A Reliable Higher Power ArF Laser with Advanced Functionality for Immersion Lithography.

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ABSTRACT

193nm ArF eximer lasers are expected to continue to be the main solution in photolithography, since advanced lithography tecnologies such as Multiple patterning and Self-aligned double patterning (SADP) are being developed. In order to appliy these tecnologies to high-volume semiconductor manufactureing, the key is to contain chip manufactureing costs. Therefore, improvement on Reliability, Availability and Maintainability of ArF excimer lasers is important.[1] We works on improving productivity and reducing downtime of ArF exmer lasers, which leads to Reliability, Availability and Maintainability improvemnet. First in this paper, our focus drilling tecnique, which increases depth of focus (DoF) by spectral bandwidth tuning is introdueced. This focus drilling enables to increase DoF for isolated contact holes. and it not degrades the wafer stage speed.[2] Second, a technique which eables to reduce gas refill time to zero is introduced. This technique reduces downtime so Availavility is expected to improve. In this paper, we report these tecniques by using simulation resutls and partially experimental resutls provided by a semiconductor manufacturer.

Keywords: 32nm node, ArF excimer laser, Injection Lock, Line narrow, 193nm lithography, Immersion, Spectral bandwidth, High power, sTGM, sGRYCOS, sMonitoring, sMPL, Focus drilling, Directed Self Assembly, Double patterning, Multi patterning, Gas refill free

1. INTRODUCTION

Today, 193nm ArF exmier lasers are used not only for immersion lithography but also for advanced lithography technologies such as Double patterning, Multiple patterning, Self-aligned double patterning (SADP). However, these technologies tend to increase the number of lithography processes, which directly increase the chip cost. In order to realize both advanced lithography and contained chip cost, improvement on Reliability, Availability and Maintainability of ArF laser is reqiured.[1]

Our latest 193nm ArF excimer laser GT63A is developed to meet this reqiurement. The main specifications of GT63A and those of our recent lasers for comparison are shown in Table 1.

We have worked on the following two techniques as new functions of GT63A.

1. Improvement on process margin by focus drilling
2. Reduction of gas refill time to zero

ArF model	GT62A-1S	GT62A-1SxE	GT63A
Wavelength	193	193	193
Power	60	60/90	60/90
Pulse energy	10	10/15	10/15
Max. rep rate	6000	6000	6000
FWHM	N.A	N.A	N.A
E95	0.3	0.3	0.3
High E95 mode (sMPL)****	< 2.5	< 2.5	< 2.5
Durability (Expected)			
MO Chamber	60*	60*	60* / 40**
PO Chamber	60*	60*	60* / 40**
LNM	60***	60***	60***

* sGRYCOS technology

** sGRYCOS technology and High power operation

*** MPL (Multi Positioning LNM)

**** FD technology

Table1: Main specifications of GPI lasers

2. IMPROVEMENT ON PROSESS MATGIN BY FOCUS DRILLING

2.1 Issue of Isolated Contact Holes Patterning

Due to the target CD reduction driven by the recent rapid shrinkage of ULSI patterns, DoF for contact holes significantly degrades. DoF for isolated features degrades more than that of dense features, hence the issue of low DoF became critical in the production of logic devices.

In order to increase DoF, the technique called focus drilling is used. One of the focus drilling techniques, called EFESE_Rx, has already been implemented on ASML immersion platform. The DoF increase is achieved by applying a tilt to the wafer stage during scan. An alternative way of focus drilling is to broaden the spectral bandwidth of laser. In this method the DoF increase is achieved by tuning the light source, not by tilted stage, so the method is recently attracting a lot of attentions. We found from the simulation result that in the focus drilling by the spectral bandwidth broadening, the symmetry of spectral shape impacts on DoF (Fig.1).

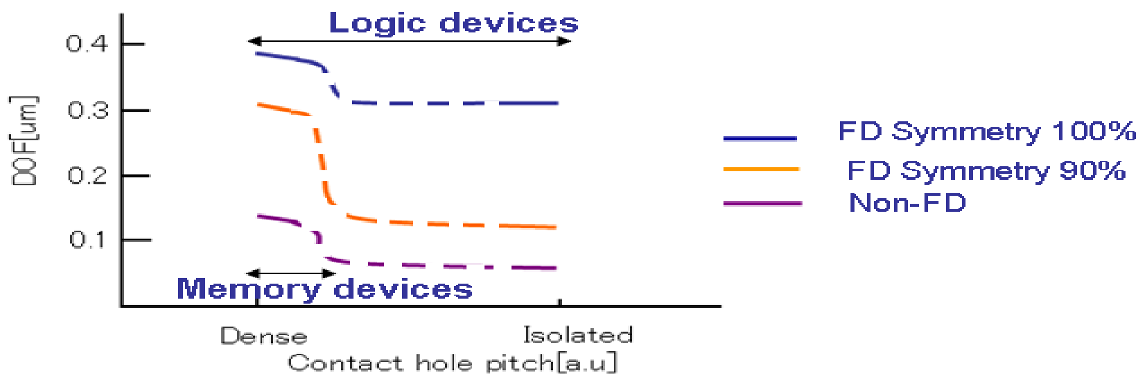
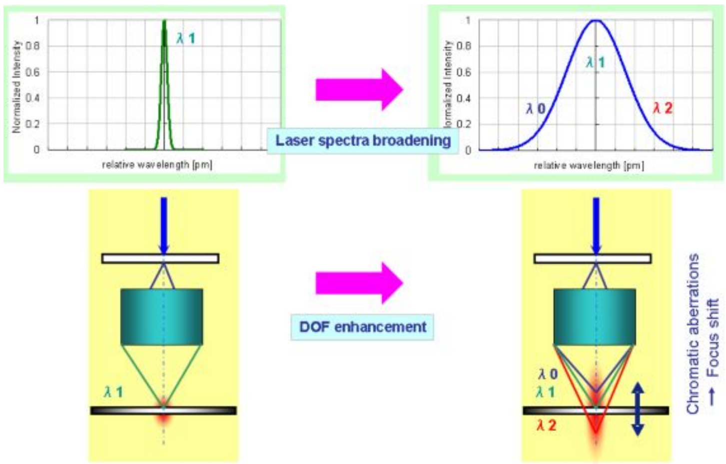


