Status of "AURORA-2S" and Its Facility for X-ray Lithography

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Abstract

A compact racetrack-type synchrotron light source "AURORA-2S" (A2S) based on the matured normal-conducting technology has been completed and proved its excellent capability; potential to accumulate over 1A, 12 hours of beam lifetime at the designed current 500mA for instance, after years of improvements and intensive long-term operation. In February 2000, we carried out the whole-month continuous operation and recorded more than 96% uptime, equivalent to 670/696 hours in service in one month. The machine is now in regular operation for R&D of X-ray lithography system in cooperation with our original compact and high-dose beamline (B/L), and the second version prototype of SR stepper.

1 INTRODUCTION

A2S was assembled in 1997 and commissioned in 1998.

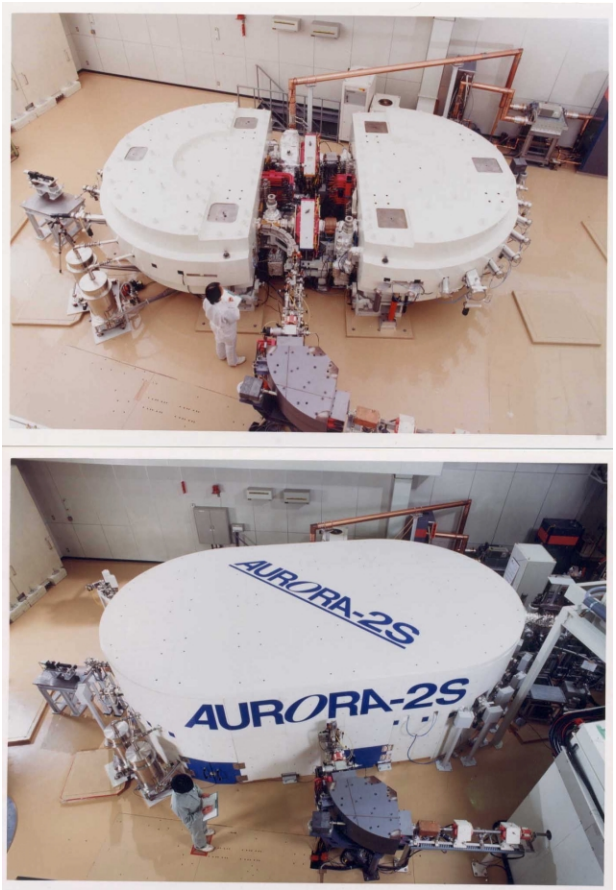

Figure 1: Overall view of AURORA-2S (A2S), before (upper) and after (lower) covered with self-shielding.

The initial commissioning was reported in EPAC'98 [1], and successive improvements in PAC'99 [2], with the summary of developing history of AURORA family [3]. A2S has now been completed as a very reliable machine, and being in service for various experiments, dominantly for X-ray lithography. As seen in Fig. 1 (lower), the storage ring is now entirely covered with neutron shields, becoming very safe from radiation hazard in the results.

2 DESIGN FEATURES OF A2S

The most outstanding feature of A2S originates in the 2.7 Tesla normal-conducting bending magnets. The second is no existence of defocusing quadrupoles, thus it has only focusing ones, each in the straight section. Major parameters are listed in Table 1.

Table 1: Parameters of AURORA-2S.

Energy	0.7	GeV
Circumference	11.0	m
RF voltage	200	kV
Harmonic number	7	
RF frequency	191.3	MHz
Energy aperture	7.27	MeV
Energy loss	24.4	keV/turn
Synchrotron frequency	0.215	MHz
Momentum compaction	0.196	
Tune : horizontal	1.46	
vertical	0.73	
Natural emittance	530.	π nm·rad
Energy spread	0.449	MeV
Radiation damping time:		
horizontal	2.13	msec
vertical	2.10	msec
longitudinal	1.04	msec
Bunch length	27.9	mm
Touschek life time	30.4	hours(at 1A)
Bending Field	2.7	Tesla
Quadrupole(QFonly, noQD)	12.5	Tesla/m

The ring takes over many advantages of the first superconducting AURORA, and a cost-effective system has come true in the results, adopting an active radiation-protecting method. The concept of self-shielding is schematically described in Fig. 2, where the inter-bending section is reinforced by heavy lead plates for protecting γ-rays, and the overall surfaces around the ring are covered with polyethylene plates for neutrons (Fig.1). It occupies the footprint smaller than 7m x 4m, including these shieldings. The ring provides twenty B/L's at the maximum from the two bendings.

