

SPECTROSCOPY SYSTEM FOR LCLS PHOTOCATHODES*

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Abstract

Photocathode reliability is important from an operational standpoint. Unfortunately LCLS copper photocathodes have not always been reliable. Some have operated well for long periods of time while others have required continual maintenance. It is believed that the observed variations in quantum efficiency, emittance and lifetimes are inherently surface related, corresponding to changes in composition or morphology. The RF Electron-gun Cathode, Electron Surface Spectrometer, or RECESS, system has been commissioned to study this by making essential measurements that could not be obtained otherwise. These involve photocathode surface chemical characterization. The system is designed to use a combination of angle-resolved ultraviolet and x-ray photoelectron spectroscopy and is capable of either stand-alone operation or interoperability with a beam line at SSRL. Here we report on the first commissioning spectra and the direction of the project going forward.

INTRODUCTION

Cu photocathodes used at SLAC have operational lifetimes that vary from tens of thousands of hours down to single-digit hours. This variation is difficult to predict, due to a lack of understanding of either the emitting surfaces or the vacuum environments in which they operate. Increasingly, evidence suggests that the optimum surfaces are not atomically clean but rather are coated by layers that alter the material's work function. These coatings may come from vacuum interactions or may be residual from fabrication steps. In either case the variations in quantum efficiency, emittance, and lifetimes are thought to result from changes in surface composition and morphology, analogous to other photoemissive systems. Understanding photocathode performance is increasingly dependent on surface science models and techniques.

Unfortunately the design of the LCLS RF gun makes it difficult to study photocathodes in-situ. It is not possible to deposit fresh surfaces or to use plasma or sputtering-based cleaning techniques for surface preparation. Furthermore no techniques exist that can infer chemical information from electrons accelerated to MeV levels. Therefore separate experiments are being carried out in a dedicated surface science system to make essential measurements that could not be obtained otherwise, in order to aid in accurately predicting photocathode performance. The RECESS (RF Electron-gun Cathode, Electron Surface Spectrometer) surface science system was designed specifically to study LCLS photocathodes and is currently configured for ultraviolet or x-ray photoelectron spectroscopy (Figs. 1,2).

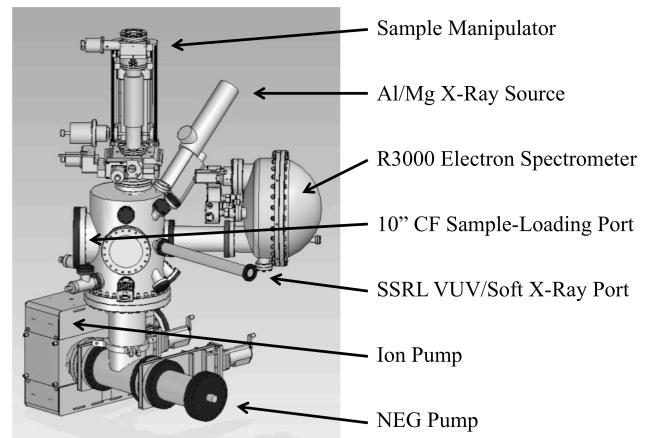


Figure 1: RECESS system configured for operating on a beam line at SSRL.



Figure 2: Photo of RECESS system configured for stand-alone operation.

LCLS photocathodes are fabricated from high-purity copper. First they undergo a dry hydrogen braze at 950 °C followed by diamond fly-cutting to a surface roughness < 10 nm rms. Then they are vacuum fired at 650 °C for 24 hours, welded to their base flange, and then vacuum fired again at 550 °C for another 24 hours. Once the photocathodes are installed, RF processing occurs until the desired RF conditions are achieved without breakdown. Typical operating conditions in a S-band (2856 MHz) RF gun are 1.5 µs RF pulses at 120 Hz with 10 MW of input power. This creates accelerating gradients > 100 MV/m at the photocathode. A 1.6 ps laser pulse of 10-20 µJ at 253 nm generates a 5.5 MeV beam at between 100-200 pC. These numbers illustrate that the operating photocathode environment is not a typical UHV environment. Because of this care must be taken to connect the results obtained in the RECESS system to those projected to occur in the gun.

