

PHOTOCATHODE DRIVE LASER UPGRADE FOR THE ADVANCED PHOTON SOURCE LINAC*

J. Dooling[†], W. Berg, A. Lumpkin, P. Piot, Y. Sun, K. P. Wootton, A. Zholents
Argonne National Laboratory, Lemont, IL, USA

Abstract

We discuss the need for a new photo-cathode (PC) gun drive laser for the Advanced Photon Source Upgrade (APS-U) linac. As context, the characteristics associated with the current system are presented. The proposed new drive laser is based on a Ytterbium (Yb) gain medium and is capable of multi-kHz operation (although presently only 30 Hz is needed for injection into the particle accumulator ring in support of APS-U). The pulse charge specification is 1 nC.

INTRODUCTION

In a photoinjector system the main components are the rf gun, the photocathode, and the drive laser matched in wavelength and pulse energy to generate sufficient charge for the application. With our present Cu photocathode quantum efficiency, the UV harmonic near 260 nm is needed to obtain the micropulse-charge target in support of the Advanced Photon Source Upgrade (APS-U) operations and linac experiments. A Ytterbium-based photocathode gun drive laser is proposed for the linac to replace the existing antiquated Nd:Glass laser. The proposed laser will readily operate at 30 Hz providing 0.3 mJ of 257-nm UV radiation per pulse yielding 1 nC from our Cu cathode, s-band gun in support of user operations. In addition, the laser allows generation of lower-charge, low-emittance electron beams for high-brightness experiments in the APS Linac Extension Area. An advantage of updating the PC Gun drive-laser is that the gun beamline includes a 3-meter-long s-band accelerating structure; this provides an additional 35-40 MeV of energy at the linac output over what is presently available from either of the two thermionic-cathode guns. Higher linac output energy is essential for high-charge operation of the new storage-ring. We outline the laser physics requirements for our LCLS-I-style PC gun and summarize the expected beam performance.

CASE FOR A NEW PC GUN DRIVE LASER

Our present Nd:Glass CPA drive laser does not have sufficient energy to generate the 1-nC micropulse charge at 30 Hz specified for operations support, and it is no longer supported by the vendor. Our focus is on the Pharos laser systems built by Light Conversion. Light Conversion specializes in Ytterbium (Yb)-based femtosecond laser sources for industrial, medical, and scientific applications.

Advantages

- Modern laser system with controls and diagnostics (turn key)—less effort required to maintain the laser
- Yb-based fiber lasers are competitively priced, and offer better stability and reliability than conventional Titanium-Sapphire systems.
- SLAC National Laboratory is moving to these systems and away from Ti:Sapphire-based lasers
- Backup source for operations
- Low-emittance beams for high-brightness experiments (e.g., Advance acceleration concepts, Compton backscattering, Microbunching)
- Improved timing stabilization, reduced jitter
- Calibration of fast diagnostics (e.g., impulse response function for fast detector deconvolution)
- Yb-based system has a broader gain-bandwidth allowing for shorter pulses than the present Nd-based system. Yb mode-locked pulses can be as short as 50 fs.
- The Yb-doped medium lases between 1030 and 1070 nm with an upper excited state in the 970-980 nm range. This allows for efficient diode laser pumping. Nd also has this advantage, but the difference between the Nd upper excited state, 808 nm and the lasing level, 1053 nm, is greater leading to a larger quantum defect which appears as lost as heat in the laser medium.
- Operating with a fundamental wavelength at 1 micron is inherently safer than 700-800 nm (Ti:Sapph).

Disadvantages

- Quenching where the excited atoms emit spontaneously rather than via cavity-defined stimulated emission.

EXISTING ND:GLASS CPA SYSTEM

Oscillator and Amplifier

The existing PC gun laser is based on a chirped-pulsed amplifier (CPA) design employing an oscillator seed followed by a regenerative amplifier (regen), utilizing Nd:Glass as the gain medium [1, 2]. In 2010, the amplifier flash-lamps were replaced with high-efficiency, high-power 805-nm laser diodes, significantly reducing thermal loading on the phosphate-glass laser rods. The 1.8-m folded-cavity regen is shown schematically in Fig. 1. This system as well as the oscillator (not shown) will be replaced.

