Development of compact synchrotron light source for X-ray lithography

M. Ida, M. Takahashi, M. Ohishi, S. Mandai, H. Ukikusa and Y. Kohno
Advanced Technology Development Department,
Ishikawajima-Harima Heavy Idustries Co., Ltd, (IHI) Japan

Abstract

IHI has developed a prototype compact synchrotron light source "LUNA" for X-ray lithography of semi-conductors. It consists of a 45 MeV linear accelerator and an 800 MeV synchrotron.

We have got 50 mA beam cuttents at 800 MeV and its lifetime is more than 3 hours. Now, we are doing machine study to get more beam current and lifetime. And we have begun researches with this light since November 1991 in our facility.

1 INTRODUCTION

Synchrotron radiation (SR) is expected to be used for various industrial needs, especially for X-ray lithography. IHI has developed compact synchrotron light source named LUNA (Lithography Use New Accelerator).

The project was started in April 1988. LUNA was installed at IHI Synchrotron Radiation Facility (ISRF) in Tsuchiura Facility near Tsukuba in April 1989. We succeeded in accelerating the electron beam to 800 MeV and ovserved X-rays in December 1989. We got 50 mA at storage mode (800 MeV) in March 1991. And now, the lifetime is more than 3 hours.

2 OUTLINE OF LUNA

2.1 Layout

The layout of ISRF (1F only) is shown in Fig.1. It is a two-story building. Synchrotron Room is surrounded with 1.7 m walls against the radiation rays. Experimental Room II will be class 1000 clean room for lithography. The floor of Synchrotron Room and Exprimantal Room II has been designed to suppress microvibrations.

2.2 Basic Parameters

The basic parameters of LUNA are shown in Table 1. We chose those parameters so as to set the peak wavelength around 10A. LUNA is a very compact synchrotron light source as conventional type. It consists of the low energy linear accelerator (Linac), the beam transport (BT) system and the square ring as a synchrotron and a storage ring.

The ring is shown in Fig.2. It has four normal cells, the lattice of which is F-D-B. The horizontal and vertical tunes for the operating points are 1.75-2.00 and 0.75-1.00, respectively. The spectrum at 800 MeV and 50 mA is shown in Fig.3.

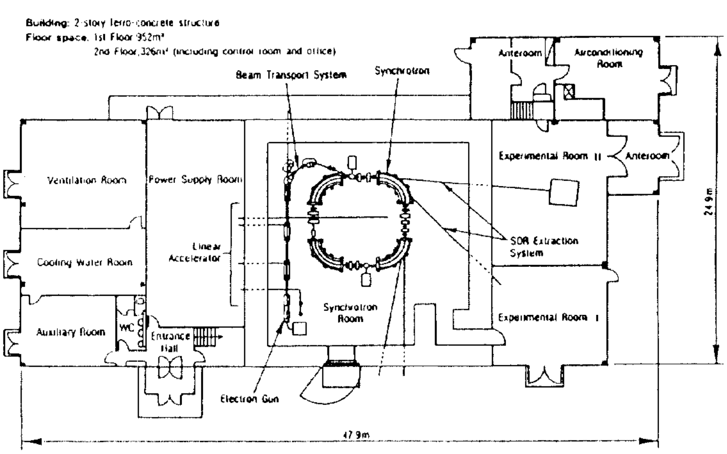

Fig.1:Layout of ISRF (1F)

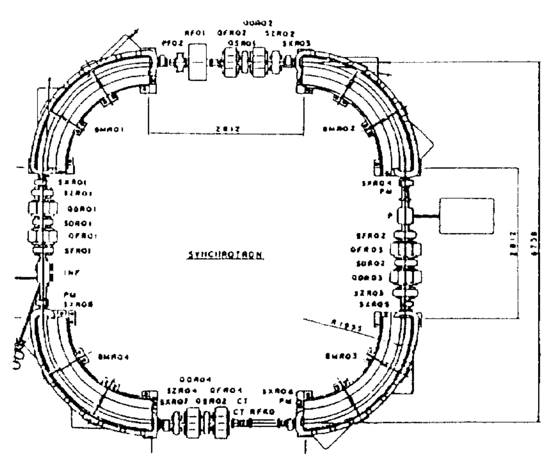

Fig.2:Ring of LUNA

Table 1:Basic parameters of LUNA (designed values)

