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ABSTRACT

The multiple patterning ArF immersion lithography has been expected as the promising technology to satisfy leading edge device requirements. Gigaphoton carries out developments to improve device yields and to reduce costs of operation in exposure. One of them is ultra-narrowing spectral bandwidth of light source without Helium gas usage. The ingenious configuration of Line Narrowing Module (LNM) allows E95 bandwidth to reach 200 fm from 300 fm in Helium free operation. Narrower bandwidth will improve exposure latitude. Helium free operation will reduce operational costs and will be independent of Helium gas shortage. Second is improving stability of bandwidth. 5 fm E95 bandwidth shot average can be realized by adopting a new fast actuator and a new control method. Stable bandwidth will improve CD uniformity. They are also able to broaden a bandwidth tuning range and to make a bandwidth tuning speed faster. New type LNM and new bandwidth control that Gigaphoton has developed realize ultra-narrow bandwidth, Helium free operation, stable bandwidth, broad bandwidth tuning range and fast bandwidth tuning speed. They will contribute to the improvement of device yield in cutting edge exposure condition and the reduction of operational costs. These functions can be upgradable for our ArF excimer laser.

Keywords: ArF excimer laser, narrow spectral bandwidth, stable spectral bandwidth, helium free, multiple patterning immersion lithography

1. INTRODUCTION

Gigaphoton has provided cutting edge ArF excimer laser as lithography light source. Lasers of Gigaphoton have been introduced to most of semiconductor plants all over the world and have contributed to developments of lithography technologies.

The multiple patterning ArF immersion lithography has been expected as the promising technology to satisfy leading edge device requirements. In cutting edge exposure condition, the improvement of device yields and the reduction of operational costs are demanded. For improvement of CD performance in exposure, narrow spectral bandwidth and stable bandwidth control are required. Narrower bandwidth can enhance exposure latitude without an impact on depth of focus (Fig.1). More stable bandwidth can reduce CD variation. For sustainable high volume manufacturing, Helium free operation is needed. Nowadays, because of worldwide increase of Helium gas demands, price of Helium becomes higher and higher (Fig.2) and the risk that a supply of Helium gas becomes unstable is increasing. Therefore, Helium free operation independent of Helium gas shortage is required [1] [2] [3].

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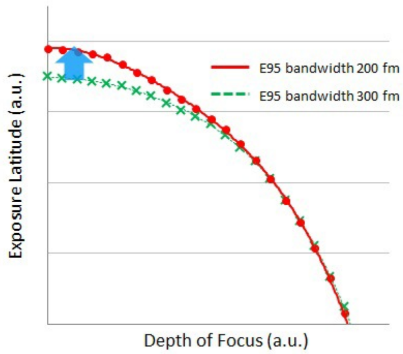

Fig.1 Simulation of exposure latitude enhancement by narrower bandwidth
E95 bandwidth 200 fm can enhance exposure latitude up to 10% without an impact on depth of focus. This data is simulated by Gigaphoton.

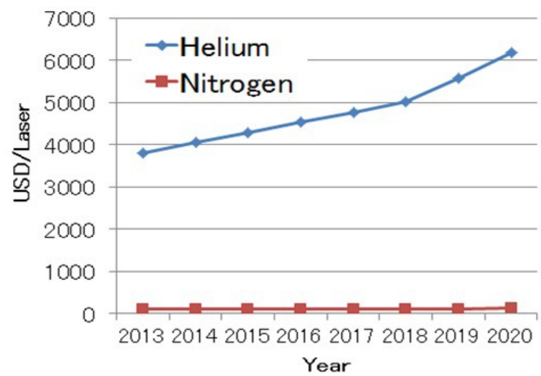

Fig.2 Change of purge gas price; Helium gas and Nitrogen gas
Price of Helium gas is much higher than that of Nitrogen gas and becomes higher every year.

2. NARROWING BANDWIDTH IN HELIUM FREE OPERATION

2.1 Narrowing bandwidth system

Line Narrowing Module (LNM) is a key module to narrow bandwidth in an excimer laser. LNM is located within oscillation resonator. LNM receives light beams from a discharge chamber and returns only particular wavelength light beams to the discharge chamber.

