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ABSTRACT

Multiple patterning ArF immersion lithography has been expected as the promising technology to satisfy tighter leading edge device requirements. A new ArF excimer laser, GT64A has been developed to cope with the prevention against rare resource shortage and the reduction of operational costs. GT64A provides the sophisticated technologies which realize the narrow spectral bandwidth with helium free operation. A helium gas purge has usually been employed due to the low refractive index variation with temperature rises within a line narrowing module(LNM). Helium is a non-renewable resource and the world's reserves have been running out. Nitrogen gas with an affordable price has been used as an alternative purge gas of helium on the restrictive condition of low thermal loads. However, the refractive index variation of nitrogen gas is approximately ten times more sensitive to temperature rises than that of helium, and broadens a spectral bandwidth in the high duty cycle operations. The new LNM design enables heat effect in laser shooting at optical elements and mechanical components in the vicinity of an optical path to be lower. This reduces thermal wavefront deformation of a laser beam without helium gas purge within LNM, and narrows a spectrum bandwidth without helium purge. Gigaphoton proved that the new LNM enabled E95 bandwidth without control to improve a lot with nitrogen purge.

Keywords: DUV, ArF, photo-lithography, line narrow, 193nm lithography, Immersion, spectrum bandwidth, helium free

1. INTRODUCTION

Gigaphton has provided a lot of semiconductor plants with DUV light sources equipped with lithography tools for more than a decade. ArF eximer lasers over 300 units have been installed and have been running worldwide to meet the needs for high volume manufacturing of leading-edge semiconductor devices. A DUV laser consumes a large amount of resources to operate. As one of valuable resources, the noble gas helium has been used as a purge gas within LNM due to its extremely low thermal fluctuations of refractive index. The helium purge within LNM enables E95 bandwidth to be narrower. E95 bandwidth is one of key factor of a DUV laser for lithography performance such as image contrast. Namely, helium's unique property has determined semiconductor device performance and the yield. However, helium is a non-renewable resource and the world's reserves have been running out. This has caused the inflation of helium gas price for years. Gigaphoton has social responsibilities for saving rare resources, and our mission is to realize narrower E95 bandwidth with helium free operation[1][2].

2. Current LNM

Gigaphoton's ArF eximer laser is the injection lock system consisting of a master ocscillator(MO) and amplifier by a power oscillator(PO) as shown in Fig.1[3]. The MO has a LNM of a key module to decide a spectrum bandwidth

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performance.

2.1 Configuration of current LNM

A LNM has a grating to realize the extremely narrow bandwidth. The grating is arranged in Littrow configuration in which the diffracted beam propagates exactly in the opposite direction to the incident beam as illustrated in Fig. 2. The diffraction phenomena at the grating can be described through the diffraction formula;

$$2n\,d\;\sin\theta = m\lambda \qquad (1)$$

where *n* is the refractive index of the purging gas in the LNM, *d* is the period of the grating, is the incidence/diffracted angle on the grating, *m* is the diffraction order, and λ is the oscillating wavelength.

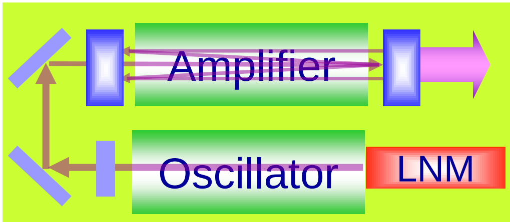

Fig.1 Schematic of Injection Locked based twin platform.