Fig.1: Relation between contact hole pitch and DOF

2.2 Solution for the Issue

As will be mentioned in section 2.3.2.1, we found that the symmetry of spectral shape impacts on DoF, therefore we works on broadening the spectral bandwidth without degrading the symmetry of spectral shape. We have succeeded in increasing DoF using our focus drilling technique which is realized by broadening of the laser spectrum. This technique, in principle, will not slow the wafer stage speed. DoF varies with the spectral bandwidth. The principle is shown in Fig.2.[2]



DOF : Depth of focus

Fig.2: Correlation between spectral bandwidth and focus position

In general, ArF eximer laser used for photolithography generates light with a very narrow spectral bandwidth. This means that a wavelength of light is focused on a single position on a wafer and consequently it is difficult to obtain high DoF. On the other hand, in the case of light with a broadened spectral bandwidth, multiple wavelengths of light are focused on different positions along axial direction, thus the DoF can be increased.

The contact holes patterning based on this principle is realized without changing the wafer stage position. Therefore, contact holes can be patterned without reduction in wafer stage speed.

The correlation of the spectral bandwidth tuning and DoF is evaluated by a simulation (Fig.3). DoF increases as spectral bandwidth is broadened, while DoF becomes lower as spectral bandwidth is narrowed. In general, when Exposure Latitude is largely taken, DoF degrades, and therefore it is needed to take low Exposure Latitude to obtain increased DoF.[2]

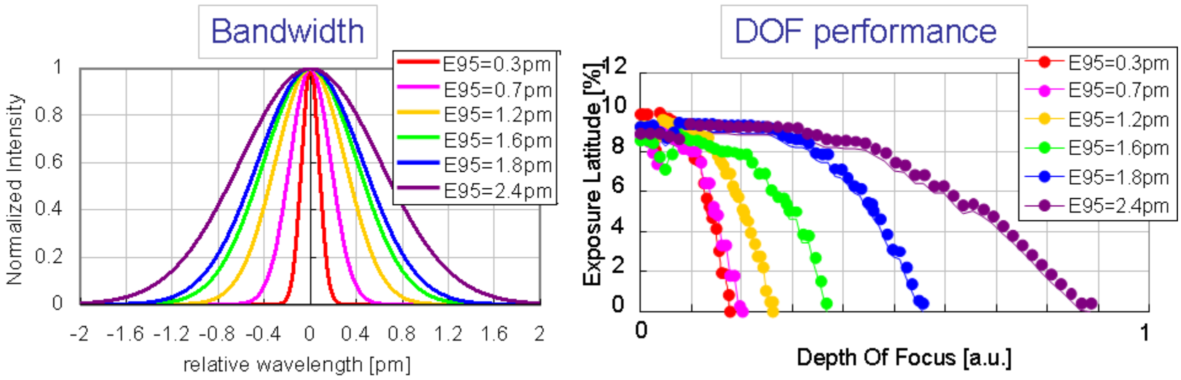


Fig.3: Correlation of spectral band width and DoF

GPI laser equipped with our new Line Narrowing Module (LNM) succeed in broadening spectral bandwidth by switching modes in the LNM (Fig.4). The Normal mode and FD mode switching and WFA enable to continuously change the spectral bandwidth from E95=0.3pm to 2.4pm.

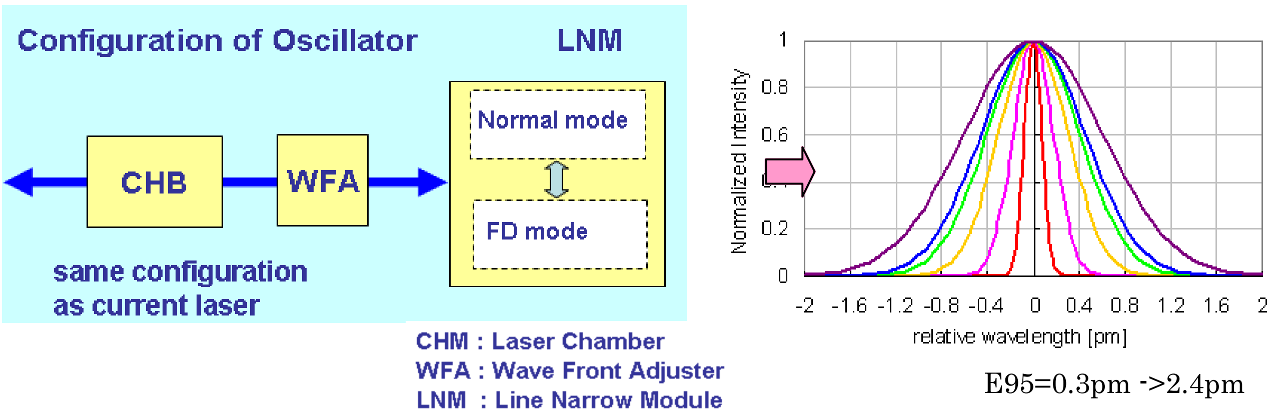


Fig.4: How spectrum bandwidth tuned

2.3 Performance Required for Focus Drilling

2.3.1 Target of Spectral Bandwidth Tuning Range

First in this section, E95 and Convoluted BandWidth (CBW) value are explained. E95 indicates a bandwidth including 95% of entire spectral energy. CBW is a convolution of a measured laser spectral and instrumental function.

