# Design of 1.2 GeV Synchrotron Light Source for X-ray Lithography at Samsung Heavy Industries

Keeman Kim, Bumsoo Han, Kihun Joh, Sungmyun Kim, Byungmun Kim, Heunggyu Park, Jongpil Park, Jinsoo Kim, Wongu Kang, Kyungwoo Kang, Yuri Kim, Sangil Lee, and Younghee Kim
Samsung Heavy Industries Daeduk R&D Center
Yousung-Gu, Moonjee-Dong 326, Daejeon, Korea 305-380

*ABSTRACT*

An 1.2 GeV electron storage ring being designed at Samsung Heavy Industries Daeduk R&D Center is optimized for X-ray lithography works for high density semiconductor devices and micro-machining. The lattice is a variation of a FODO arrangement with four quadrupole doublets. The circumference of 57.6 m includes four 2.1-m-long straight sections and two 3.09-m-long dispersion-free straight sections making the synchrotron a racetrack shape. Two dispersion-free straight sections are located between the doublets and reserved for diagnostics and insertion devices. The harmonic number is 96 and the corresponding RF frequency is 499.654 MHz. The critical X-ray wavelength from sixteen 1.16-m-long bending magnets is 9.55 Å and a superconducting wiggler is also included in the design considerations. The major features of the light source will be described.

## I. INTRODUCTION

Samsung Heavy Industries Daeduk R&D Center is a part of SAIT (Samsung Advanced Institute of Technology) Daeduk site which is located at the central part of Korea. The accelerator laboratory at Daeduk R&D Center is devoted for the development of accelerator technologies and applications. Current research activities include the development of electron accelerators for irradiation processing purpose, applications of electron irradiation processing[1] and the development of a synchrotron light source.

During the past decade, synchrotron radiation has come into wide use as a most powerful source of X-rays for studying the structure of matter and various physical processes. Many synchrotron radiation facilities are operational or under construction throughout the world and 2-GeV PLS (Pohang Light Source), which is located at the southeastern part of Korea, is also operational. An industrial synchrotron light source is also being investigated at Samsung Heavy Industries and the most promising site of the light source will be Daeduk Science Town. The synchrotron light source will be able to generate the X-ray for various scientific and industrial research including spectroscopy, diffraction analysis, chemical analysis, photochemical reaction, and biotechnology. As a matter of fact, from the viewpoint of the X-ray quality, the machine does not offer a definite advantage over PLS except the geographical convenience. Though the importance of opportunity for basic research activity targeted by other third generation synchrotron light sources is not overlooked, the design of the lattice is not optimized for insertion devices or for a low emittance beam. The machine is optimized for semiconductor lithography and MEMS (Micro-Electro-Mechanical System) and the main object of the design is to produce a most adequate photon flux at the most useful photon energy for lithography.

## II. DESIGN CONSIDERATIONS

In order to design an efficient lithography light source, the X-ray wavelength from bending magnet[2] is the first thing to consider. Useful X-ray wavelength for semiconductor lithography is 6 ~14 Å. The conventional magnet technology is able to generate the bending magnetic field of 1.5 T without serious saturation problems. When 10% margin of the magnetic field limit is take into account, the bending magnetic field of 1.35 T is a reasonable choice for the normal operation. In order to obtain a critical X-ray wavelength, $\lambda_c$, of 10 Å from the bending magnet of 1.35 T, the required energy of the electron beam is 1.18 GeV. A superconducting bending magnet is not excluded from the design consideration. Specially, industry would prefer that the storage ring be as compact as possible. The superconducting magnets can reduce the dimension of the synchrotron itself. In particular, if a storage ring is made to be small enough to be shipped in a fully assembled and almost commissioned state, a significant advantage can be achieved. One can even consider that the storage ring could be replaced during the maintenance period of the ring in manufacturing industries. However, the overall system size is mainly determined by the length of beamlines and the decision was made to use a well established conventional magnet technology also to reduce the possibility of accidents during the normal operation of superconducting magnets without the knowledge of cryogenics at manufacturing industries. Using a mature conventional magnet technology could also help ensure programmatic success. An installation of a superconducting wiggler is also included in the design consideration in order to provide hard X-ray for micro-machining.

