A SHORT PULSE Ti:Sapphire LASER SYSTEM FOR PHOTOCATHODE RESEARCH AT SLAC*

J.Corbett, R.Coffee, A.Fry, S.Gilevich, N.Hartmann, W.Helml, P.Hering, E.Jongewaard, D. Kelley, J.Lewandowski, W.Polzin, J.Sheppard, P.Stefan, T.Vecchione, S.Weathersby, M.Woods, F.Zhou
SLAC National Accelerator Laboratory, Menlo Park, CA, 94025, USA

Abstract

A new laser laboratory has been constructed at SLAC to test and characterize photocathode gun physics and develop diagnostics for ultrafast FEL applications. At the heart of the laboratory is a dual-purpose Ti:Sapphire oscillator/regen laser that can deliver either 1.5-3.5 ps or 25 fs pulse durations. The primary objectives of the photocathode research are to identify reliable Cu cathode cleaning recipes and to produce high quantum efficiency with low beam emittance. The ultrafast applications program is presently aimed at developing spectral-encoding systems for shot-to-shot pulse arrival time diagnostics with 10's of fs timing resolution. In this paper we review the laser system and update status of the physics programs.

INTRODUCTION

A short-pulse, high-power Ti:Sapphire laser system has recently been commissioned at SLAC for photocathode research and ultrafast applications. The photocathode research is focused on surface preparation techniques using the spare LCLS electron gun and LCLS-II gun presently in fabrication. Laser cleaning, quantum efficiency, beam emittance and cathode exchange procedures are high priority topics [1]. The ultrafast program is presently focused on detailed analysis of spectral-encoding configurations for x-ray/laser pulse-arrival time diagnostics. Together these two programs time-share the Ti:Sapphire laser in a single laboratory making full use of the infrastructure on a daily basis.

In the following sections we outline optical, timing and Ti:Sapphire laser operation for the two applications.

ASTA LASER SYSTEM

ASTA, the Accelerator Structure Test Area, features a concrete shielding vault located in the original Klystron and Microwave laboratory at SLAC. Over time the vault has been used to hot test RF systems ranging from basic microwave components to x-band guns and Compton backscattering. To further increase the capabilities of the laboratory, the 5m x 7m room adjacent to the ASTA vault has been outfitted with a high-power Ti:Sapphire laser. A hole drilled through the 4'-thick concrete wall allows laser beam transport into the vault and an auxiliary optical bench provides a staging area for FEL development projects. As illustrated in Figure 1, the air-conditioned laboratory is protected by a modern laser safety system and equipped with electronics racks containing LLRF for laser/RF synchronization.

The Ti:Sapphire laser system is based on a mode-locked Vitara oscillator seeding a Legend Elite regenerative
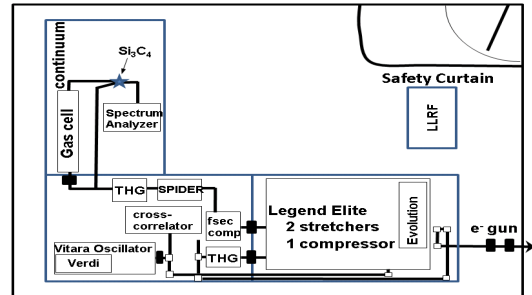

Figure 1: Plan view of the ASTA laser system.

amplifier, both products of Coherent®. The oscillator operates at 68 MHz (42nd sub-harmonic of 2856 MHz) and can be phase-locked to the LCLS RF distribution. Software control of two intra-cavity prisms and a spectrally selective slit allows easy control of the bandwidth and center frequency. An automated mode-locking feature simplifies startup and the PowerTrack system maintains optimal alignment of the pump beam for stable output power. The Vitara produces a pulse train of 30fs IR pulses with bandwidth up to 125nm and 500mW output power.