The spectral bandwidth tuning range required for lasers with focus drilling function is from E95=0.3pm to 2.4pm. The spectral bandwidth of 0.3pm is for usual circuit patterning, while 2.4pm is needed to obtain sufficiently high DoF for isolated holes patterning. This value is obtained from the result of the correlation of CBW and DoF as shown in Fig.12 and corresponds to 0.02um, which is one tenth of required DOF of 0.2um.

2.3.2 Symmetry of Spectral Shape

2.3.2.1 Simulation Result

As mentioned previously in this paper, DoF changes with spectral bandwidth. Other than this factor, we found in the simulation that the symmetry of spectral shape impacts DoF. The impact was significantly seen in isolated features than in dense features. As a result, the influence for DoF can be more significant in isolated features than in dense features.

The simulation condition is NA=1.2, E95%=2.4pm, and Dense (contact hole diameter/Pitch: 80um/160um) and Isolated (contact hole diameter/Pitch: 80um/720um) features. The influence on dense contact holes is shown in Fig.5. In Dense features, when the spectral shape varies by 10%, the influence on DOF becomes 0.08um, which is not so significant.

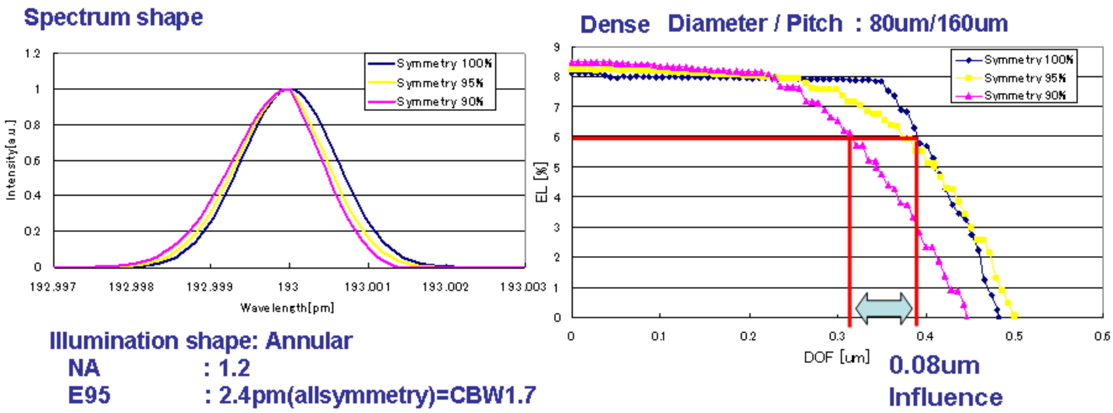


Fig.5: Correlation of the symmetry of spectral shape and DOF (Dense)

While, the simulation result on isolated contact holes is shown in Fig.6. On the isolated features, when the symmetry of spectral shape varies by 10%, the influence for DOF become 0.19um, this is significant. Thus, especially in imaging isolated features, the symmetry of spectral shape can be an important parameter for DoF.

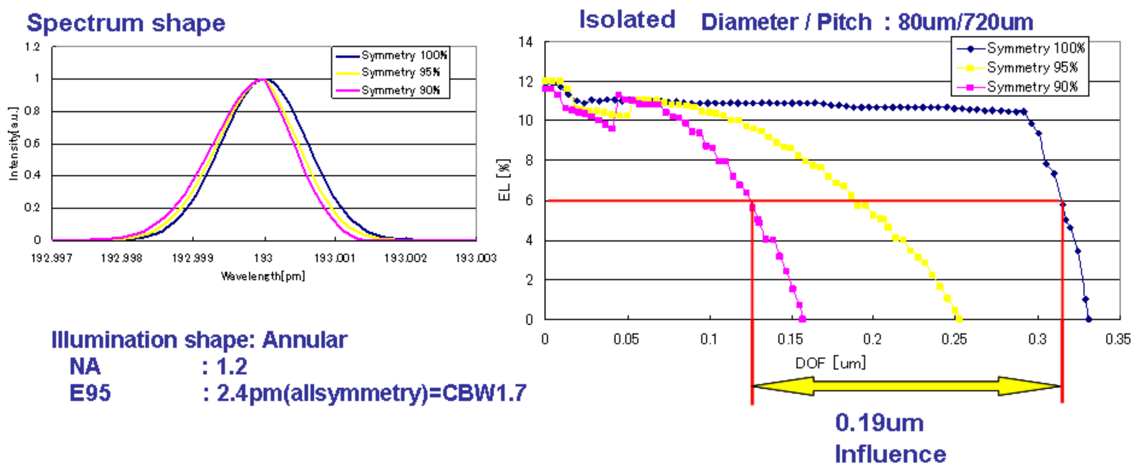


Fig.6: Correlation of the symmetry of spectral shape and DoF (Isolated)

2.3.2.2 Required Value for the Symmetry of Spectral Shape

The required value for the symmetry of spectral shape on isolated features is more than 95%. This value is obtained from the correlation of DOF and the symmetry of spectral shape obtained by the simulation result in section 2.3.2.1.As shown in Fig.7, the symmetry for which the DOF of 0.2um can be achieved is more than 95%. This value is set as the required value for the symmetry of spectral shape for isolated features.