Another important design consideration is the lattice structure. The lattice of a storage ring and the characteristic of an electron beam is tightly bonded together. The FODO lattice and the Chasman/Green lattice[3] are the most reasonable lattices for a small size storage ring. The FODO lattice is the very basic lattice and most of booster synchrotrons employ the FODO lattice. The FODO lattice has relatively a large emittance which is not desirable for insertion devices and the high energy physics research, but does not hurt X-ray lithography. As a matter of fact, the vertical width of the X-ray from a 10-m beamline at 1.2 GeV storage ring is a few millimeter and lithography requires at least a few centimeter, which can be achieved by three methods, the use of a vibrating X-ray mirror, the scanning of target assembly, and the wobbling of the electron beam. However, the X-ray mirror is not only difficult and costly to manufacture but also the uniform irradiation of X-ray is difficult to achieve. Though moving target assembly could be a good solution for LIGA (LIthographie, Galvanoformung, Abformung) process, the mechanical vibration can hurt the high density semiconductor lithography where the resolution of ~0.1μ is required. The wobbling of the electron beam is considered to be a better solution for a dedicated lithography machine. The FODO lattice is suitable for the wobbling of the beam. The Chasman/Green lattice is also one of the most widely used lattices for small size storage rings. The Chasman/Green lattice has undulator-type straight sections with a low emittance. However, the cross section of the beam at bending magnets becomes an upright cigar shape and the beam is difficult to wobble. Therefore, the 1.2 GeV electron storage ring with the FODO lattice using 1.35 T bending magnets seems to be matched to the lithography process.

If the X-ray lithography technique becomes to be put into semiconductor fabrication lines, more than one storage ring are expected to be required and one full energy injector which serves for many storage rings will be an ideal choice. However, a 200~300 MeV linac injector will be the primary choice of the injection system for the storage ring and the storage ring will also have the function of a booster at current stage. In order to prevent instabilities due to ion-trapping, approximately the half of the RF buckets in the ring will be left empty.

## III. DESIGN SPECIFICATIONS

Table 1 shows the preliminary design specification of the linac injector. The nominal beam energy of the linac is 200 MeV and the operating frequency is 2.856 GHz. An energy doubler is not included in the preliminary design and the pulse duration of the modulator is 2 μsec. However, the design of the modulator has an expandable structure in order to accommodate the possible upgrade with energy doublers which require a longer pulse duration of modulators.

Table 2 shows the preliminary design specification of the storage ring. The basic structure of the machine is a racetrack type FODO lattice with quadrupole doublets. MAD input for the lattice is listed in Table 3. Here, parameters for magnetic filed strength are not optimized yet. The storage ring has four 2.1-m dispersive straight sections and two 3.09-m dispersion free straight sections. 2.1-m straight sections will be used for injection and RF system. A superconducting wiggler is also planned to be installed at the one of the 2.1-m straight sections. 3.09-m straight sections are reserved for a future insertion device and other purpose such as an optical klystron. The quadrupole doublets at the both ends of dispersion free straight sections make the beta functions at the straight sections suitable for the future expansion of insertion devices. The schematic of synchrotron radiation extraction with the lattice structure is shown in Figure 1. Figure 2 shows Beta functions and dispersion function. The dotted lines in Figure 3 show the bending magnet photon flux of the storage ring per unit horizontal angle as a function of photon energy at the electron energy of 1.2 GeV and 1.4 GeV, respectively and the solid line shows that of PLS for the reference. Here the electron currents are assumed to be 300 mA.

