PRESENT STATUS OF THE 600-MeV ETL STORAGE RING AS AN ELECTRON UNDULATING RING FOR VLSI LITHOGRAPHY

T. Tomimasu, T. Noguchi, S. Sugiyama, T. Yamagaki, T. Mikado and M. Chiwaki
Electrotechnical Laboratory
Sakura, Niihari, Ibaraki, 305, Japan

ABSTRACT

In order to achieve a wide area exposure of synchrotron radiation (SR) in VLSI lithigraphy, the development of the ETL storage ring "TERAS" as an electron undulating ring has been continued since 1983. Stably vertical and horizontal undulating motions of stored beams are demonstrated around a horizontal design orbit of TERAS, using two steering magnets of which one is used for vertical undulating and another for horizontal one. Each steering magnet was inserted into one of the periodic configulation of guide field elements. As one of useful applications of undulating electron beams, a vertically wide exposure of SR has been demonstrated in VLSI lithography. Another proposal is for high-intensity, uniform and wide exposure of SR from a wiggler installed in the electron undulating ring.

INTRODUCTION

In synchrotron radiation lithography for the microfabrication of electronic submicrocircuits, high-intensty, uniform and wide exposure of synchrotron radiation (SR) is most desirable. The small flux divergence of SR, however, is proportional to $1/\gamma$ ($\approx$ electron energy E(MeV)/0.511) and is the narrower at the higher energy electron ring with a horizontal orbit. Therefore, the vertically wide exposure of SR is quite impossible in the ordinary ring.

The geometrical shape of the stable orbit is a result of periodic configulation of guide field elements. Insertion of a small steering magnet into one of the periodic configulation, however, can cause a small perturbation in the periodic configulation.

In the development of TERAS as an electron undulating ring proposed in 1983,[1] it has been shown that small vertical deflection of the stored beam with the steering magnet causes a vertical undulating motion of the beam around the horizontal design orbit and horizontal deflection also causes a horizontal undulating motion in the same manner.

THE 600-MeV ETL STORAGE RING "TERAS" [2]

Fig. 1 shows the layout of TERAS, beam lines and beam ports for experiment. TERAS consists of eight 45 bending magnets (n = 0, r = 2m), four triplet focusing systems, a septum magnet, a kicker coil, an RF cavity, two steering magnets (B_V and B_H) and ultrahigh vacuum system. The circumference is 31.45m. The main parameters of TERAS are shown in Table 1.