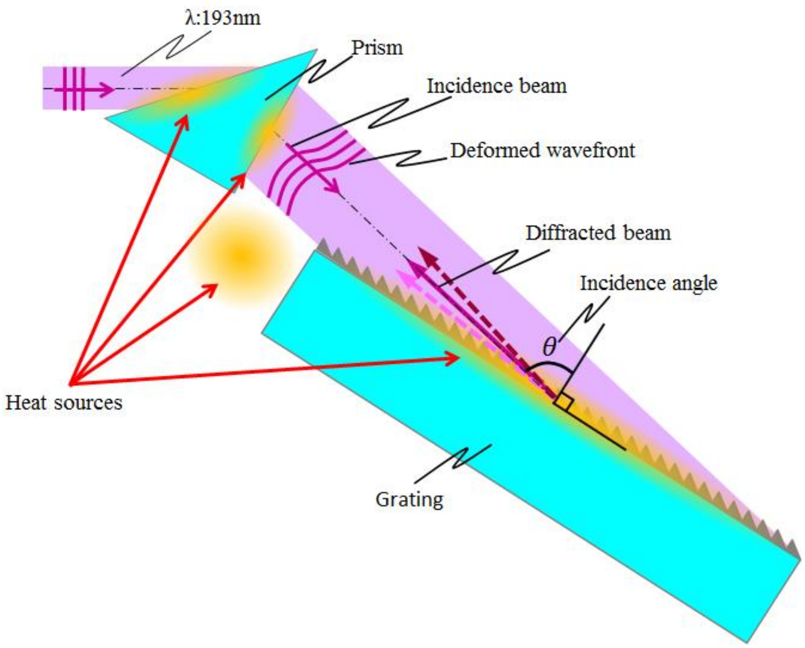

Fig.2 Schematics of Current LNM

2.2 E95 bandwidth degradation mechanism and E95 bandwidth performance in the current LNM

Laser shooting makes rises the temperatures of optical elements such as a prism and a grating, and mechanical components near optical paths within LNM. These temperature gradients generated in the optical paths create awful complicated refractive index distributions three dimensionally. The wavefront of propagating beam is deformed by the refractive index gradients to have higher order aberrations as shown in Fig.2. This varies locally incidence angles of rays on the grating in Eq.(1) and enables more multiple wavelengths to oscillate. Consequently, E95 bandwidth is degraded according to the magnitude of heat effects in the current LNM as shown in Fig.3. Furthermore, E95 bandwidth with nitrogen purge becomes broader than that with helium as shown in Fig.3 in the current LNM, because the refractive index variation of nitrogen is ten times more sensitive to temperature rises than that of helium as shown in Table.1.Therefore, helium is employed as a purge gas within LNM.

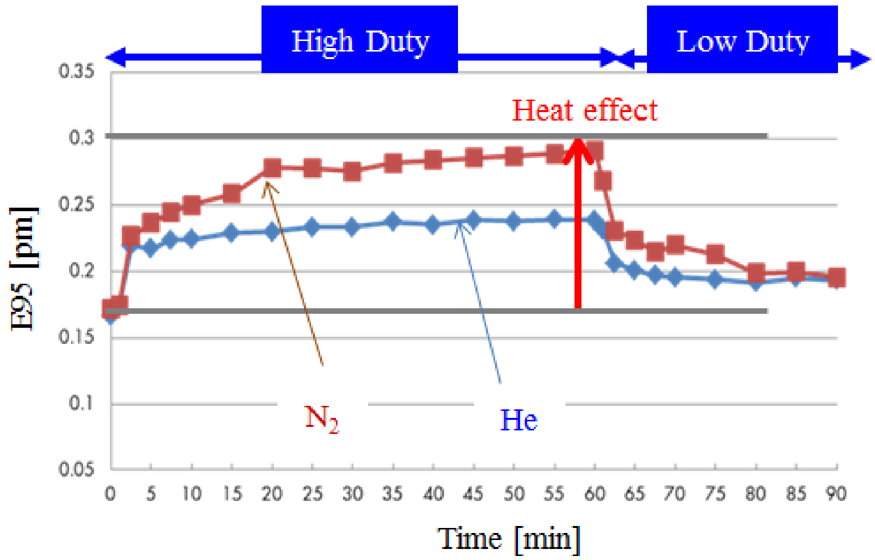

Fig.3 Typical E95 bandwidth without control in the current LNM

Speces	Refractive index	dn/dT
N2	1.000315	-0.9×10^{-6}
He	1.000035	-0.09×10^{-6}

Table1. Refractive index and dn/dT

3. E95 bandwidth in the new LNM

The new LNM enables heat effect in laser shooting at optical elements and mechanical components in the vicinity of an optical path to be lower. This reduces thermal wavefront deformation of a laser beam without helium gas purge within LNM as illustrated in Fig.4. The less aberration of a laser beam makes possible a narrower spectrum bandwidth because of the more uniform incidence angle on a diffractive grating. Actually, the thermal degradation of E95 bandwidth was improved a lot at highest duty cycle 75%, even nitrogen purge with the new LNM as shown in Fig.5.

