Progress of Excimer Laser Technologies

Dr. Hakaru Mizoguchi
Laser Research Department, Research Division, Komatsu Ltd.
1200 Manda, Hiratsuka-shi, Kanagawa Japan

Biography

Dr. Hakaru Mizoguchi is General Maneger of Laser Research Department in Central Research Center. He has been working in the field of excimer laser for micro-lithography since 1990. He has worked in Komatu Ltd. since 1982 and has developed high power CO2 laser until 1987. After that he has been a visiting researcher in Max-Plank-Institute in Goettingen, Germany from 1988 to 1990 by scholorship of Komatsu Ltd. He obtained doctor degree in laser engineering from Kyushu University in 1994. He is member of the Japan Society of Applied Physics and the Laser Society of Japan.

Abstract:

Resent technical progress of laser technologies for microlithography is discussed here. The performance of highly durable 2kHz KrF excimer laser, and next generation light source of 2kHz ArF excimer laser, which are realized by the new technologies, are discribed. We also discuss about its impact on microlithography. Further more F2 laser development program in Japan and its latest result which is achieved by Komatsu on fundation of MITI are reported.

Data:

1. Introduction

The micro-lithography technology has rushed in the era of KrF excimer laser lithography through the era of a g-line, i-line of mercury lamps. KrF excimer laser steppers are installed voluminously to semiconductor mass production factories which require design rule less than 0.3.m. Design rule subsequent to 64Mbit DRAM is already a real situation. At present the operation in the volume as large as 1000 units in accumulated number in the world. KrF excimer laser stepper is now main actor in 256Mbit DRAM manufacturing. Also 300mm silicon wafer is becoming standard of the process. And productivity and CoO becomes critical issues of KrF excimer laser stepper. On one hand, ArF excimer lithography is being advanced by combined effort by semiconductor manufacturers and equipment makers. ArF excimer laser lithography has become most

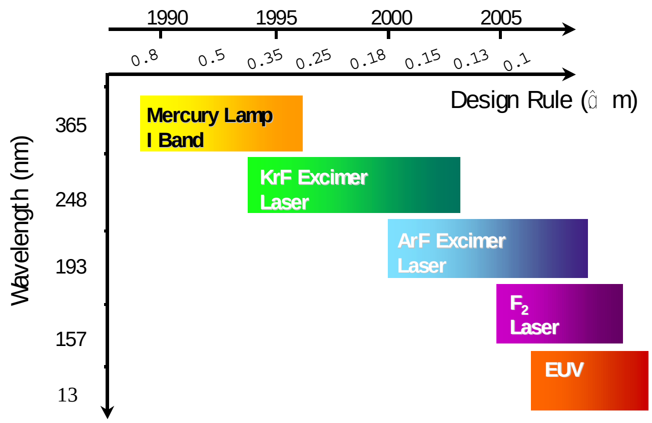


Figure 1. Road map of optical Lithography

probable candidate of lithography technology subsequent to 4Gbit DRAM which requires 0.13-0.10.m or less design rule. Furthermore for sub-0.10.m design rule region, F2 laser, electron beam projection, and

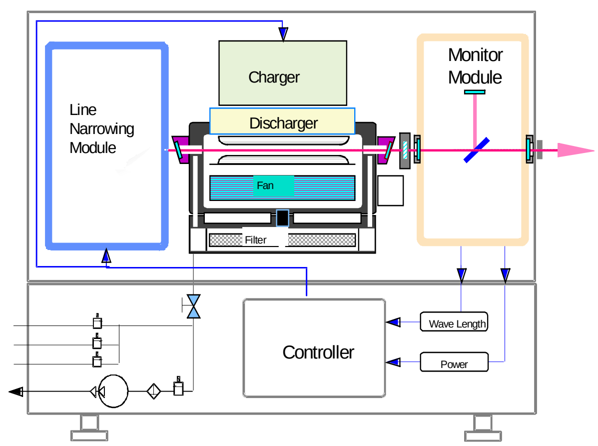


Figure 2. Schematic diagram of excimer laser

EUV have been examined at several organizations (Figure 1).

