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NSLS Source Development Laboratory

Ilan Ben-Zvi, Eric Blum, Erik D. Johnson, Sam Krinsky, James B. Murphy, and Li-Hua Yu

Brookhaven National Laboratory, National Synchrotron Light Source, Upton Long Island, New York, 11973

ABSTRACT

The National Synchrotron Light Source (NSLS) has initiated an ambitious project to develop fourth generation radiation sources. To achieve this goal, the Source Development Laboratory (SDL) builds on the experience gained at the NSLS, and at the highly successful BNL Accelerator Test Facility. The SDL accelerator system will consist of a high brightness short pulse linac, a station for coherent synchrotron and transition radiation experiments, a short bunch storage ring, and an ultra-violet free electron laser utilizing the NISUS wiggler. The electrons will be provided by a laser photocathode gun feeding a 210 MeV S-band electron linac, with magnetic bunch compression at 80 MeV. Electron bunches as short as 100 μm with 1 nC charge will be used for pump-probe experiments utilizing coherent transition radiation. Beam will also be injected into a compact storage ring which will be a source of millimeter wave *coherent* synchrotron radiation. The linac will also serve as the driver for an FEL designed to allow the study of various aspects of single pass amplifiers. The first FEL configuration will be as a self-amplified spontaneous emission (SASE) FEL at 900 nm. Seeded beam and sub-harmonic seeded beam operations will push the output wavelength below 200 nm. Chirped pulse amplification (CPA) operation will also be possible, and a planned energy upgrade (by powering a fifth linac section) to 310 MeV will extend the wavelength range of the FEL to below 100 nm.

1. Introduction

The Brookhaven National Laboratories National Synchrotron Light Source (NSLS) is a so called 'second generation' synchrotron radiation source, designed as a dedicated user facility to serve a diverse research community. Its two storage rings provide radiation from the infra-red to hard x-rays. While the NSLS storage rings have been continuously upgraded to provide state of the art performance and reliability, opportunities exist for the development of accelerator based *coherent* sources of radiation. To maintain its position at the forefront of synchrotron radiation based research, the NSLS has initiated an ambitious project to develop fourth generation sources of coherent radiation. This effort, dubbed the Source Development Laboratory (SDL), is really a consolidation of several projects, and a response to recent developments within the Department of Energy (DOE) and the synchrotron users community.*

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THE NSLS SOURCE DEVELOPMENT LABORATORY

Ilan Ben-Zvi, Eric Blum, Erik D. Johnson, Sam Krinsky, James B. Murphy, and Li-Hua Yu

Brookhaven National Laboratory, National Synchrotron Light Source,
Upton Long Island, New York, 11973

ABSTRACT:

The National Synchrotron Light Source is a second generation dedicated facility serving a diverse user community with two storage rings that provide radiation from the infra-red to hard x-rays. To maintain its position at the frontier of radiation based research, the NSLS has initiated an ambitious project to develop fourth generation radiation sources. To achieve this goal, the Source Development Laboratory (SDL) builds on the experience gained at the NSLS, and at the highly successful BNL Accelerator Test Facility. The SDL accelerator system will consist of a high brightness short pulse linac, a station for coherent synchrotron and transition radiation experiments, a short bunch storage ring, and an ultra-violet free electron laser utilizing the NISUS wiggler. The electrons will be provided by a laser photocathode gun feeding a 210 MeV S-band electron linac, with magnetic bunch compression at 80 MeV. Electron bunches as short as 100 μm with 1 nC charge will be used for pump-probe experiments utilizing coherent radiation which also serves as a diagnostic of the beam produced by the linac. Beam will also be injected into a compact storage ring which will be fitted with a superconducting S-band RF cavity. The ring will thus be a source of millimeter wave *coherent* synchrotron radiation. The linac will also serve as the driver for an FEL designed to allow the study of various aspects of single pass amplifiers. The first FEL configuration will be as a self-amplified spontaneous emission (SASE) FEL at 900 nm. Seeded beam and sub-harmonic seeded beam operations will push the output wavelength below 200 nm. Chirped pulse amplification (CPA) operation will also be possible, and a planned energy upgrade (by powering a fifth linac section) to 310 MeV will extend the wavelength range of the FEL to below 100 nm.

