The DARPA Compact Superconducting X-Ray Lithography Source Features[1]

Richard Heese
National Synchrotron Light Source
Brookhaven National Laboratory
Upton, New York 11973

Swarn Kalsi
Grumman Space & Electronics Systems
Bethpage, New York 11714

Eddie Leung
General Dynamics Space Systems
San Diego, California

Abstract

Under DARPA sponsorship, a compact Superconducting X-Ray Lithography Source (SXLS) is being designed and built by the Brookhaven National Laboratory (BNL) with industry participation from Grumman Corporation and General Dynamics. This source is optimized for lithography work for sub-micron high density computer chips, and is about the size of a billiard table (1.5 m x 4.0 m). The machine has a racetrack configuration with two 180° bending magnets being designed and built by General Dynamics under a subcontract with Grumman Corporation. The machine will have 18 photon ports which would deliver light peaked at a wave length of 10 Angstroms. Grumman is commercializing the SXLS device and plans to book orders for delivery of industrialized SXLS (ISXLS) versions in 1995. This paper will describe the major features of this device. The commercial machine will be equipped with a fully automated user-friendly control systems, major features of which are already working on a compact warm dipole ring at BNL. This ring has normal dipole magnets with dimensions identical to the SXLS device, and has been successfully commissioned.

INTRODUCTION

Technology transfer from BNL to Grumman has been underway with DARPA funding since the end of 1988. The main objective is to develop U.S. capability for manufacturing the compact superconducting x-ray light sources (SXLS) suitable for application in a semiconductor factory environment. Grumman along with its team member General Dynamics is working towards commercialization of the synchrotron technologies developed at BNL. Grumman is seeking orders from the chip fabricators for delivery of SXLS sources beginning 1995.

As the design and fabrication of the complex superconducting dipoles requires considerable time and effort, the project is being executed by BNL in two phases. In Phase I a machine has been constructed with low field (1.1 Tesla) normal dipole magnets, with the same bending radius as the superconducting magnets. With this low field dipoles the energy of the machine is limited to 200 MeV. For Phase II, the low field dipoles are replaced with superconducting magnets to enable the ring to reach energy of 700 MeV and generate light peaked at 10 Angstrom for lithography. The key parameters of the SXLS are provided in Table 1.

Table 1. Key Parameters of SXLS

Parameter	Value	Unit
Energy	700	MeV
Beam Current	500	mA
Critical Wavelength	10	Angstrom
Beam lifetime	~6	Hours
Magnetic field in dipoles	3.85	Tesla
Beam bending radius	0.6	m
Beam circumference	8.5	m
Injection energy	100-200	MeV
RF frequency	211.54	MHz
RF voltage	150	kV
Vacuum pressure	10^{-9}	Torr
Radiated power	5.5	W/mrad/A

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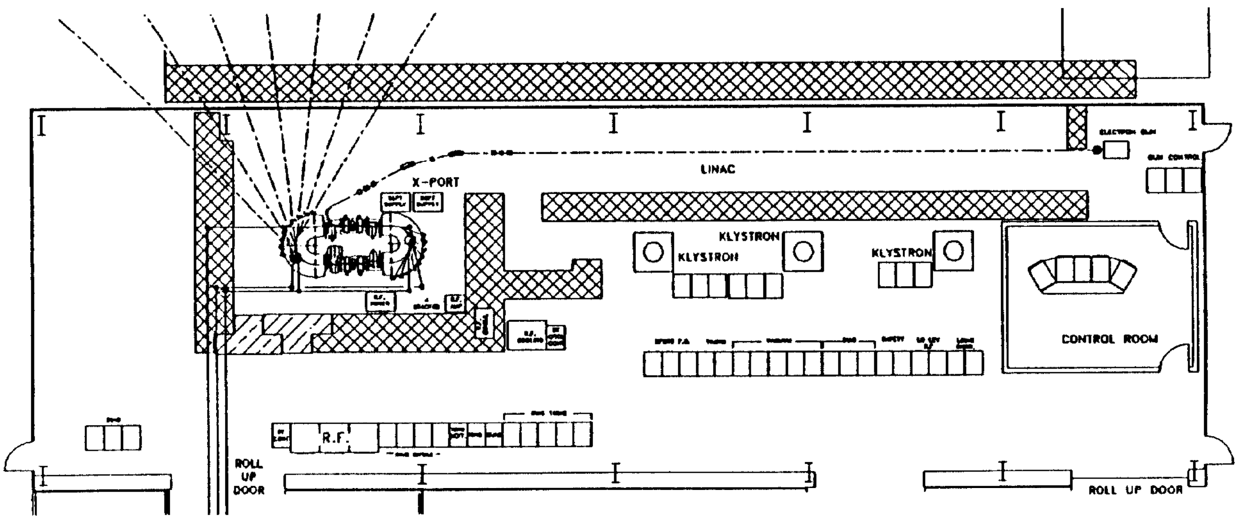