The magnet etructure is a combination of eight homogeneous-field magnets with a same entrance and exit angle of 11.7 and four triplet focusing systems. The advantages of this design are three fold: First, the fablication of the homogeneous-field magnet is easy; second, the handling is very easy because of no field correction; third, some position tolerances in the radial direction of the magnets are relaxed. The vertical focusing is provided by the edge angle 11.7 of the bending magnets B_d and four quadrupole magnets Q_d, while the horizontal focusing is provided be eight quadrupole magnets Q_f. The lattice order is 0/2 B_d Q_f Q_d Q_f B_d 0/2. Four sextupole magnets were also installed, but any improvement in the 1/e lifetime was not fonnd. The two steering magnets B_V and B_H act as perturbators; B_V is used for vertical deflection and B_H for horizontal deflection.
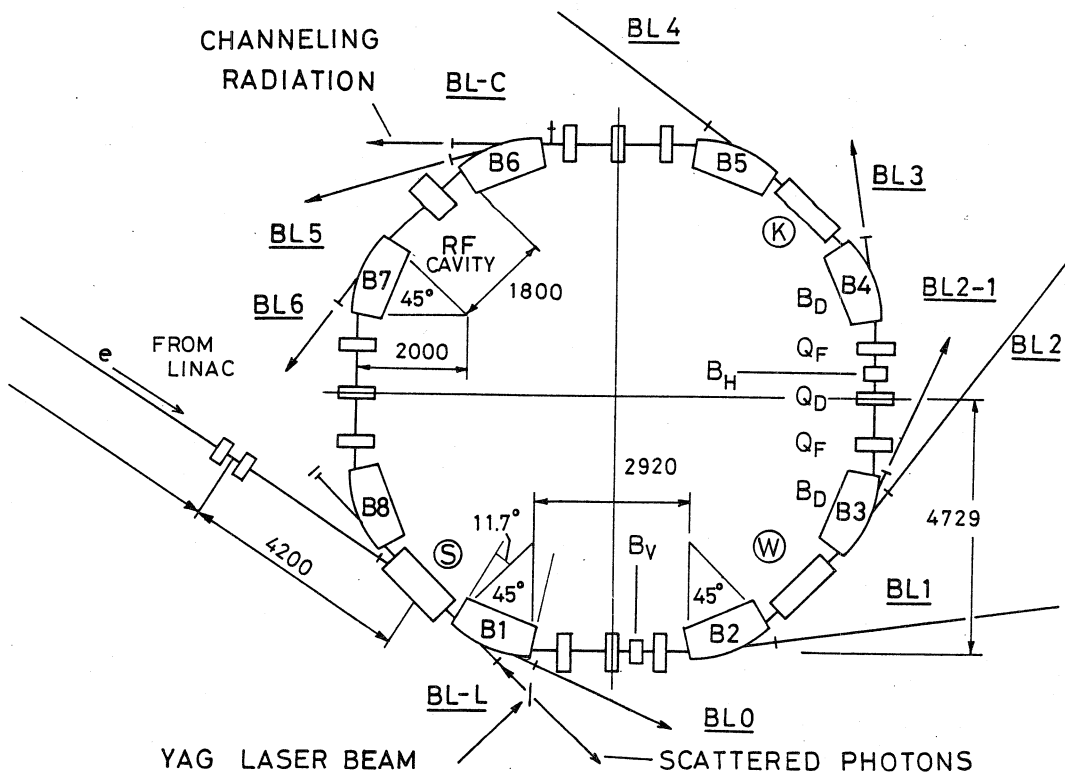
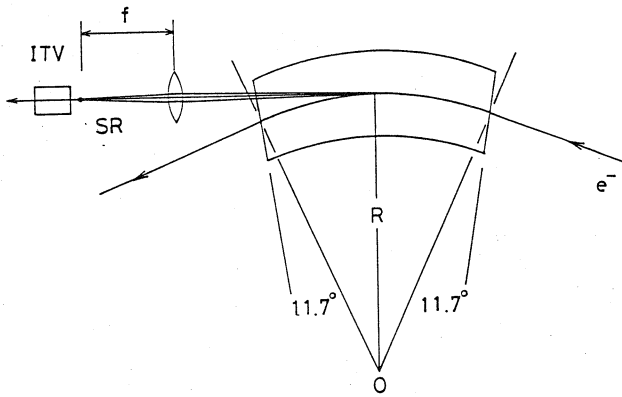

Fig. 1 Layout of TERAS, beam lines and beam ports.

Fig. 2 Layout of beam size and position measurement.

Fig. 3 Beam size and 1/e lifetime.

MEASUREMENT OF STORED BEAM SIZE AND POSITION

Fig.2 shows the layout of the measurement of stored beam size and position. The SR beam is focused on a TV photo-sensor covered with a filter using an optical lens. The size and position of the stored beam is always monitored viewing the focused SR spot with a TV monitor. The beam size can be changed by adjusting exciting current supplied to Q_f or Q_d. The 1/e lifetime of the stored beam is longest when the cross section of the beam is round as shown in Fig.3. The 1/e lifetime of a 100 mA stored beam is 4.8 hours at 600 MeV in August, 1984. Fig.3 also shows that the center of the beam slightly moves up by 0.5 mm when the crose section is round at the beam line 3.

Very small variation in vertical electron orbit causes unacceptable changes in the SR position at the experimental area because of the narrow divergence of the SR beam and the long distance from the source point to the experimental area. In order to overcome this problem, Baer et al. developed a simple orbit monitoring and control system for reproducing the vertical position of the SR beam in SSRL.[3] The system consists of a pair of trim coils that provide equal horizontal dipole fields. The coils straddle the source point and are spaced by about 180 (about 15 m) in the phase of the vertical betatron oscillation. They can produce a local orbit distortion in the vicinity of the source point with a small residual corresponding to 5% of the peak local distortion elsewhere in the ring.

VERTICAL UNDULATING MOTION OF STORED BEAM

Their idea of the orbit distortion, however, is unpractical in a small ring with a uertical betatron oscillation number close to unit like TERAS, since the pair of coils produces a orbit distortion around almost a half part of the ring.