DISCLAIMER

Bio-sketch for Erik D. Johnson:

Erik D. Johnson obtained his bachelors degree at the University of Minnesota, and Ph.D. at Cornell University, both in the field of Chemical Engineering. At BNL he holds the appointment of physicist in the National Synchrotron Light Source department, and as a member of the Beamline Research and Development group, has been involved in the development and utilization of synchrotron radiation instrumentation. He is currently the project manager for the NSLS Source Development Laboratory.

Correspondence Information:

All phone numbers are in the area code (516) with 282 exchanges [282-xxxx]

Author	Extension	FAX	E-mail
Ilan Ben-Zvi	5143	3029	ilan@bnl.gov
Eric Blum	2438	3029	blum@bnllls1.nsls.bnl.gov
Erik Johnson	4603	3238	erik@bnl.gov
Sam Krinsky	4740	4745	krinsky@bnlls1.nsls.bnl.gov
Jim Murphy	5160	3029	jbm@bnlls1.nsls.bnl.gov
Li-Hua Yu	5012	3029	yu@bnlls1.nsls.bnl.gov

Mailing address for all authors:
BNL-NSLS Building 725
Upton New York, 11973-5000

The SDL is comprised of three major programs:

- 100μm Compressed Bunch Experiments for Transition Radiation (CTRE)
- μ-Ring Compact Storage Ring with High Frequency RF (CSRE)
- UP-FEL Ultraviolet Project Free Electron Laser (UP-FEL)

The motivation and historical development for this project are described in this paper. An overview of related activities and the current SDL design are also provided, followed by some concluding remarks.

2. Historical Development

The NSLS has been engaged in the development of proposals for a Free Electron Laser user oriented facility operating in the Ultra-Violet for more than five years. The Deep Ultra-Violet Free Electron Laser (DUV-FEL) conceptual design report[1] was released in January of 1993. It details the scientific motivation, and describes a user facility designed to meet those needs. The DUV-FEL could produce picosecond pulses of UV radiation at wavelengths as short as 75 nm and peak power of several hundred megawatts. An extension of this technology would operate in a chirped pulse mode which could produce 4 femtosecond pulses at 88 nm with peak power of 100 GW[2].

As work progressed at the NSLS, a general awakening within the community had occurred which emphasized the need for source development. One element of this perspective is the realization that, even as they are coming on line, the third generation synchrotrons are inadequate for certain types of experiments. These include non-linear effects and dilute systems where higher peak power is required, or many types of intensity correlation studies where spatial coherence beyond the capabilities of existing sources is beneficial[3]. A second driving force in the recent FEL renaissance has been the advances in many aspects of the accelerator physics.

Experiments conducted at the BNL Accelerator Test Facility and other laboratories have demonstrated dramatic improvements in electron beam brightness in the last several years. The current state of development is such that short wavelength FEL's based on amplifier designs can be realistically considered. The theoretical description of the FEL process has also advanced significantly, yielding innovative FEL designs such as the sub-harmonically seeded amplifier.

Recognizing the significance of these developments, the DOE commissioned the National Research Council to perform a study of Free Electron Lasers and Other Coherent Sources of Radiation to aid in evaluating their role in DOE programs. Released in August of 1994, the report[4] recommends establishing a FEL user facility in the far-infrared and supporting the use of existing laser technology in the near-infrared and visible (located in individual investigators laboratories).

In the VUV and X-ray regions, the report recommends pursuing proof of principle experiments at existing synchrotron sources, and supporting the development of technology for FELs in these wavelength regions.

3. SDL Evolution

Anticipating the outcome of the report, the NSLS initiated several activities during the last year known collectively as the Ultraviolet Project. One component of this work has been supporting a major share of the operation of U11 and the construction of the U13U low energy branch line as sites for proof of principle experiments in UV science which might later be performed at an FEL facility. In this respect, the program seeds the science, and can serve as a focal point for UV based research at BNL. A second major activity has been the development of a collaboration to pursue UV-FEL R&D at Brookhaven utilizing components from other projects at BNL and elsewhere. The kernel of the collaboration was suggested in a workshop 'Towards Short Wavelength Free-Electron Lasers' [5] held at BNL in May of 1993.