LNM has a grating and a rotatable beam expander prism. The grating is located in Littrow configuration in which a diffraction angle equals to an incident angle. In this case, the grating equation is subscribed as follows;

$$2nd\sin\theta = m\lambda \tag{1}$$

where, n is a refractive index of purge gas, d is a groove spacing of the grating, θ is an incident angle and a diffraction angle from a normal line of the grating, m is a diffraction order and λ is an oscillation wavelength [4]. Light beams with other wavelengths are diffracted at other diffraction angles and they are obscured by an aperture at an entrance of the discharge chamber. Thereby only particular wavelength light beams are oscillated. The rotatable prism can change the incident angle θ, which can adjust the oscillation wavelength [2].

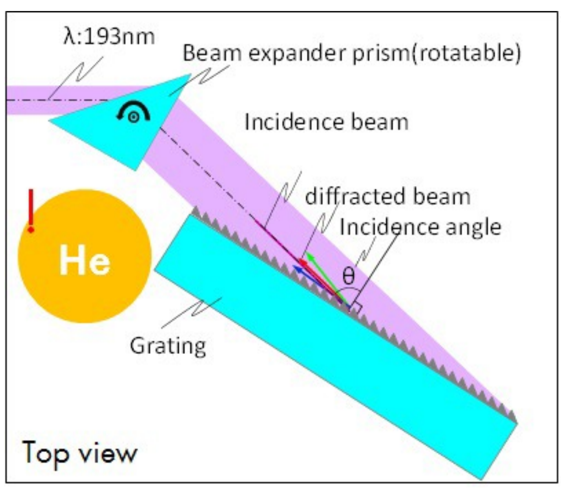

Fig.3 Scheme of narrowing bandwidth
The grating diffracts the incident light beams and narrows bandwidth. The rotatable beam expander prism selects oscillation wavelength.

Laser beam heats up purge gas in LNM. Generally, a refractive index of gas depends on the temperature. Temperature distribution caused from laser beam can produce distribution of refractive index, which leads fluctuation of wavefront. This wavefront fluctuation means that light beams have multiple incident angles to the grating, and the beams are diffracted at diffraction angles according to these wavelengths. Some beams with unexpected wavelength return to the discharge chamber, which broadens bandwidth.

In order to obtain narrower bandwidth, Helium gas has been used as purge gas because $\mathrm{d}n/\mathrm{d}T$ of Helium gas is 1/10 of Nitrogen gas, where $\mathrm{d}n/\mathrm{d}T$ is temperature dependence of a refractive index n (Table.1). Fig.4 shows the difference of the heat effects influence between Helium gas and Nitrogen gas. In Helium gas purge, the influence of heat effects is smaller than in Nitrogen gas purge because of the difference of $\mathrm{d}n/\mathrm{d}T$.

Table.1 Refractive index $\boldsymbol{n}$ and its temperature dependence $\mathbf{d}\boldsymbol{n}/\mathbf{d}\boldsymbol{T}$
$\mathbf{d}\boldsymbol{n}/\mathbf{d}\boldsymbol{T}$ of Helium gas is 1/10 as large as that of Nitrogen gas.

Purge gas	**Refractive index $\boldsymbol{n}$**	$\frac{\mathbf{d}\boldsymbol{n}}{\mathbf{d}\boldsymbol{T}}$
Nitrogen	1.000315	-0.9×10^{-6}
Helium	1.000035	-0.09×10^{-6}

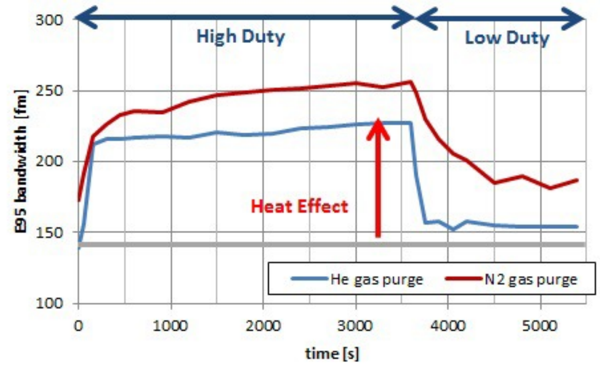

Fig.4 Results of heat effect in current type LNM without bandwidth control
The heat effect with Nitrogen gas is larger than that with Helium gas.

