Reliability report of high power injection lock laser light source for double exposure and double patterning ArF immersion lithography

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ABSTRACT

ArF immersion technology is spotlighted as the enabling technology for the 45nm node and beyond. Recently, double exposure technology is also considered as a possible candidate for the 32nm node and beyond. We have already released an injection lock ArF excimer laser, the GT61A (60W/6kHz/10mJ/0.35pm) with ultra line-narrowed spectrum and stabilized spectrum performance for immersion lithography tools with N.A.>1.3, and we have been monitoring the field reliability data of our lasers used in the ArF immersion segment since Q4 2006. We show GT series reliability data in the field. GT series have high reliability performance. The availability that exceeds 99.5% proves the reliability of the GT series. We have developed high power injection lock ArF excimer laser for double patterning, the GT62A (90W/6000Hz/15mJ/0.35pm(E95)) based on the GigaTwin (GT) platform. Number of innovative and unique technologies are implemented on GT62A in order to reduce running cost of laser. We have introduced unique technology to enable 40 billion pulse lifetime of laser chambers to drastically reduce running cost. In addition, we have improved lifetime of Line Narrowing Module significantly by changing optical path. Furthermore, the extension of gas refill intervals was achieved by introducing new gas supply module and sophisticated gas control algorithm. We achieved the reduction of operation cost and down time by introducing these three technologies.

Keywords: double- exposure, Immersion, 32nm node, NA>1.3, ArF excimer laser, Injection Lock, high power, energy stability,

1. INTRODUCTION

193nm ArF light sources are widely used in semiconductor mass production from the 90 nm node and beyond.1) And the ArF immersion technology is even spotlighted as the enabling technology for the 45nm node and beyond. Beyond that, double patterning is considered to be most promising technology to meet the requirement of the next generation 32nm node. To achieve this, market demands for ArF light source are getting more severe, for example, higher power and narrower spectral bandwidth are required for higher throughput and higher NA lithography respectively.

With these backgrounds, we released reliable ArF light source for the 65nm node in 2005, the GT40A2) (4kHz/45W/0.5pm (E95)) based on injection lock technology developed in corporation with ASET3) in 2002.

In 2006, we succeeded in releasing second generation model, the GT60A with higher power (6kHz/60W/0.5pm(E95)) for higher throughput and higher NA first immersion tool. The third generation model, the GT61A (6kHz/60W/0.35pm(E95)) with narrower spectral bandwidth was released for higher NA lithography at the 45nm node in the following year. The fourth generation model, the GT62A (6kHz/90W/0.35pm) is developed and released to the market in order to meet the requirement of double patterning lithography at the 32nm node. For the GT62A, a variety of technologies to reduce the running cost of laser is introduced, which is applicable backward for the previous GT series lasers. In this paper, we report on the innovative and unique technology to reduce running cost of GT series and reliability data of the GT series in the field.

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Technology Node (typical)	Main driver	Requirement for ArF Laser light source	GT model
32 nm	double patterning higher throughput	6kHz/90W/0.35pm(E95)	GT62A
45 nm	higher NA	6kHz/60W/0.35pm(E95)	GT61A
50 nm	higher throughput higher NA	6kHz/60W/0.50pm(E95)	GT60A
65 nm	higher throughput	4kHz/45W/0.50pm(E95)	GT40A

Table 1. Technology nodes and required performance for ArF light sources

2. RELIABILITY OF THE GT SERIES

Now ArF lithography moves into high volume production, and reliability of the laser is industry's common request. We evaluated reliability by the following items as market reliability indicators.

MTBF (Mean Time Between Failures) This shows the robustness of laser.
MTTR (Mean Time To Repair) This shows the easiness to recover from failure.
Availability "Availability" shows system available time by percentage of total time.

We report on the reliability data of the GT series.