One of the projects it proposed was utilizing the ARPA linac at BNL (built originally for the SXLS project) with an undulator known as NISUS (Near Infrared Scaleable Undulator System)[6]. The 10 meter long NISUS undulator was built by STI Optronics, at a cost of over 8 $M, for Boeing Space and Defense in Seattle as part of a contract with the US Army Space & Strategic Defense Commands Directed Energy Weapons Program. On loan to BNL, NISUS arrived in December 1994, and is currently undergoing modification for use in FEL experiments ultimately leading to a ultraviolet FEL. The Ultraviolet Project FEL (UP-FEL) does not have all of the features designed into the DUV-FEL proposal, but will ultimately provide radiation comparable in peak power and wavelength to the DUV-FEL. Although meant to be an R&D machine, the UP-FEL should provide an opportunity to explore applications (and foibles) of this type of source for research. Experience gained on this machine will be invaluable in the design of a user oriented facility.

This element of the SDL, while sited at BNL, is part of a broad based collaboration involving many institutions in a program of FEL amplifier R&D leading to the development of short wavelength FEL technology, as recommended by the NRC report. Apart from BNL, this effort includes other DOE laboratories (CEBAF, LBNL, LANL, SLAC), industrial partners (Boeing, Grumman, STI-Optronics), and universities (Duke, UCLA). This program will build on the established strengths and capabilities of the participating institutions in an effort to pursue the development of what will become the 'Fourth Generation' source for research.

One goal of the larger collaboration is the development of techniques to produce extremely short (compressed) bunches to achieve very high peak currents[7]. In pursuing this development, it became clear that the 100 μm electron bunches could be a useful tool independent of any 'down-stream' accelerator. One proposed experiment is to study the response of dielectric materials to electromagnetic stimulation. The realization of the experiment is to pump a dielectric target with electrons from the accelerator, and probe it with transition radiation produced by a second electron bunch impinging on a metal foil. The delay can be varied to measure the response as a function of time after excitation. Time dependent properties of the scattered radiation such as intensity, polarization, angular distribution, and spectrum can thus be measured.

In another parallel activity, the potential of extremely short length bunches was realized as a source of coherent synchrotron radiation. One proposal described the modification of the existing compact storage ring to include a 3 GHz RF system[8]. These modifications would result in stored electron bunches of 300 μm in length. The synchrotron radiation produced by this beam would be coherently enhanced at millimeter and longer wavelengths. The development of this alternative to FEL technology could potentially address some of the recommendations of the NRC study in the far infra-red. It became clear that each of the source development projects described above could be pursued utilizing many shared, and often recycled, components.

4. SDL Project Overview

Figure 1 shows the layout of the Source Development Laboratory. As currently designed, the SDL accelerator system will consist of a high brightness short pulse linac, a station for coherent synchrotron and transition radiation experiments, a short bunch storage ring, and an ultra-violet free electron laser utilizing the NISUS wiggler. The electrons are provided by a laser photocathode gun of the type developed at the BNL-ATF. It feeds the 210 MeV ARPA linac which will be modified to include magnetic bunch compression after the second linac section at approximately 80 MeV, and to provide for the addition of a fifth acceleration section. With the bunch compressor operating, electron bunches as short as 100 μm with 1 nC charge can be generated for pump-probe experiments utilizing coherent transition radiation. The radiation from the Coherent Transition Radiation Experiment (CTRE) also serves as a diagnostic of the electron beam quality produced by the accelerator. The electron beam can also be injected into the modified XLS storage ring. Fitted with a superconducting S-band RF cavity, the ring will be a source of millimeter wave *coherent* synchrotron radiation, forming the basis of the Coherent Synchrotron Radiation Experiment (CSRE). The linac is also the driver for the UP-FEL, which is designed to allow the study of various aspects of single pass amplifiers.