The regen is a custom-built chirp-pulse amplifier which includes an internal stretcher/compressor pair to produce 1.5-3.5 ps pulses and internal stretcher/external compressor combination to produce 25-35 fs pulses. Regen pumping is provided by a Q-switched, diode-pumped solid state (DPSS) yttrium lithium fluoride (YLF) laser frequency-doubled to 527 nm. The Ti:Sapphire crystal is housed on a temperature-stabilizing thermoelectric cooler and Pockels cells switch the beam in and out of a single cavity to amplify either the ps or fs output beam. Typical cavity output energies are of order 5mJ or 2.5mJ/pulse after the compressor stages. Switching between picosecond mode and femtosecond mode requires exchanging the seed beam input mirror to the stretcher and amplified output beam mirror leading to the compressor. Operation of the regen at 760 nm for picosecond-pulse photocathode research and at 800 nm for femtosecond-pulse output is described further below.

PHOTOCATHODE OPERATION

The LCLS electron gun design features a 120Hz, 1.6-cell photocathode design with dual-feed RF coupling to minimize the dipole field component [2]. The copper cathode material was chosen in part to permit the entire end plate of the half cell to be formed from a single piece, allowing gun operation at the highest possible field values. For optimum quantum efficiency, it is desirable to

illuminate the copper with short wavelength UV light. For this application the wide bandwidth of the Ti:Sapphire emission spectra allows the regen to operate with reliable, high-power output at 760 nm. Frequency doubling and re-mixing with the original IR in a Type-II BBO crystal yields 253 nm (4.9eV). Depending on pulse length, the tripling efficiency can be up to 15%, hence the compressed 2.5mJ IR light can produce up to 400uJ/pulse at 253 nm.

   Immediately following the frequency tripler the UV beam traverses a pair of dichroic mirrors to reject residual 760/380 nm components in the beam. As indicated in Figure 2, the resulting UV light passes through a half-waveplate/thin film polarizer combination to extract a fraction of the UV energy for on-line pulse length measurement in a cross-correlator. Similar to effects observed at the LCLS injector laser laboratory, the waveplate transmission degrades with time creating up to 15% insertion loss.
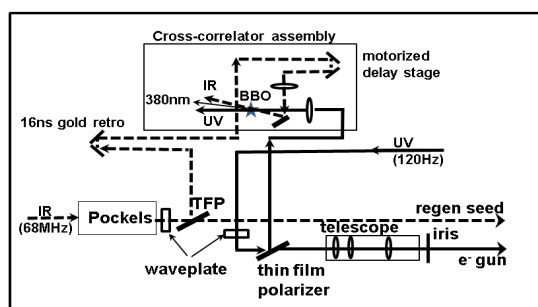

Figure 2: Cross-correlator schematic.

The cross-correlator is a straight-forward optical arrangement that mixes the sampled UV light with 30fs oscillator pulses extracted via fast-switching Pockels cell. A gold retroreflective mirror arranged in a compact 2-pass configuration synchronizes the 68MHz oscillator beam to the 120Hz UV from the regen. As indicated in Fig. 2, both beams are focused and spatially overlapped onto a BBO crystal to generate a 380 nm sum frequency signal proportional to the overlap integral. A diode centered on the 380 nm output measures the relative UV power at each time slice - no iris or bandpass filter needed. Sweeping the arrival time of the IR beam across the UV pulse with a motorized stage completes the cross-correlation measurement. The cross-correlator has sufficient time resolution to measure picosecond pulse lengths and reveal detailed structural artifacts on the UV pulse introduced in the regen and/or tripler.