2.1 MTBF of GT series

The definition of MTBF in this report is shown as follows.

$$MTBFi = \frac{3\_months}{number\_of\_error}$$

where MTBFi is calculated for a single laser. Note if number of error is zero, MTBFi = full hours in the quarter.
After calculating MTBFi for all install base lasers, all MTBFi are averaged to obtain MTBF.

$$MTBF = \frac{\sum MTBFi}{number\_of\_install\_base}$$

Fig.1 shows MTBF of GT series. Continuously stays around 2,200 hours. The GT series shows very few failures and stable operation has been achieved.

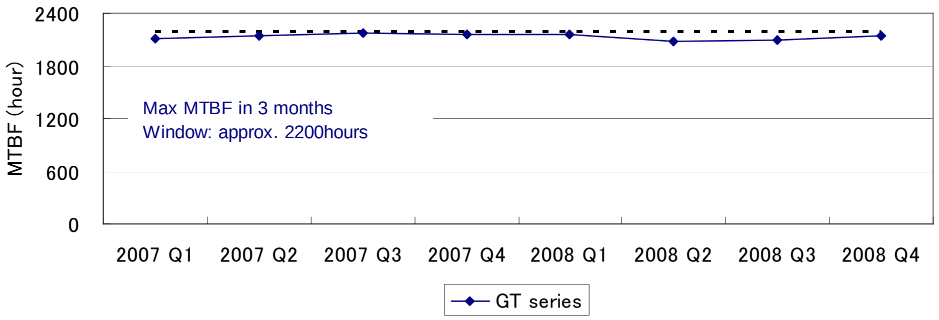
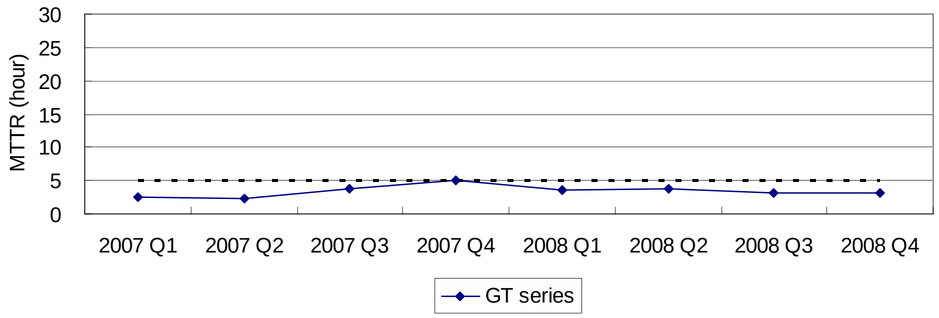


Fig.1 MTBF of GT series up to Q4 2008

2.2 MTTR of GT series

The definition of MTTR is calculated as sum of all repair time in 3 months for all install base lasers divided by number of repairs.

Fig.2 shows MTTR of GT series. MTTR stays below 5 hours. The downtime due to the failure is suppressed to very short time



. Fig.2 MTTR of GT series up to Q4 2008

2.3 Availability of GT series

The definition of Availability in this report is shown as follows.

Availability = [Total Hour – (Scheduled Downtime + Unscheduled Downtime)] / [Total Hour]

Availability of GT series up to Q4 2008 is shown at Fig.3 . GT series have high reliability performance. Various technologies used for GT series are contributing high reliability. The availability that exceeds 99.5% proves the reliability of the GT series.

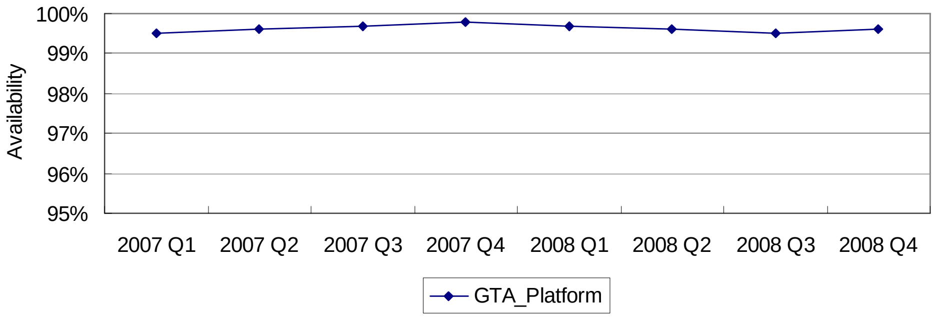


Fig.3 Availability of GTA lasers up to Q4 2008

GT series meet industry highest standard. MTBF continuously stays around 2,200 hours. MTTR stays below 5 hours. Availability continuously stays above 99.5%.