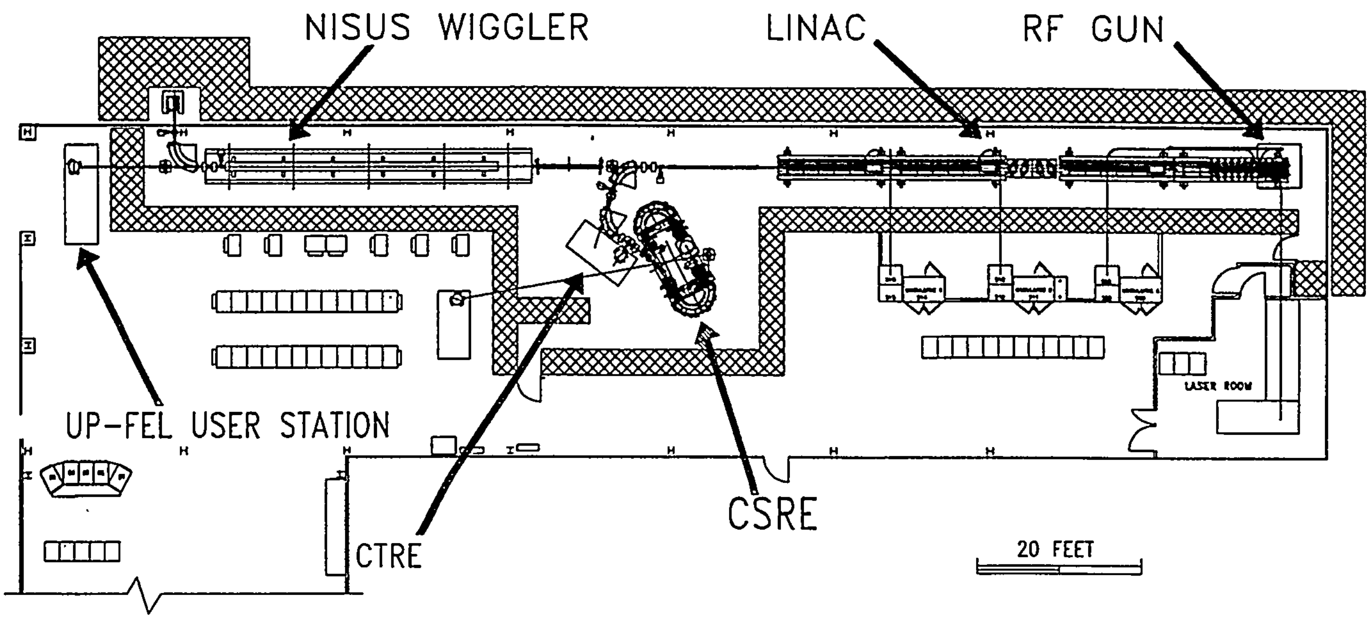

Figure 1: Schematic view of the Source Development Laboratory. CTRE and CSRE are the coherent transition radiation experiment, and the coherent synchrotron radiation experiment respectively. The linac configuration shown is for 210 MeV electron beam energy.

The initial phase of FEL development involves self-amplified spontaneous emission (SASE) at wavelengths down to 900 nm, and seeded beam operation utilizing only the NISUS wiggler. Sub-harmonic seeding experiments will be possible with the addition of a energy modulation wiggler and a dispersive section upstream of NISUS. Design studies of these components of the FEL are currently under way. Chirped pulse amplification (CPA) operation will also be studied and a planned energy upgrade (by powering a fifth linac section) to 310 MeV will extend the wavelength range of the FEL to below 100 nm.

5. Closure

All of this activity occurs against the backdrop of difficult times for the funding of research in the US, and difficult choices for the operation of its large research facilities. For BNL, one of these decisions has been to pursue source development. The same motivations that led to the creation of the NSLS drive this effort; to provide the users of its facilities the best possible sources of radiation for their research. Hopefully this new initiative at BNL will meet with the same degree of success the NSLS has enjoyed, and form the basis for the 'next generation' user science.

6. Acknowledgments

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