PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Extending green technology innovations to enable greener fabs

Kenji Takahisa, Young Sun Yoo, Hitomi Fukuda, Yuji Minegishi, Tatsuo Enami

Extending green technology innovations to enable greener fabs

Kenji Takahisa, Youngsun Yoo, Hitomi Fukuda,Yuji Minegishi and Tatsuo Enami
Gigaphoton Inc., 400 Yokokura-Shinden, Oyama-shi, Tochigi, JAPAN 323-8558
e-mail:kenji_takahisa@gigaphoton.com

ABSTRACT

Semiconductor manufacturing industry has growing concerns over future environmental impacts as fabs expand and new generations of equipment become more powerful. Especially rare gases supply and price are one of prime concerns for operation of high volume manufacturing (HVM) fabs. Over the past year it has come to our attention that Helium and Neon gas supplies could be unstable and become a threat to HVM fabs. To address these concerns, Gigaphoton has implemented various green technologies under its EcoPhoton program. One of the initiatives is GigaTwin deep ultraviolet (DUV) lithography laser design which enables highly efficient and stable operation. Under this design laser systems run with 50% less electric energy and gas consumption compared to conventional laser designs. In 2014 we have developed two technologies to further reduce electric energy and gas efficiency. The electric energy reduction technology is called eGRYCOS (enhanced Gigaphoton Recycled Chamber Operation System), and it reduces electric energy by 15% without compromising any of laser performances. eGRYCOS system has a sophisticated gas flow design so that we can reduce cross-flow-fan rotation speed. The gas reduction technology is called eTGM (enhanced Total gas Manager) and it improves gas management system optimizing the gas injection and exhaust amount based on laser performances, resulting in 50% gas savings. The next steps in our roadmap technologies are indicated and we call for potential partners to work with us based on OPEN INNOVATION concept to successfully develop faster and better solutions in all possible areas where green innovation may exist.

Keywords: DUV, KrF, ArF, photo-lithography, natural resources, green manufacturing, open innovation, injection-lock laser

1. RESOURCE CONSUMPTION BY LITHOGRAPHY LASERS

It has been more than a decade since semiconductor fabs started to implement lithography tools with DUV light sources, and more than 4,000 units have been installed around the world up to now. Every DUV scanner has one DUV laser unit and each one of them requires significant amount of resources to operate. These resources are laser gases, which are mainly Neon, and electric energy. If we take a fab with 10 KrF lasers and 10 ArF lasers, typical annual resource usages are 4 million liters of laser gas, 300 MWh of electric energy and heat management cost. The total estimated operating cost for this fab is $3M every year.

Furthermore the issue is not only cost but more importantly it involves natural resources which we all need to try to preserve by best possible ways as our responsibility to the society. Supporting semiconductor high volume manufacturing is our corporate mission and we have determined to provide the fabs with innovative technologies that enable more efficient, more cost effective and greener fab operations.

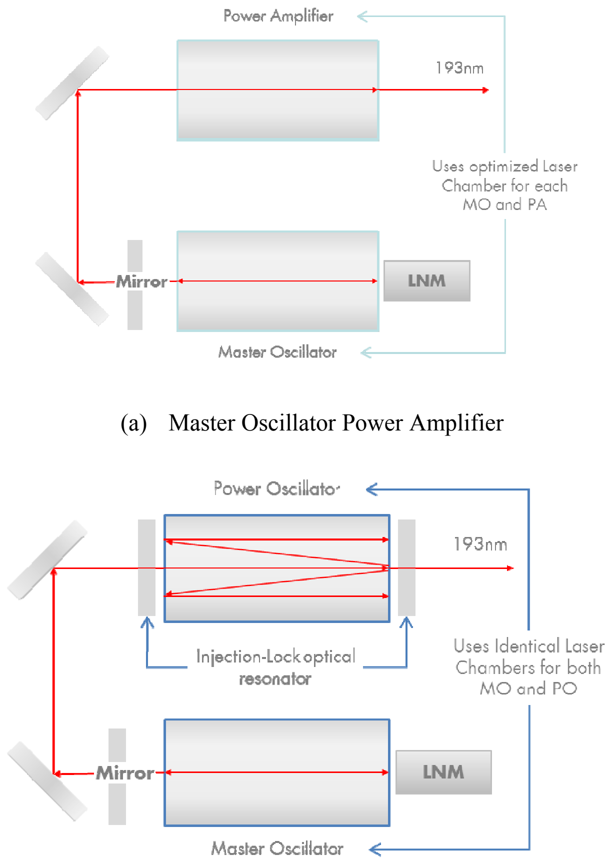
2. LASER DESIGN CHOICE FOR GREEN SOLUTION