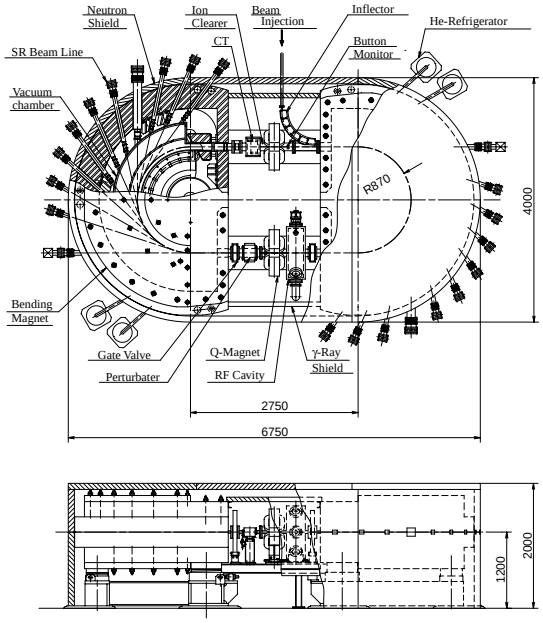

Figure 2: Schematic of A2S.

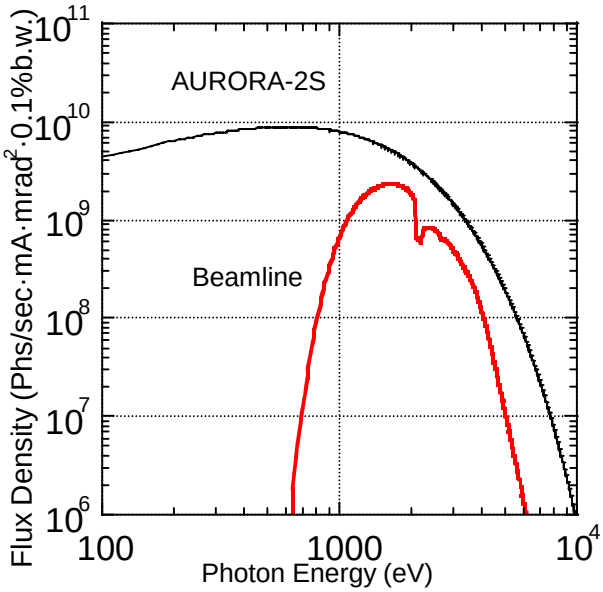

Figure 3: X-ray spectra of A2S and beamline.

The critical wavelength of A2S is 1.4 nm (Fig.3), therefore, it is a typical soft X-ray source. After passing through the B/L housing Pt-coated mirror and Be-foil, however, the spectra somewhat shift to a shorter-wavelength area. Majority of the remainder at the end of B/L lies around 1.5 keV (0.8nm).

3 FACILITY AND EXPERIMENTAL SETUP

We installed A2S prototype rather in a small area as shown in Fig.4, the space of which is 11m x 19m. Therefore, it is not practical to execute many experiments simultaneously. There are the injector microtron (lower right), beam transport line, storage ring, many B/L's including beam monitoring ports (they are rather short!),

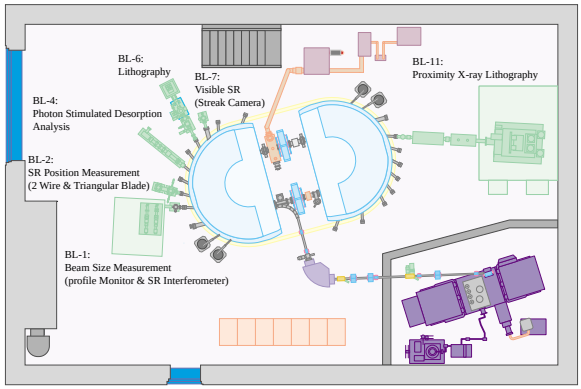

Figure 4: Layout of A2S prototype (Injector, BT, storage ring, etc.) and experimental setup.

RF power source (upper center) and other electrical apparatus in the same room. The beam measuring results are also presented in this conference [4].

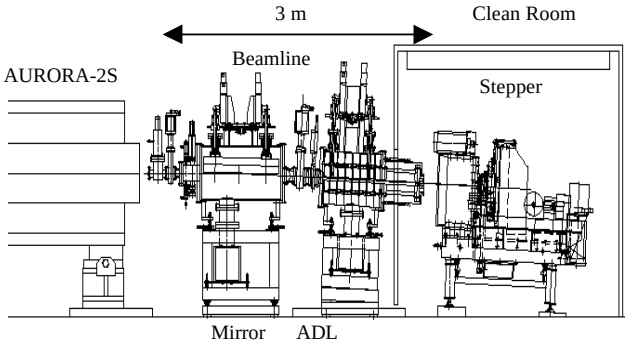

Figure 5: Schematic of compact beamline for X-ray Lithography.

The dominant BL-11, the schematic of which is in Fig.5 and parameters in Table2, offers a high-dose exposure system to make X-ray lithography experiments in great progress. It consists of a single scanning mirror, acoustic delay line (ADL), and Be-foil at the front end.

Table 2: Parameters of XRL beamline.

