RF GUN PHOTOCATHODE RESEARCH AT SLAC*

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Abstract

LCLS is presently operating with a third copper photocathode in the original rf gun, with a quantum efficiency (QE) of ~1×10^{-4} and projected emittance $\gamma\varepsilon_{x,y}$=0.45 µm at 250 pC bunch charge. The spare LCLS gun is installed in the SLAC Accelerator Structure Test Area (ASTA), fully processed to high rf power. As part of a wider photocathode R&D program, a UV laser system and additional gun diagnostics are being installed at ASTA to measure QE, QE lifetime, and electron beam emittance under a variety of operating conditions. The near-term goals are to test and verify the spare photocathode production/installation sequence, including transfer from the final holding chamber to the rf gun. Mid- and longer-term goals include development of a rigorous understanding of plasma and laser-assisted surface conditioning and investigation of new, high-QE photocathode materials. In parallel, an x-ray photoemission spectroscopy station is nearing completion, to analyze Cu photocathode surface chemistry. In this paper we review the status and anticipated operating parameters of ASTA and the spectroscopy test chamber.

INTRODUCTION

A program to study the electron emission characteristics of the LCLS rf photoinjector copper cathode has begun with the goal of establishing robust cathode exchange procedures and surface preparation techniques pre- and post-installation that reliably produce high QE, low e-beam emittance cathode surfaces. To this end SLAC is installing a UV drive laser system and beam diagnostics at the SLAC Accelerator Structure Test Area (ASTA) where the spare LCLS rf gun has been fully processed to high rf power [1]. In addition, a high-resolution photoemission electron spectrometer system is being constructed to allow detailed cathode surface characterization to help understand QE-limiting processes affecting the cathodes during fabrication, processing, and use.

This paper describes the gun test facility being constructed at ASTA, the photoemission electron spectrometer system, and the initial measurements and studies to be conducted at these facilities.

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ASTA TEST STAND

An rf gun test stand being installed at ASTA replicates the first 1.4 m of the LCLS injector [2], to permit full testing and qualification of spare LCLS rf guns and to provide a facility for studying cathode processing techniques. This test stand allows the study of cathode and gun performance at LCLS operating conditions, without interruption of LCLS beam delivery to users. The two major systems required to provide this capability are the beam line diagnostic components and the gun drive laser system, both of which are described more fully below.

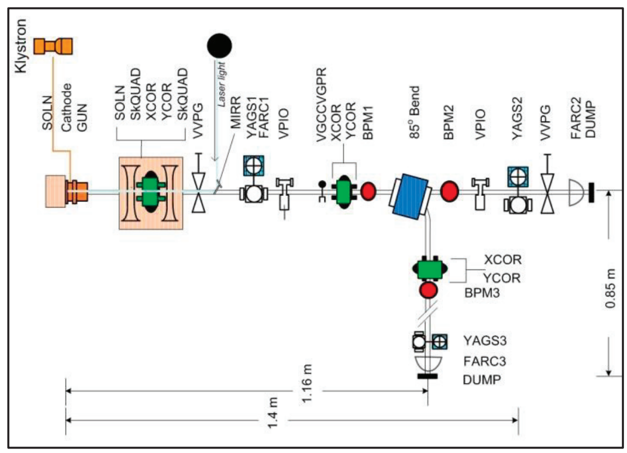

Figure 1: RF photocathode gun beam line layout. See text for explanation.

Beam Line Components

The beam line has a complete set of vacuum pumps, diagnostics, and isolation valves to facilitate gun changes and future modifications. The complete system is fully bakeable to 150°C. After processing, the gun vacuum is in the range of 3×10^{-10} Torr when the rf is off.

Figure 1 shows the beam line components being installed in the radiation shielded ASTA bunker. A spare LCLS rf gun is powered by 10 MW of s-band rf to generate a 115 MV/m gradient in the 1.6 cell structure. Laser illumination of the copper photocathode produces electron bunches at 120 Hz, with up to 1 nC of charge at a nominal energy of 6.0 MeV. These bunches are focused by the gun solenoid (SOLN) onto a Faraday cup (FARC2) located 1.4 m downstream of the cathode. Beam position monitors (BPM) and corrector dipole magnets (XCORs and YCORs) provide beam position and steering control. A Ce:YAG screen (YAGS2) is used in conjunction with the gun solenoid to measure beam emittance. A spectrometer consisting of an 85-degree bend, a BPM (BPM3), a profile monitor (YAGS3), and a Faraday cup

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(FARC3) allows measurement and tuning of the energy spectrum. A 1.3 m long beam line is to be added after the straight-ahead profile monitor (YAGS2) to accommodate installation of a pair of quadrupoles and a pepperpot along with a screen. This beam line assembly enables emittance measurement, while leaving the gun solenoid at a fixed field. Bunch charge is measured using both Faraday cups and BPMs. LCLS operational experience has shown that beam current toroids are not required.