One of the initiatives is the GigaTwin DUV lithography laser platform based on injection-lock technology [1]. It is the design choice based on two essential needs for high volume manufacturing fabs: efficiency and stability. GigaTwin lasers

Optical Microlithography XXVIII, edited by Kafai Lai, Andreas Erdmann, Proc. of SPIE Vol. 9426, 942628
 · doi: 10.1117/12.2180275

require only half the resources such as electric energy or gas compared to lasers on different design [2]. Together with other technical advances, injection-lock technology enables our laser systems to be technically and ecologically viable for HVM.

Injection-lock is a newer approach to a twin-chamber laser system and offers some advantages over master oscillator power amplifier (MOPA) systems used in other lithography equipment (see Fig. 1 (a)). In a traditional MOPA system, the master oscillator laser chamber generates a narrow spectrum seed light through an optical resonator consisting of a line-narrowing module (LNM) and a mirror. This light is then introduced into the power-amplifier chamber, where the power is amplified through a single-pass or double-pass amplification process. In the GigaTwin injection-lock technology platform, the narrow-spectrum seed light is generated by the master oscillator using the same process and technology as the MOPA systems. However injection-lock systems use a regenerative resonator with a pair of optical mirrors for power amplification chamber (see Fig. 1 (b)). The seed beam is regenerated by the round trip during the excitation lifetime of the dimer used (approximately 20 ns), which is equivalent to six-pass amplification. This is how the injection-lock system yields higher output energy efficiency compared to around two passes in traditional MOPA systems.



(a) Master Oscillator Power Amplifier

(b) Injection-lock system

Fig.1 Basic two laser architectures for lithography

A further benefit gained by this efficiency is gas usage reduction. All excimer lasers for micro lithography are gas lasers with one or two gas chambers. The laser gas contains fluorine which reacts with metal particles coming out from electrodes. During laser operation as fluorine concentration goes down, fresh gas needs to be introduced and at the same time degraded gas needs to be exhausted. This is how laser consumes gases. Since the amount of metal particles depends on electric energy applied between discharge electrodes, low electric energy means less metal particles, resulting in less laser gas degradation. Normally injection-lock technology consumes 50% less gas.

3. ROADMAP AND LATEST PROGRESS TO FURTHER ENABLE GREENER FAB

On top of design advantages of injection-lock technology, Gigaphoton has set a long term goal to further cut down gas reduction to one quarter and electric energy consumption to half by 2019 compared to our laser in 2013 when the roadmap was drawn [3]. Taking into the consideration that heat management cost is reduced when efficiency increases and electric energy consumption is cut down, total cost savings will be 70% by the end of the roadmap (see Fig. 2).

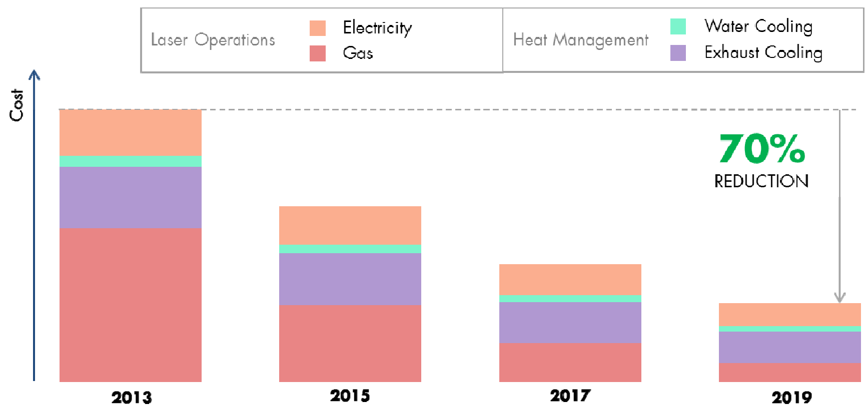


Fig.2 Gigaphoton green roadmap

As the first step in our roadmap, we have developed two innovative technologies to reduce electric energy and gas usage, bringing down the total cost by 35%.