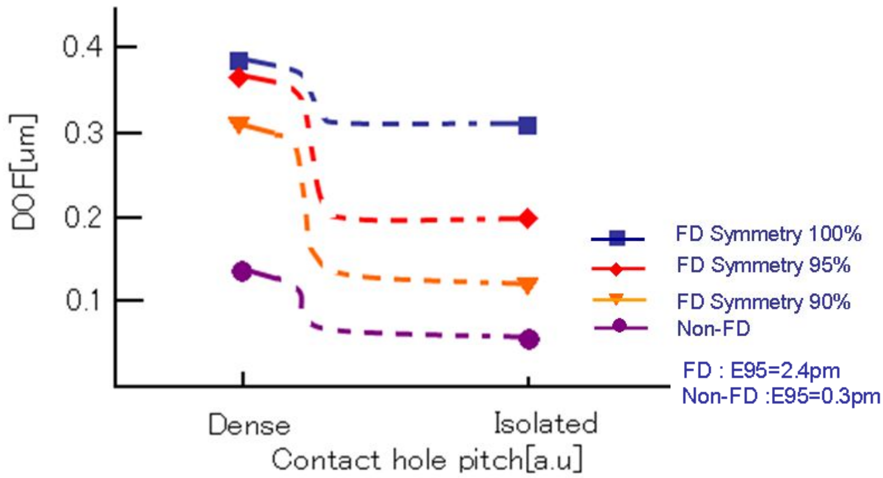


Fig.7: Correlation of contact hole pitch and DOF and its required value.

The definition of the symmetry of spectral shape in this paper is that the ratio of the amount of the gravity center of upper level 10% shifted from the central wavelength of E95 (Formula 1, Fig.8).

Symmetry[%] =(1 - | a / b |) x 100・・・formula 1

a : Gravity center of Upper level 10%

b : Spectral width E95/2

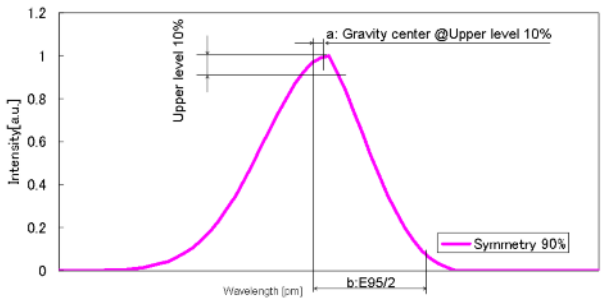


Fig.8: The definition of the symmetry of spectral bandwidth

2.4 Result of Performance Evaluation

2.4.1 Result of Spectral Tuning Range

The results of spectral bandwidth tuning with E95=0.3pm, 0.7pm, 1.4pm, 2,4pm is respectively shown in Fig.9. The spectral bandwidth is tuned from 0.3pm to 2.4 pm at E95.

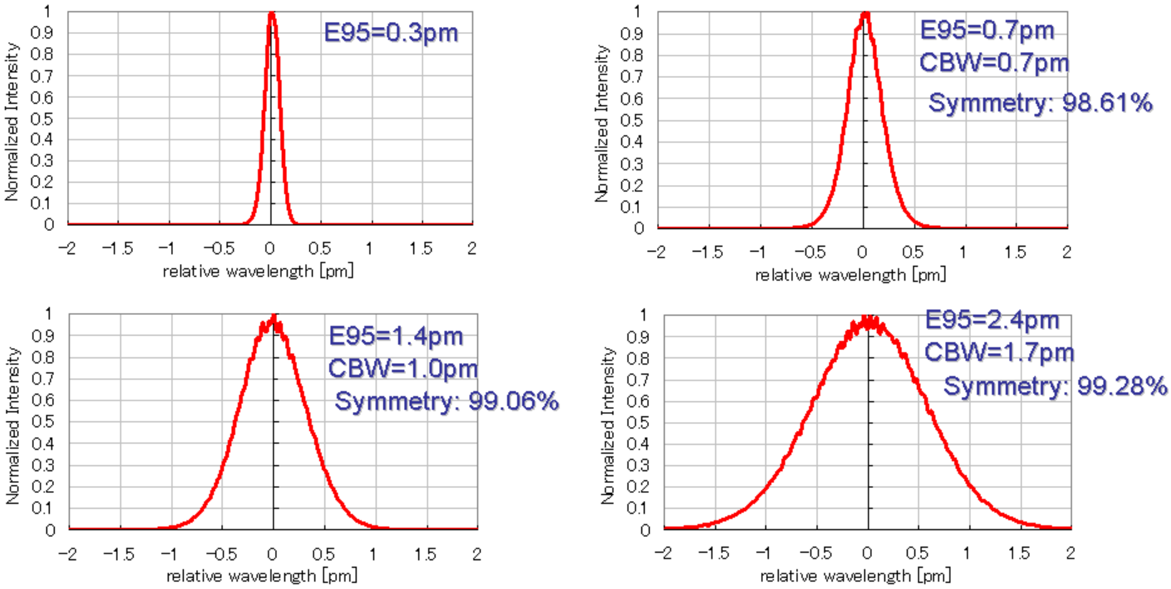


Fig.9: Spectrum shape variability

2.4.2 Result of the Symmetry of Spectral Shape in Middle Term

The result of the symmetry of spectral shape in a short term is shown in Fig.9. The symmetry of spectral shape result in more than 98.6% in E95=0.7pm, 1.4pm, 2.4pm. This exceeds the required value of 95%. E95=0.3pm is the spectral bandwidth when usual circuit features is patterned, for reference.

