論文 / 著書情報
Article / Book Information

題目(和文)	Xenonガスジェット型13.5 nm 極端紫外線プラズマ光源のZピンチダイナミクスに関する研究
Title(English)	Z-pinch Dynamics in a Xenon Gas Jet Type 13.5 nm Extreme Ultraviolet Plasma Source
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種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	創造エネルギー　　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
学生氏名： Student's Name	黄　斌	指導教員（主）： Academic Advisor(main)	堀田　栄喜　　教授
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The main goals of the research reported in this thesis are as follows. The first one is to diagnose the plasma produced in a 13.5 nm Xe DDP EUV source, in order to understand the plasma dynamics during the whole discharge process. Then, to further understand the plasma dynamics in the EUV source and explain some experimental phenomena, the second goal is to simulate the plasma behaviors in the DPP EUV source. Finally, based on both experimental and numerical investigations, we propose possible ways to optimize the EUV source. Although this work focuses on the 13.5 nm Xe DPP EUV source for EUV lithography, the extent of the plasma diagnostic techniques and simulation code are not limited to this specific devices. Instead, they can be applied to other plasma sources with similar properties. The main conclusions of this thesis are:

1) The time-resolved EUV emission was measured and the preferred experimental conditions were quantified, and analyzed with MHD simulation. The preferred inlet gas pressure was 25 Torr, and the preferred electrode gap length was 16 mm. The inlet gas pressure played a dominant role in determining the EUV radiation. According to the simulation, higher pressure (and thus initial density) can delay the pinch time, alter the final pinch state, and lead to a lower pinch temperature. In contrast, there was a peak pinch density when initial density was 2×10^{16} cm^{-3}. The optimum initial density for EUV output is $2\sim3\times10^{16}$ cm^{-3}.
2) The plasma dynamics in Z-pinch were studied with both time-resolved plasma imaging and MHD simulation. The initial discharge radius was about several mm. At stagnation, the emission became strongest, with a pinch radius of ~0.1 mm. After that, due to Zippering effect, the radiating column was elongated and then moved along *z* axis. The simulation showed that during implosion phase, a shock front was formed ahead of the magnetic piston. The heating mechanisms for ions and the electrons during implosion were shock heating and Joule heating, respectively. At pinch stagnation, the kinetic energy of plasma was transferred to thermal energy, and caused the abrupt increasing of electron and ion temperature, achieving an ideal condition for EUV radiation.
3) The electron density was on the order of $10^{18}\sim10^{19}$ cm^{-3} in the Z-pinch. The EUV intensity peaked quite near electron density maximum (~10^{19} cm^{-3}) during the pinch process, within the theoretical optimum electron density range for EUV radiation.
4) The most probable ion velocity was ~18 km/s. Most ions had kinetic energy smaller than 500 eV. The ion velocity distribution follows SMB fitting.
5) The EUV radiation fluctuation due to MRT instabilities was observed experimentally, and studied

numerically and analytically. Pinhole imaging reveals that the MRT instabilities can be suppressed with sufficient RF pre-ionization; however, when it existed, its wavelength was always around 1 mm. The evolution of MRT instabilities with single mode, multi-mode, and random mode perturbations were simulated. Higher order harmonics appeared when the MRT entered into non-linear regime. Modes with shorter wavelengths grew faster than longer ones. The mode coupling effect played an important role in the evolution of multi-mode MRT instabilities, which led to the generation of a series of new modes. For random mode perturbation, the final dominant modes tended to converge to a mm-scale wavelength around 1 mm, consistent with the experimental result. According to the analytical solution of the MRT instabilities, short wavelength modes perturbation cannot penetrate into the plasma shell deeply, and were thus localized near the surface region. Only those modes with wavelength on the order of shell thickness or longer can penetrate into the shell and further develop during Z-pinch. For the resting modes, the ones with shorter wavelengths grow faster; thus the final dominant modes are those with wavelengths ~1 mm.

6) The influences of MRT instabilities on pinch stagnation and EUV output were investigated and three mitigation methods were proposed to optimize the EUV source. MRT instabilities was proved to cause the temperature and density fluctuations along *z* axis, which was responsible for the non-uniformity of the EUV radiation. Longer wavelength perturbation caused a more pronounced the fluctuation. The RF pre-ionization can suppress the initial amplitude of perturbation and thus mitigate the MRT instability. In addition, higher *dI/dt* can suppress temperature and density fluctuation along *z* axis, thus improving the source uniformity. The preferred pulsed current frequency is 1.4-1.6$\times 10^7$ rad s^{-1}. Finally, the simulation results showed that the MRT instability can be suppressed by applying an axial magnetic field. The preferred axial magnetic field is 500 G.

In conclusion, potential ways to optimize the EUV source includes controlling the initial density to be 2~3$\times 10^{16}$ cm^{-3}; designing a pulsed current frequency to be 1.4-1.6$\times 10^7$ rad s^{-1}; and applying axial magnetic field ~500 G.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).