第 31 卷 增刊 I
2007 年 7 月
高 能 物 理 与 核 物 理
HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS
Vol. 31, Supp. I
Jul., 2007

Production of EUV Power with SECRAL*

ZHAO Huan-Yu[1,2;1)] ZHAO Hong-Wei[1] SUN Liang-Ting[1] ZHANG Xue-Zhen[1]
SHENG Liu-Si[3] TIAN Chao-Yang[3] ZHANG Guo-Bin[3]

1 (Institute of Modern Physics, Lanzhou 730000, China)
2 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)
3 (University of Sciences and Technology of China, Hefei 230026, China)

Abstract The high power EUV source is one of key issues in the development of EUV lithography which is considered to be the most promising technology among the next generation lithography. However neither DPP nor LPP seems to meet the requirements of the commercial high-volume product. Insufficiency of DPP and LPP motivate the investigation of other means to produce the EUV radiation required in lithography. ECR plasma seems to be one of the alternatives. In order to investigate the feasibility of ECR plasma as a EUV light source, the EUV power emitted by SECRAL was measured. A EUV power of 1.03W in 4π sr solid angle was obtained when 2000W 18GHz rf power was launched, and the corresponding CE was 0.5%. Considering that SECRAL is designed to produce very high charge state ions, this very preliminary result is inspiring. Room-temperature ECR plasma and Sn plasma are both in the planned schedule.

Key words EUV light source, ECR plasma, EUV power

1 Introduction

Extreme Ultraviolet (EUV) lithography is considered to be the most potential solution for 32-22nm half pitch patterning in integrated circuits manufacture[1]. As one of the key issues in the development of EUV lithography, the high power EUV source draws intense focus of many research communities throughout the whole world. For a commercial use of EUV lithography, a throughput of 120 wafers per hour will be necessary[2]. This requires the light source to output a EUV power of 115W near 13.5nm wavelength in 2% bandwidth at the entrance of the illumination system (so-called intermediate focus, IF). Except for the output EUV power, the stability and lifetime of the light source as well as that of the optical system are expected. To meet the requirements of the lithography for EUV light sources, great efforts have been made by many research groups on plasma based light sources, such as gas discharge produced plasma (DPP) and laser produced plasma (LPP), and great progress has been made[3—5]. However, it seems that both DPP and LPP meet the frustrations which are difficult to overcome for now[6].

It is well known that the radiation near 13.5nm which is required in EUV lithography is dominated by 4d-5p transitions of Xe XI[7] or the so-called 'unresolved transition array' (UTA) of Sn VIII to XIII[8]. Electron cyclotron resonance (ECR) ion sources are widely used throughout the whole world because of their distinguished performance in the production of multiply charged ions. The highly charged ions and the hot electrons in ECR plasma provide intense radiation in X-ray[9—12] and EUV range[13—15]. In addi-

---

Received 20 April 2007
* Supported by Knowledge Innovation Project of CAS (KJCX1-09) and National Natural Science Funds for Distinguished Young Scholar (10225523)
1) E-mail: zhaohy@impcas.ac.cn

tion, it was confirmed that high temporal stability of the radiation output can be achieved by ECR plasma. So ECR plasma provides us the realizability of a EUV light source with novel concept. In order to investigate the feasibility of ECR plasma as a EUV light source, the EUV power emitted from SECRAL[16] (Superconducting ECR ion source with Advanced design in Lanzhou) has been measured recently.

2 Experdimental setup

In order to measure the emitted power near 13.5nm wavelength, a multi-layer Mo/Si mirror, of which the reflectivity efficiency can reach about 50% near 13.5nm, was mounted on the axis of the source at a distance of about 860mm from the center of the plasma. A XUV photodiode (AXUV100) was applied to measure the current generated by the reflected photons. Between the ML mirror and the photodiode, a movable Zr film was installed to avoid the visible light reflected by the mirror reaching the diode or producing any signal. The product of the reflectivity of the ML R and the transmission of the Zr film T is plotted versus wavelength in Fig. 1. It has to be mentioned that the EUV light we used for the calibration of the ML mirror was polarized, so a factor of 1/2 will be needed in the case of unpolarized light.

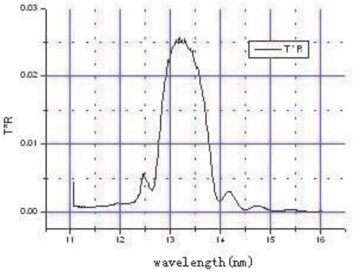

Fig. 1. Product of reflectivity of ML and transmission of Zr $T*R$ vs. wavelength.

We have known that ECR plasma is an intense X-ray light emitter, and the photodiode we used for the measurements is very sensitive to X-ray. In order to prevent the scattered X-ray disturbing our measurements, the photodiode was put into a lead box. In addition, a lead collimator was installed at the extraction side of the ion source, so that only a part of radiation emitted in a small solid angle around the axis could be detected. The measurement results revealed that the component of the photon-generated current induced by X-ray was reduced to below 10%.