This manuscript reports about the resent technical progress of laser technologies. And describes about the performance of highly durable 2kHz KrF excimer laser, and next generation light source of 2kHz ArF excimer laser which are realized by the new technologies. And discuss about its impact on microlithography. Also introduces F2 laser development program in Japan and its preliminary result, which is done by Komatsu funded by MITI.

2. Requirement for the laser light source and progress of performance

The constitution of laser light source is shown in figure 2. The excimer laser is consisting of monitor module to monitor laser light, line narrowing module which narrows band oscillation, and pulse power module to produce a high speed electrical pulse to enable an electric discharge for producing the laser gain in the chamber. We will discuss about technical points of these modules.

The requirement of laser source is as follows;

(1) Wavelength: Shorter wavelength is essential to realize higher resolution of pattern image. KrF (248 nm) > ArF (193 nm) > F2 (157 nm)

(2) Spectral bandwidth: The demand for higher NA lens of stepper that aimed for a resolution improvement is increasing. High NA lens requires smaller spectrum bandwidth.

(1) Output power: The demand of higher productive stepper requires higher output power laser.

(2) Cost of Ownership: CoO (Cost of Operation) is related closely to a reliability / durability of a laser device. Longer maintenance interval is very important to realize low maintenance cost.

Corresponding to these points, the performance of laser source has been continuously improved. Table 1 shows past progress and future road map of laser source of Komatsu lasers.

3. Resent Technical Progress of Laser Technology [1)]

Komatsu has been developing several original technologies that enable high precision and durable laser device.

(1) RF pre-ionization based chamber

A radio frequency electric discharge through dielectric body has uniform and widespread property, because dielectric layer works as the stabilization impedance of the electric discharge of a distributed circuit, (RF pre-ionization). Therefore an ideal uniform distribution of initial electron can be produced. Output stability of excimer laser with RF pre-ionization is very high. This technology enables higher repetition rate operation.

(2) Solid state switch pulsed power technology

All solid-state pulsed power supply that combined saturable reactor and GTO are developed. Even at more than one kHz repetition rate region. There is no wear malfunction because it does not use an electric discharge. Even quality of elements is stable. Therefore the life of pulsed power supply is improved to over a few years.

(3) High resolution narrowing, monitor module

Narrow-band excimer laser achieved its spectral performance by arranging a spectral selection element such as prism, diffraction grating, etalon etc. inside a laser resonator. Also it is equipped with the sensor that measures spectral bandwidth, central wavelength, output energy, and these parameters are stabilized by feed back control system. In ultra-violet region, the absorption in optical element for a wavelength selection element and monitor element changes optical characteristics. This problem is improved by using materials with ultra violet resistance and small absorption. Also the drift of a wavelength detection element is calibrated on real time by using a atomic

Table 1. Progress & Road Map of Laser Source

		..1998	1999		2000	2001
	Komatsu product	G10		G20		G40
KrF 248nm	Spectral-bandwidth	0.7 pm	0.6pm	0.6 pm	0.5 pm	0.4 pm
	Output power	10W 1000Hz	10W 1000Hz	20W 2000Hz	20W 2000Hz	30W 4000Hz
	Maintenance Interval (chamber)	5 Billion	7 Billion	10 Billion	12 Billion	15 Billion
ArF 193nm	Spectral-bandwidth	0.7 pm			0.5pm	< 0.5 pm
	Output power	5W 1000Hz			10W 2000Hz	20W 4000Hz
	Maintenance Interval (chamber)	2 Billion			5 Billion	10 Billion
F2 157nm	Spectral-bandwidth				0.2 pm	0.2 pm
	Output power				20W 2000Hz	40W 4000Hz
	Maintenance Interval (chamber)				5 Billion	7 Billion