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METHODS

For commissioning purposes the main chamber, base support structure, vacuum components, VG Scienta R3000 electron spectrometer and Al/Mg x-ray sources were each installed. A test sample was mounted that consisted of a copper substrate with a gold on nickel sample in the center. Electron spectra were then recorded.

RESULTS

The system performed as expected. It was able to clearly resolve the gold on nickel sample from the surrounding copper substrate.

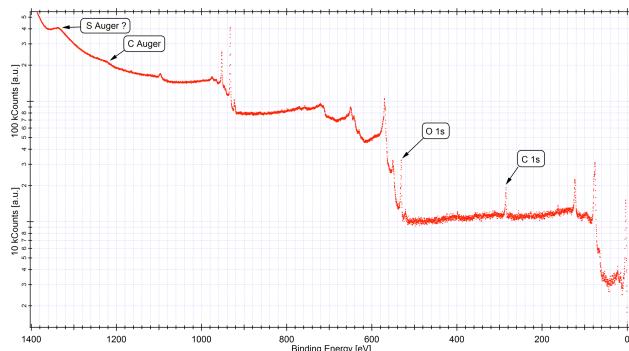


Figure 3: Electron spectrum taken showing characteristic features of an oxidized copper substrate.

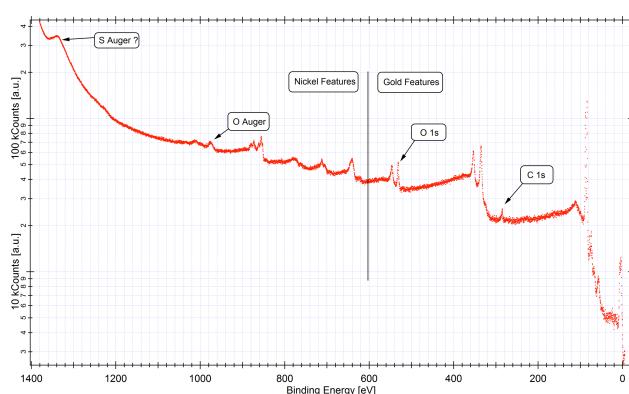


Figure 4: Electron spectrum taken showing characteristic features of the gold on nickel test sample.

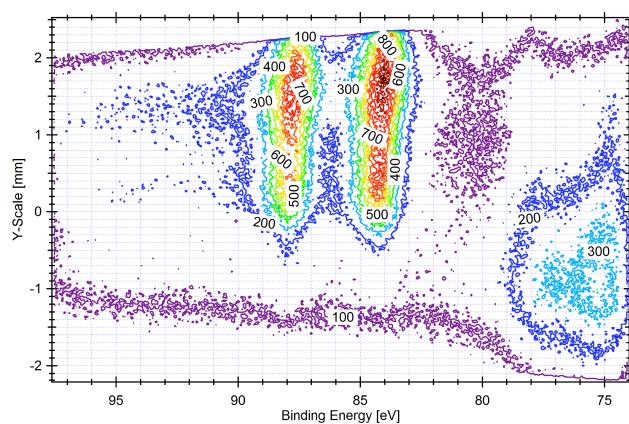


Figure 5: Spatially resolved electron spectrum showing the transition from the copper substrate to the gold on nickel test sample.

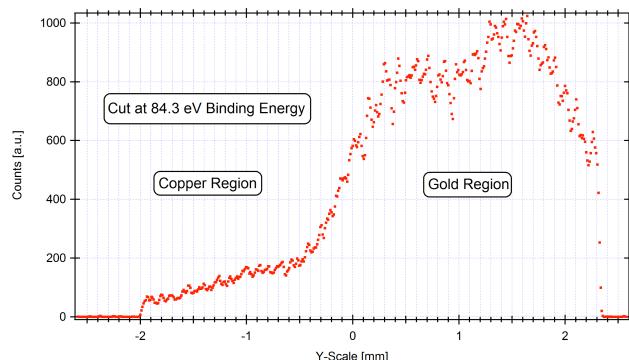


Figure 6: Spatially resolved electron spectrum showing the transition from the copper substrate to the gold on nickel test sample. The spatial resolution is estimated to be on the order of 1 mm.