3 Experdimental results

The EUV photon-generated currents of the SECRAL plasma with 45% and 50% of the designed maximum magnetic fields were measured, respectively. The corresponding magnetic fields for 45% of the designed fields are 1.665T at the injection peak, 0.99T at the extraction peak, 0.36T at the middle, and the radial field at the chamber wall is 0.9T; those for 50% fields are 1.85T, 1.1T, 0.4T, and 1.0T, respectively. As we have known that Xe^{10+} is responsible for the EUV radiation near 13.5nm wavelength, high magnetic field configuration is not necessary. Indeed it was confirmed in our measurements that low magnetic field configuration was more favorable for the production of the expected EUV radiation. That is in accordance with the performance of SECRAL in the production of Xe^{10+}. The incident microwave frequency was 18GHz, and the power varied from 200W to 1700W for 50% magnetic field, and from 200W to 2000W for 45% magnetic field. Xeon plasma was investigated; sometimes Oxygen was mixed to optimize the photon-generated current. The measured photon-generated currents are presented in Table 1.

Based on the reflectivity of the ML mirror, the transmission of the Zr film, the solid angle range accepted by the photodiode and the responsibility of the photodiode, the EUV power emitted in 4π sr solid angle was estimated. The derived EUV power under 45% excitation is presented versus rf power in Fig. 2.

Table 1. The measured photon-generated current under 45% and 50% of designed maximum fields.

P/kW Id/nA B	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
45% excitation	0.666	1.191	1.804	2.197	2.62	2.986	3.277	3.568	4.94	5.041
50% excitation	0.999	1.427	1.775	1.426	1.459	2.844	3.071	3.138	/	/

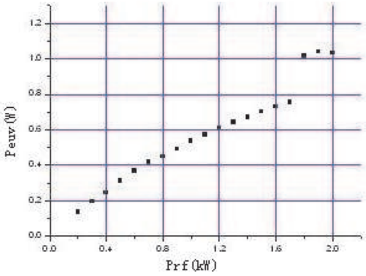

Fig. 2. Derived EUV power emitted in 4π sr solid angle vs. rf power (with 45% designed magnetic fields).

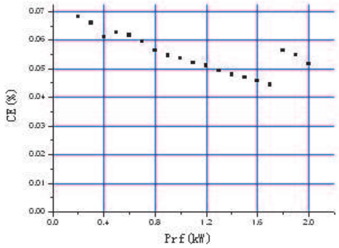

Fig. 3. CE vs rf power (with 45% designed magnetic fields).

The evolution of the corresponding CE (conversion efficiency) with rf power is also presented (Fig. 3). Here, the CE is the ratio of the output EUV power in 4π sr solid angle to the feeding rf power. As we have expected the EUV power increases with the increasing rf power. In contrast, the CE descends slowly with the increasing rf power. A EUV power of 1.03W was obtained at 2.0kW rf power, and the corresponding CE was 0.05%. It is obvious that more EUV power could be output if more rf power was injected. It has to be mentioned that the plasma was some unstable due to the lead shield put in the vacuum, which leads to the break of the measured current in the process of increasing rf power. The sudden change of vacuum condition was also observed at the same time.

4 Conclusion and outlook

It has to be mentioned that for simplicity the EUV radiation emitted by plasma was assumed isotropic during the evaluation of the EUV power output, which is not the case in ECR plasma. In addition Xe^{10+} ions are not considered to be mainly produced on the axis of the source, which means our condition for the EUV measurement is not optimized. Actually we expect to measure the EUV radiation off the axis as long as the conditions permit. However, the very preliminary results on SECRAL in the production of EUV power are inspiring. The results imply that ECR plasma is potential to provide the EUV radiation which is required in EUV lithography, and the precondition is the improvement of the intensity and stability of the light source. We plan to measure the EUV power on a room-temperature ion source-LECR2M in future. In addition, Sn plasma is in our planned schedule, since Sn is a much stronger radiation emitter near 13.5nm wavelength.

5 Acknowledgments

The authors are grateful to Zhang Guobin and his colleagues for their helpful technical support.

References

1 ITRS, 2005 Edition, Lithography

2 Stamm U. J. Phys., 2004, **D37**: 3244

3 Bakshi V. EUV Source Workshop Summary and EUV Source Technology Status, SEMATECH EUV Source Workshop, San Jose, CA, USA, 27 Feb., 2005

4 Stamm U, Kleinschmidt J, K. Gäel et al. EUV Source Development at XTREME Technologies an Update, SEMATECH EUV Source Workshop, San Jose, CA, USA, 27 Feb., 2005

5 Furukawa H, Murakami M, KANG Y G et al. Estimations on Generation of High Energy Particle from LPP EUV Light Sources, 2004 EUVL Symposium

6 Jonkers J. Plasma Sources Sci. Technol., 2006, **15**: 8

7 Akira S. J. Plasma Fusion Res., 2003, **79**: 315

8 Krüken T, Bergmann K, Juschkin L et al. J. Phys., 2004, **D37**: 3213

9 Bernhardi K, Wiesemann K. Plasma Phys., 1982, **24**: 867

10 Girard A. Rev. Sci. Instr., 1992, **63**: 2676

11 ZHAO H Y, ZHAO H W, MA X W et al. Rev. Sci. Instrum., 2006, **77**: 03A312

12 Barue C, Briand P, Girard A et al. Rev. Sci. Instr., 1992, **63**: 2844

13 Grüling P, Hollandt J, Ulm G. Nucl. Instr. and Meth. Phys. Res., 1999, **A437**: 152

14 Merabet H, Kondagari S, Bruch R et al. Nucl. Instr. And Meth. Phys. Res., 2005, **B241**: 23

15 Hitz D. 3rd International EUVL Symposium, 01-04 Nov. 2004, Miyazaki, Japan

16 ZHAO H W, WEI B W, LIU Z W et al. Rev. Sci. Instrum., 2000, **71**: 646