A Trend in Pulse-Powered Plasma Radiation Source

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Recent progress of semiconductor power devices has shifted our interests on pulsed-power energy driver from a huge energetic system to a high-average-power compact generator. Intense extreme ultraviolet radiation sources have been developed using those devices. It is considered that they can be the light sources for microscopy and the next generation microlithography. A trend and a prospect for the pulse powered radiation sources are briefly described.

Keywords : pulse power generator, extreme ultra violet (EUV), radiation source, high energy density plasma

1. Introduction

By a properly formed electromagnetic pulse, we can make an extremely high energy density condition that can be utilized for generation of high power lasers, high current particle beams, intense radiations and thermonuclear fusion. During the last two decades, power semiconductors extend the capability of pulse power devices and they have found various new application fields such as materials, energy, environmental, biochemical and/or medical technologies. When a conditioned electromagnetic energy is put into a certain material, they can be heated up to form a plasma with a condition appropriate for coherent or incoherent emission of extreme ultraviolet (EUV) radiation. The source plasma has advantages for various applications, such as EUV or soft-X-ray microscopy, spectroscopy, materials processing, and microlithographic imaging. In particular, a bright radiation from a discharge produced high energy density plasma is expected to be a possible light source in EUV region for the next generation lithography.

2. Plasma-Based Bright Radiation Sources

The source plasma is produced through a pinching process. A schematic of the pinching plasma is shown in Fig.1. As shown in the figure, self magnetic field $B_\theta = (\mu_0 I^2) / (8\pi R^2)$ induced by the plasma current I , confines the radiating plasma. Thus the plasma parameters appropriate for the radiating plasma, both incoherent and coherent extreme ultraviolet sources, can be basically controlled by the discharge condition.

2.1 Coherent Radiation Sources When parameters of a highly ionized plasma is properly controlled, the plasma can make a lasing condition. In the discharge laser scheme, a fast pulse power drives the plasma in a capillary tube to make a highly ionized, appropriate plasma condition for stimulated amplification radiation in Ne(neon)-like or H(hydrogen)-like ions. For example, a typical operating condition of the discharge pumped Ne-like Ar laser is shown in Table.1.

In the discharge pumped laser scheme, a fast pulse power generator drives a discharge plasma in a capillary tube to make a long, cylindrical lasing plasma. Continuous efforts are made for energetic operation at shorter wavelength. Correlation between

Fig. 1. Cylindrical radiating plasma formed by pinching process

the discharge dynamics and the plasma parameter that leads to a lasing condition are investigated and the dominant operating parameters for an energetic lasing are clarified, using experimental, analytical, and numerical approaches⁽¹⁾. The results indicate that the dynamics of pinching plasma plays a crucial role to make appropriate lasing plasma.

2.2 Incoherent Radiation Sources EUV lithography is considered to be the successor of optical processing. In the lithography system using EUV light source, at EUV region any materials absorb the radiation so strongly that the optics must be composed of reflecting components and the entire process must be taken place in vacuum. That requests the source should be a plasma in vacuum and the average power has to be more than 110W, at wavelength of 13.5nm, into a bandwidth of 2%. Two different approaches are developing for making the EUV source plasma; laser produced plasmas and discharge produced plasmas. Mainly from the point of construction cost and system efficiency, interests in discharge produced plasmas are increasing.

The discharge produced plasma is compressed and heated through a pinching process. At the stagnation phase, the compressed plasma emits the radiation. When we control the operating parameters so as to make a proper plasma parameter, the compressed plasma is expected to emit a bright radiation centered at 13.5nm. Compared with the laser produced plasma, the discharge plasma has a number of advantages. In particular, the discharge device has a lot of control parameters, such as electrode geometry, working gas density, its distribution and

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Table 1. Typical operating condition of pulse-powered discharge (Ne-like argon) laser

Driver Energy	~1kJ
Capillary Diameter	3mm
Capillary Length	100-300mm
Filling Pressure	100-1000mTorr(Ar)
Current Rise Rate	10^{11} - 10^{12} A/sec
Pre-ionization Current	50-90A

Fig. 2. Schematic of a pulse power generator for plasma source

current shape. Optimization of these parameters should bring a source quality sufficient for the lithography system⁽²⁾.

2.3 Pulse Power System for Plasma Radiation Source

The discharge produced plasma is generated by a fast pulse power generator with high repetition capability and long life time. Switching devices such as MOS-FET(Metal-oxide semiconductor field effect transistor), SITHy(Static induction thristor), IGBT are the key components for the pulse powered generator.

A schematic of the typical pulse power device for the discharge produced radiating plasma is shown in Fig.2. The device consists of a primary pulse forming section driven by the semiconductor power devices, a step-up pulsed transformer PT, and two-stage magnetic pulse compression unit that is driven by magnetic switches MS. Through the pulse-forming and compression processes, finally it drives a discharge current of ~10 kA with a few 100nsec of pulse width.

3. Conclusion and Prospect

Supported by the technological progress of semiconductor power devices, high average power plasma radiation sources have been developed and expected to be used in a variety of applications. Although the EUV lithography is probably the most challenging application, the basic operation of plasma based radiation source can be predictable and scalable with the aid of numerical analysis based on Magneto-hydrodynamics. All of the experimental, analytical, and numerical results indicate advantageous property of the discharge produced radiating plasma as the high average power bright radiation source, in particular, for the next generation lithography light source⁽³⁾.

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