Next, the symmetry of spectral shape and spectrum stability in a middle term is shown in Fig.10. The term is 3 days and the oscillation pulses are 330 Million pulses. The spectral symmetry is Average 98.53% stability: +/-0.64%, which means it has enough margin for the required value of 95%. The graph of CBW is a reference.

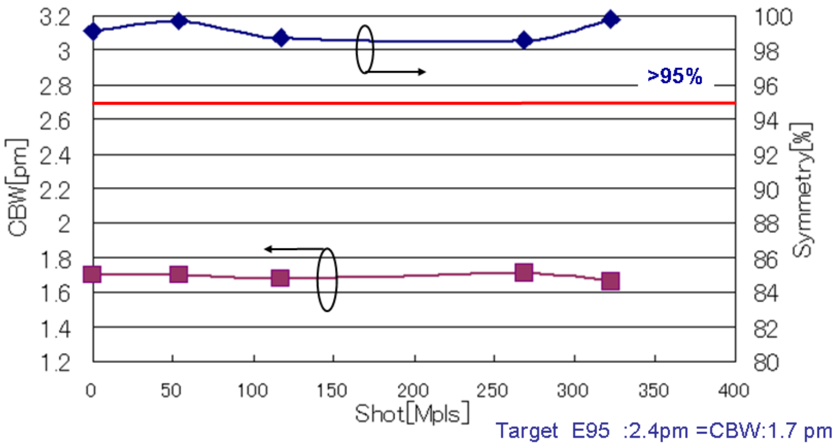


Fig.10: short term CBW stability and the symmetry of the spectral shape

2.4.2 Result of the Symmetry of Spectral Shape in Long Term

Finally, the symmetry of spectral shape and spectral stability in a long term is shown in Fig.11. The term is 56 days. The symmetry of spectral shape is Average: 98.74% and stability: +/-0.93%, which means it has enough margin for the required value of 95%. The graph of CBW is reference.

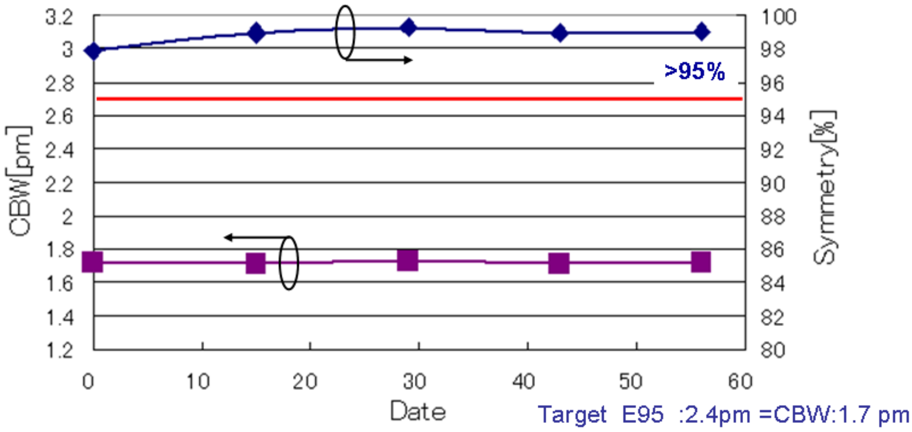


Fig.11: Long term CBW stability and the symmetry of spectral bandwidth

The result of the symmetry of spectral shape of more than 97.8% is obtained in short, middle and long terms. The result sufficiently exceeds the required value of 95%.

2.5 Experimental Exposure Result in the Field

2.5.1 Improvement on Depth of Focus Margin

Experimental exposure was carried out on an exposure tool coupled with GPI eximer laser at a user site to evaluate our newly developed LNM for focus drilling. The result indicates that the DoF is increased at contact holes patterning. Fig.12 shows the correlation of DOF and CBW at the exposure. DOF of 0.2um can be obtained at CBW of 1.25pm under the conditions of target CD of 85 nm, pitch=365 nm, annular illumination settings with NA=1.2. [2]

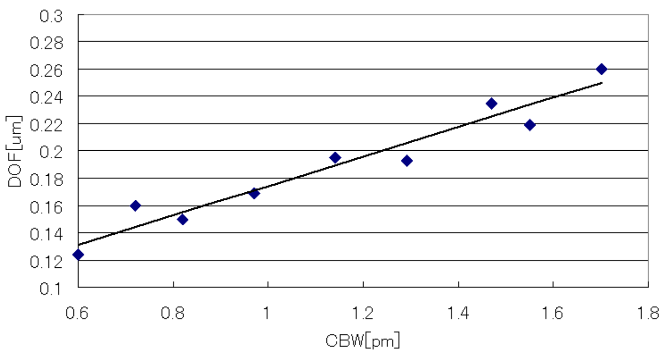


Fig.12: Correlation of DOF and CBW

Reference: Alena Andryzhyieuskaya, et al., "High-range laser bandwidth turning for focus drilling" Proc. SPIE 8167, 81671X ,(2011)

2.5.2 Confirmation of Proximity Matching

The result of experimental exposure at a user site with the focus drilling methods of EFESE_HR and EFESE_Rx, both named by ASML, is introduced. EFESE_HR increases DoF by combination of scanner and laser bandwidth tuning, while EFESE_Rx increases DoF by stage tilt. First, comparison of DoF in EFESE_HR and EFESE_Rx evaluated by process window is shown in Fig. 13. The DoF is substantially the same in the both methods.