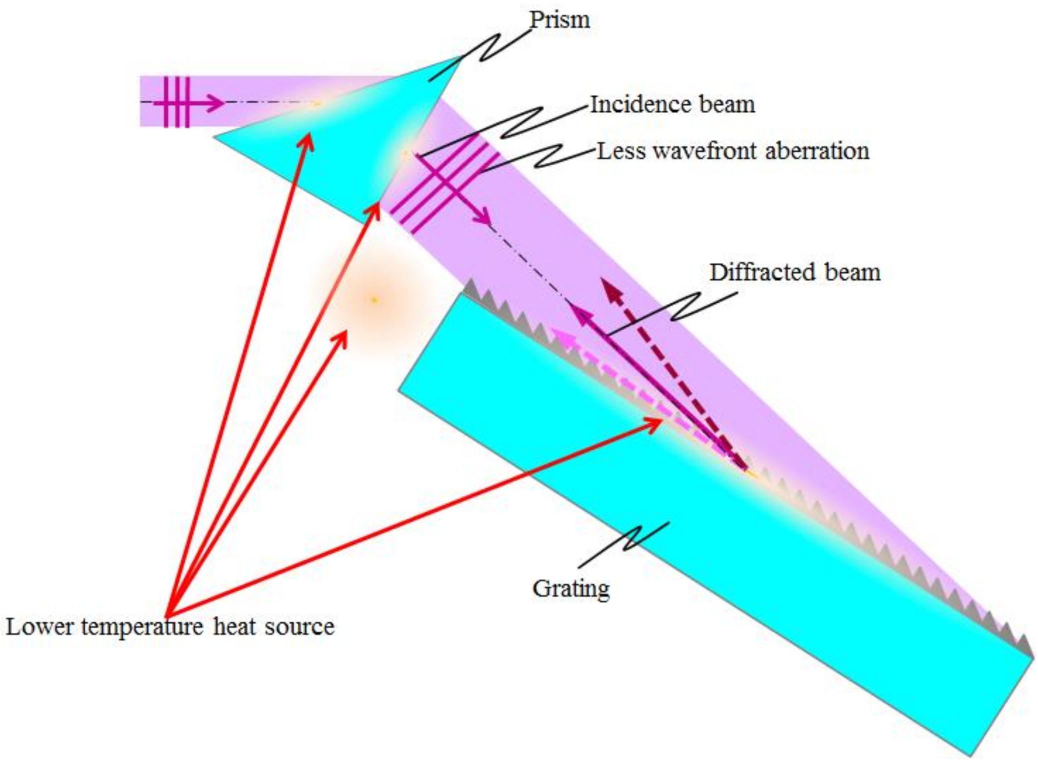

Fig.4 Schematics of heat effect reduction in the new LNM

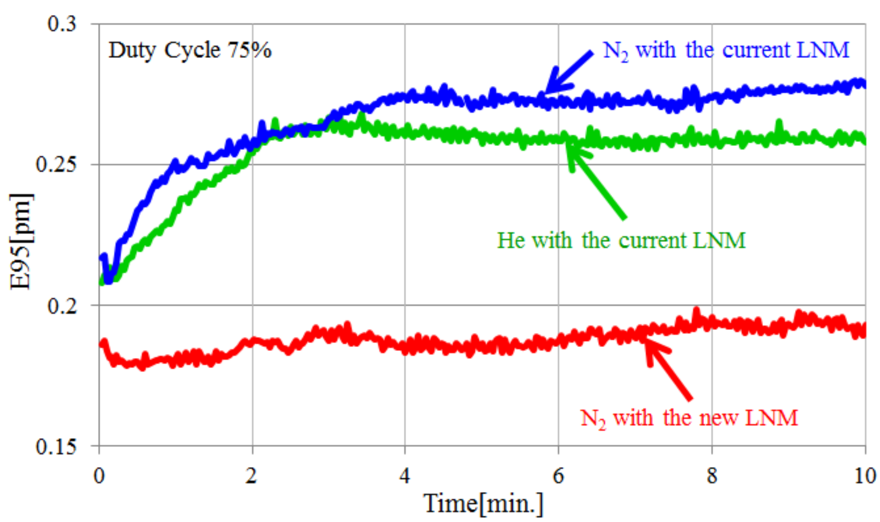

Fig.5 E95 bandwidth without E95 control in the new LNM

4. Impact confirmation of main laser performance with the new LNM

There is no difference between the two E95 burst average histograms of the current LNM and the new LNM for 750 bursts with E95 set point 0.3pm as shown in Fig.5(a) and Fig.5(b). Also, the worst wavelength moving average(MA) histograms of the current LNM and the new LNM for 2000 bursts is almost same as shown in Fig.6(a) and Fig.6(b). The same apply to the worst wavelength