Table 1: 760/253 nm Photocathode Laser Parameters

Parameter	Value	Units
Pulse Energy, IR	2.5	mJ
Pulse Energy, UV	0.4	mJ
Available UV on Cathode	40	μJ
Pulse duration (FWHM)	1.5 – 3.5	ps

 Following the cross-correlator pick-off stage, the main UV beam passes through a second motorized waveplate/thin film polarizer combination to regulate UV power to the cathode. A telescope constructed in a D-F-D lens combination expands, focuses and collimates the UV light onto an adjustable iris. By tuning the telescope and iris diameter the UV beam profile can be controlled at the cathode [3]. A three-lens optical configuration relays the UV light through a series of evacuated transport tubes and on a small optical bench at the electron gun to form a de-magnified image of the iris on the photocathode (M=1/4.5). The beam on the optical bench is split for diagnostic purposes leading to a GigE virtual cathode camera (VCC) and an Ethernet power meter. A feedback system based on beam centroid as calculated at the VCC actuates the final turning mirror to maintain beam position on the cathode. For laser cleaning operations an insertable lens concentrates UV power on the cathode and the VCC feedback system is used to raster beam position. An estimated 10uJ/pulse in a 1mm diameter spot and 20uJ/pulse in a 0.12 mm diameter spot are needed for gun operations and laser cleaning, respectively.

Laser Timing

   For photocathode operations the 120Hz UV laser pulse must be synchronous with the 2856MHz RF frequency at the gun. To achieve phase-lock, a 119MHz fiber-optic EVR clock from the LCLS is used as reference. Sum- and difference frequencies are generated at 68/476MHz for the laser, 2856MHz for the klystron and 102MHz to clock the PAC/PAD chassis in the LLRF [4]. Nominally, the out-of-the-box Vitara oscillator free-runs at ~68MHz (14.7ns). A photodiode monitoring the Vitara output connects to the Synchronize and Delay Generator (SDG) controlling the regen pump laser timing and Pockels cells.

   To achieve global synchronization, the oscillator is referenced to the LCLS timing fiducial via a dedicated PAD/PAC system, with local synchronization using a Coherent SynchroLock chassis (SLAP). To synchronize the regen output to the gun, the SDG is triggered by a 120Hz EVR TTL pulse with fine tuning of the pulse arrival time controlled through EPICS software. The same infrastructure enables Schottky scans of the laser pulse arrival time at the gun. Similar PAC/PAD systems use field probes in the cavity cells to regulate power to gun and forward/reverse RF power measurements to tune the resonant frequency, respectively.

ULTRAFAST RESEARCH OPERATION

The first ultrafast experiments in the ASTA laboratory focused on investigations of single-shot cross correlation diagnostics for time-resolved x-ray pump/probe experiments at the LCLS. To measure relative laser/x-ray timing, the x-ray pulse can be used to photoionize a thin Si_3N_4 membrane to induce a rapid change in free carrier density and associated optical transmission [3]. Simultaneously, a temporally chirped sample of the optical pump beam is used to create a spectral 'timeline' to mark the relative delay between the x-ray and the optical pulses.

   By recording the onset of spectral modulation within the optical continuum, the relative pulse arrival time is

resolved at the 25 fs rms level. The research is important both for practical timing applications and to understand
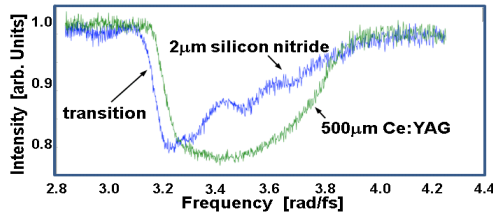

Figure 3: Spectral encoding tests at ASTA.

carrier dynamics in different membrane materials for future applications. To date tests in the ASTA laboratory have been made using a Sapphire plate and gas cell to generate chirped continuum light, and plans are underway to use hollow-fiber techniques. Examples of continuum interactions with a UV pulse are shown in Fig. 3.

For many ultrafast research applications, it is desirable to obtain short, high peak-power pulse structure for efficient non-linear conversion processes. With Ti:Sapphire, short pulse production is best achieved at λ∼800 nm where the cavity emission linewidth is broad. As a result, the requirements for both 760 nm and 800 nm laser operation at ASTA drove the custom regen design with dual stretcher/compressor architecture.