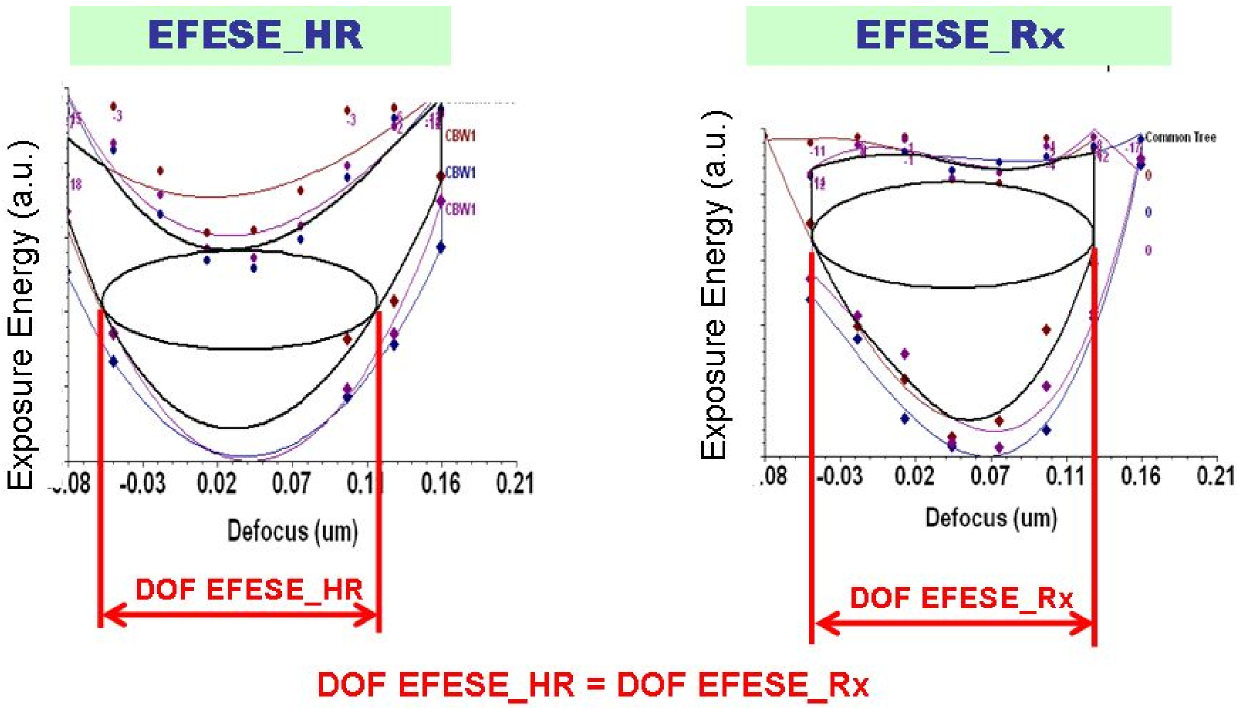


Fig.13: DOF of EFESE_HR and EFESE_Rx

Second, the Critical Dimension (CD) is compared. The correlation of line pitch and CD in EFESE_HR and EFESE_Rx is shown in Fig.14. Compared with the CD variation in EFESE_Rx, that of EFESE_HR become less than +/-5%, hence we can determine that the CD variation in EFESE_HR is the same level as that of EFESE_Rx. From this result, EFESE_HR has the same performance as EFESE_Rx, therefore EFESE_HR can be used at the common process.

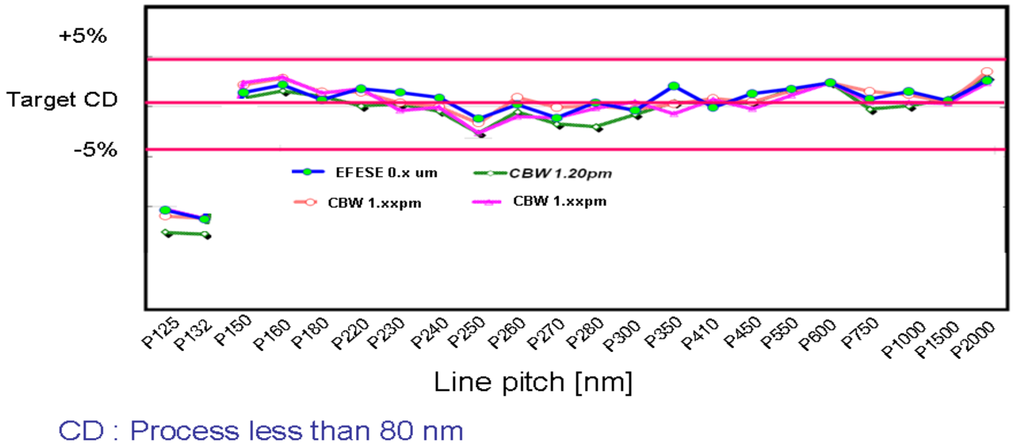


Fig.14: Relation of Line pitch and Critical dimension

3. REDUCING GAS REFILL TIME ZERO

3.1 Background and Challenges

To improve Availability of laser, downtime needs to be reduced. Downtime consists of:

-Scheduled downtime for periodic modules replacement and laser gas refill time

-Unscheduled downtime for failures unexpectedly occurs (Fig.16).