Laser light enters the radiation bunker through a 10 cm diameter penetration in the 1.2 m thick concrete shielding. The system drive laser, rf and beam line controls, as well as power supplies and chillers are located adjacent to and atop the radiation bunker.

Gun Drive Laser

The gun photocathode is illuminated by a frequency-tripled, chirped-pulse amplification Ti:Sapphire laser operating at 253 nm with an output energy up to 500 µJ per pulse at 120 Hz. The drive laser consists of a mode-locked oscillator (Vitara), followed by a pulse stretcher, spectral filters for temporal pulse shape control, a regenerative amplifier (Legend Elite), a compressor, and finally the frequency tripler, all manufactured by Coherent.

Table 1: Photocathode laser parameters.

Parameter	Value	Units
Wavelength, IR/UV	760/253	nm
UV Tuning Range	2-3	nm
Pulse Energy, IR	4	mJ
Pulse Energy, UV	0.4	mJ
UV on Cathode	40	µJ
Repetition Rate	120	Hz
Average Power, IR	500	mW
Average Power, UV	50	mW
Pulse duration (FWHM)	1.5 – 3.5	ps
Avg. on cathode	5	mW

The oscillator operates at 68 MHz (a sub-harmonic of the linac 2856 MHz) and is locked to the LCLS linac rf source (476 MHz) via a phase-lock loop. The oscillator seed beam is stretched to allow high-gain amplification in the regenerative amplifier (regen). Regen pumping is provided by a 120 Hz, Q-switched, diode-pumped solid state (DPSS) yttrium lithium fluoride (YLF) laser frequency-doubled to 527 nm (20 W Coherent Evolution). The regen naturally peaks at 800 nm but an “edge” mirror is installed to tune the wavelength to 758 nm.

The oscillator spectrum is then limited in bandwidth via Gaussian spectrum interference filters so that after the final compressor the shortest transform-limited pulse duration can be reached, about 1.5 ps. The compressor is then detuned away from the Fourier limit, by the addition of a linear chirp, to reach the specified pulse length of 3.5 ps FWHM.

UV (253 nm) light is generated through a third-harmonic tripler module using two nonlinear crystals. Through an appropriate choice of crystal pair (second HG and third HG) and beam size, a conversion efficiency >10% is obtained, which also preserves the natural transverse Gaussian beam shape of the Ti:Sapphire amplifiers.

A scanning cross-correlator, that uses portions of the UV and oscillator beams, measures the pulse length. The transverse beam profile is established by clipping the magnified Gaussian beam with a circular aperture and relay-imaging the aperture to the plane of the photocathode. The size of the clipping aperture defines the spot diameter on the cathode. Magnification of the Gaussian beam at the clipping aperture is controlled with a three-lens zoom telescope, which can be adjusted from slightly clipping the laser beam at the aperture to greatly over-filling the aperture, which produces a flat-top profile. Obviously, the clipping aperture affects the amount of transmitted UV energy, but the system easily meets specifications. While the system was designed to produce a flat-top transverse profile, recent results indicate that a clipped Gaussian profile produces lower emittance electron beams [3]. This has the added benefit of using far more of the full UV laser beam diameter, thereby reducing the total laser power required and/or cathode QE required. Introducing an additional lens into the laser transport system allows reduction of the spot size on the cathode to approximately 30 um for cathode cleaning.

The UV energy reaching the cathode is remote-controlled by rotating a zero-order half-wave plate behind a thin-film polarizer. The pulse energy on the photocathode is regulated by measuring the electron bunch charge level at a BPM detector and keeping the charge constant by feedback. The UV energy at the cathode is also monitored on the optical table at the gun. The beam profile at the cathode is monitored using the “virtual cathode” concept; a beam splitter creates a second beam path to the virtual cathode camera (VCC), with a path length identical to the beam path directly to the photocathode.

The drive laser will be installed in a dedicated laser lab adjacent to the ASTA bunker and the UV light will be transported through a penetration in the bunker shielding wall to the rf gun via transport tubes evacuated to $\sim 10^{-7}$ Torr. Preparation of the laser lab is nearly complete and laser installation is expected to occur in June of this year.

