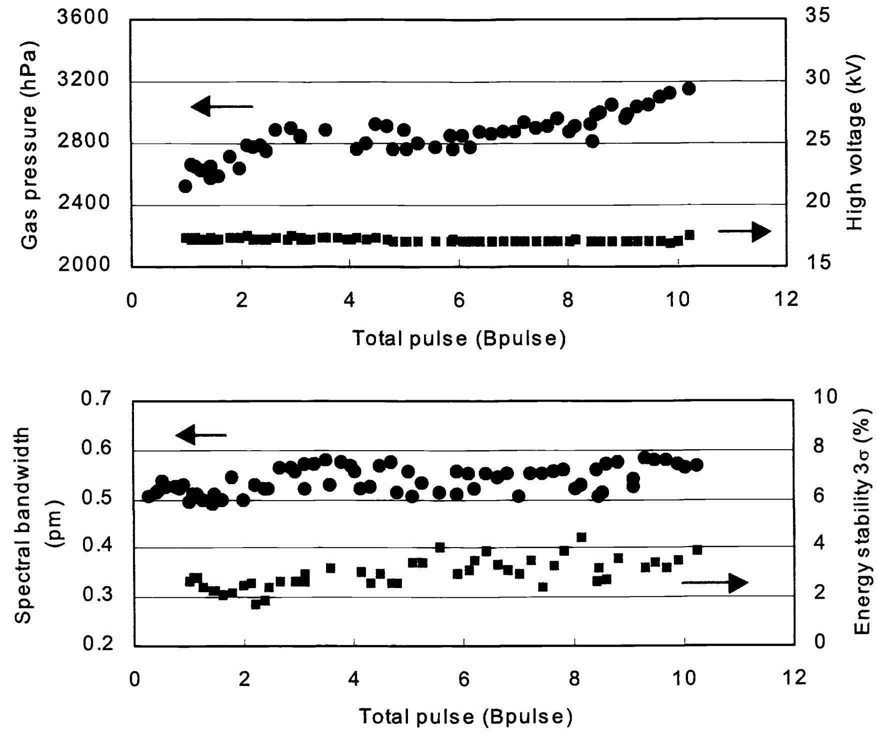

Figure 10 Laser performance in durability test

5. COO

The total CoO of the lithography process is very expensive. From the excimer laser maker's point of view, we can contribute to reducing it by elongating module maintenance intervals and enhancing reliability. Above all, a laser chamber accounts for about 50 % of all costs, this value is defined as running cost per 1 billion pulses. As we described in previous section, our development has been always focused to the consumable element, electrodes and optical parts and so on. Target maintenance intervals of G20K and G21K are shown in Table 3.

Table 3 Target maintenance intervals

Item	**Target intervals of G20K and G21K**	
	2000.Q1	**2000.Q3**
Gas life time	**>200Million pulses/ 7days**	**>200Million pulses/ 7days**
Window	**>5Billion pulses**	**>5Billion pulses**
Laser chamber module	**>10Billion pulses**	**>12Bilion pulses**
Line narrowing module	**>10Billion pulses**	**>15Bilion pulses**
Monitor module	**>10Bilion pulses**	**>15Bilion pulses**
Front mirror	**>10Bilion pulses**	**>15Bilion pulses**

6. SUMMARY

Our continuous improvement has corresponded to progress in lithography process. The newly developed KrF excimer laser machine G21K has enough performance, spectrum bandwidth less than 0.5pm and integrated energy stability within +/- 0.35%, so it will be available for 0.13μm design rule. This machine pioneers to extend the generation of the lithography tool with KrF excimer. On the other hand, ArF excimer laser, its wavelength is 193nm, has just been prepared for mass production by further technology. Therefore, these two types of lasers will have to compete against each other on common technical issues.

7. REFERENCE

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