The unscheduled downtime have been reduced by improvement on the quality of lasers, and the time for periodic modules replacement is also reduced by replacing the modules at the same timing of the maintenance of, for example, an exposure tool. Therefore, we worked on the gas refill reduction, which appears to be the most difficult technological challenge. The impurities in the laser chamber of eximer lasers increases proportionally to the number of oscillation pulses.(fig.17) The laser output energy decreases with the impurities increase, therefore, gas refill is required. The gas refill is to exhaust the gas inside the laser chamber to vacuum and then fill the fresh gases to the chamber. GPI ArF eximer laser needs a gas refill every 15 days. We worked on suppressing the impurities below a certain level against the number of pulse oscillations, and succeeded in eliminating the gas refill time. This improvement enables to reduce the gas refill time of 480 minutes per a year to zero.

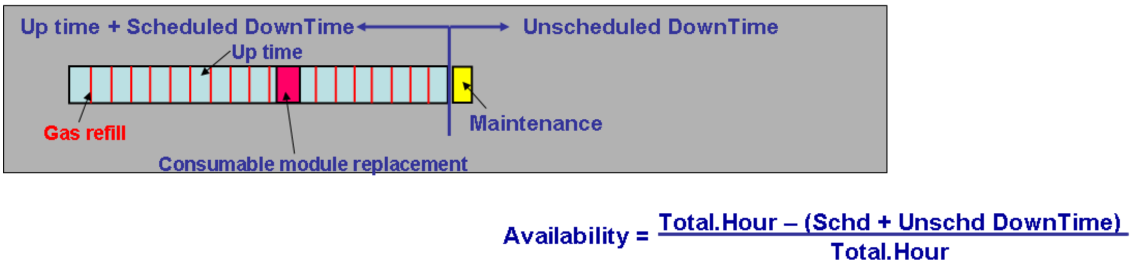


Fig.16: Up time+ Scheduled Down time and Unscheduled Down time

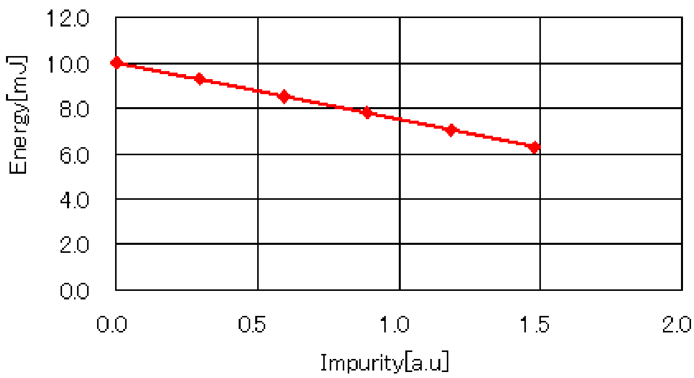


Fig.17: Correlation of impurity and output energy

3.2 Targets of Gas Refill Time and Gas Consumption, Confirmation Method

The targets of gas refill and gas consumption are explained. The target of gas refill time is to reduce the time of 480 minutes per a year to zero. The target of gas consumption is the same amount as that of the regular gas refill carried out every 3 days. In order to confirm the performance, the amount of the impurities in the laser chamber and the consumption of gas need to be examined.

The amount of the impurities are obtained in an experiment and also in actual exposure process in a user site. However, in the user site, it is impossible to directly measure the gas contained in the laser chamber. Therefore, confirmation is carried out by analyzing the transition of input energy to laser chamber and the gas pressure rise in the laser chamber. The laser controls the chamber according to the demand to output energy, which is send from the scanner.

When output energy is not sufficient for the demand from the scanner, due to a reason such as impurities increase, input energy is increased. Further more, the laser is designed to control the energy by increasing the gas pressure in the laser chamber when output energy decreases. [3,4] Hence, the amount of impurities in the chamber can be indirectly measured by evaluation of the transitions of input energy and gas pressure of the laser chamber. The amount of gas consumption is obtained by computational calculation with an assumed condition of shot rate 200Mpls/30day.

3.3 Result

3.3.1 The Amount of the Impurities and Operation Data in the Field.

The measurement result of the amount of impurities are shown in Fig.18. When the new gas control is off, the amount of the impurities increase. Contrary to this, under the new control, the impurities increase do not exceed the certain amount. There is no trend of impurity increase and the mount of impurities does not exceed threshold of gas refill. From these result, it is possible to say that the output energy needed for laser performance can be maintained without gas refill.

Input energy to the laser chamber at actual exposure process in the user site is shown in Fig.19, and the transitions of gas pressure in the laser chamber is shown in Fig.20. The outstanding variations can not be seen in both gas pressure and input energy. From this, it is possible to say that laser performance can be maintained. Thus, laser chamber can provide laser performance without gas refill.