Table 1. Preliminary design specification of the injection linac.

| | |
|---|---|
| Injection Energy | 200 MeV |
| Energy Spread | < 1 % |
| Beam Pulse | 2 ns x 200 mA |
| Total charge in SR | 60 nC |
| Time required to fill-up SR | < 5 min |
| Klystron Frequency | 2.856 GHz |
| Repetition Rate | optimized at 10 Hz |
| Number of Modulator | 2 |
| Modulator Pulse Duration | 2 μsec (expandable to 4 μsec) |

Table 2. Preliminary design specification of the storage ring.

| | | |
|---|---|---|
| Nominal Electron Energy | 1.2 GeV | |
| Nominal Beam Current | 300 mA | |
| RF Wavelength | 0.6 m (499.654 MHz) | |
| Harmonic Number | 96 | |
| Circumference | 0.6 x 96 = 57.6 m | |
| Straight Sections | 2.1m x 4, 3.09m x 2 | |
| Beam Size at 3-m Straight Section | ~1.5 mm | |
| Natural Emittance | 0.6 mm mrad | |
| Dipole Magnet | 1.16m x 16 | |
| Bending Radius | $18.56/2\pi = 2.9539$ m | |
| | 1.2 GeV | 1.4 GeV |
| Bending Magnet Field Strength | 1.356 T | 1.581 T |
| X-ray Characteristics | | |
| $\lambda_c$ from bending magnet | 9.54 Å | 6.01 Å |
| $\lambda_c$ from 8-T wiggler | 1.62 Å | 1.19 Å |
| bending magnet X-ray power (300 mA assumed) | 18.66kW | 34.56kW |

## IV. CONCLUSION

The electron synchrotron light source being investigated at Samsung Heavy Industries Deasuk R&D Center is based on proven light source technologies. A 200~300 MeV linac seems to be the most promising injection system and it could help to improve the basic accelerator technology of our industry. The utilization of well understood technologies together with state-of-the-art diagnostics and feedback system, ensures that the synchrotron light source will perform up to specifications. The soft X-ray from bending magnets will be suitable for lithography works and a superconducting wiggler will be able to provide the hard X-ray for micro-machining. The synchrotron radiation facility will be open to the wide area of scientific and industrial research.

Table 3. MAD input data for the storage ring.

```
TITLE, "STARLIGHT"
DSS  : DRIFT, L=0.47
DS1  : DRIFT, L=0.12
DS2  : DRIFT, L=0.25
DSU  : DRIFT, L=1.545
DSI  : DRIFT, L=2.1
DSP  : DRIFT, L=0.6
DSD  : DRIFT, L=0.6
QV   : QUADRUPOLE, L=0.125, K1=-1.75
QD   : QUADRUPOLE, L=0.25, K1=-1.75
QF   : QUADRUPOLE, L=0.25, K1=2.64
QDD  : QUADRUPOLE, L=0.25, K1=-1.8
QDF  : QUADRUPOLE, L=0.25, K1=3.1
SD   : SEXTUPOLE, L=0.1, K2=0
SF   : SEXTUPOLE, L=0.1, K2=0
BM1  : SBEND, L=1.16, ANGLE=PI/8., E1=PI/16., E2=PI/16.
FODOD : LINE=(DSU, QDD, DSD, QDF, DSP, &
    BM1, DSS,  QD, DSI,  QF, DS1,  SF, DS2, &
    BM1, DSS,  QD, DS1,  SD, DS2, &
    BM1, DSS,  QF, DS1,  SF, DS2, &
    BM1, DSS,  QD, DS1,  SD, DS2, &
    BM1, DSS,  QF, DS1,  SF, DS2, &
    BM1, DSS,  QD, DS1,  SD, DS2, &
    BM1, DSS,  QF, DSI,  QD, DSS, &
    BM1, DSP, QDF, DSD, QDD, DSU)

USE, FODOD, super = 2
beam, particle=electron, energy=1.2
```

