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LCLS RF GUN COPPER CATHODE PERFORMANCE *

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Abstract

We report on the performance and the operational experience of the LCLS RF gun copper photocathodes used during the LCLS run I, II, III and IV. We discuss the problems of cathode surface contamination and our experience with methods to remove such contamination. Techniques to obtain high quantum efficiency (QE) while preserving the low emittance quality are discussed. Furthermore, we will present the current status of the installed cathode, its quantum efficiency and the typical injector emittances of the extracted beam.

LCLS CATHODES

Cathode performance parameters

The basic LCLS copper cathode performance parameters are summarized in table 1.

Table 1: LCLS Cathode Performance requirements

Parameter	Value
Drive laser wavelength [nm]	253
Drive laser spot on cathode [mm]	1.2
Quantum efficiency [min]	$5*10^{-5}$
Electron bunch charge [pC]	250
Beam emittance at 250 pC [μm]	< 0.5

Up to this date, three cathodes have been used to provide LCLS electron beams during the commissioning period and user runs I to IV:

Cathode #1

The first cathode was mainly used during LCLS commissioning and the first user run. This cathode was originally installed during gun assembly and has been RF processed as part of the entire RF gun assembly. The first processing of the entire gun structure lead to extensive out-gassing and clean-up of the structure which resulted in frequent RF breakdowns and violent RF breakdown events. As a result, many RF breakdown events produced a fairly large number of breakdown craters on the cathodes surface. Surface damage did not occur in the center of the cathode and performance was satisfactory during commissioning. The early part of commissioning was carried out using a repetition rate of 10 Hz at nominal charge of 250 pC. For the later part of the commissioning the machine operated at 30 and 60 Hz. Shortly after increasing the pulse rate, we observed a slow decline of the cathodes quantum efficiency. To remedy the low quantum efficiency, a first of attempt of laser cleaning was attempted. By rastering the focused drive laser beam across the cathode (up to 10 mJ/mm^2 laser fluence). This procedure improved the quantum efficiency to ~ $7*10^{-5}$ with acceptable emittances. However, the quantum efficiency decayed within a few days to an unacceptable level.

Cathode #2

Cathode #2 was installed in July of 2008 and was in operation until mid 2011. Cathode RF processing was done in the already clean gun and progresses considerably faster compared to the initial processing. No violent RF breakdowns occurred. The initial QE values were in the mid 10^{-5} range and allowed normal beam operation immediately. Similarly to cathode #1, we again observed a decay of the QE while operating at higher repetition rates (30, 60 and 120 Hz). Furthermore, the QE decayed at a rate proportional to the extracted charge. Within days to weeks the performance became unsatisfactory.

Based on results of post mortem studies on cathode #1, no laser cleaning was performed on cathode #2. To remedy the low QE limitation, we moved the drive laser to a new location on the cathode. This allowed us to continue normal operations for the duration of ~ 1 week before again moving the drive laser spot. Moving to a new location required extensive re-tuning of the injector and a considerable amount of time was spent to optimize the machine performance for each new drive laser location. The acceptable range was up to 2 beam diameters away from the cathode's center (~ 2.5 mm). Moving beyond this area significantly degraded the beam emittance due to the excessive off-axis beam trajectory.

Cathode #3

Cathode #3 was installed in May 2011. Prior to installation the cathode was hydrogen ion cleaned in a preparation chamber, which resulted in a quantum efficiency of > 10^{-4}. After installation of the cathode in the gun and RF processing a very low QE was measured (mid 10^{-6} range), which was insufficient to operate the LCLS injector. An attempt was made to in-situ hydrogen ion clean the cathode by installing the RF plasma generator on the gun itself (spare 70 degree incidence port). However, the unfavorable geometry of the gun assembly forced us to install the RF plasma source far from the cathode (distance of ~ 1.5 ft.). Consequently, the dissociated hydrogen species re-combined while travelling to the cathode and cleaning was ineffective.

To obtain a useable cathode, the aforementioned laser cleaning method was re-applied using a reduced laser fluence in order to decrease the risk of surface damage that was observed previously on cathode #1.