Table 2. Performance of G20K

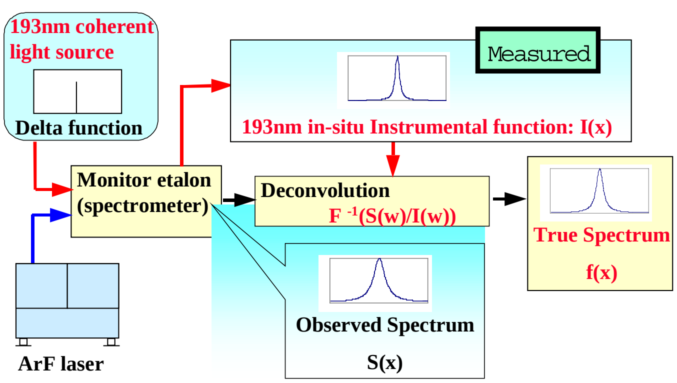
Parameter	Value	Module	Maintenance Interval
Wavelength	248 nm	Gas exchange	200 million pulse
Spectral bandwidth	0.6 pm	Window	5 billion pulse
Wavelength stability	±0.1 pm	Chamber Module	10 billion pulse
Average power	20 W	Pulsed power Module	7 years
Repetition rate	2000 Hz	Narrowing Module	10 billion pulse
Energy stability	±0.4%(.40pls)	Monitor Module	10 billion pulse

light source for absolute wavelength standard. The high accuracy absolute-wavelength stability is guaranteed by carrying out a feed back control of above sensor calibration scheme.

(4) Coherent light source for precision quality control (ArF) [7]

It is very important to control the quality of optical component, optical system and instruments for laser mass production. However at 193nm region there is no significant coherent light source, which has brightness, very narrow spectral-bandwidth and coherence. Komatsu has developed original 193nm light source cooperate with Tokyo University. This light source enables mass production of high quality ArF excimer laser.(Figure 3)

Figure3. 193nm at wavelength spectral measure ment

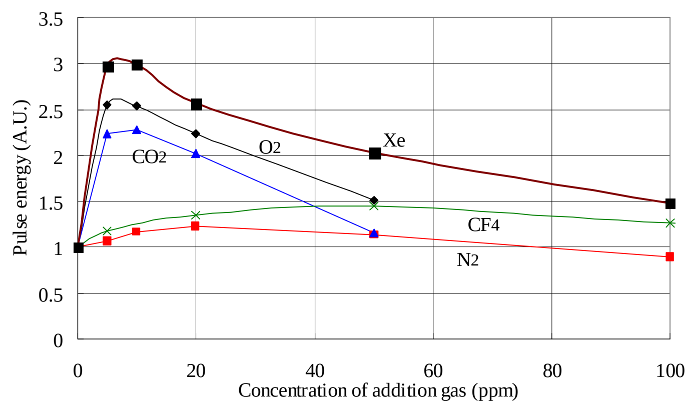


(5) Gas contamination control (ArF) [7]

The impurity in the laser gas affects on the performance of ArF laser. We have find out the mechanism of the impurity effect from cooperation fundamental research together with Kyushu University.

Further we propose to add Xe gas into the laser gas to stabilize and enhance the ArF laser performance[8] (Figure4). Also it is important to reduce the production of contamination in the laser chamber. Komatsu has developed magnetic bearing technology to avoid contamination from mechanical contact of fan rotation component in the laser chamber.

Figure4. Additional gas Effect on ArF laser power



4. Performance of 2kHz KrF excimer laser; G20K [2]

Progress of scanning stepper and 300mm wafer require the improvement of excimer laser on output performance. From the point of dose control-ability due to statistical effect and laser damage on optics, the direction of high repetition rate operation is strongly required from stepper manufacturers. We have developed next generation 2000Hz KrF excimer laser, G20K. The specification is listed in table 2. Its repetition rate was doubled over the previous model G10K, and improved pulse energy stability. In era of high throughput lithography, number of operation pulse in factory per year increases dramatically. Therefore requirement for reduction of CoO becomes stronger. On the other hand, physical load on the component of laser increases. Therefore further technical challenges are required. We have carried out a marathon test with G20K to find whether this data can be achieved certainly under realistic usage condition. An unattended test in an operation mode that imitates an

Table 3. Performance of G20A

Parameter	Value	Module	Maintenance Interval
Wavelength	193 nm	Gas exchange	50 million pulse
Spectral bandwidth	0.6 pm	Window	1.7 billion pulse
Wavelength stability	±0.2 pm	Chamber Module	5 billion pulse
Average power	10W	Pulsed power Module	4 years
Repetition rate	2000 Hz	Narrowing Module	5 billion pulse
Energy stability	±0.3%(.50 pulses)	Monitor Module	5 billion pulse

exposure process in a factory was executed for about half year. We have carried out the operation pulse more than 10 billion pulses. The change of data is still within the tolerance of the specification. In other words, exchange interval in table 1 is proved experimentally. At present we are continuing the improvement of durability under the durability test. We already have confirmed the long-term performance successfully. Good stability is maintained even up to 10 billion pulses.