Length	SR to Be window	5 m
	Be window to wafer	0.6 m
	Swing radius of mirror	3 m
Mirror	Mirror figure	toroidal
	Effective area	L800 mm x W70 mm
	Tangential radius	286 m
	Sagittal radius	110 mm
	Surface coating	Pt
Be window	Foil thickness	20 μm

Recently, it is proved to be practical to achieve an exposure rate 50 mW/cm^2 on a wafer at 500 mA, when using our original short B/L with high brightness [5]. It suggests that we could have a speed one shot at one second to expose a wafer. Dose uniformity less than 3% was confirmed within an exposure area 26 x 26 mm^2 by optimizing the mirror scanning speed. Minimum

resolution of 80 μm has already been obtained with a 15 μm proximity gap, and we are to go further up to 70 μm resolution [5]. Fig.7 shows the whole view of the compact but powerful B/L connected to A2S.

Figure 6: Photo of compact beamline for X-ray litho.

We are much encouraged by the latest result of the exposure tests that there is no deterioration in uniformity observed on the wafer, which might have possibly originated from beam fluctuations in profile and/or position. X-ray lithography is proved insensitive to the condition of SR light source, assuming our compact B/L is to be adopted.

4 OPERATION STATUS

For upgrading A2S, our main concern was directed to improve beam lifetime, therefore, it is inevitable to accelerate the vacuum aging procedure. By this reason, we concentrated on continuous operation as long as possible, especially in the period from mid-October 1999 to mid-March 2000. The effect is remarkable, as seen in Fig.7, where lifetime τ is normalized by stored current I as I*τ. One can see the prominent improvement of lifetime in accordance with increased dose integration I*t, the product of stored current I and operating time t. In this period, I*t advanced from 320 to 1050 A·hour (in Fig.7, they are plotted in red/magenta), and I*τ improved from 1 to 6 A·hour in the results, which is equivalent to 12 hours lifetime at 500 mA.

Another effort was made to reach the final goal of accumulated current. In the beginning of this year, we succeeded in proving the capability of A2S to accumulate 1A. The acceleration efficiency was about 95%, which means to inject 1050 mA is sufficient to obtain 1A stored current. After that, in February we executed one-month continuous operation resulted in the excellent record which is stated in the beginning.

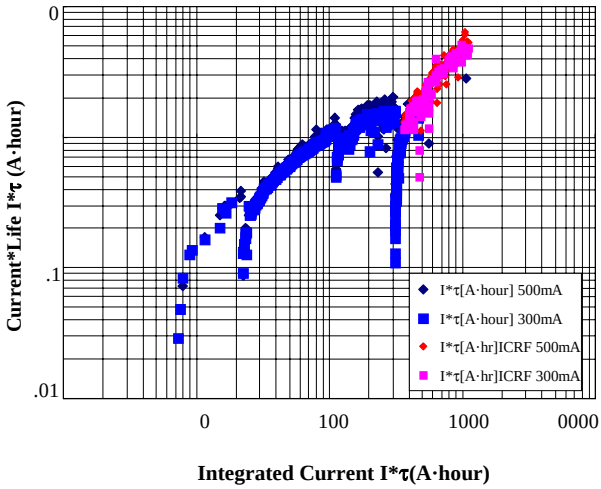

Figure 7: Life vs. Dose, still keeping improvement in accordance with dose integration.

5 CONCLUSION

After achieved over 500 mA accumulation routinely in February 1999, A2S has intensively been operated to serve SR to various B/L's, mostly to the one related to X-ray lithography. The results obtained so far are remarkable as stated; high exposure intensity competitive to conventional optical lithography, enough dose uniformity for actual ULSI production, and break-through resolution for the next generation lithography. From these results, the excellence of our original compact B/L and new SR stepper is fully clarified. At present, we judged that A2S has been completed as an industrial X-ray source for lithography. It achieved the final goal of stored current 1A. The lifetime is still expected to increase from 12 hours at 500 mA, depending on the progress of vacuum aging.

6 REFERENCES

[1] H. Miyade, et al., "Initial Commissioning of Dedicated SR Ring 'AURORA-2S' for X-Ray Lithography", Proc. EPAC'98, Stockholm, (1998) pp.2413-2415.

[2] H. Miyade, et al., "Beam Test of Compact SR Ring 'AURORA-2S' for X-ray Lithography", Proc. PAC'99, New York, (1999) pp.2403-2405.

[3] T. Hori, "Ten Years of Compact Synchrotron Light Source AURORA", Proc. PAC'99, New York, (1999) pp.2400-2402. Note: major ref's before 1999 related to AURORA-1 & -2 are all listed in this paper.

[4] D. Amano, et al., "Beam measurements of Compact SR ring AURORA-2S", submitted to this conference.

[5] S. Hirose, et al., "Performance of a Compact Beamline with High Brightness for X-ray Lithography", Submitted to 44th International Conf. on Electron, Ion, & Photon Beam Technology and Nanofabrication (EIPBN2000, May 30 - June 2), Palm Springs, California.

[6] S. Hirose, et al., "Dose Uniformity of a Compact Beamline in Routine Operation with a Storage Ring AURORA-2S", submitted to International Microprocess and Nanotechnology Conf. (MNC2000, July 11 - 13), Tokyo.