The Deep UltraViolet – Free Electron Laser

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The DUV-FEL has seen tremendous progress since our last report. Through the early part of 2001 work continued on commissioning of the linac while the undulator was being prepared for integration into the machine. On April 23, 2001 we shut down to connect the linac to the amplifier and complete the installation of the beam diagnostics in the undulator. This work was completed by the end of October with the first beam commissioning in the new configuration starting on October 26th. The first Self-Amplified Spontaneous Emission (SASE) laser light was observed on February 13th 2002. This is of course rather too brief to appreciate the accomplishments involved in each stage of the process, so I've summarized some of the highlights.

Linac Commissioning

Our principle goal was to shake out the operation of the machine which had been reconfigured and rebuilt from the old XLS linac, and to achieve the electron beam performance required for FEL operation. Adjustments were made to our photocathode gun that allowed us to increase the gradient from 89 MV/m to 105 MV/m without increasing the RF drive, which has important consequences for the electron beam performance. We also made a significant effort in diagnostics and controls to allow us to rapidly measure beam parameters and compare them with simulations. These included the implementation of

- YAG:Ce single crystal scintillators for precision electron beam imaging.
- UV laser time profile measurements with *200 ƒs* resolution.
- Electron beam time profiles with *50 ƒs* resolution.
- Slice emittance diagnostics with *200 ƒs* resolution
- Highly integrated data collection, analysis, and modeling programs.

We put these tools to good use in a number of ways including the first measurements of thermal emittance from a photoinjector, a fundamental limit on the electron beam brightness that can be achieved, which in turn establishes performance limits for the FEL. We also ran a series of experiments in coherent synchrotron radiation (CSR) in a chicane bunch compressor. Some of these diagnostics and measurements are illustrated by the beam profile shown in Figure 1 demonstrating 50 fs time resolution measurements of the electron beam profile.

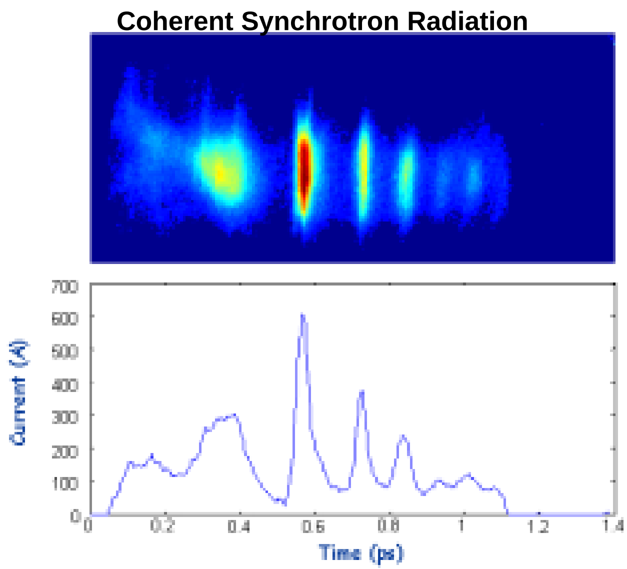

Figure 1.*Scintillator image and time projection showing 50 ƒs time resolution and intense current spikes due to CSR in the pulse compressor chicane.*

The successes of the linac development program have resulted in world-wide interest and participation in photoinjector/linac experiments and modeling using the capabilities of the DUV-FEL linac. Publications based on this work have been submitted, and they were an element of attracting our first external funding from the AFOSR.

Shutdown Activities

Leading up to the shutdown and integration of our undulator into the machine, a significant amount of work went into configuring it for our FEL experiments. The NISUS undulator was magnetically measured and corrected to minimize the trajectory and phase errors. The vacuum system was installed, and pop-in monitor diagnostics similar to those developed for the linac were built and installed. An optical alignment system was developed that allows the position of the electron beam to be compared with an alignment laser giving us a beam based alignment tool. The transport line between the linac and undulator was installed as well as a reconfiguration of the linac beam dump and the addition of a beam dump down-stream of the undulator.