Though diode pumping greatly reduced thermal effects in the 3-mm diam. Nd:Glass laser rods, operation at a sustained 30-Hz rate has been problematic. Figure 2 shows the effect on energy per pulse and spot size as the laser rep rate is varied from 2 to 30 Hz. The APS-U linac operates in a 30-Hz burst mode and injects into the particle accumulator

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[†] dooling@anl.gov

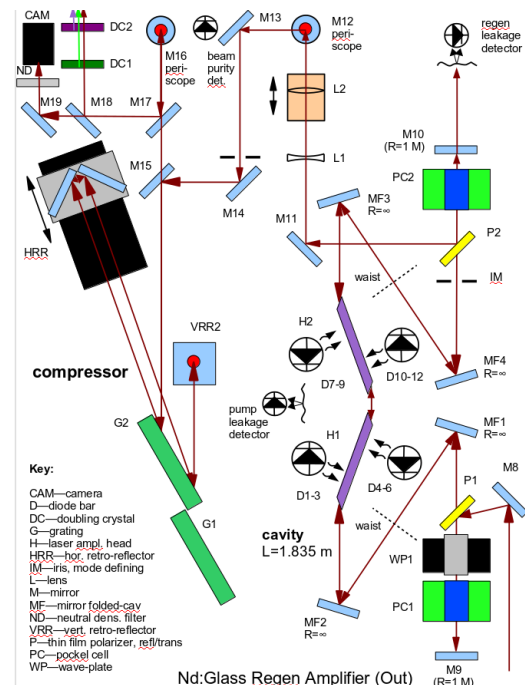
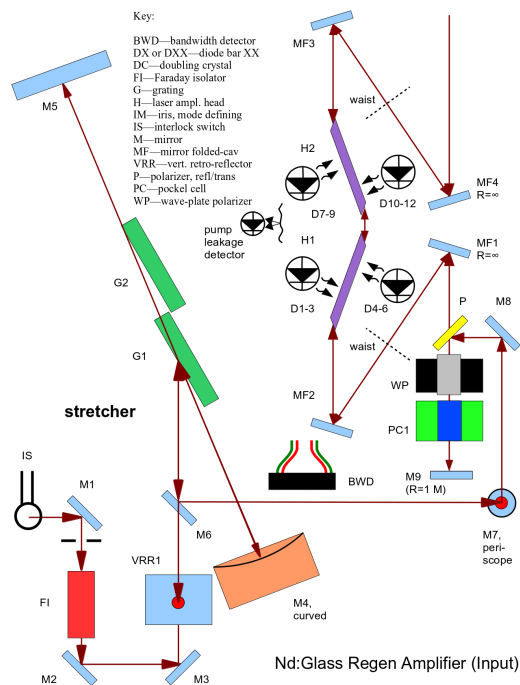


Figure 1: Nd:Glass Regen amplifier. Left: Input from the oscillator with stretcher optics. Right: Folded cavity, output with compressor, and harmonic generation (BBO) crystals.

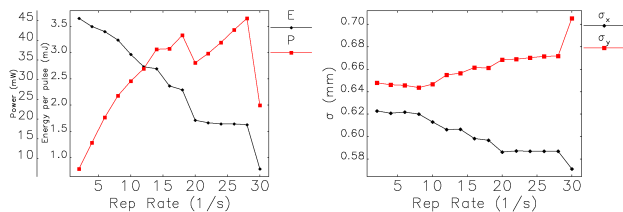


Figure 2: Nd:Glass regen performance with rep rate. Left: Energy per pulse and output power. Right: Output spot size.

ring (PAR). The PAR collects and longitudinally focuses charge for extraction to the booster at 1 Hz. For example, if 5 linac pulses are selected, the separation between each pulse is $(30)^{-1}$ s; the nominal length of this pulse train is 133.33 ms, with a period of 866.67 ms before the next train. Thus 30-Hz operation is required even at lower rep rates. For high-charge operation, up to 22 linac pulses are enabled.