3. TECHNOLOGIES TO REDUCE RUNNING COST OF LASER.

3.1 Reduce running cost of GT series

The cost reduction technology is one of the newly developed technologies for the GT62A.
In the semiconductor industry, price competition has become more intense than ever. The reduction of the equipment running cost, therefore, is one of the major concerns. We have developed a variety of technologies to reduce the laser running cost, or the cost of operation (CoO). A Number of innovative and unique technologies are implemented on the GT series in order to reduce the running cost of laser.

1) Chamber lifetime extension
The Gigaphoton Recycled Chamber Operation System (GRYCOS) technology is developed as chamber lifetime extension technology. We have already introduced this unique technology in the filed to extend the lifetime of the laser chambers up to 40 billion pulses to drastically reduce the running cost.
2) LNM lifetime extension
There is Multi Positioning LNM (MPL) technology for extension of LNM lifetime.
We have improved lifetime of the LNM significantly by effectively changing optical path.
3) Gas lifetime extension
There is Total Gas Manager (TGM) technology for extension of gas lifetime. We have improved hardware and software needed for gas control.

We have applied these technologies to the install based lasers (GT40A , GT60A , GT61A), and enabled to improve reliability as well as to reduce running cost. The details of the technologies are introduced in the following chapter.

3.2 GRYCOS technology

Our injection lock system has the following features.

1) Oscillator and amplifier chambers have identical hardware.
2) In the amplifier position, a chamber can output enough power with a smaller input power compared to one in the oscillator position. Fig.4 shows output pulse energy characteristic for input energy. Due to this conditional difference, the lifetime of oscillator chamber is shorter than that of amplifier chamber. The actual lifetime of the amplifier chamber is estimated as 40 billion pulses, while oscillator chamber is estimated as 20 billion pulses.

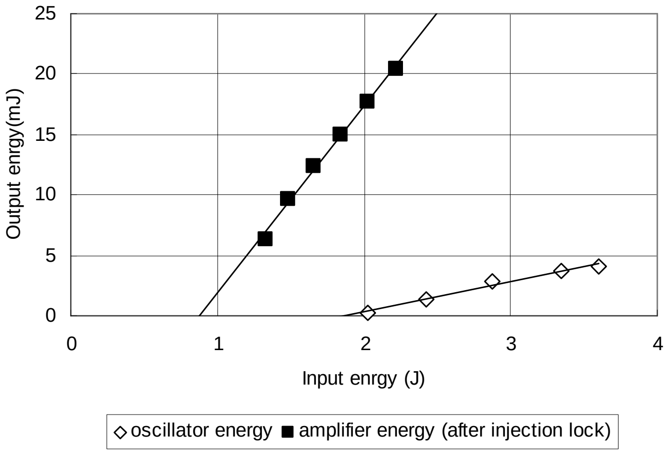


Fig.4 Output pulse energy characteristic for input energy

Fig.5 shows the trend of output energy to chamber pulse.