5. Performance of 2kHz ArF excimer laser; G20A [7]

The design scheme of ArF exposure tool seems fixing [3][4][5]. Narrow band ArF excimer laser G20A is already developed successfully. It is based on the result of element technology of the latest excimer laser that is expressed in a foregoing chapter. It employs the latest all solid pulsed power supply that uses a semiconductor-switching element, which realizes stable operation at 2000Hz. Also the RF pre-ionization method is adapted to enable stable discharge and long chamber lifetime. Furthermore absolute standard source in a wavelength measuring system is adopted to stabilize a long-term spectrum performance. The stability of pulse energy data with the fluctuation of a moving average is very important parameter at the exposure by scanning stepper. The performance of ArF excimer laser G20A is shown in table 3. It has sufficient performance of the spectrum bandwidth and pulse energy stability for the practical exposure use. It has reached to the level that already ready for the use of real mass production.

The problem of instability of electric discharge and ware of pre-ionization electrode is solved by adoption of RF pre-ionization. Consequently G20A extends the life of a chamber substantially with this new technology. Also even the life of optic parts was improved substantially by the improvement of evaluation technology by the improvement and also fluorescence measurement of the material of optic parts.

We carried out a durability test of 2 billion pulses with G10A [6] that is equal to the operation about half an year in a factory under imitated operational condition at a mass production factory. The data in the durability test is collected automatically without any adjustment and parts exchange except gas exchange that is held every 2 days. In other words even an operational aspect is done the same as the environment of a factory. This data demonstrates that the above specification values were maintained during 2 billion pulses. We would like to carry out the challenge for life extension, and we want to materialize its durability appropriate to the industrial laser even by the viewpoint of CoO. The durability test of G20A is now on going aimed to reach 5 billion pulses maintenance interval. Figure 5 shows CoO trend of KrF and ArF laser. It shows rapid CoO cost reduction of KrF and ArF lasers. Especially CoO of ArF has been decreased dramatically. In year Q4 1999, the CoO of ArF is comparable as the CoO of KrF in 1998. It means ArF is already ready for mass production from the point of economy.

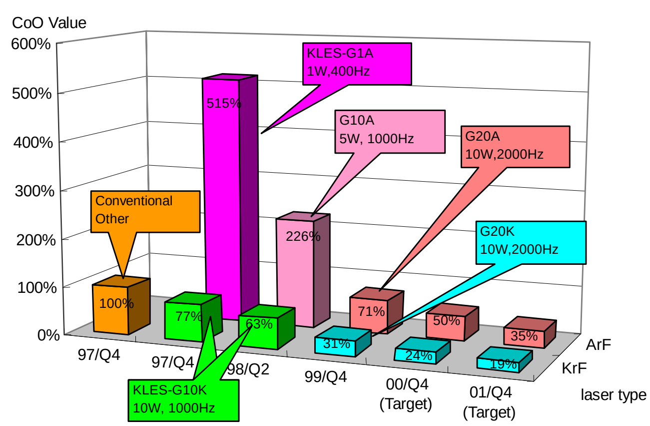


Figure 5 CoO trend of KrF/ArFLaser source

6. Development of F2 laser; G20F

F2 laser lithography is paid attention recently as the candidate of post-ArF excimer laser lithography. In case of F2 laser, considerable amount of research and

Table 4. Performance of G20F

Parameter	Value	Module	Maintenance Interval
Wavelength	157nm	Gas exchange	20 million pulse
Spectral bandwidth	0.2 pm	Window	1.7 billion pulse
Wavelength stability	-	Chamber Module	5 billion pulse
Average power	20W	Pulsed power Module	4 years
Repetition rate	2000 Hz	Narrowing Module	5 billion pulse
Energy stability	±0.5%(.80 pulses)	Monitor Module	5 billion pulse

development investment is needed if the development of the technology starts for commercialized light source from now because it is uncultivated compared with KrF and ArF. Systematic tackling is on going around the development of F2 lasers and also the basic technical development and research around the short wavelength materials by SEMATEC in U.S. Komatsu has started F2 laser research from 1997 and proved the technical feasibility of 800Hz operation in 1998, and proved the technical feasibility of 2000Hz operation in 1999[9)]. In 1999 Komatsu got a research fund from MITI concerning 2000Hz F2 laser development.

