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THE SIMULATION STUDY FOR SINGLE AND MULTI TURN ERL BASED EUV FEL

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Abstract

Photolithography technology is the core part of the semiconductor manufacturing process. It has required that the power of EUV light should be higher about ~ kW for higher throughput. ERL based EUV FEL is emerging as a next generation EUV source which can produce over 10 kW EUV power. In this simulation study, EUV-FEL design with single turn is presented. An electron beam with 40 pC beam charge is accelerated to 600 MeV and produces EUV light with 37 kW power. Secondly, multi-turn based design is also presented. Multi-turn design improved compactness for industrial application. Simulation study shows that the multi-turn design can also generate about 15.5 kW average power. This study is expected to increase the practical industrialization potential of ERL-based photolithography.

INTRODUCTION

Photolithography process means microfabrication to pattern certain circuit into wafer. It is the core part of semiconductor manufacturing process and has been evolved from I-line, Krypton Fluoride Lasers (248 nm), Argon Fluoride Lasers to Laser-Produced Plasma (LPP, 13.5 nm). However, semiconductor industries have demanded new light source with high average power over 1 kW and high repetition rate in order to produce much-integrated semiconductor [1-5]. Thus, new EUV source has been studied and Energy Recovery Linac (ERL) based Free Electron Laser (FEL) has been received attention, which is believed that can replace the LPP source. ERL is a new type of accelerator, which can reuse kinetic energy of accelerated electron beams in order to accelerate other electron beam. ERL-based FEL can supply high current over 500 A to generate high power over 10 kW per second. This field faced many beam dynamics issues such as longitudinal phase space manipulation, bunch compressing, high order effect control, energy recovery [6], and space charge effect [7]. Therefore, it is vital to consider many collective effects and beam dynamics to produce high quality EUV.

In this paper, single and multi-turn ERL simulation study was performed by using ASTRA [8], ELEGANT [9] and GENESIS simulation [10]. It includes generation of electron from dc gun, bending, compression, acceleration, bending, compression and EUV generation. Most of simulations were performed through ELEGANT code, but we used ASTRA code to optimize injector part and GENESIS 1.3 code for simulation of FEL.

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OVERVIEW

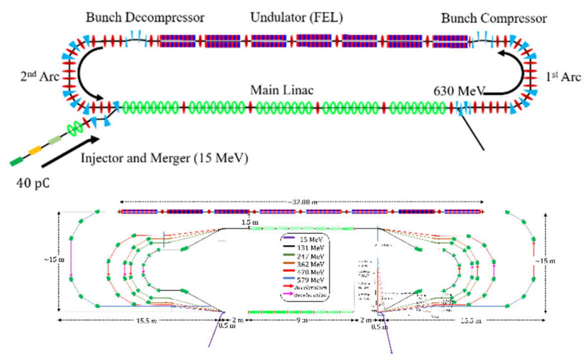

Figure 1: Layout of Single turrn(Upper part) and multi-turn design(Lower part) used in the simulation study.

In Fig.1, two designs of the EUV-FEL used in the simulation are shown. For the both designs, an electron beam with 40 pC beam charge is generated from the injector, accelerated to 15 MeV at superconducting RF cavity and transmitted to a merger. The merger compresses the beam, and transports it to linac simultaneously for both designs. However, they have different structural concept. At single turn design, electron beam circulates only one time. Thus, it requires multiple number of rf modules in the linac part as it cannot pass same linac before deceleration. Thus, the single turn design (upper part of Fig. 1) has larger size than multi turn case. Multi-turn design concept, suggested in 2011 [11], means circulating the electron beams to improve the compactness of facility. In multi-turn design (lower part of Fig. 1), electron beam circulates several times and it passes the same linac two or three times during acceleration process. This point can improve the compactness of a EUV facility.

SINGLE TURN SIMULATION RESULT

Injector in Fig. 2 consists of high average current DC photocathode gun, two solenoids, buncher cavity, superconducting RF cavities and merger that transfers the beam to main linac. DC photocathode gun produces 40 pC bunch charge and accelerates it to 960 kV with 1.3 GHz repetition rates.

In single turn design, superconducting RF cavities In Fig. 3 accelerate the beam from 15 MeV to 638 MeV while it makes chirp of electron beam linearly. It also recovers the kinetic energy of the used beam down to 15 MeV. Dump magnets separate high and low energy electron beam to dump the low energy beam. After the electron beam passes matching section that consists of 4

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quadrupoles, a path of electron beam is turned around 180° by isochronous arc as shown in Fig. 4.

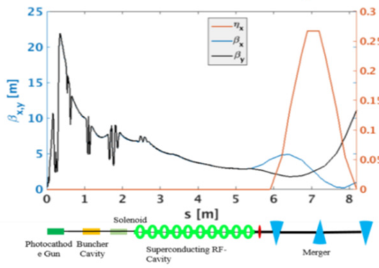


Figure 2: Injector layout and betatron function.

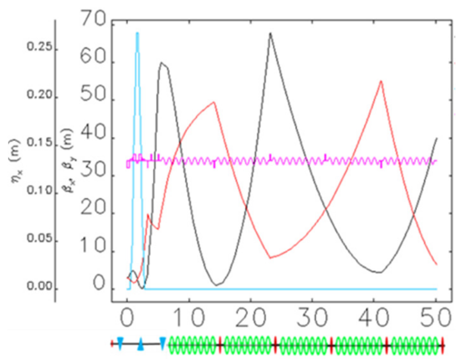


Figure 3: Linac layout and betatron function.