Figure 1. SXLS Facility layout at BNL

The overall configuration of the superconducting machine with its supporting equipment is shown in Fig. 1 at the BNL commissioning site. The main components of the SXLS machine are LINAC injector, an injection transfer line from the LINAC to the ring, pulsed septum and kicker magnets, a radio frequency (RF) accelerating cavity, two 180° superconducting bending magnets, two sets of triplet normal magnets, and ancillary vacuum and cooling equipment. Commissioning of the SXLS at BNL is planned for the fall of 1993.

STORAGE RING

The plan view of the storage ring is shown in Fig. 2. The storage ring is compact and has two superconducting dipole magnets with a beam bend radius of 0.6 m. Total beam circumference is 8.5 m and the overall dimensions of the ring are 4.2 m x 1.8 m. The height of the x-ray light port is 1.4 m. Two focusing magnet assemblies are provided, each consisting of a sextupole magnet sandwiched between two quadrupole magnets. These magnets employ normal coils and laminated iron yokes.

Superconducting Magnets

The two superconducting magnets form the most complex part of the ring. The magnets produce a maximum field of 3.85 T in the beam region. The magnets are air-cored and employ warm beam chambers. In addition to the main dipole field coils, superconducting trim coils are also incorporated for generating quadrupole, sextupole and radial field components. BNL developed the magnet design. General Dynamics is responsible for engineering design and construction of the magnets. A cutaway view of the magnet is shown in Fig. 3. The magnet coils are split into two sections, the upper and lower parts. The coils employ NbTi superconducting cable that was developed for the Relativistic Heavy Ion Collider (RHIC) being constructed at BNL. They are supported by a cold mass structure having a low magnetic permeability. Each magnet has 9 ports for extracting the x-ray light.