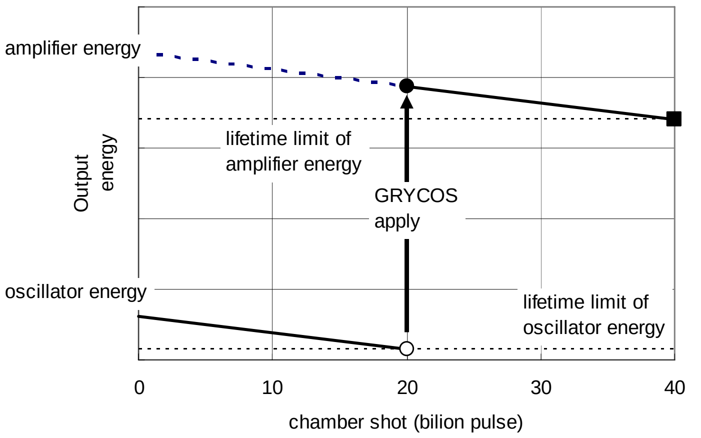


Fig.5 trend of output energy to chamber shot

In the GRYCOS technology, the oscillator chamber that has reached its lifetime of 20 billion pulses is used as the amplifier chamber until reaching another 20 billion pulses. As a result, each chamber can be used until it reaches 40 billion pulses, and the number of chambers is able to be degreased up to 2/3 compared with the conventional method. Table2 shows chamber replacement times simulated for total of 80 billion pulse operation.

method	Amplifier chamber replacement times	oscillator chamber replacement times	Total chamber replacement times
Conventioal	2	4	6
GRYCOS	0	4	4

* during 80 billion pulses

Table 2 chamber replacement times during 80 billion pulses

Below you will see the field data of GT40A laser for which the GRYCOS technology is applied at 26 billion pulses.
Its conditions are as follows.

GT40A laser		GRYCOS applied
Amplifier chamber at 26 billion pulses	->	26 billion pulses (chamber that reached lifetime at oscillator position)
Oscillator chamber at 26 billion pulses	->	0 billion pulses (new chamber)

Fig.6 shows the trend of the energy stability (dose stability). Fig.7 shows the trend of spectrum bandwidth (E95). Fig.8 shows the trend of wavelength error. All performances remain stable after the GRYCOS is applied. We verified stable laser performances after application of the GRYCOS technology in the field from these data.

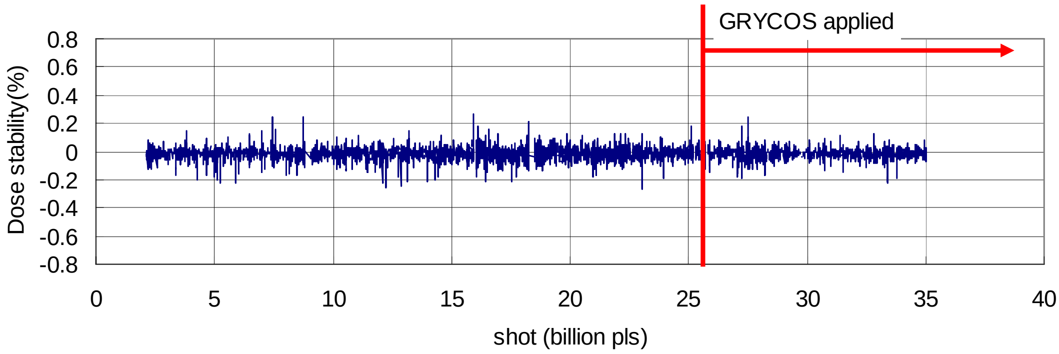


Fig. 6 trend of the energy stability (dose stability)