Variation of the compressor horizontal retroreflector (HRR) allows for control of the output pulse duration as presented in Fig. 3. The regen output collimating telescope also affects compressed IR pulse duration. IR pulse duration was measured using an autocorrelator. Autocorrelation data and Gaussian fit for an HRR setting of 113 mm are plotted in Fig. 3, left. The right-hand plot shows the effect of HRR position for two separate collimator configurations; data in the left-hand figure was obtained for the shorter IR pulse arrangement. The shorter pulse configuration data was fit with a hyperbolic function of the form, $\sigma_t^2 = \sigma_0 + A(z^2 - z_{min}^2)$; whereas, for the longer pulse data, a simple linear fit was used.

For reduced space-charge effects and transverse emittance from the PC, a UV pulse duration of 2.5 ps was requested. Streak camera measurements in the UV indicated the need to move the HRR away from maximum compression [3]. However, operation of the laser away from maximum compression has been shown to produce undesirable spectral components [4] in Nd:Glass. We hope to minimize this effect in the new Yb-based system.

Transport Optics

A schematic of the Laser Room (LR) transport optics is presented in Fig. 4. Here selection can be made between the RF Gun Test Stand and the Linac tunnel and PC gun. We do not anticipate significant changes to these optics. A simplified image of the LR to linac tunnel transport line is given in Fig. 5. The transport line is configured as a 1:1 optical relay line and short enough so that real waists (image locations) can be avoided. Real waists on optical components

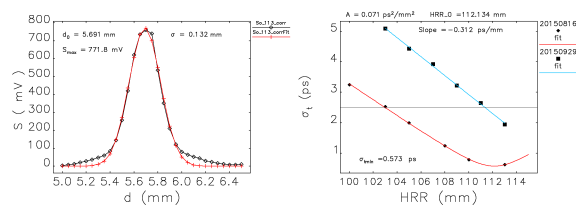


Figure 3: Left: IR autocorrelator data and fit for HRR=113 mm. Right: variation of IR pulse duration with HRR position for two separate regen output collimator configurations. Horizontal line is drawn at $\sigma_t = 2.5$ ps. Left plot was obtained with the collimator in the shorter IR pulse set-up.

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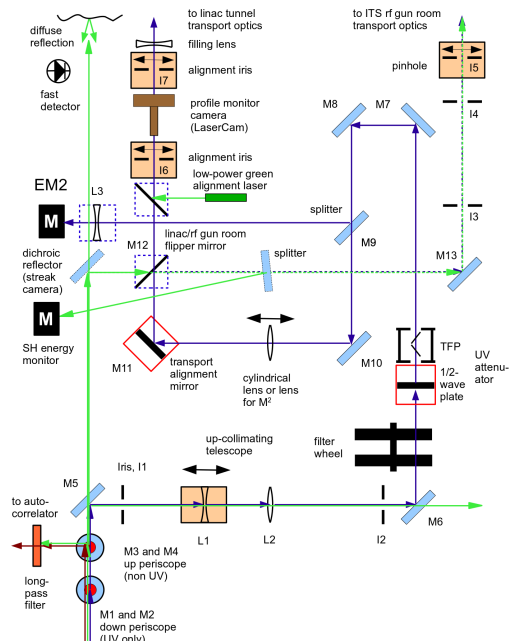


Figure 4: Laser Room transport optics.