2.2 New type LNM

New type LNM realizes E95 bandwidth 200 fm controls in Helium free operation. Ultra-narrow bandwidth will enhance exposure latitude, which improves device yield. Helium free operation will contribute to reduction of the operational costs and the independence of Helium shortage.

Gigaphoton has developed new type LNM in order to realize sufficiently narrow bandwidth even though Nitrogen gas is used as purge gas. Ingenious configuration of new type LNM can reduce the rise of purge gas temperature. Fig.6 shows E95 bandwidth of new type LNM in Helium free operation. Lower heat effect in LNM reduces thermal wavefront deformation. It realizes ultra-narrow bandwidth, namely less than 200 fm E95 bandwidth in high duty oscillation without bandwidth control in Nitrogen gas purge.

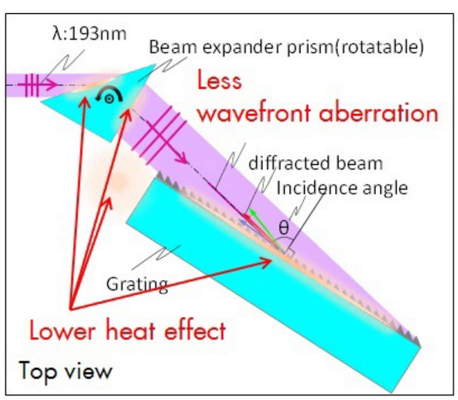

Fig.5 Configuration of new type LNM
Lower heat effect around the grating and the prism can reduce thermal wavefront deformation.

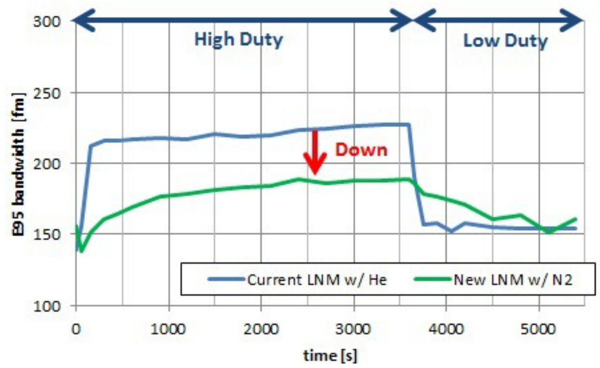

Fig.6 Results of heat effect without bandwidth control in new type LNM
The heat effect in new type LNM with Nitrogen gas is smaller than that in current type LNM with Helium gas.

3. BANDWIDTH CONTROL

3.1 Bandwidth control system

For improvement of CD uniformity, it is important to keep bandwidth constant. As described above chapter, the grating in LNM plays a role to narrow bandwidth. When light beams with plane waves enter the grating, the beams with wavelength λ_1 are only diffracted at the diffraction angle equal to the incident angle. On the other hand, when incident beams have spherical waves, the beams with not only $\lambda_1$but also λ_2 and λ_3 wavelengths are diffracted at the diffraction angles equal to the incident angles. Then, more wavelengths in more spherical waves are oscillated, which can broaden bandwidth. A two-lens optical unit within resonator can change curvatures of light waves according to the distance between the two lenses. Thereby, bandwidth can be controlled by moving a position of the lens. Fig.7 shows the scheme of the bandwidth control system.

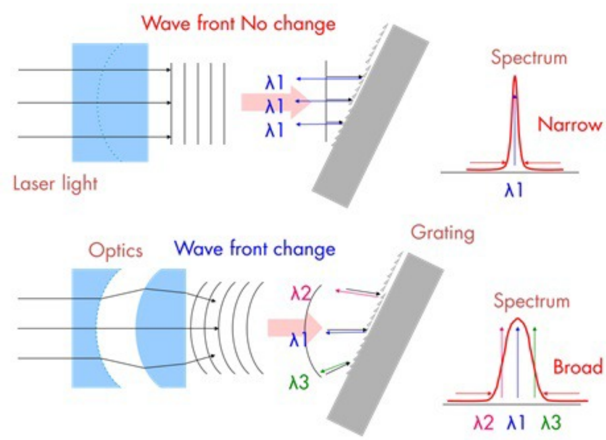

Fig.7 Bandwidth control system
The two-lens optical unit can change the curvature of wave fronts. When wave front has curvature, more wavelengths are diffracted by grating and oscillation bandwidth becomes broad. Therefore, changing the distance between lenses can control oscillation bandwidth.