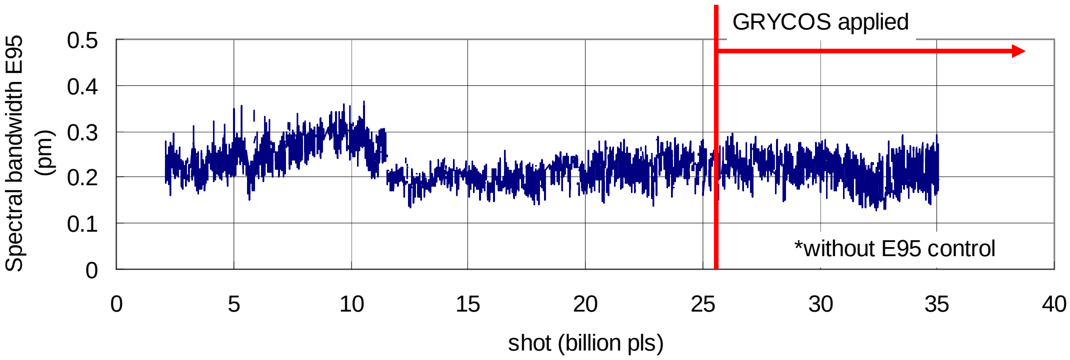


Fig.7 trend of spectrum bandwidth

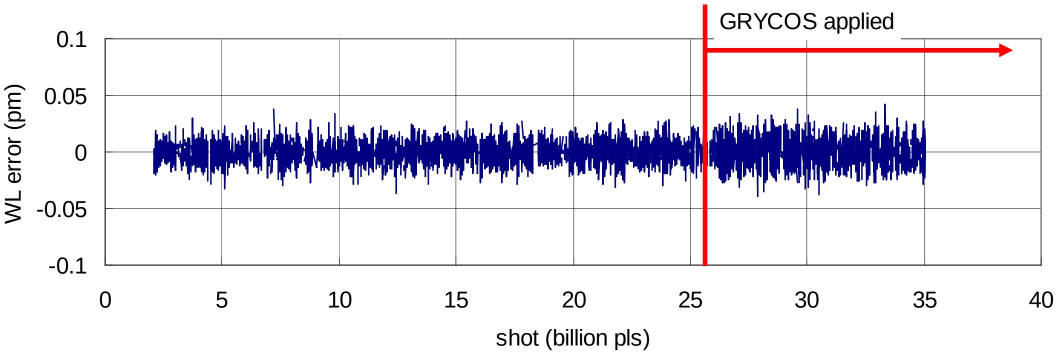


Fig.8 trend of WL error

3.3 MPL technology

The LNM consists of optical components such as prisms and gratings. The grating deteriorates by irradiation of laser beam on its surface. As the grating deteriorates, the reflectance drops and lowers the efficiency of the LNM. The deterioration is observed only on surface where the beam irradiated. As for the surface where beam doesn't irradiate, deterioration of grating efficiency is not observed. In MPL technology, the lower half of the grating surface is firstly used and then the upper half is used by changing the LNM position, thus we enabled the effective use of the grating. Fig.9 shows concept of MPL.

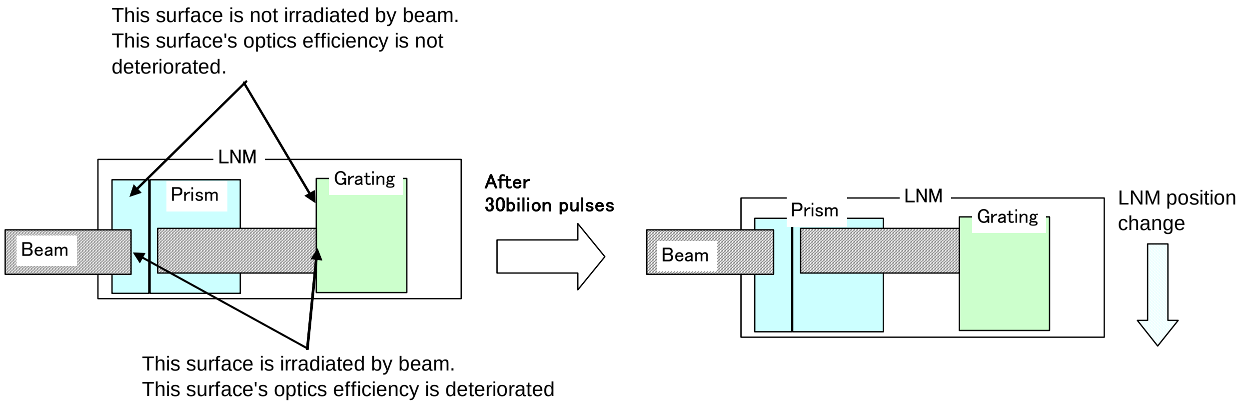


Fig. 9 Concept of MPL

We succeeded in extending the lifetime of LNM significantly by effectively changing optical path (by LNM position change). Since this allows recovery of the LNM efficiency, the lifetime of LNM extended from 30 billion pulses to 60 billion pulses. The number of LNM is able to be degreased up to 1/2 compared with the conventional method.