FUTURE WORK

Photocathode Qualification

Going forward there are two experiments planned. The first is to use electron spectroscopy, QE, and work function measurements to characterize photocathode surfaces before and after use in the gun. Ultimately, QE performance in operation will be correlated to surface compositions measured in RECESS, paying particular attention to atomic species that are not expected to undergo significant changes as photocathodes are exchanged. If present, mobile impurities will also be identified. The goal is to determine a reliable chemical fingerprint that qualifies photocathodes as being able to deliver high QE without further processing, something that is now anecdotally known to be possible. This approach doesn't ignore the fact that chemical changes will occur during transfer but rather acknowledges that chemical fingerprinting is possible regardless. This same approach may also be extended to characterize fabrication processes such as hydrogen brazing or vacuum firing.

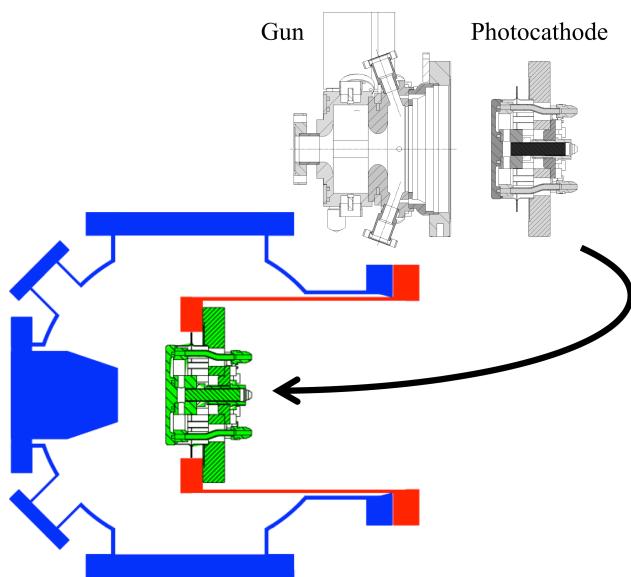


Figure 3: Configuration for upcoming experiments. The spectroscopy chamber and spectrometer are blue, the cathode flange is green and a re-entrant flange is red. Not shown are the x-ray source, QE collector, fused silica viewport, UHV pumps and gauges or the system RGA.

Surface Decomposition

The second experiment is to characterize the composition and structure of the cathode non-copper surface layers, under UHV conditions, using a beam of atomic hydrogen. This will be done by gently dismantling the surface layers using atomic hydrogen and applying electron spectroscopy, QE, and work function measurements, either serially or in parallel, with this surface decomposition. It is likely that atomic hydrogen will react at room temperature with all common elements present in the surface layers, i.e. carbon, oxygen, and sulfur, to form volatile products that are then pumped

away. The source produces an atomic hydrogen beam by passing hydrogen gas through a heated tungsten capillary. For the geometry anticipated in the RECESS system, an atomic hydrogen flux capable of removing one molecular layer from the cathode surface in 100 seconds should result in a system pressure rise of $<5 \times 10^{-9}$ Torr. Additionally, RGA scans will be made during atomic hydrogen treatments. In this way surface layer gaseous decomposition products will be identified as a function of time, to correlate any change in surface layer composition with “depth”.

For the most part, the RECESS system is already configured for these experiments. A low-cost re-entrant flange will soon be added to mount photocathodes on-axis to both the electron spectrometer and the x-ray gun as well as a photocurrent collector and a fused silica viewport to permit UV light incident on the photocathode. All necessary vacuum gauges, RGAs, pumps and valves for UHV operation are already installed. QE measurements will be performed using a monochromatized broadband light source in conjunction with a biased Keithley picoammeter. Work functions will be extrapolated from QE curves using the standard Fowler method.

Finally, depending on funding, there are several engineering improvements that need to be made. First of these is that the x-ray source requires differential pumping to obtain proper UHV operating conditions. The second is that the sample holder should be improved to include rotary motion and precision sample positioning, therefore allowing the spectrometer to be used for ARPES. Third is that a shutter for the R3000 analyzer needs to be installed in order to protect it from future experiments involving chemically reactive environments. It is hoped that each of these improvements will be made incrementally over the next year.