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著者	堀田栄喜
Author	EIKI HOTTA
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Discharge Produced Plasma EUV Light Source
放電プラズマによる EUV 光源

Eiki Hotta
堀田栄喜

Department of Energy Sciences, Interdisciplinary Graduate School of Science and Engineering,
Tokyo Institute of Technology
Nagatsuta 4259 J2-35, Midori-ku, Yokohama, Kanagawa 226-8502, Japan
東京工業大学大学院総合理工学研究科創造エネルギー専攻
〒226-8502　神奈川県横浜市緑区長津田町 4259 J2-35

To produce high performance LSIs, EUV light source at 13.5 nm for micro lithography is under development. The development started with xenon, however, to attain higher conversion efficiency, tin is now used as fuel. Since the required EUV power at the intermediate focus is 180 W which is much larger than that currently attained by discharge produced plasma, further research is required. Current status of EUV source will be given.

1. Introduction

In order to realize the higher performance of large-scale integrated circuit (LSI) by increasing the processing speed, the half-pitch (hp) of LSI has been more and more decreasing along the well-known Moore’s law for more than 30 years, which tells that hp decreases by 0.5 in every 3 years. The technology which achieved the higher degree of integration of LSI is the lithography.

ArF eximer laser at 193 nm is currently used as a light source for micro lithography. However, since the printable hp is proportional to the wave length of light source as given by Rayleigh’s equation, the development of a new light source with shorter wave length is demanded. The potential next generation light source is the extreme ultraviolet (EUV) light source at 13.5 nm. The development has started in 1997 by EUVLLC in the United States. In Japan, EUVA [1] was established in 2002 to develop fundamental technologies for EUV lithography, especially for the development of EUV light source and EUV optics.

In this presentation, the principle and the current status of EUV light source will be given.

2. Requirements for EUV light source

EUV used for lithography has wave length of 13.5 nm and is easily absorbed by materials including gases. Therefore, the reflection optics must be used instead of lens optics and EUV must be transmitted in vacuum. The maximum obtainable reflectivity of multi-layer Mo/Si mirror is around 70%, therefore the transmitted power at a wafer through the illumination system with several mirrors and a mask is less than 1% of the power obtained at the intermediate focus (IF).

According to ITRS2007 [2], requirements for the EUV source are summarized as follows; for the high volume manufacturing (production of exposed 100 wafers of 300 mm in diameter per hour), the source power at IF within 2% band width at 13.5 nm should be 115 W supposing the resist sensitivity of 5 mJ/cm^2. However, 180 or 200 W at IF is required recently for the realistic resist sensitivity of 10 mJ/cm^2. Since the collection efficiency of the multi shell mirror is around 10-20%, the radiation power of plasma should be more than 1800 W, while the power of several 100s W is currently obtained . The life time of the source module should be more than 30,000 hours. Therefore the issue is to develop a high power and debris free EUV light source.

3. EUV light sources

There are two types of EUV light sources, that is, laser produced plasma (LPP) and discharge produced plasma (DPP) sources which are based on high-density and high-temperature xenon (Xe), tin (Sn) or lithium plasmas. The development of EUV light sources started with Xe as fuel gas. However the conversion efficiency of Xe is shown to be lower compared with that of Sn, and thus Sn becomes the most used fuel at present.

3.1 *Principle of DPP sources*

Simple emission model (Collisional-Radiative Model) estimates that the optimum electron density and temperature of plasma are 20-40 eV and 10^{17}-10^{19} cm^{-3}, respectively. To produce such hot and dense plasma, the dynamic Z-pinch is used. The plasma is compressed and heated by a current sheet and a shock wave driven by the current sheet, and the kinetic energy of imploding plasma is converted to the thermal energy near the maximum pinch. However, the produced hot and dense plasma can be sustained for only a short duration less than 100 ns because the plasma pressure exceeds the magnetic pressure, which causes the low conversion efficiency (CE) from the electric to EUV energy.

3.2 *Xe DPP source*

The development of EUV source started with Xe which has a peak spectrum at 11.5 nm, for which a Mo/Be multi layer mirror has high reflectivity. However, stepper makers refused to use a mirror containing Be and determined to use a Mo/Si mirror which has its peak reflectivity at 13.5 nm. This caused the incompatibility of the EUV emission peak of Xe and the reflection of mirror. Therefore, the improvement of CE became the main issue.

Another issue is the debris mitigation. It was shown that current with high increase rate and short duration could reduce the debris from electrodes and insulators [3]. The ultimate method to reduce the debris from insulator is not to use the insulator but to use gas jet. In this case the electrode structure as shown in Fig. 1 is used and EUV is collected from radial direction [3]. In addition an annular coaxial helium gas curtain works to reduce the debris further. In general such gas jet does not have any well-defined boundary and it is believed that the initiation of Z-pinch is difficult. However, we were successful to get Z-pinch and to observe EUV emission as shown in Fig.2.

The maximum CE of Xe ever obtained was less than 1% and therefore to get higher EUV power, higher electric input power is necessarily required and this leads to higher heat load on electrodes. To reduce the input power, Sn which has higher CE became to be used.

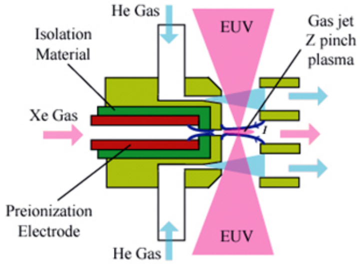

Fig.1 Schematic of gas-jet Z-pinch light source

3.3 *Laser assisted Sn DPP source*

Sn has many line spectra at 13.5 nm emitted by highly charged ions as shown in Fig. 3, thus the CE will be higher [4]. Low-power pulse laser is used to vaporize Sn and initiate discharge, therefore it is called laser assisted DPP (LADPP) source.

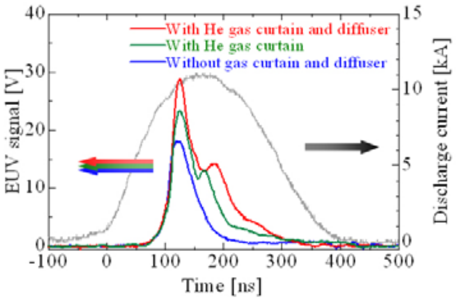

Fig.2 Wave forms of discharge current and EUV output signals with and without curtain gas

The size of generated Sn plasma is small enough to be used for EUV light sources.

An issue is to attain high repetition rate operation to obtain higher EUV power, which is prevented by the residual Sn vapor between electrodes. Measurement of residual Sn vapor by laser induced fluorescence (LIF) confirmed that the possible repetition rate will be more than 50 kHz.

Even if Sn has higher CE, heat load on electrodes in high repetition rate operation is another issue and a system with rotating disk electrodes, a part of rim of which is bathed in a Sn bath to remove excess heat and recover the evaporated Sn pit, was proposed and being successfully tested.

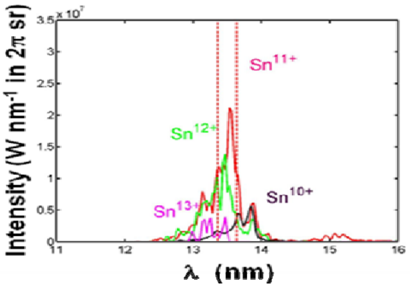

Fig.3 Spectral intensities of Sn ions

4. Summary

The development of EUV source started with Xe, however Sn was substituted for Xe because of its low CE. LADPP source is being successfully tested and the first LADPP EUV light source will hopefully be installed in a β machine in a few years.

Acknowledgment

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