3.2 New bandwidth control

In the bandwidth control system, the speed of an actuator moving the lens has limited the speed of bandwidth control and then the stability of bandwidth. For more stable bandwidth control, we adopt a very fast actuator with thirty times faster speed than that of current actuator. Furthermore, we change a bandwidth control method in order to utilize that fast speed. Fig.9 shows the comparison of moving speed between the new actuator and the current actuator. The new actuator can eliminate 40 fm deviation of E95 bandwidth within 0.1 s while the current actuator cannot eliminate the deviation and has more than 20 fm deviation of E95 bandwidth. Fig.8 shows the shot performance of the new bandwidth control method. The new bandwidth control allow E95 bandwidth shot average to become less than 5 fm. Narrow bandwidth will contribute to the reduction of CD variation.

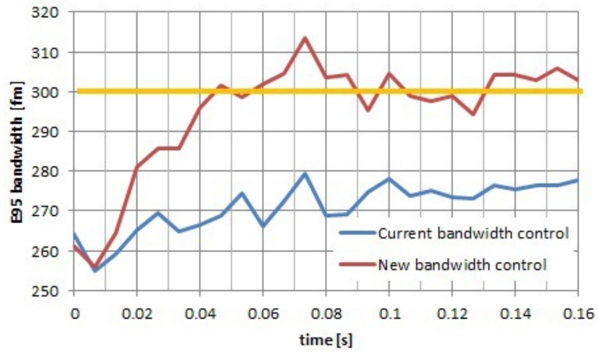

Fig.8 Comparison of E95 bandwidth at beginning of wafer
Deviation of E95 bandwidth in new bandwidth control is eliminated more quickly than in current bandwidth control.

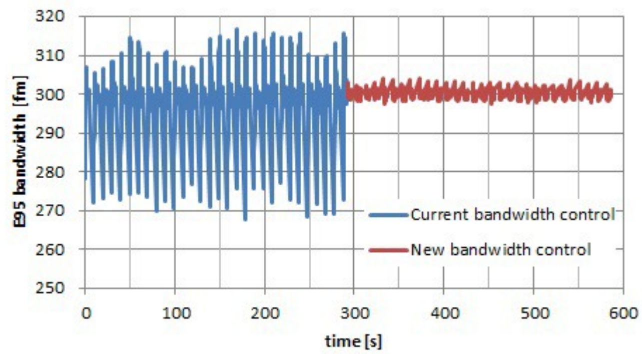

Fig.9 Comparison of E95 bandwidth shot average
E95 bandwidth shot average in new bandwidth control is much smaller than that in current bandwidth control.

4. RESULT OF NEW TYPE LNM AND NEW BANDWIDTH COTROL

4.1 Bandwidth control

Fig.10 shows results of new type LNM and new bandwidth control. You can see that new type LNM realize 200 fm E95 bandwidth control and that new bandwidth control realize 5 fm E95 bandwidth shot average error. Furthermore, the combination of these functions can realize these results simultaneously in Helium free operation.