The idea of the electron undulating ring presented here is on the storage ring dedicated to VLSI lithography, especially making use of vertical undulating motion of the stored beam around the whole horizontal orbit of the ring by a single steering magnet to expand the exposed area of SR.
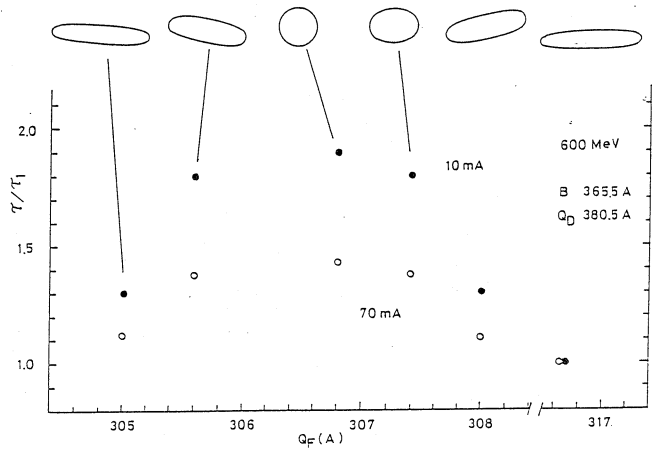
Recently we have demonstrated the actual expansion of exposed area in the SR lithograohy in the previous report [4], in which the idea of the electron undulating ring mentioned here has not been described.

The behavior of the vertical undulating electron beam has been observed by using the optical lens and TV set shown in Fig.2 at seven beam ports (BL-L, BLO, BL2-1, BL3, BL-C, BL5, BL6) shown in Fig.1. Since the beam position could not be observed at the bending magnets of B_D2, B_D5 and B_D8, the steering magnet B_V was inserted into each periodic configilation of TERAS in turn and the observation of the undulating beam was repeated for each configilation of B_V. A typical pattern of the vertical undulating beam found in TERAS is shown in Fig.4. It should be noted that two nodes of the undulating motion are found near B_D4 and B_D7. The maximum vertical deviation from the horizontal orbit
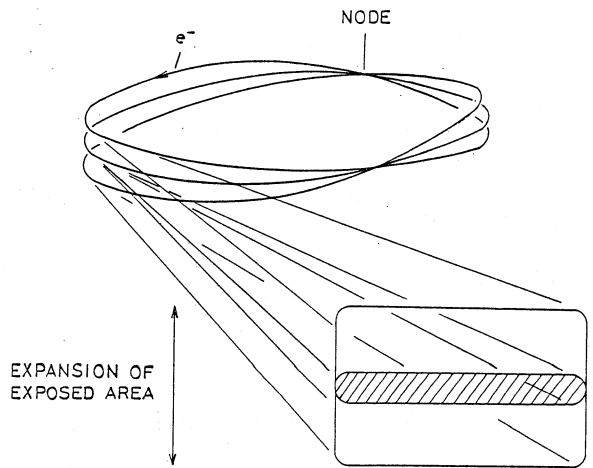

Fig. 5 Expansion of exposed area by vertical undulating method.
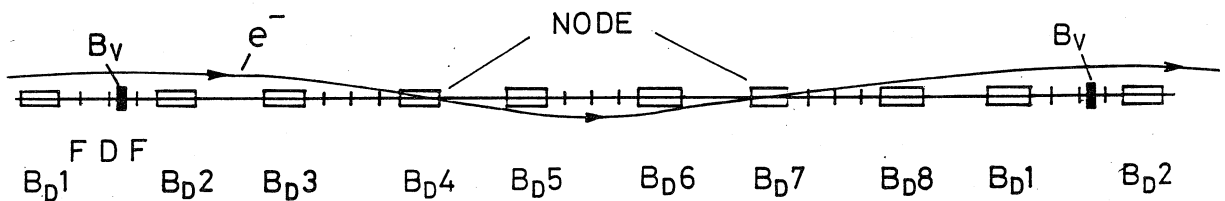

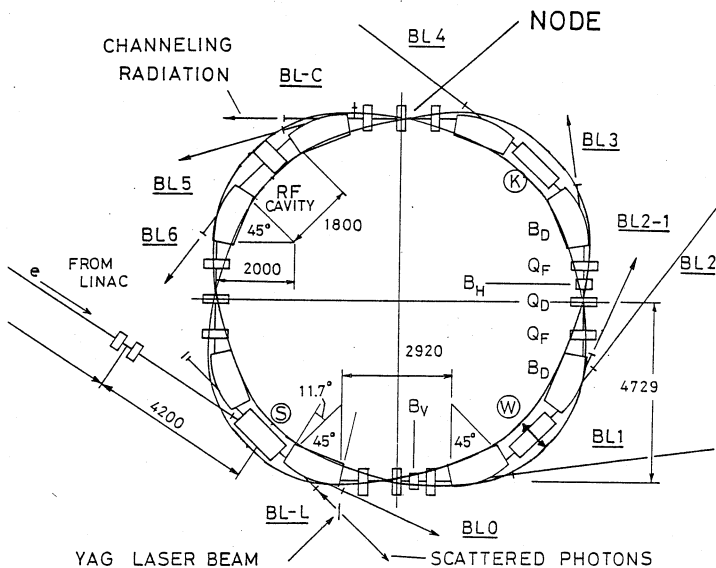Fig. 4 Typical pattern of vertically undulating motion of stored beam.