3.3 Reduce gas refill time (TGM technology)

The extension of gas lifetime is one of the demands from the market for ArF light source. The longer the gas lifetime is, the lower the gas refill frequency becomes. As the result, wafer productivity is improved. To satisfy the demand, both hardware and software are improved for the gas control.

In general, the causes of the gas deterioration are the consumption of fluorine and generation of impurities. Therefore, the addition of fluorine and control of the amounts of impurities by exhausts and injections were already performed in order to extend the gas lifetime. In addition, the chamber with a little generation of impurities was developed in the GT series.

However, fluorine partial pressure should be accurately controlled and the amount of impurity should be kept smaller by exhausts and injections. for a further gas lifetime extension. To satisfy the demand, both hardware and software are improved for the gas control. 8)

1) New gas supply module for the improvement of injection and exhaust accuracy
   (to improve accuracy control of fluorine partial pressure)
2) New gas control algorithm for adapting to the change of operating condition
   (to improve control accuracy of fluorine partial pressure and to keep the amount of impurities smaller by exhausts and injections.)

Fig.10 shows the trends of fluorine partial pressure for pulse at both the new control and the conventional control. These improvements enable the stable fluorine partial pressure with less than 1kPa error.

Fig.11 shows the trend of amount of impurities for pulse at both the new control and conventional control. This improvement enables the amount of impurity to be kept smaller by the exhausts and the injections.

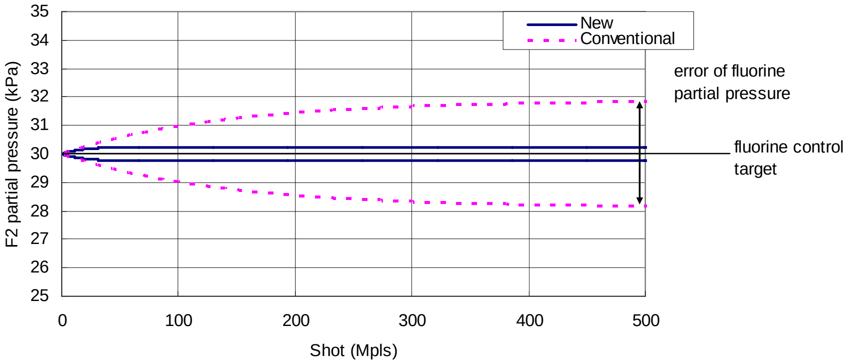


Fig.10 comparison of fluorine partial pressure by using new control and conventional control

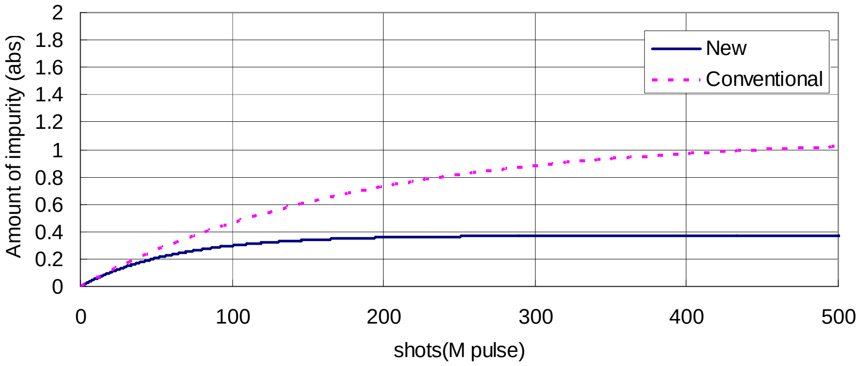


Fig.11 trend of amount of impurities for pulse at both the new control and conventional control

These improvements enable the extension of the gas refill interval from 3 days to 15 days, and as the result, downtime of only 24 times / year is realized;

By introducing the TGM technology to the GT40A we have confirmed the 15day gas lifetime performance.
Its conditions are as follows.