Another major aspect of the shutdown was the implementation of the safety systems and documentation to allow operation of the reconfigured machine. This included novel shielding for the undulator for both x-rays and neutrons which can be easily moved to allow servicing of the undulator components. The interlock system was extended, and the Safety Assesment Document was completely revised and approved. With all of these elements in place, we started commissioning the machine on October 26th.

importance of controlling the quality of the output light from the FEL to support a broader range of research, particularly in atomic and chemical physics. In what has become a BNL signature experiment, the High Gain Harmonic Generation (HGHG) FEL was developed and tested at the ATF in 1999. The team lead by NSLS physicist Li-Hua Yu demonstrated that seed light at 10 microns (infra-red light) could produce microbunching in the electrons that could then be amplified at harmonics of the input light. To extend the principle to much shorter

NISUS Then and Now

Figure 2. *(Left) NISUS after it was placed in the SDL building in 1996. (Right) NISUS during installation of the new components on June 3, 2001.*

Current Events and Future Plans

On February 13, 2002 Self Amplified Spontaneous Emission (SASE) lasing was achieved. The 400 nm lasing is an important milestone on the way to the ultimate goal of the DUV-FEL, which is sub-harmonically seeded high gain harmonic generation (HGHG) at wavelengths below 100 nm. The SASE result proves that we have produced electron beam that meets the stringent requirements for lasing, and that the beam based alignment scheme developed for the DUV-FEL can reduce the trajectory errors to well within the tolerance required for lasing.

While it is an important milestone, it is just the next of many steps on the path to implementation of advanced light source technology that builds upon years of work at BNL's ATF and NSLS. The ultimate goal of the DUV-FEL is to produce very short and intense pulses of light at wavelengths shorter than 100 nm (vacuum ultra-violet light).

In a SASE FEL one simply uses the spontaneous emission at the beginning of the long magnetic undulator to provide the starting signal. This is very convenient but it is also variable and noisy, since the electrons are randomly distributed as they enter the undulator. Scientists at BNL long ago recognized the

wavelengths in the DUV-FEL requires much better electron beam quality than the original HGHG experiment.

To meet this challenge NSLS physicist William Graves spearheaded the beam physics and metrology development program at the SDL. The recent SASE lasing clearly speaks to the success of that effort. For

SASE Signal at DUV-FEL

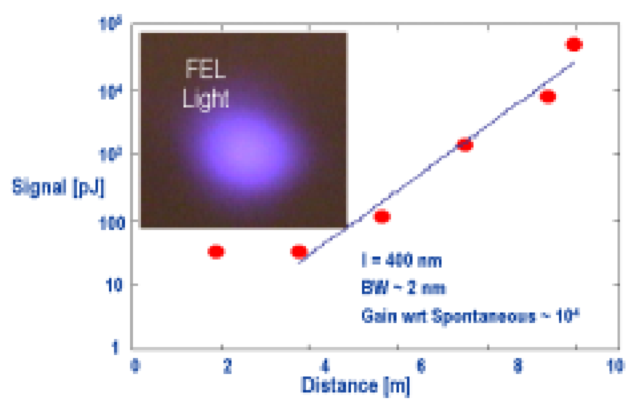

Figure 3. *The instrumentation in the DUV-FEL allows the measurement of the growth in light intensity as the beam travels through the 10 meter long NISUS undulator. Exponential gain of the light is clearly observed.*

this FEL commissioning measurement SASE light at 30 times the spontaneous emission background would have indicated sufficient beam quality to proceed with the DUV-FEL experiment. We were all pleasantly surprised to observe a laser intensity 20,000 times higher than the original spontaneous emission.

At least two factors contributed to this high output and its comparatively rapid attainment: The exquisite quality of our electron beam, and the beam-based alignment scheme that allows rapid and precise correction of the electron beam trajectory. More studies are planned to investigate the results while we proceed with implementation of the DUV-FEL. In the meantime, BNL scientists, along with collaborators from DESY and SLAC, are pursuing studies in fundamental electron beam physics with the DUV-FEL to further understand the processes involved and to help pave the way toward shorter wavelength FEL's out to x-ray energies.

Many people, too numerous to mention here have contributed our recent success and our prospects for a bright future. To learn more about them and their work, please visit our web site at:

http://nslsweb.nsls.bnl.gov/nsls/org/SDL/