3.1 Electric energy reduction technology

The technology to reduce electric energy is called "eGRYCOS" which reduces electric energy by 15% without compromising any of laser performances. The eGRYCOS consists of two technical advancements. The first one is a newly designed gas flow channel shape so that we can reduce fan rotation speed to obtain the same gas flow speed between discharge electrodes. Fan speed was successfully decreased by more than 10% without any performance penalty. The second improvement is optimized pre-ionization. Pre-ionizer generates uniform distribution of ions prior to main discharges, and the improvement can improve radiation efficiency by 20%. As a result a laser can operate at lower voltage and still keep the same performance.

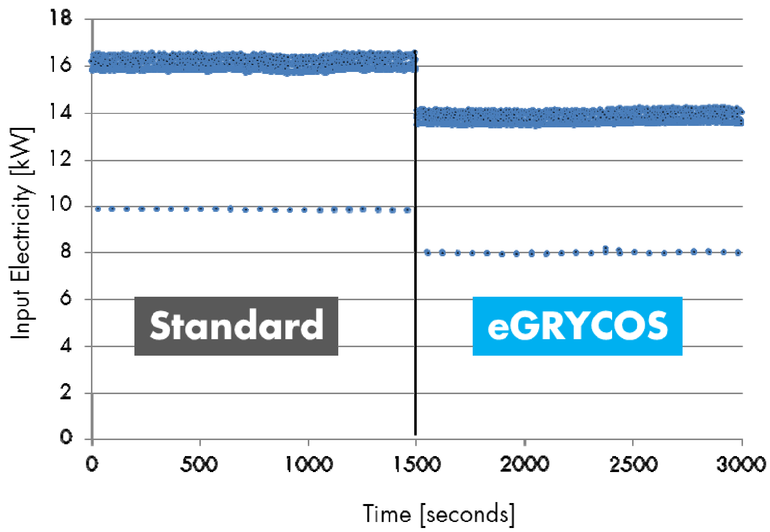


Fig.3 Electric energy consumption by eGRYCOS technology

Fig. 3 is actual electricity data showing eGRYCOS requires smaller electricity. At high duty cycle operations the electricity was improved from 16.2 kW to 13.8kW at around 1,500 second when eGRYCOS option was turned on. Data points at lower end indicate electricity when laser is in idle mode. Electricity savings by eGRYCOS are 15% and 20% at high duty cycle and idle mode respectively.

3.2 Gas reduction technology

The gas reduction technology is called eTGM and it is an improvement of gas management system, optimizing the gas injection and exhaust amount based on laser performance, resulting in 50% gas savings. Laser gas in discharge chambers deteriorates during laser operation as explained in section 2. Laser actively control gas pressure and its contamination level by injecting fresh gas and exhausting existing gas. Major laser performances such as laser energy and spectrum purity vary depending on gas contamination, gas pressure and fluorine concentration. Since gas injects and exhausts are continuously done on the background while a laser is under operation to expose wafers, the gas control must be carefully carried out without impacting laser performances. Fig. 4 shows the gas consumption trend comparison between eTGM and TGM over 500 Million pulses – an extensive period of laser operation. One can observe 50% saving.

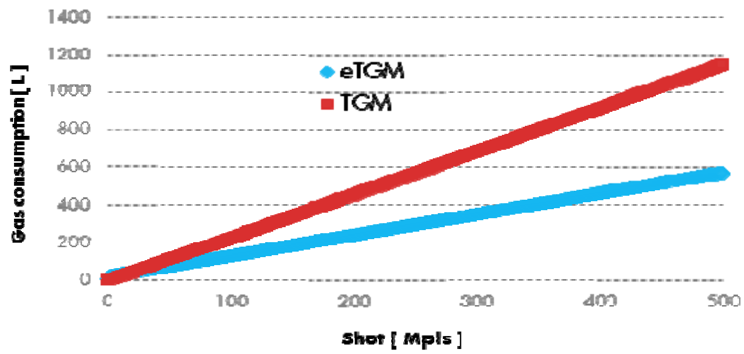


Fig.4 Gas consumption by eTGM technology in comparison to its predecessor, TGM

4. NEXT STEP: OPEN INNOVATION

Our next step in the roadmap is to cut down another 15-20% electric energy reduction and halving gas consumption. These technologies will be called hGRYCOS (h-series GRYCOS) and hTGM (h-series TGM) respectively, and collectively called "h-series" technologies.