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SUMMARY OF POST MORTEM ANALYSIS OF CATHODE #1

The composition of surface contamination of cathode #1 has been studied by surface science techniques using the SSRL facility. XPS and XAS measurements revealed mainly hydrocarbon species on the surface but also species that can be associated to the copper bulk chemistry (Pb, Bi, S). Surface morphology has been studied by SEM, optical microscopy and micro-interferometry. The latter techniques revealed the impact of laser cleaning. Figures 1 and 2 show the indentations caused by the laser exposure that occurred during the laser cleaning attempt.

ATOMIC HYDROGEN ION CLEANING

Atomic hydrogen cleaning has been used previously to generate an atomically clean surface of metals and semiconductor cathodes [1-2]. This technique is also applied to other equipment to effectively remove hydrocarbon and carbon contamination (e.g SEM sample chambers [3]). To clean LCLS copper cathodes, a dedicated chamber was build. Two commercially available RF plasma dissociator devices have been used and their effectiveness evaluated. The first model we tested was an EVACTRON® Model 25 (XEI Scientific, Inc., Redwood City, CA, USA) and the GV10x (IBSS Group Inc., San Francisco, CA USA). Both devices operate by the same principle. The EVACTRON® Model 25 uses a 20 Watt RF source, whereas the GV10x operates at up to 100 W. Both instruments require a hydrogen pressure in the milli-Torr range and a lengthy pump down is required before the QE can be measured. We plan to test a third atomic hydrogen source that operates in the 10^{-9} Torr range and generates ions by thermal cracking (H-flux Atomic Hydrogen Source, Physikalische Instrumente, Frankfurt/M, Germany). Surface cleaning was achieved with both RF plasma devices. However, the time needed to achieve the same result was less using the GV10x. Typical exposure times are 20 min to an hour. QE improvements were achieved up to the 10^{-4} range with both devices. The QE was measured in the preparation chamber using a UV light source (253 nm) and a biased electrode. The photocurrent

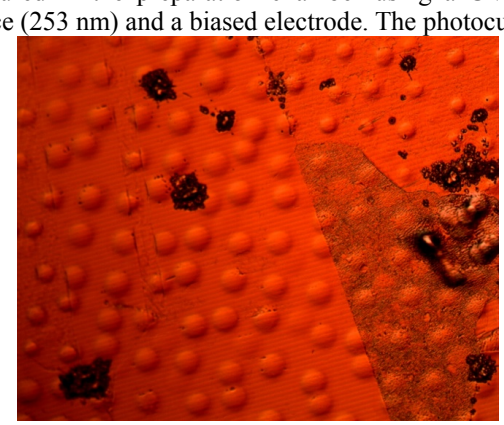

Figure 1: Microscope 20x image of cathode #1 (horizontal image field ~ 700 µm); courtesy of J. Feng, V. Yashchuk and H. A. Padmore of LBNL.

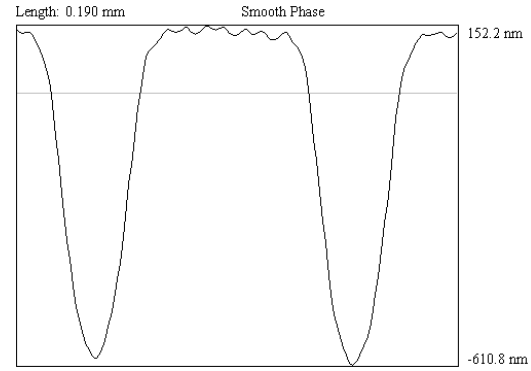

Figure 2: Lineout of micromap image showing indetations caused by laser cleaning; courtesy of J. Feng, V. Yashchuk and H. A. Padmore of LBNL.

was measured and the QE calculated. As mentioned above, the transfer of hydrogen plasma cleaned cathodes to the gun was impossible without QE degradation due to air exposure which is currently unavoidable with our RF gun system design.

LASER CLEANING

The method of laser cleaning has been applied previously to remove surface contamination from copper cathodes at SLAC and elsewhere [4,5,6]. Subsequent surface analysis of cathode #1 revealed surface damage due to the high laser fluence. Also, with the first cathode we were not able to maintain the high QE obtained immediately after performing this procedure.

The application of this technique to cathode #3 used a laser fluence of 5 mJ/mm^2. At this laser fluence a small vacuum rise occurred (~ $2*10^{-11}$ Torr) indicating contaminant removal. No RF was applied to the gun during laser exposure. A sufficiently small step size was chosen during the cleaning scan to guarantee overlap of the cleaning locations in order to achieve a uniformly cleaned area. The imaging of the cathodes surface reveals a change of reflectivity. This is an indication of damage to the cathode's surface. The extend is currently unknown as the cathode currently provides the LCLS electron beam and further investigation is not feasible at this time.