moving standard deviation(MSD) as shown in Fig.6(c) and Fig.6(d). Furthermore, the worst energy MA histograms of the current LNM and the new LNM for 2000 bursts is almost same as shown in Fig.7(a) and Fig.7(b). The same apply to the worst energy MSD as shown in Fig.7(c) and Fig.7(d). These suggest the new LNM has no influence on main laser performance of E95 stability with control, wavelength stability and energy stability.

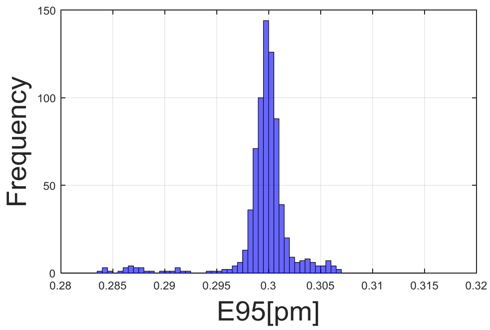

Fig.5(a):
E95average for 750 bursts with control in current LNM.

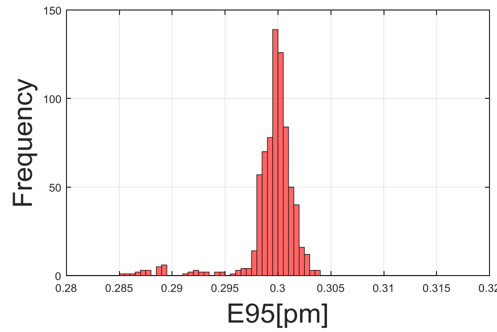

Fig.5(b)
E95 for average 750 bursts with control in new LNM.