The catadioptic imaging system seems most possible candidate up to now. One reason is laser does not need to be narrowed because there is not the problem of color aberration. However it has still principally difficult to carry out the design that holds down aberration over a whole wide field. Thereupon, there are several alternative proposal of dioptric system. Achromatized lens design in this wavelength region is difficult because optical material that is usable in deep ultra

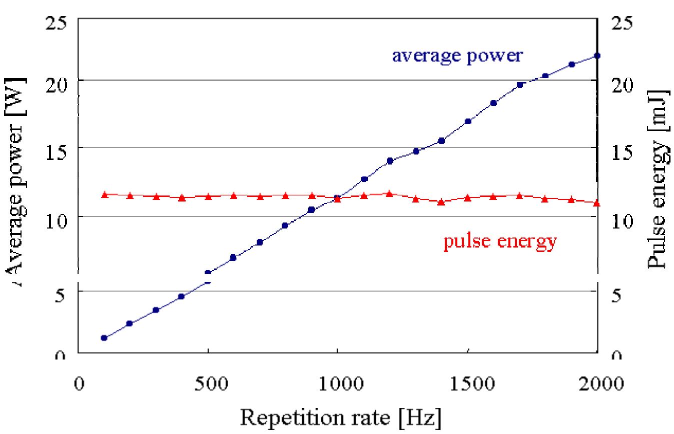


Figure 6. 2000Hz operation data of F2 laser

violet is limited and the problem of the color aberration is unavoidable in case of dioptric systems. There are several candidates to solve this issue. One is combination of extremely narrowed spectral bandwidth (0.1 – 0.2 pm) laser and monochromatic imaging lens. Another is combination of narrowed spectral bandwidth around 0.5 pm laser and partially achromatized imaging lens. At present each exposure tool supplier is still researching a substantial exposure device that has large field size, overlay functioned and the experimental produce-able of an actual device.

We are now developing 2kHz F2 laser for microlithography until 1Q in 2000. Table 4 shows the target performance of G20F. We suggest line-narrowing technology of F2 laser will be very important if we consider about the risk of development of imaging optic system. Figure 6 shows the performance of 2000Hz F2 laser. We believe the data promise the successful performance of G20F.

Conclusion:

KrF excimer laser steppers are installed voluminously to semiconductor mass production factories which require design rule less than 0.3.m. Design rule subsequent to 64Mbit DRAM is already a real situation. At present the operation in the volume as large as 1000 unit in accumulated number in the world. KrF excimer laser stepper is now main actor in 256Mbit DRAM manufacturing. Also 300mm silicon wafer is becoming standard of the process. And productivity and CoO becomes critical issues of KrF excimer laser stepper. 2kHz KrF excimer laser G20K proposes final solution for these two issues that is productivity and CoO.

On one hand, ArF excimer lithography is being advanced by combined effort by semiconductor manufacturers and equipment makers up to now. ArF excimer laser lithography has become most probable candidate of lithography technology subsequent to 4Gbit DRAM which requires 0.13-0.10.m or less design rule. ArF excimer laser lithography has finished the stage of principle demonstration, and it steps up to the stage that goes inspecting the practicality such as stability, productivity, and economic efficiency. The issues of ArF excimer laser such as stability, durability, CoO are already solved by the 2kHz ArF excimer laser G20A.

Furthermore sub-0.10.m design rule region F2 laser, electron beam projection, EUV has been examined at several organizations. Japanese organization ASET and SELETE are starting the research of F2 lithography development. Komatsu has started F2 laser research from 1997 and proved the technical feasibility of 800Hz operation in 1998, and proved the technical feasibility of 2000Hz operation in 1999. In 1999 Komatsu got a research fund from MITI concerning 2000Hz F2 laser development.

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