In the original construction, the regen amplifier used a Z-shaped cavity configuration characteristic of the Legend Elite. To accommodate 760nm operation, a two-mirror 'chicane' was installed in one of the arms of the Z enabling an extra a long-pass mirror to be installed to suppress build-up at 800 nm. Switching between 'femtosecond' mode and 'picosecond' mode required a detailed sequence of re-routing the beam through separate stretcher/compressor pairs, swapping one of the intracavity chicane mirrors and re-optimising the cavity.

In the Spring of 2013, a decision was made to upgrade the femtosecond pulse configuration from 35fs to 25fs, i.e. upgrade the laser from the Coherent USP to the USX option. The upgrade included installation of a propriety spectral shaping filter to reject seed power within ±25 nm of the 800 nm center frequency (Fig. 4) and a complete re-build of the USX stretcher and compressor assemblies. Seed power suppression in the central 800 nm range allows power build-up in the spectral wings to increase bandwidth. The goal was to amplify ∼70 nm bandwidth at the 800 nm center frequency to generate 25fs IR pulses.

In the process of tuning the system, it was found the IR spectrum was limited to <50 nm due to the finite bandwidth of the multipass chicane mirrors. When the standard Z-shape configuration was restored to eliminate the chicane mirrors, a 70 nm spectrum was recovered with 25 fs pulse duration at 800 nm as measured at a SPIDER. The calculated transform limit was ∼20.5 fs.

The challenge was then to accommodate efficient 'switching' between 800 nm (femtosecond) mode and 760 nm (picosecond) mode without re-introducing the intracavity chicane mirrors. The primary concern was build-up of amplified spontaneous emission at 800 nm during 760 nm operation which could potentially deplete

population inversion in the Ti:Sapphire. The solution proved to be focusing the seed beam at cavity injection
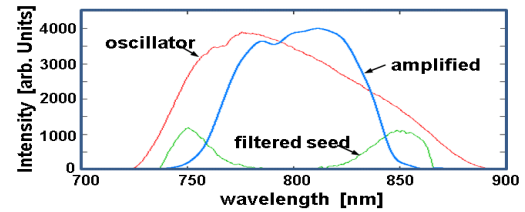

Figure 4: Spectral shaping for the USX upgrade.

and efficient tuning of the cavity pump to achieve fast build-up of the 760 nm seed component. As a result the laser can now be 'switched' between ps and fs operation by re-routing beam through the appropriate stretcher/compressor assemblies with only minor changes to timing and tuning of the regen cavity.

FUTURE OUTLOOK

With the laser laboratory infrastructure in place the experimental programs are now underway. Laser cleaning of the spare LCLS gun will be followed by QE studies, emittance measurements and investigations of temporal and spatial beam profile. The LCLS-II gun will then be processed and characterized in the ASTA vault. The ultrafast program will test hollow-fiber systems for bright continuum generation and probe deeper into physics of ultrafast carrier dynamics in thin membranes. Carrier-envelop phase stability experiments are then planned for seeding and EEHG applications.

ACKNOWLEDGMENTS

REFERENCES

[1] E. Jongewaard, et al, 'RF Gun Photocathode Research at SLAC', IPAC12, New Orleans, Louisiana, 2012.

[2] R. Akre, et al, '.Commissioning the Linac Coherent Light Source Injector', PRST-AB 11, 030703 (2008).

[3] F. Zhou et al., "Experimental Studies with Spatial Gaussian-Cut Laser for the LCLS Photocathode Gun", SLAC-PUB-14571.

[4] R. Akre, et al, "LCLS LLRF Upgrades to the SLAC LINAC", PAC07, Albuquerque, NM, 2007.

[5] M. Bionta, et al, "Spectral Encoding of x-ray/optical Relative Delay" Optics Express, 19, 21855 (2011).