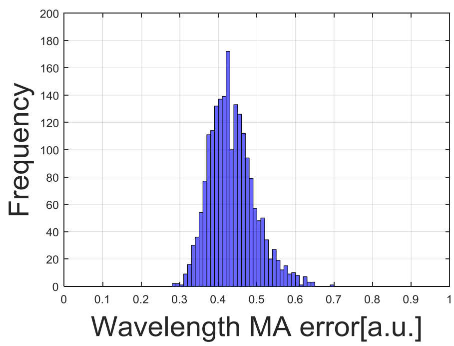

Fig.6(a):
Worst wavelength MA for 2000 burst in current LNM

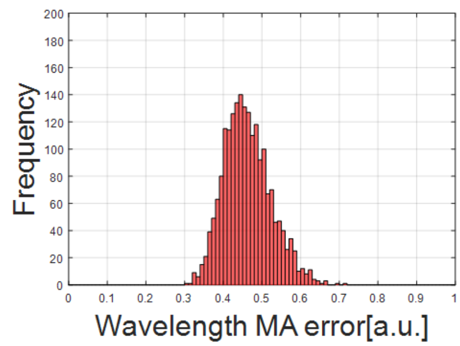

Fig.6(b):
Worst wavelength MA for 2000 burst in new LNM

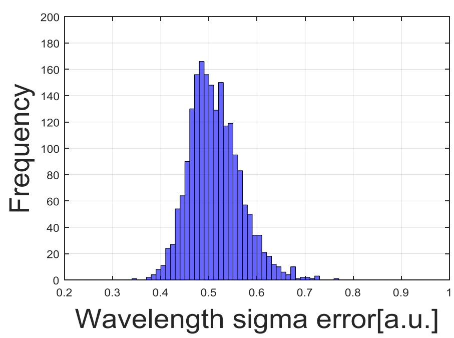

Fig.6(a):
Worst wavelength MSD for 2000 burst in current LNM

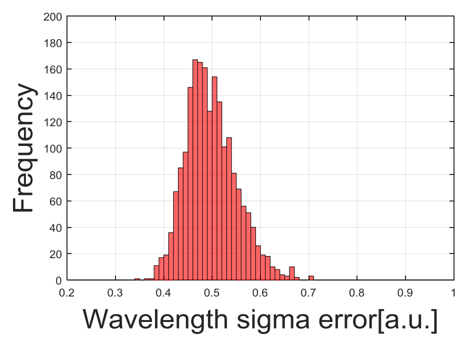

Fig.6(b):
Worst wavelength MSD for 2000 burst in new LNM

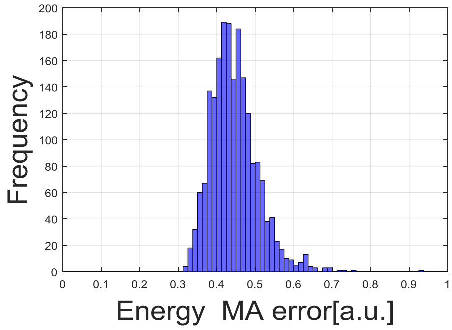

Fig.7(a):
Worst energy MA for 2000 burst in current LNM

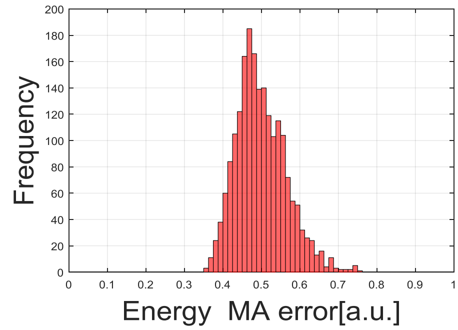

Fig.7(b):
Worst energy MA for 2000 burst in current LNM

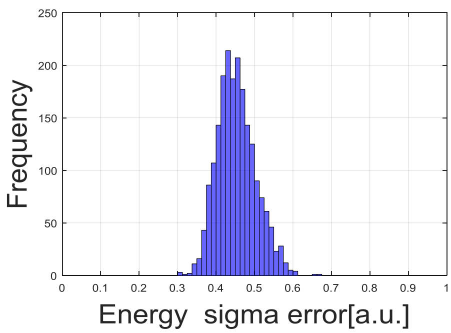

Fig.7(a):
Worst energy sigma for 2000 burst in current LNM

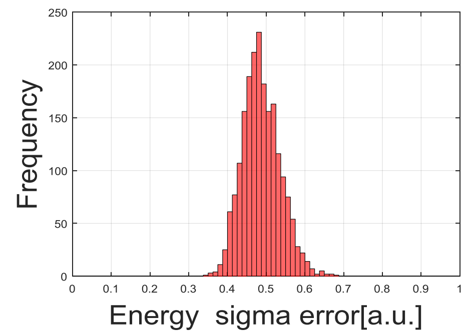

Fig.7(b):
Worst energy sigma or 2000 burst in current LNM

5. SUMMARY

The new LNM was developed to reduce the thermal degradation of E95 bandwidth without helium purge. Actually, it was proved that E95 bandwidth was greatly improved to be narrower even nitrogen purge by the new LNM. Furthermore, it was confirmed that the new LNM has no influence other main laser performance, such as E95 stability with control, wavelength stability and energy stability.

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