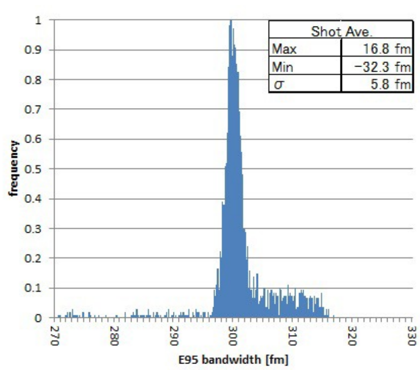

Fig.10-(a) Current type LNM and current bandwidth control

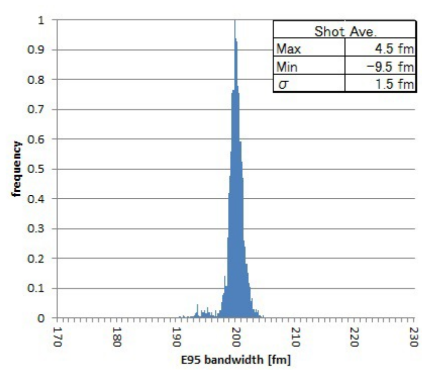

Fig.10-(b) New type LNM and current bandwidth control

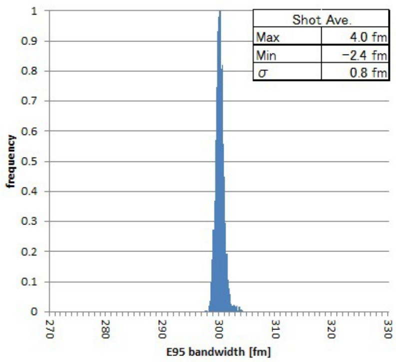

Fig.10-(c) Current type LNM and new bandwidth control

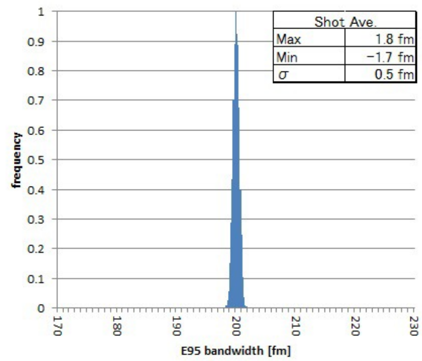

Fig.10-(d) New type LNM and new bandwidth control

Fig.10 Histograms of E95 bandwidth shot average in several combinations of LNM and bandwidth control
New type LNM realizes 200 fm E95 bandwidth control. New bandwidth control can reduce dispersion of bandwidth.

4.2 Bandwidth target tuning

New type LNM and new bandwidth control also have an effect on changing bandwidth target. Realizing narrow bandwidth can broaden tuning range of bandwidth. Fig.11 shows that E95 bandwidth target can change from 200 fm to 450 fm arbitrarily. Fast bandwidth control can realize quick change of bandwidth. Fig.12 shows that 250 fm change of E95 bandwidth target is completed within 0.1 s.

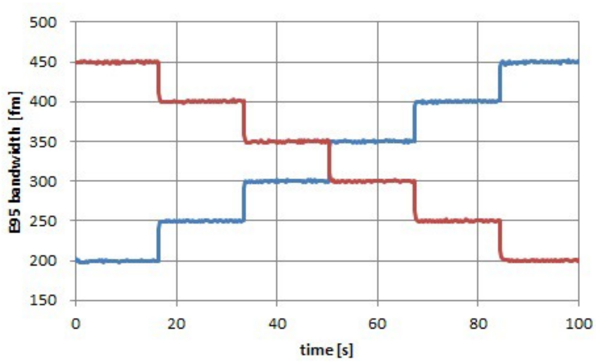

Fig.11 Tuning range of bandwidth
E95 bandwidth target can change from 200 fm to 450 fm arbitrarily.

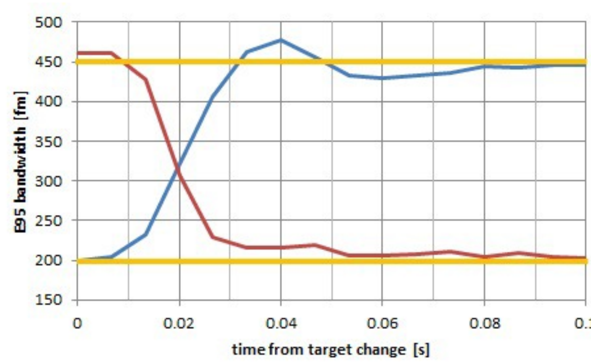

Fig.12 Tuning speed of bandwidth
E95 bandwidth target change is completed within 0.1 s.

5. SUMMARY

Gigaphoton has developed new type LNM and new bandwidth control. These functions realize ultra-narrow bandwidth, Helium free operation, stable bandwidth control, broad bandwidth tuning range and fast bandwidth tuning speed. They will contribute to improvement of device yield in cutting edge exposure condition and reduction of operational costs. These functions can be upgradable for our ArF excimer laser.

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