PHOTOEMISSION SPECTROSCOPY STATION

A specialized, multifunction, ultrahigh vacuum (UHV) photoemission electron spectrometer station is being assembled for characterization and development of copper photocathode surfaces for the LCLS injector RF photocathode electron gun.

The station will provide element-specific cathode surface characterization, with spatial resolution, in a clean, UHV environment. General areas of study include

1) correlation of surface composition and QE, 2) quantitative characterization of surface treatment effects, such as laser cleaning, 3) optimization of surface treatment procedures, applicable to both initial cathode fabrication and possible in situ cathode maintenance within the gun, and 4) initial evaluation of improved cathode transfer/installation procedures.

Different light sources will be used for the required sample-excitation photon beams: VUV/soft x-ray synchrotron radiation from the Stanford Synchrotron Radiation Light Source (SSRL), a laboratory Al/Mg x-ray source, UV lamp sources, or possibly UV laser beams.

Figure 2 illustrates the photoemission spectroscopy station. A flexible, adjustable support system allows the station to utilize various beam lines at SSRL, with various exit beam heights and exit angles. The heart of the station is a VG Scienta R3000 UPS/XPS hemispherical electron spectrometer, which is illustrated on the left-hand side of the figure. A precision sample manipulator, seen on the top of the chamber, receives samples installed through a large, 10-inch OD Conflat port, located on the right-hand side of the chamber in the figure. This large port and robust manipulator will permit study of complete RF gun copper photocathode assemblies. The station is pumped by a 500 L/sec ion pump and non-evaporable getter pump, and will also be equipped for initial studies with a residual gas analyzer and atomic hydrogen source. Additional facilities will be added in the future. Final assembly of the station will occur in June of this year and the first photoemission spectra from copper samples are expected in July of this year.

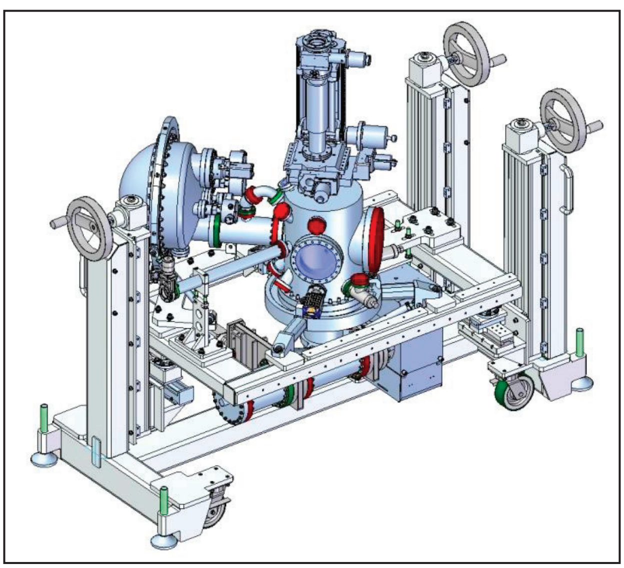

Figure 2: Photoemission spectroscopy station for copper photocathode studies.

INITIAL MEASUREMENT PROGRAM

Cathode and gun performance are characterized by the QE of the cathode, the QE lifetime, and beam emittance. QE is defined as the ratio of the number of emitted electrons to the number of incident laser photons. It is necessary to measure the QE with a sensitivity of better than ~3×10^{-6}. Thermal emittance (emittance/incident laser spot size) ~0.5 μm/mm, for bunch charges in the range of 1-2 pC, must be resolved. These levels of sensitivity and resolution for the QE and emittance at low charge are achieved in the LCLS Injector and thus available in the Gun Test Stand through the use of identical diagnostic systems (Note that operationally, the LCLS bunch charge is in the range of 20 pC-1 nC. Thermal emittance must be measured at 1-2 pC to avoid dilution due to space charge at the 6 MeV beam energy in ASTA). An important near-term goal for the cathode research program is to develop robust copper cathode QE activation procedures. The initial approach to this issue is to study laser cleaning techniques. Laser cleaning experiments will first be performed using cathode test chambers with a variety of laser intensities and fluence "recipes" to obtain the required operational QE value of ~4×10^{-5} and ideally be able to reliably duplicate the QE value of ~1×10^{-4} currently seen with the LCLS cathode [4]. Aggressive laser cleaning is expected to result in high QE but may cause surface damage that increases the thermal emittance. Candidate cleaning recipes must be tested in the full rf gun system to demonstrate acceptable thermal emittances of <1 μm/mm. In addition, the gun system is required to demonstrate long QE lifetime at full charge production (1 nC) in the rf gun environment.

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