With regard to hGRYCOS, we estimate electricity energy reduction could be possible by design optimization in electric circuit. One concept we are working on is better electrical matching between pulse power module and chamber to obtain better efficiency of electricity translation. However gas control has been continuously improved over the last decade and additionally halving the consumption is a real challenge. We need to consider recycling or reusing resources to meet the goal for hTGM (recycling concept is shown in Fig. 5).

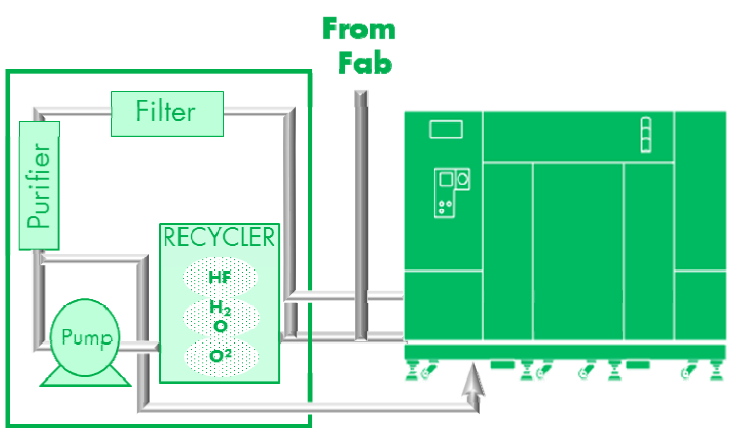


Fig.5 hTGM; gas recycling concept

Gas recycling technologies are completely outside of our expertise and require development from scratch, thus developing them by a single company would be very time consuming. We believe collaboration with external partners is the key to success for timely development and therefore we have been promoting OPEN INNOVATION to support such partnership. While some projects are initiated, we are still open to start working with new partners without limitation to gas recycling area but in variety of areas where green innovation may exist.

5. SUMMARY

Utilities such as gases and electricity of DUV lasers in semiconductor fabs costs non negligible and more importantly involves natural resources which we would like to preserve as our corporate responsibility to society.

In this paper the basic laser design choice was detailed and showed the advantages of injection-lock systems over the other solution with respect to light generation efficiency as well as gas consumption. Based on the injection-lock systems we have shown our green cost reduction roadmap up to 2019 to reduce resource consumption to significantly low level. Then as the first step in our roadmap we have developed two innovative technologies; the first one is eGRYCOS, educing electric energy by 15% without compromising any of laser performances and the other one is eTGM, optimizing the gas injection and exhaust amount based on laser performance which results in 50% gas consumption savings.

In the endeavor to future development for green innovations, we promote open innovation to work with external partners.

REFERENCES

[1] Tanaka, S., Tsushima, H., Nakaike, T., Yamazaki, T., Saito, T., Tomaru, H., Kakizaki, K., Matsunaga, T., Suzuki, T., Wakabayashi, O., Nagai, S., Fujimoto, J., Inoue, T. Mizoguchi, H., "GT40A: durable 45-W ArF injection-lock laser light source for dry/immersion lithography," Proc. SPIE, 6154, 615420 (2006)

[2] Fukuda, H., Young Sun, Y., Minegishi, Y., Hisanaga, N., Enami, T., "Advanced Excimer Laser Technologies Enable Green Semiconductor Manufacturing," Proc. SPIE, 9052, 90522J (2014)

[3] Young Sun, Y., Fukuda, H, Minegishi, Y., Hisanaga, N., Enami, T. "Advanced Excimer Laser Technologies Enable Green Semiconductor Manufacturing," MNC Advanced Photolithography, 6P-7-4 (2014)