Energy	45 MeV (injection)
	800 MeV (storage)
Current	50 mA
Lifetime	30 min
Critical wavelength	21.8 A
Peak wavelength	9.2 A
Bending angle	90 deg
Bending radius	2 m
Tune	1.75 (horizontal)
	0.75 (vertical)
Circumference	23.5 m
RF frequency	178.5 MHz
Harmonic Number	14

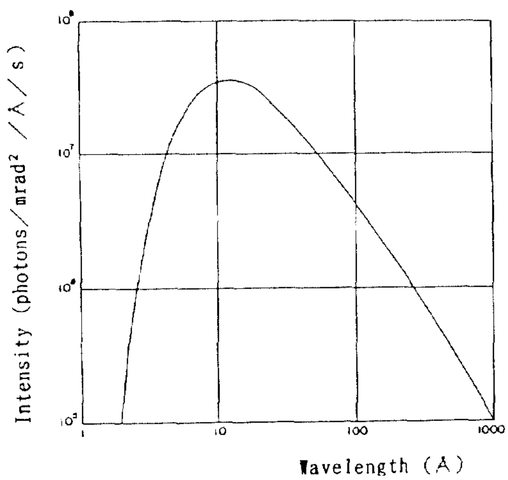

Fig.3:SR spectrum (800 MeV, 50 mA)

3 COMPONENTS OF LUNA

3.1 Linac

We chose low injection energy mainly for compactness and cost. The linac consists of an Electron gun, a Buncher (0.5m), No.1-No.3 regular acceleration tube (1.5m, 2m, 2m, respectively). The acceleration tubes are the constant impedance type. We have two S-band Klystrons (KLY) with a frequency of 2856 MHz. One is an 8 MW KLY for Buncher and No.1, the other is a 22 MW KLY for No.2 and No.3 regular acceleration tube. The beam current is 100 mA with 1-2 μs pulse width. And we know that the emittance is 10^{-6} m·rad with image scanning. The energy spread is 10^{-2}.

3.2 Inflector and Perturbator

We use the inflector with septum and the perturbator at injection mode. The bending angle of inflector is 20 deg. The pulse width of perturbator is 0.5-2 μs. The injection point is 40 mm, and the bump orbit is 20 mm distant from the central orbit.

3.3 Ring Magents

The four 90 deg bending sector magents (BMR) are made of three 30 deg sector blocks because of easiness of manufacture. The block is made of silicon steel plates with 0.5 mm thickness, because the magnetic field is raised to 1.33 T within 1 minute during acceleration. The mechanical orbit radius is 1955 mm. The pole gap is 50 mm (max), and the pole has shims for good magnetic field. The field is 1.33 T at 800 MeV storage mode.

The four horizontal focusing magnets (QFR) and the four vertical focusing magnets (QDR) are also made of the silicon steel plates. The bore radius is 48 mm, and the yoke length is 200 mm. The field gradient is 13 T/m (max).

The eight horizontal steering magnets (SXR) and the four vertical steering magnets (SZR) are also made of the silicon steel plates. The four sextupole magnets (SFR,SDR) and the two skew magnets (QSR) are made of solid iron.

3.4 RF system

The RF cavity is a re-entrant type. The inner diameter is 520 mm, and the length is 480 mm. We have 40 kW power supply for the RF cavity, and it supplies power of about 3 kW, 70 kV for RF cavity at normal operation.

3.5 Vacuum system

The vacuum chambers are made of SUS316L. The cross section of a straight chamber is like a race track with 32 mm inner height and 92 mm inner width. The cross section of a bending chamber is rectangular with 30 mm inner height and 92-150 mm inner width. As main pumps, we have ten triode sputter ion pumps whose capacity are 400 liter/s. And other pumps are fifteen nonevaporable getter pumps, six titanium getter pumps, one cryo-pump, and three turbo molecular pumps.

3.6 Monitors and Control system

To measure beam current, we have eight fast current transformer (fast CT) in LUNA and one direct current CT (DCCT) in the ring. To observe beam profile, we have three screen monitors made of a almina-type ceramics. To measure closed orbit distortion (COD), we have eight button-electrode-type position monitors at both ends of four straight sections of the ring. To measure the tunes, we have RF knockout electrode. And to get various information from SR, we have SR monitors at some ends of the SR beam lines.

We chose a distributed control system with personal computers.