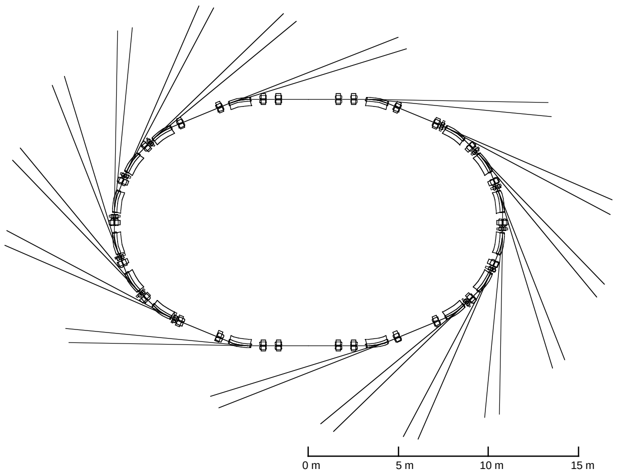


Figure 1. Lattice structure and schematic of synchrotron radiation extraction.

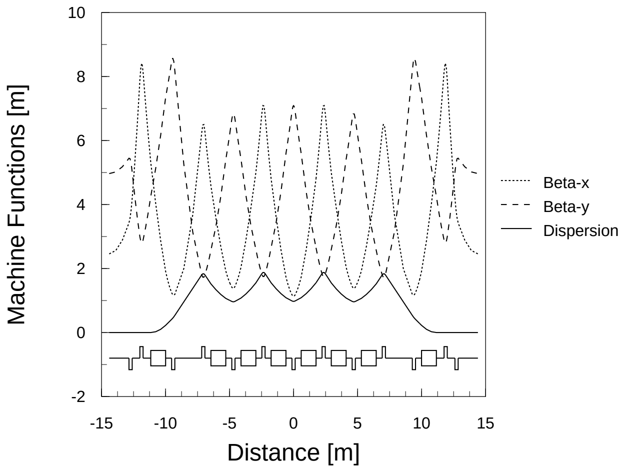


Figure 2. Beta functions and dispersion function for the storage ring under designing.

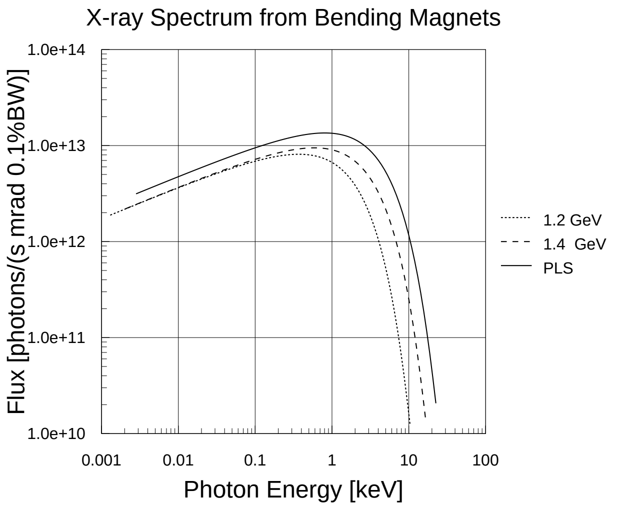


Figure 3. Photon flux per unit horizontal angle as a function of photon energy. The beam current is assumed to be 300 mA. dotted lines are for the storage ring under designing and solid line is for PLS.

## V. REFERENCES


[1] B. Han, K. Kim, K. Joh, S. Kim, B. Kim, H. Park, J. Park, J. Kim, W. Kang, K. Kang, Y. Kim, S. Lee, and Y. H. Kim, "Applications of Industrial Electron Accelerators at Samsung Heavy Industries," these proceedings.

[2] A. Hofmann, Stanford Synchrotron Radiation Laboratory ACD-Note 38, 1986.

[3] R. Chasman and G. Green, Brookhaven National Laboratory, BNL-21849, 1976.