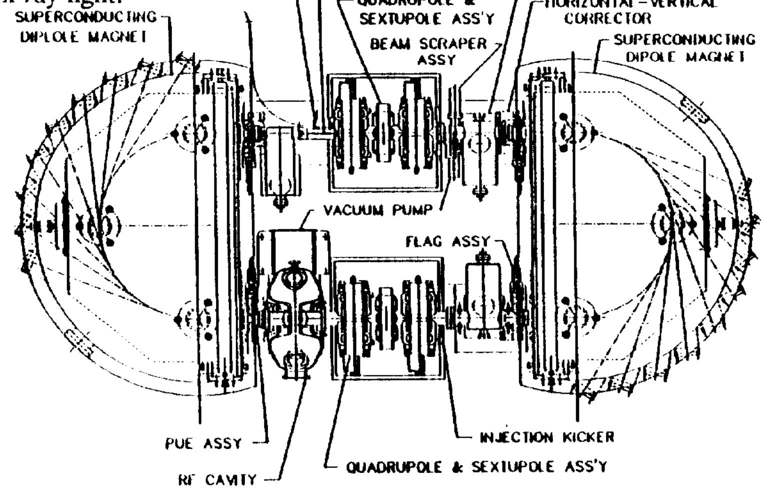

Figure 2. Plan view of the SXLS ring

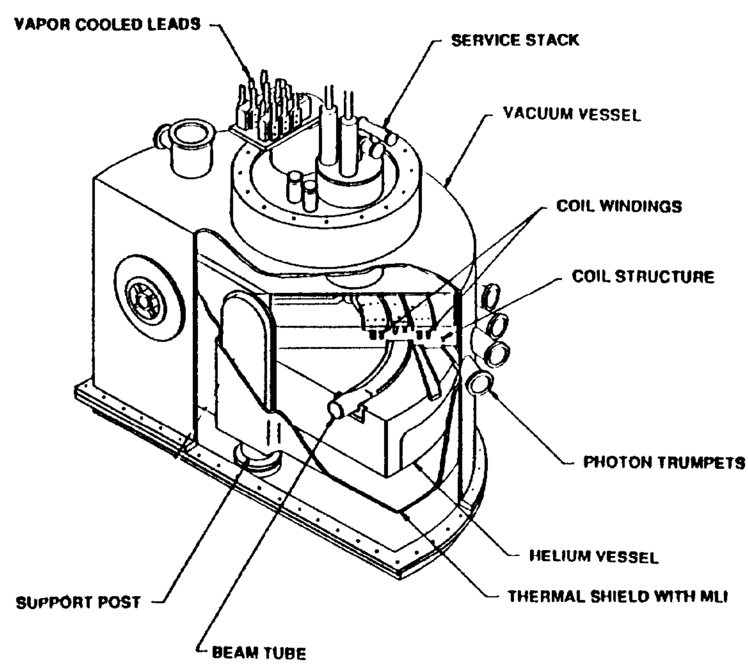

Figure 3. A superconducting dipole magnet assembly

RF System

The ring has an RF cavity that has a single gap (to conserve space) and is capacitively loaded. The cavity operates at 211.5 MHz and is supplied from a 65 kW amplifier. The amplifier is on order with ------ and is expected to be delivered this summer. The RF cavity is being characterized by measurements on a full-scale model. An order shall be placed for the construction of the cavity during the spring of 1991.

Injection System

A 200 MeV LINAC shall be employed for filling the ring. As shown in Fig. 1 the LINAC is connected to the ring through a transfer line. The LINAC is on order with Beta Corporation and is expected to be delivered in the summer of 1992. The transfer line components are in the final stage of designing. They will be constructed in-house by BNL and are expected to be in-place before the LINAC arrives at BNL.

Vacuum System

The beam chamber inside the dipole magnets is rectangular in cross-section and is maintained at room-temperature. In the straight section, the beam chamber has a circular cross-section. The system is designed for an operating pressure of 10^{-9} Torr or better with 500 mA of stored beam. The pumping is accomplished with a combination of pumps, i.e. Sputter ion pumps (SIP), titanium sublimation pumps (TSP), and non-evaporable getter pumps (NEG). A NEG strip pump built into the dipole chamber provides uniform pumping in this area. In the straight section and on the RF cavity SIP, TSP and NEG pumps are employed. To facilitate low energy injection, both the straight section and the dipole chambers have ion clearing electrodes.

Control System

The key goal in this area is to develop a highly reliable and fully automated control system suitable for operation of SXLS in a production environment. A control system for industry environment would require the following two features:

- Maintain proper performance and safety of the accelerator and associated equipment by monitoring and controlling beam parameters and supporting subsystems.
- Provide automation and information necessary to assure commercially-adequate system availability, operability, and fault-tolerance capability to factory standards.

Other key features to be incorporated in this control system are modularity to ensure ease of maintenance, a high degree of reliability, and a self-diagnosis capability.

A highly graphic oriented control system has been developed for the Phase I ring (warm machine) and it is being extended to be a more automated system for the Phase II (cold machine). The control system for the cold machine would have most of the features desired in the industry type control system but it might not be fully-hardened for the industry environment.

The control system consists of a distributed cluster of work stations which functionally and physically distribute the control system tasks. The controls are clear and direct, enabling the operator to determine the state of the machine quickly and easily. The control system is based on the three building blocks: 1) Hewlett Packard UNIX workstations which communicate over an ethernet local area network, 2) CAMAC modules for interfacing between the computers and the SXLS hardware over HPIB buses, and 3) a TACL software package (developed by CEBAF of Newport News, Virginia). This control system provides a graphic interface for the rapid development of operator displays and control logic.

SYNCHROTRON RADIATION CHARACTERISTICS

The SXLS will support a maximum of 18 beamlines. Fig. 4 shows synchrotron radiation as a function of the wavelength. The peak flux is at a wave length of 10 Angstrom. Half of the radiation power is emitted above the critical wave length and half below.

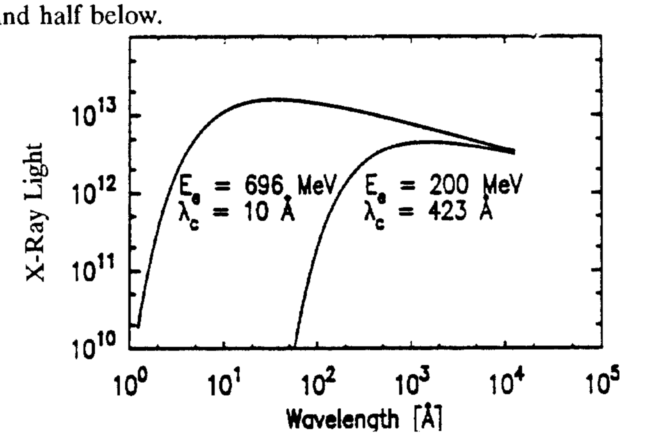

Figure 4. Synchrotron radiation as a function of wavelength

CONCLUSIONS

The success of the warm ring has amply demonstrated that the lattice selected for SXLS works. It is a forgone conclusion that upon completion in 1993 the SXLS would achieve (and probably exceed) all its goals. With this evidence Grumman is offering the industrialized version of this machine to the chip manufacturing industry for deliveries beginning 1995.