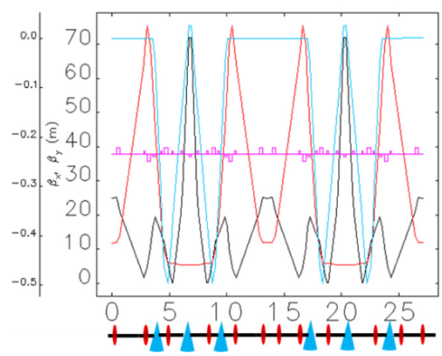
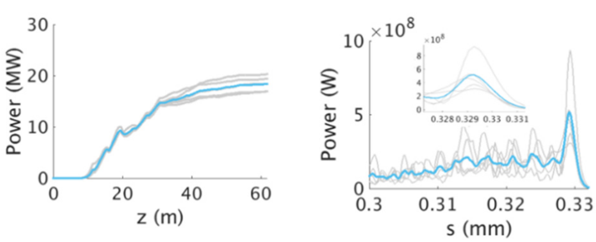


Figure 4: Isochronous Arc betatron function.



(a) (b)

Figure 5: Single turn FEL Simulation. (a) Growing of mean power in the undulator line. (b) Shape of the photon pulse.

Arc has symmetric TBA structure to make it achromatic for the 90 degree bending. One 90° bending arc includes 6 quadrupole magnets and 3 bending magnets which has 30° bending angle. Four quadrupole magnets are added at the beginning part and end part to keep the horizontal and vertical beta function as periodic and symmetric. Two quadrupole magnets are added at the front of the arc and the other two are added at the end of the arc. Simulation result shows that R_{56} of the arc is only 0.15 μm. At bunch compressor, current of the beam is increased to 600 A to generate high power EUV.

FEL simulation results with GENESIS 1.3 code are shown in Fig. 5. Mean power of pulse is growing up 20 MW, which are averaged over 5 simulation results with different seeding number. From this result, average power of facility is calculated as 37 KW. It shows that ERL FEL can produce EUV with extremely high average power for the lithography process.

MULTI TURN SIMULATION RESULT

To decrease the size of whole machine, we did study about the multi-turn design as shown in Fig. 1 (lower part). Multi-turn design has same injector with single turn case. After injection, electron beam encounters two rf modules. Phase of rf cavity is designed to minimize the chirp to decrease the nonlinear transverse kick at the arc. We used 85° for the one cavity and 95° for the another. It makes the electron beam have almost zero chirps, so it can avoid to increasing the emittance when the beam is passing the arcs.

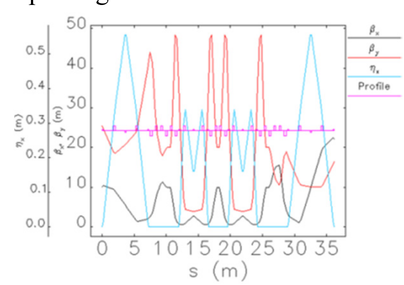


Figure 6: Example of isochronous Arc of multiturn ERL.

Core of multi-turn design is 180 bending arc. It should bend the electron beam without reducing emittance and keep the betatron function proper. Good example of arc is shown in Fig. 6. It is designed to have two symmetric parts. First part consists of 3 bending magnet and 2 quadrupoles. It starts from spreader (a bending magnet which spread out the electron beam for different energy) which is located at the end of each RF module. Second part consists of two TBAs which is similar for the single turn case. The whole arc is isochronous, even though second part itself is not isochronous. Maximum arc size for completed design is about 15 m which improves compactness of the EUV facility.

FEL simulation results for multi-turn design are shown in Fig. 7. It shows that peak power of pulse about 0.3 GW and mean power about 5 MW, which are averaged over 5 simulations with different seeding number. The pulse of the photon beam is about 81 um. From this result, average power of facility is calculated as 15.5 KW. Compared with single turn design result, it decreases almost as half, however, there are still enough number of photons for the lithography.

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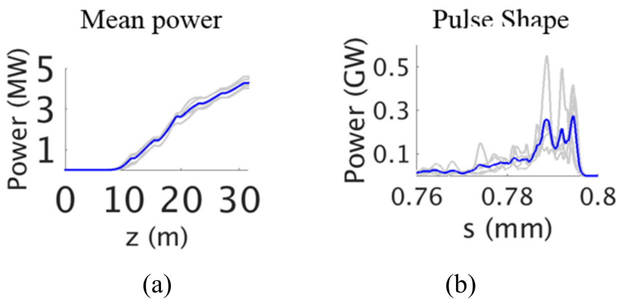

Figure 7: Multi turn FEL Simulation results. (a) Growing of mean power. (b) Pulse shape of the photon beam.

CONCLUSION

Single and multi-turn ERL based EUV-FELs are designed. It accelerates electron beam to about 600 MeV and FEL power exceeds 10 KW for the both cases and its wavelength is 13.5 nm. We expect that these designs can be helpful to realize the industrial application of accelerator.

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