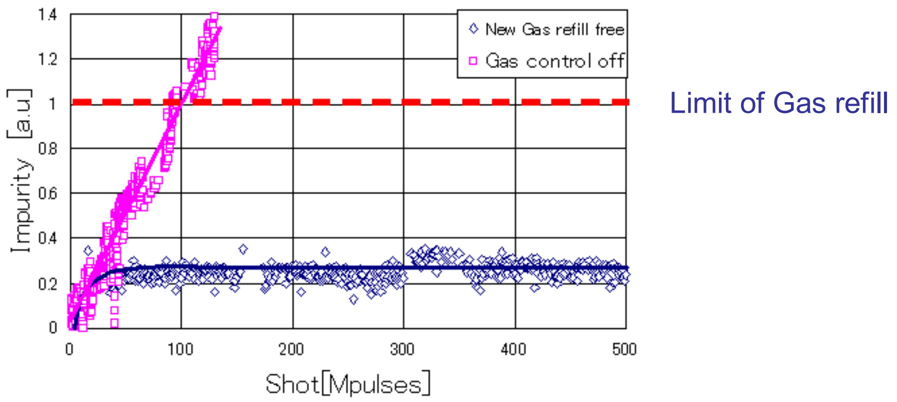


Fig.18: the number of shots and impurity

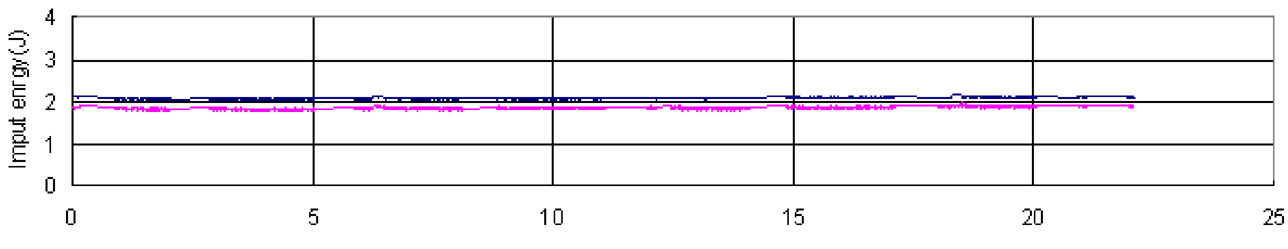


Fig.19: Transition of Input energy without gas refill

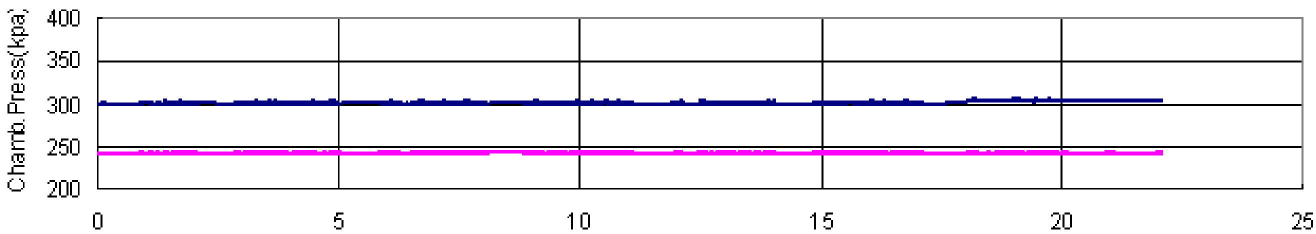


Fig.20: Transition of gas pressure without gas refill

The amount of fluorine gas and argon gas consumption at gas refill carried out every 15 day and that of new gas control (no gas refill) are shown in Table 2. Under the same condition of pulse oscillation at 2000Mpls/30days, less amount of gas is consumed in the new gas control.

	Gas consumption [Little･atm / 1day]	
	F2 gas	**Ar gas**
Refill/15day *1	**48.3**	**277**
New Refill/No day *1	**47.3**	**269**

These values are guideline in a standard operating environment and can vary according to the given conditions including the pipe connection system used.

*1: Shot rate 2000Mpls/30days

Table2: gas consumption in existing gas control and new gas control

4. CONCLUSION

DoF is increased using our focus drilling method by the spectral bandwidth tuning. Spectral bandwidth and the symmetry of spectral shape are key parameters for DOF. GPI focus drilling enables to tune spectral bandwidth from 0.3pm to 2.4pm. The symmetry of spectral shape of 95% is maintained. The spectral bandwidth is stable in all short, middle (15 days) and long (56 days) terms. DoF increase is confirmed by experimental exposure. In the exposure test at a user site, the depth of focus margin in EFESE_HR was the same as that in EFESE_Rx. In addition, since process parameters are also the same, focus drilling by spectral bandwidth tuning can be applied without process condition change.

Our new control method enables to reduce gas refill time to zero. The improved control can suppress the impurities under a certain level without exhausting the gases in laser chambers to vacuum. Thus, laser gas refill time is reduced to zero. This function has already been applied to the actual exposure in the user site, and chamber input energy and gas pressure is confirmed to be stable over the 15 days. The gas consumption is the same level as that of filled at regular gas refill. These functions are ready for actual use in high-volume production.

Application to the products

GPI has released a new laser model GT63A, which is equipped with focus drilling as optional and new gas control. These techniques can be applied existing lasers, Focus drilling function can be applied to GT61A to GT62A-1SxE, new gas control function can be applied to GT62A-1S to GT62A-1SxE.

The productivity of eximer laser is improved by focus drilling and new gas control, GPI continues to develop exmier lasers and would like to support microfablication technologies.

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