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The Drive Laser for the APS LEUTL FEL Rf Photoinjector

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The APS LEUTL free-electron laser (FEL) is a high-gain, short-wavelength device requiring a high-current, low-emittance beam. An rf photoinjector driven by a laser is used to provide the requisite beam. The drive laser consists of a diode-pumped Nd:Glass oscillator and a chirped pulse amplification (CPA) system consisting of a grating stretcher, a flashlamp-pumped Nd:Glass regenerative amplifier, and a grating compressor. The system generates 4-mJ pulses in the IR with a pulse length as short as 2 ps FWHM and a repetition rate of 6 Hz. Nonlinear doubling crystals are used to generate fourth-harmonic output of ~500 μJ in the UV (263 nm), which is required to exceed the work function of the copper cathode in the gun. This paper describes the drive laser as well as the extensive controls implemented to allow for remote operation and monitoring. Performance measurements as well as the operating experience are presented.

1. System Goals

Difficulties with past FELs have often been attributed to inadequate beam quality. In an attempt to produce better beams, rf photoinjectors are being employed. The use of photoinjectors has placed the burden (and the blame) of producing high quality beams on the attendant drive lasers. The challenge of rf photoinjector drive lasers is to produce phase locked, high intensity, short UV pulses of high spatial and temporal quality (single mode, nearly transform limited), often in pulse length and repetition rates not available through the commercial laser industry [1].

The Advanced Photon Source (APS) Low-Energy Undulator Test Line (LEUTL) FEL [2] utilizes an rf photoinjector to produce a high brightness, high-current beam. The LEUTL drive laser was constructed to provide light for an S-band, 1.6-cell gun with a copper cathode designed to produce 1 nC of charge in a roughly 5-ps bunch at 10-Hz repetition rates [3]. Copper has a work function (~4.5 eV) that requires UV (less than about 275 nm) wavelengths for photoemission. Its low quantum efficiency ($\sim 10^{-5}$) demands high laser intensities (~200 μJ) to liberate the desired (1 nC) charge. Beam dynamics in the S-band (2.856 GHz) gun dictate a laser pulse in the 2- to 10-ps range (depending on the laser spot size, gun field gradient and output charge).

In addition to meeting the above specifications, the LEUTL drive laser was designed to be remotely controlled and integrated into the APS site-wide EPICS control system [4]. Near "hands off" operation of the laser also required a design with inherent long-term stability, as well as active feedback systems. High availability was also a consideration as systems at the APS traditionally operate continuously (24/7/365).

2. System Description

A main design guideline for the LEUTL laser system was to use commercial components and systems wherever possible. Indeed, the laser subsystems were obtained from two vendors while modifications, optical transport, and controls were done "in-house." The system consists of a Time-Bandwidth Products GLX-200 diode-pumped Nd:Glass oscillator that is actively mode-locked to an external 119-MHz clock. The clock is the twenty-fourth subharmonic of the linac rf frequency. The oscillator produces pulses of less than 200 fs, centered at 1053 nm, with about 80 mW of average power. After a set of diagnostics (including a spectrometer, autocorrelator, power meter, diode, and camera), the oscillator light is sent into a Positive Light custom chirped-pulse amplification (CPA) system. A grating stretcher provides a ~ 500-ps pulse (150 ps/nm) over a 3-nm bandwidth. The stretched pulse is amplified in a two-head flash-lamp-pumped Nd:Glass (6% doped Q-98) regenerative amplifier. A Pockels cell is used to select and trap a single pulse from the oscillator, while a second Pockels cell is used to "switch out" the amplified pulse. The amplifier produces pulses of about 9 mJ of energy at 6 Hz. After compressing the pulse in an adjustable four-pass single-grating system, nonlinear harmonic-generation

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crystals (presently KTP and KDP) are used to produce green (527 nm) and finally UV (263 nm) light.

The output of the Positive Light system is then directed through dichroic separators (to remove most of the green and IR light) and, after various diagnostics, is sent through an enclosed transport line to either the linac tunnel and final optics for steering onto the cathode, or to a separate test-area available for rf and gun development. Diagnostics include a single-shot autocorrelator, an energy meter, CCD cameras, and photodiodes. The transport lines are vacuum capable, but are presently not evacuated. Most laser controls, readbacks, diagnostics, and beam-steering optics are integrated into the APS control system.

3. Controls

The APS employs an EPICS-based control-system with embedded VME and VXI-based processors (running the VxWorks real-time OS). An X-windows GUI (MEDM) with a number of laser-specific screens is provided for user and operator controls. A library of general utilities and analysis programs (SDDS) are also available [5]. A VME crate with an assortment of interface electronics allows for most aspects of the laser system to be controlled from any X-windows client. For instance, laser system status (interlocks, power supply currents, etc.) and environmental conditions are read through ADCs and binary status bits, laser system controls (power supply on/off, shutters, triggers, etc.) are controlled through VME boards as well as GPIB-based equipment. A video system with multiplexer, real-time digitizer, and freeze frame allows for laser spot analysis at various points on the optical table and transport line. Diagnostics allow for pulse to pulse correlation of laser energy and electron beam charge.

4. Measured Performance

The LEUTL drive laser has met most of the design goals, but a few compromises in the parameters had to be made. The repetition rate had to be reduced from 10 Hz to 6 Hz due to thermal lensing and birefringence in the glass rods. The compressed IR level is lower than desired due to a low efficiency (80%) grating. In addition, UV beam quality is poor (with much transverse structure) and harmonic-conversion efficiency is poor (< 10%) due to inappropriate crystal selection. However, IR stability is good (±5%) and UV stability is excellent ($2\sigma = \pm5\%$ over minutes to hours) partly due to saturation of the crystal. Pointing stability is also good with resolution-limited centroid jitter measurements on the order of 0.3% of the beam spot (FWHM) near the cathode.

5. Operating Experience

The laser system has been operational (delivering UV to the cathode or "virtual cathode") for over 500 hours (not including testing and commissioning). Often the laser system is run for 12- to 24-hour periods to support beam studies. During long runs, the laser system typically requires no human intervention. From standby, the system may be remotely started and typically reaches nominal output energy and stability within an hour. Presently, the only controls that need to be adjusted locally on a regular basis are the amplifier cavity mirrors. While the laser is generally meeting the design goals and expectations, early difficulties with power supply failures, environmental controls, and optical damage to the amplifier rods imply that more development is needed to maintain long-term availability.

6. Future Directions

Three areas of near-future enhancements are planned for the operational LEUTL drive laser. Optical enhancements include replacing the compressor grating with a high-efficiency component, replacing the harmonic generation crystals, and implementing a spatial filter. Control upgrades include feedback systems for amplifier cavity mirror alignment and long-term drift compensation for alignment errors and energy drifts. Finally, spare components and prealigned, quickly replaceable subassemblies are being acquired to ensure high availability of the laser system.

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