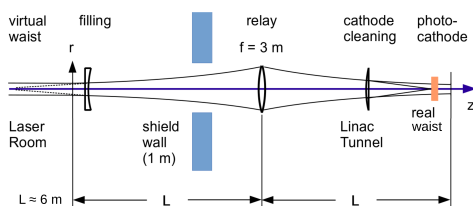


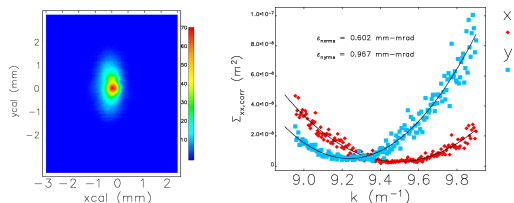
Figure 5: Laser Room to Linac tunnel transport optics.

such as mirrors can cause damage due to the high UV ($\lambda_{uv} = 263 \text{ nm}$) radiation intensity. UV transmission from the LR (EM2) to the photocathode in the linac tunnel is typically 55-60 percent.

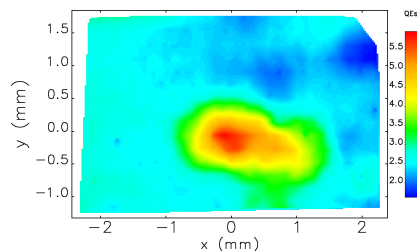
Photocathode Gun

Performance parameters of the APS-U PC Gun [5] such as quantum efficiency (QE), emittance, and energy spread are related to laser characteristics including pulse duration (just discussed), spot size, and total energy.

Typically the rms spot sizes on the PC have been kept 0.2-0.3 mm to maintain good electron beam quality. An example of the laser spot imaged on the virtual cathode (VC) is presented in Fig. 6. Gaussian fits yield $\sigma_x = 0.2 \text{ mm}$ and $\sigma_y = 0.38 \text{ mm}$. Spot size on the cathode must not be made too small while high-power rf is applied to the gun cavity.

Figure 6: Left: VC image with $\sigma_x = 0.2 \text{ mm}$ and $\sigma_y = 0.38 \text{ mm}$. Right: Solenoid emittance scan.

During an early emittance study, the rms spot size on the cathode was reduced to approximately 0.1 mm. With 8.5 MW of s-band rf applied (100 MV/m) and 70 μJ of incident UV energy, large extracted charge was observed on the PC Gun current monitor reaching 9.5-10 nC. This was probably not extracted in a single pulse but more likely occurring over a significant fraction of the 1- μs rf pulse. The high-intensity laser spot may have initiated a plasma discharge sustained over the remaining portion of the applied rf. Following this event, a region of elevated QE was observed on the cathode as shown in Fig. 7.

Figure 7: Quantum efficiency map of the photocathode. Values are given in quantities of 10^{-5} .

Solenoid-scan, whole-beam normalized emittance measurements in the PC Gun beam line shown in Fig. 6 yielded $\epsilon_{nx} = 0.6 \mu\text{m}$ and $\epsilon_{ny} = 1.0 \mu\text{m}$ at 125 pC. Larger spot sizes with commensurate higher emittance are employed for higher charge needs of operations. The present laser system has demonstrated the ability to generate 900 pC per pulse from a copper cathode by expanding the spot to a diameter of 1.9 mm. Assuming E_p incident on the PC is 100 μJ and our goal is to generate 1 nC per pulse, the required QE can be determined as $\eta = Q\lambda_{uv}/(ehcE_p) = 4.75 \times 10^{-5}$.

DISCUSSION AND SUMMARY

Running with the PC gun allows for use of an additional s-band accelerating structure not available to the thermionic-cathode gun beams; thus providing a 35-40 MeV boost to the final linac beam energy. Operating with higher energy in the linac has been shown to allow for better injection efficiency from the PAR to booster at elevated charge.

A new Yb-based PC gun drive laser system planned for the APS-U is expected to deliver more reliable, low-emittance beams for high-brightness as well as other experiments in the Linac and the Linac Extension Area (LEA) [6, 7]. The ability to easily run the laser at 30 Hz while generating 1-nC of charge per pulse offers the opportunity achieving higher charge for user operations.

ACKNOWLEDGEMENTS

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