Extremely long life and low-cost 193nm excimer laser chamber technology for 450mm wafer multipatterning lithography

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ABSTRACT

193nm ArF excimer lasers are widely used as light sources for the lithography process of semiconductor production. 193nm ArF excimer lasers are expected to continue to be the main solution in photolithography, since advanced lithography technologies such as multiple patterning and Self-Aligned Double Patterning (SADP) are being developed. In order to apply these technologies to high-volume semiconductor manufacturing, the key is to reduce the total operating cost. To reduce the total operating cost, life extension of consumable part and reduction of power consumption are an important factor. The chamber life time and power consumption are a main factor to decide the total operating cost. Therefore, we have developed the new technology for extension of the chamber life time and low electricity consumption. In this paper, we will report the new technology to extend the life time of the laser chamber and to reduce the electricity consumption.

Keywords: 193nm ArF excimer lasers, extend the life time of the laser chamber, reduce electricity consumption, long life, total operating cost,

1. INTRODUCTION

193nm ArF excimer lasers are widely used as light sources for the lithography process of semiconductor production. At first, ArF excimer lasers have been used in semiconductor productions at the 90nm node and recently ArF excimer lasers have begun to be used for the 32nm node, by the progress in the immersion technology and the multi-patterning technology. And the transition from 300mm wafer to 450mm wafer is expected to happen in this decade. Furthermore, considering current status of development of the lithography technology using a next-generation light source, or extreme ultraviolet (EUV) light source, the start of mass production with the next-generation light source is estimated to start from 2015. Therefore, there is a need for extension of 193nm immersion lithography technology. In order to apply these technologies to high-volume semiconductor manufacturing, 193nm ArF light source requirements are higher power and less total operating cost. To reduce the total operating cost, life extension of consumable part and reduction of power consumption are important factor. Therefore, we have developed the new chamber technology which enables low electricity consumption and long lifetime.

We have developed three technologies to realize low electric power consumption and extremely-long life time. Table 1 shows newly developed technologies. For reduction of electric power consumption, we improved the insulation parts inside chamber to avoid abnormal surface discharge at low CFF rotation speed. For extension of chamber life time, we developed two technologies. Firstly we enhanced the pre-ionization and secondly we applied “G-electrode” technology to pre-ionization electrodes. By applying these three technologies, we achieved 19% reduction of electricity consumption and over 60 billion pulses chamber life time.
Table 1. newly developed technologies

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<th>Newly developed technologies</th>
<th>Effect</th>
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<td>Improve the insulation parts inside chamber</td>
<td>To avoid abnormal surface discharge at low CFF rotation speed</td>
<td>Electric power consumption 19% decrease</td>
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<td>Enhance pre-ionization</td>
<td>Localized discharge is prevented and electrode consumption is decreased</td>
<td>Life time &gt;60 billion pulses</td>
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<td>“G-electrodes” for pre-ionization electrode</td>
<td>Maintain stable pre-ionization for longer period</td>
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2. TECHNOLOGY OF LASER CHAMBER

2.1 Function of laser chamber
The function and composition of chamber are shown in Fig.1. A function of excimer laser chamber is generation of excimer laser light. A laser chamber is filled with Ar gas and Fluorine gas with Neon as a buffer gas. A high voltage is applied to one pair of electrodes in laser chamber from pulse power module. And 193nm light is generated by discharge excitation. For efficient lasing it is necessary to have stable discharge, which is supported by high speed gas flow between two electrodes. The high speed gas flow is created by a cross flow fan inside the chamber.

2.2 Function of high speed gas flow
For stable discharges, high speed gas flow inside the chamber is required. The Cross Flow Fan (CFF) is used to make such high speed gas flow. Fig.2 shows chamber cross section view. After a discharge, we need to have high speed gas flow to blow.

![Fig.1 The function and composition chamber](image-url)
discharge product away before the next discharge. If gas flow speed is low, the clearance become too small and causes an abnormal discharge.

**Fig.2** The function and composition of high speed gas flow

2.3 Function of pre-ionization

To generate and maintain the stable discharge, pre-ionization function is very important. If chamber does not have the pre-ionization function, electron drift is small. Because the gap between electrodes is over 10mm and chamber gas pressure is about 400kPa. In this condition, it is difficult to generate and maintain the stable discharge. For stable discharge, there must be proper amount of electrons in the discharge area. The pre-ionization supplies electrons to discharge area before main discharge and make the main discharge stable. Therefore, the laser chamber is equipped with the pre-ionization function. Fig.3 shows pre-ionization function.