Rastering of the laser spot across the cathode's surface again created the grid-like electron beam emission pattern but subsequent scans using a larger spot size and smaller steps created a more uniform emission pattern. Figures 3 and 4 depict the emission pattern from the laser cleaned cathode, imaged using the solenoid set to point to point imaging on a YAG screen. Using this technique, we achieved a QE of mid 10^{-5} and emittances of ~ 0.7 µm in both x and y planes.

During the following weeks of operation we observed a slow increase in quantum efficiency and, more importantly, also a decrease in emittances (figure 5 and 6). Currently, the QE is > 7-8*10^{-5} with emittances of ~ 0.4 µm in the x and y planes. This improvement is not

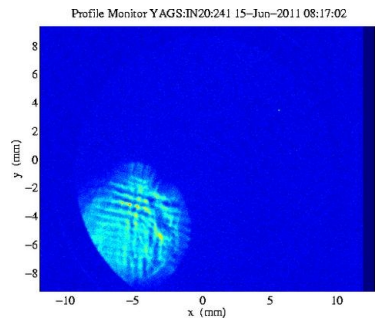

Figure 3: Emission pattern after laser cleaning of cathode.

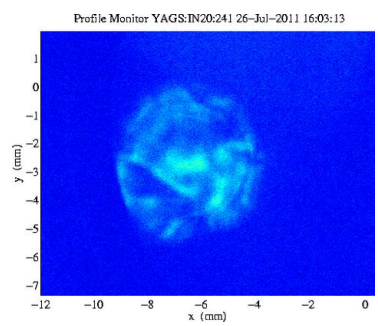

Figure 4: Uniform emission pattern after refinement of laser cleaning method. Structure is dominated by crystal grains.

fully understood. The QE increase may be attributed to the slow improvement of vacuum conditions in the RF gun. The continued effort of machine tuning contributes to improved injector emittances.

SUMMARY AND CONCLUSIONS

For optimal LCLS performance a cathode with minimal surface contamination is required. Cathode surface contamination may be a result of cathode preparation and flange assembly before it is installed in the RF gun or contamination may result from the operation of the cathode in the gun itself. Contributions to surface contamination are residual gas species present in the gun vacuum system but also species segregating from the bulk of the cathode may play a significant role. To ensure reliable operation of the LCLS electron source, it is important to understand the surface physics and chemistry taking place at the cathode surface. Ideally, clean cathodes are needed to provide a performing cathode immediately after installation.

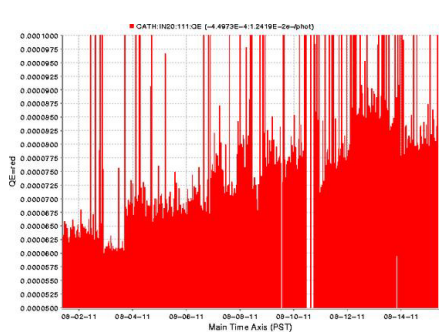

Figure 5: History of quantum efficiency after laser cleaning shows an upward trend.

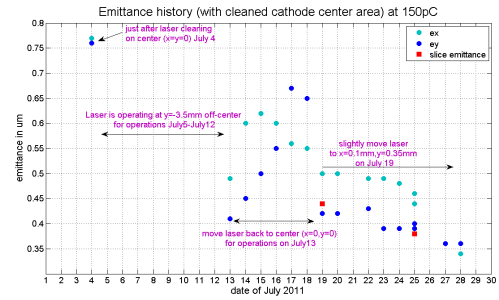

Figure 6: History of injector emittances after laser cleaning shows an upward trend.

The laser cleaning technique has been applied to the LCLS cathode and procedure parameters have been optimized to allow removal of surface contaminants and restoring the QE while maintaining the low emittance electron beam emission required for successful LCLS operation. At SLAC, an R&D program has been launched, focussing on cathode preparation techniques, surface science and performance testing under real operating conditions using a test facility with a second identical RF gun combined with diagnostics to study critical cathode performance parameters.

ACKNOWELEDGMENT

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