Pulse energy: 11.25mJ
Repetition rate: 4kHz
Duty cycle: 25% and 75% (changed alternately)
Total pulse count: 2billion pulses

Fig.12 shows the trend of energy dose stability. Fig 13 shows the trend of spectrum E95 measured with an external spectrometer. Dose and spectrum performance change due to the gas deterioration has been becoming small by implementing the TGM technology compared with conventional data (: the repeat of 100 Million pulses gas lifetime). Fig.14 shows the trend of wavelength error. All performances were very stable and deterioration was not observed during the gas lifetime.

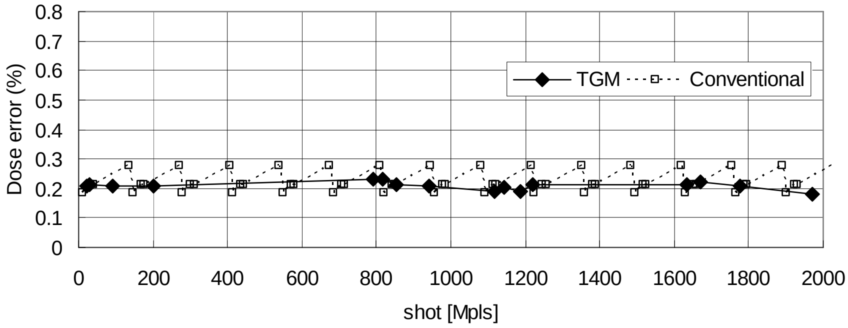


Fig.12. Trend of energy dose stability in during gas life

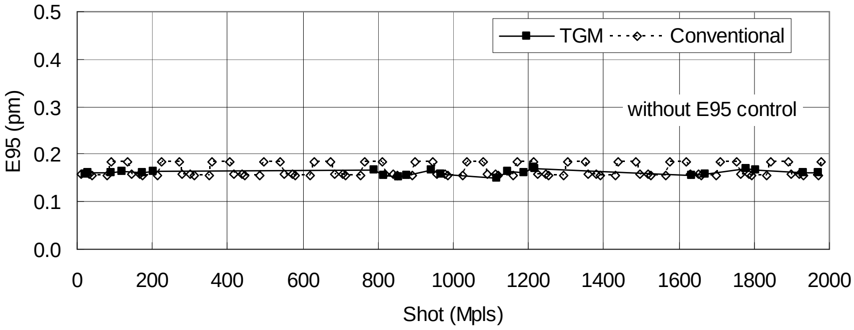


Fig. 13 Trend spectrum E95 measured with external spectrometer

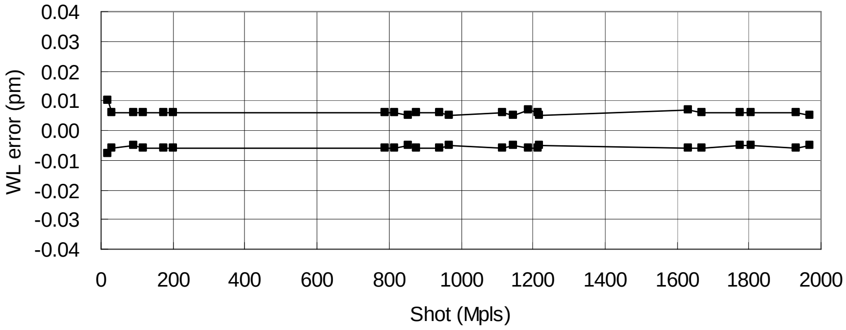


Figure14. Trend of wavelength error in during gaslife

4. SUMMARY

GT series show highly reliabile performance. GT series meet industry highest standard. MTBF continuously stays around 2,200 hours. MTTR stays below 5 hours. Availability continuously stays above 99.5%. The innovative and unique technologies are implemented on GT series in order to improve reliability. Running cost of laser is reduced significantly by introducing these technologies compared with the past. The improved effect of each technology becomes it as follows

GRYCOS ;	Chamber lifetime extension	20 billion pulses -> 40 billion pulses
MPL ;	LNM lifetime extension	30 billion pulses -> 60 billion pulses
TGM ;	Gas lifetime extension	3days -> 15days

These three technologies can be applied to all the laser types built on GT platform.

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