**Fig.3** The function and composition of pre-ionization

2.3 The factor which determines chamber lifetime

The electrode consumption was the main factor for limiting the chamber life time. The chamber electrode will be consumed by discharge in proportion to a laser pulse count. When electrode consumption reach acceptable value, laser chamber also reach the end of it’s life time. To extend the chamber lifetime, we have developed the specific electrode "G-electrodes" that reduce consumption of a main discharge electrode.[1],[2] The former electrodes are consisted of only metals. This means that it is difficult to prevent the ablation by main discharge. The other hand, the G-electrode has
protection film on the surface of metal. This film protects the metal from the ablation by discharges. By this technology introducing, current chamber life time was achieved 40 billion pulses. Fig. 4 shows current chamber consumption of electrode. In this time, we target on further extension the chamber life time by our new technology.

![Fig. 4 Current chamber consumption of electrode](image)

2.4 Analysis of total Electricity consumption

We investigated the current total electricity consumption. As the result, the rete of Cross flow fan (CFF) rotation electricity consumption is large (48%). Fig. 5 shows current total electricity consumption. From this result, we target to reduce CFF electricity consumption by our new technology.

![Fig. 5 Total electricity consumption](image)

3. NEW CHAMBER TECHNOLOGY

As show Table 1, we have developed three technologies to realize low electric power consumption and extremely-long life time chamber.

3.1 Improvement of the insulation parts inside chamber

In current chamber, the high speed gas flow by high CFF rotation speed is necessary to prevent the abnormal surface discharge. However, in this new chamber, the new insulator prevents an abnormal surface discharge. Fig. 6 shows the
effect of new insulation parts. As the result, between the discharge product by former pulse and main discharge become smaller and gas flow can be set lower, and CFF rotation speed can be set slower speed.

By improving the insulator, abnormal surface discharge is prevented. Fig.7 shows relation between clearance safety margin and CFF rotation speed. The dotted line is the criterion value for clearance. Under the criterion you will have abnormal surface discharges. The reduction of CFF rotation speed by the new technology was 23% by simulation. Reduction of 23% CFF rotation speed is directly translated into 40% less electricity power consumption. Fig.8 shows relation between CFF rotation speed and CFF power consumption. Based on the previous data that about half of total electricity consumption was used on CFF rotation, this means we can save 19% of laser total electricity consumption by this new technology. Fig.9 shows laser total electricity consumption by applying the new technology.

Fig.6 Effect of new insulation parts

Fig.7 Relation between clearance safety margin and CFF rotation speed (simulation)

Fig.8 Relation between CFF rotation speed and CFF power consumption

Fig.9 Laser total electricity consumption by applying the new technology
3.2 Enhanced Pre-Ionization
For extension of chamber life time, we developed the pre-ionization enhancement. If pre-ionization is not strong enough, localized discharge are occurred. By improving pre-ionization strength, localized discharge can prevent and electrode consumption is decreased and the chamber lifetime is extended.

3.3 Applying “G-electrodes” for pre-ionization electrode
To maintain stable pre-ionization for longer period and to reduce consumption of pre-ionization electrode, we applied “G-electrodes” for pre-ionization electrode. By improving pre-ionization electrode lifetime, stable pre-ionization is secured for a long period. Therefore, electrode consumption is decreased and the chamber lifetime is extended. Fig.10 shows consumption of electrode with current and new chamber design. In the new chamber, thanks to these two new technologies (enhance pre-ionization and “G-electrodes” for pre-ionization electrode), electrode consumption is decreased 45%.

![Fig.10 consumption of electrode with current and new chamber](image)

4. PERFORMANCE OF NEW CHAMBER

4.1 Durability performance
Fig.11 shows Dose stability performance of new chamber during 60 billion pulses. Dose stability is very stable and maintained 60 billion pulses.

![Fig.11 Dose stability performance during 60 Billion pulses](image)
Fig. 12 shows Wavelength error performance of new chamber during 60 billion pulses. Wavelength error is very stable and maintained 60 billion pulses.

![Wavelength error performance during 60 Billion pulses](image)

Fig. 13 shows Bandwidth stability performance of new chamber during 60 billion pulses. Bandwidth stability is very stable and maintained 60 billion pulses.

![Bandwidth stability performance during 60 Billion pulses](image)

5. CONCLUSION

GIGAPHOTON has developed extremely efficient and long-life 193nm excimer laser chamber.

- Improved insulator in the chamber enables 19% reduction of electricity consumption
- Enhanced pre-ionization and applied “G-electrodes” for pre-ionization electrode to realize 60 billion pulse chamber life time.

GIGAPHOTON will start supplying newly designed chambers to the field upon completion of practical preparations.
6. REFERENCES