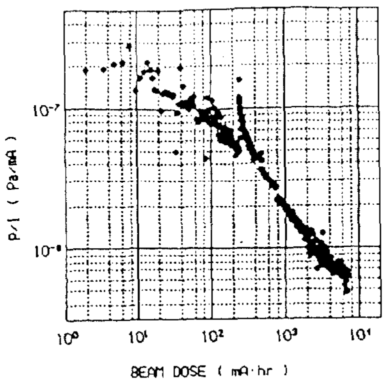

Fig.4:Vacuum pressure and beam dose

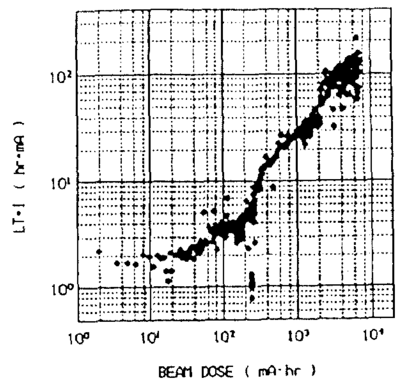

Fig.5:Lifetime and beam dose

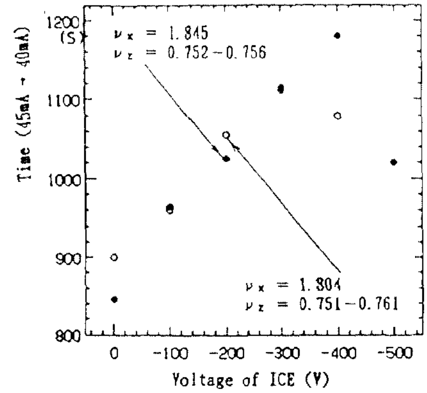

Fig.6:Lifetime and voltage of ICE

4 STATUS AND RESULTS

We need current of only 60 mA at 45 MeV injection mode to get current of 50 mA at 800 MeV storage mode.

As we get more beam dose, the vacuum pressure becomes lower.(See Fig.4) The vacuum pressure is lower than 3×10^{-7} Pa at 50 mA,800 MeV storage mode. And, as we get more beam dose, also the (1/e) life time of beam becomes longer. (See Fig.5) The life time of beam is about 3 hours with initial current of 50 mA and beam energy of 800 MeV. And we have made sure that lifetime becomes longer by using ion clearing electrode (ICE) with DC voltage.(See Fig.6) We can gain more lifetime of 40% by using ICE.

Using SR, we measured the size and the stability of beam.

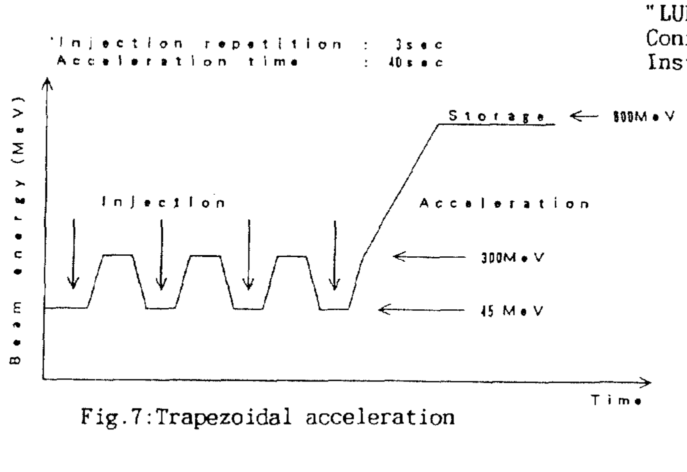

Fig.7:Trapezoidal acceleration

5 FUTURE PLANS

5.1 More Current and Longer Lifetime

To get more current at storage mode, we are doing trapezoidal acceleration which is one of multi-shot injection methods.(See Fig.7)

We are planning to raise the beam energy at storage mode. We can get the beam energy of 900 MeV without any exchange of equipments. We made sure that the bending magnets and the power supply can make good field of 1.5 T for 900 MeV operation.

To get longer lifetime of beam, we are going to use DC and RF electric field of ICE.

5.2 Researches using SR

We will install a SR beam line from synchrotron Room to Experimental Room II in this summer. And we will start some researches for X-ray lithograpy with the SR beam line.

6 REFERENCES

1. S.Mandai "Development of Compact Synchrotron Light Source "LUNA"" 14th International Conference on High Energy Accelerators, Tsukuba, Japan,1989

2. M.Takahashi"Development of compact synchrotron "LUNA" for X-ray lithography" 4th International Conference on Synchrotron Radiation Instrumetation, Chester, England, 1991