Fig. 6 Typical patterns of horizontal undulating motion of stored beam found in TERAS.

Fig. 7 Expansion of exposed area of high-intensity wiggler radiation by vertical and horizontal undulating method.

occurs near the steering magnet B_V. The maximum deviation is about $+$ 10 mm for a steering magnetic field of 50 gauss and the vertical tilt angle of the undulating beam near the nodes is about $\pm$ 2.5 mrad. These vertical deviation and tilt angle of the undulating beam are very useful in expanding the exposed area of SR in VLSI lithography. The pressure rise due to gas desorption from the chamber wall caused by SR from the undulating beam was also observed when the steering magnet B_V was operated at a magneti-field of 100 gauss. This implies that the deviation of the beam is so large as to close to the chamber wall.

Fig.5 shows schematically the principle of the expansion of exposed area of SR by the use of the undulating beam in TERAS.

HORIZONTAL UNDULATING MOTION OF STORED BEAM

A typical pattern of the vertical undulating beam found in TERAS is shown in Fig.6. It should be noted that four nodes of undulating motion are found near Q_D of each periodic configlation. The maximum horizontal deviation from the designed orbit occurs near each open section. The maximum deviation is about $\pm$ 5 mm for a steering magnetic field of 100 gauss and the horizontal tilt angle of the undulating beam near the nodes is about $\pm$ 2.5 mrad.

The pressure rise due to gas desorption from the chamber wall caused by SR was also observed when the steering magnet B_H was operated at a magnetic field of 100 gauss, but the pressure rise was not so large compared with the case of the vertical undulating beam.

Fig.7 shows schematically the principle of the expansion of exposed area of high-intensity wiggler radiation by the use of the vertical and horizontal undulating beam proposed here.
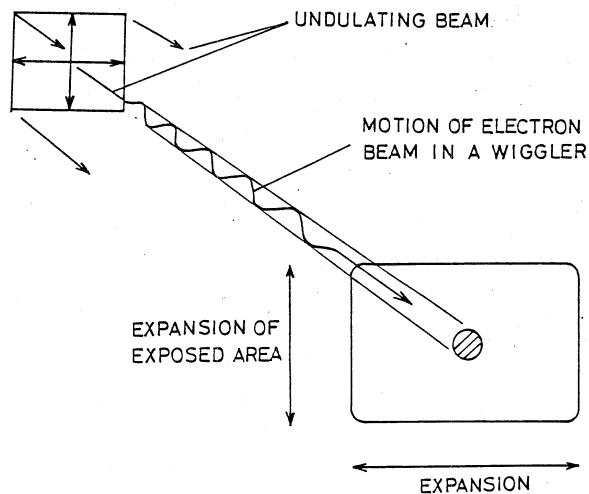
REFERENCES

1) T. Tomimasu, Proc. 2nd China-Japan Joint Symposium on Accelerator for Nuclear Science and Their Applications, Lanzhou, 11-13 Oct., p.135, 1983
2) T.Tomimasu et al., IEEE Trans., NS-30, No.4, 3133, 1983
3) A. D. Baer et al., IEEE Trans., NS-22, No.3, 1794, 1975
4) H. Tanino et al., Japan. J. Appl. phys. 22, L677, Nov., 1983

Table 1

( ) shows final target

Max. energy	600 MeV (800 MeV)
Stored current	150 mA (300 mA)
Circumference	31.45 m
Radius of curvature	2.000 m
Average radius	5.000 m
Lattice	$0/2\,B_d Q_f Q_d Q_f B_d\,0/2$
No. of dipole magnets	8
No. of quadrupole magnets	12
No. of sextupole magnets	(4)
Betatron freq.	$\nu_x \simeq 2.2$
	$\nu_z \simeq 1.3$
Rf freq.	162.1 MHz
Rf power	1.4 kW at 600 MeV-100 mA