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COMPARISON BETWEEN H-ION AND HEAT CLEANING OF CU-METAL CATHODES*

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Abstract

Understanding the quantum efficiency (QE) of a metal photocathode in an s-band RF gun is important to limit the drive laser energy requirement and provide the best quality electron beam. Systematic measurements of the qe vs. wavelength for varying surface contamination have been performed on copper samples using x-ray photoelectron spectroscopy (XPS). The sample is first cleaned to the theoretical limit of QE using a 1 keV hydrogen ion beam. The H-ion beam cleans an area approximately 1cm in diameter and has no effect on the surface roughness while removing essentially all contaminants and lowering the work function to 4.3eV[1]. The sample is then exposed to atmospheric contaminants (nitrogen and oxygen) and measured again with XPS to determine the degree of contamination and their effect on the QE. These results and comparison with theory are presented.

MOTIVATION

As a user facility, LCLS is required to provide x-rays beams to users 90% of the scheduled operating time. This places severe reliability requirements upon the accelerator components, especially those with known poor reliability or marginal performance. Considerable effort has been made to improve the reliability and performance of the critical components in the injector. However the cathode QE and lifetime remain problematic even for metal cathodes. Therefore it is necessary to understand the limiting factors of QE, investigate possible surface cleaning techniques and establish a reliable method for transferring cathodes to the gun and preserving the QE during gun operation. This paper describes a portion of these studies.

DESCRIPTION OF THE APPARATUS

A portion of the experimental layout is shown in Figure 1, which gives a schematic layout of the H-ion gun, the broadband light source with scanning monochromator and the biased copper sample or cathode. The 18 volt bias is only used during the QE measurements and is replaced with a short for measuring the ion current when the ion gun is operated. This apparatus is in the load lock chamber which is connected by a UHV valve to the "small spot" chamber where the XPS is located. The sample or cathode is transferred from the load lock to the XPS chamber for the surface contaminant measurements.

Studies were made of coupon samples 2.5cm dia x .25cm thick, as well as on Gun Test Facility and ARDB cathodes. The coupons were prepared using the same diamond machining vendor as will turn the LCLS gun cathodes. Hand-polished coupons were also tested. This cleaning and characterization methods described here have become a standard processing procedure for GTF and ARDB cathodes.

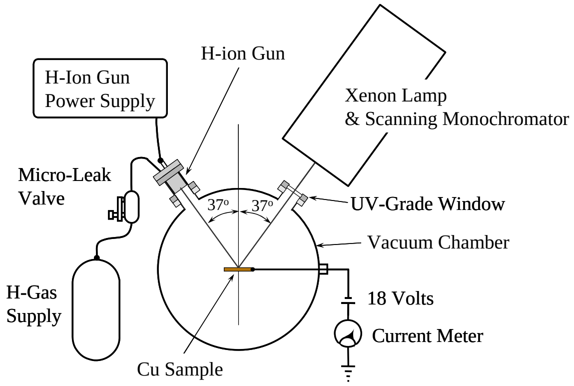

Figure 1: Layout H-ion gun and QE measurement system.

EXPERIMENTAL RESULTS

Reproducibility of H-ion cleaning process

Figure 2 shows QE measurements for two different, but identically prepared polished sample. Both the before and after cleaning the QE curves are identical illustrating the good reproducibility of both preparation and cleaning processes.

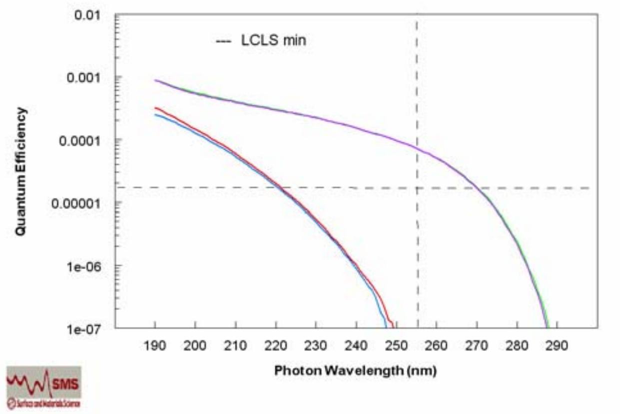

Figure 2: Plots of QE vs. wavelength for two hand-polished samples prepared using the same process.

The data in Figure 2 was obtained for two hand-polished samples which were then H-ion cleaned with a ~1 microampere, 1 keV beam for an integrated charge of 10 and 13 milli-Coulombs. The dashed lines indicate the LCLS drive laser wavelength and minimum QE for producing a 1 nano-Coulomb electron bunch.

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Exposure to nitrogen and atmospheric gases

A determination of clean copper to absorption of gasses is illustrated in Figure 3. In these tests, the single-crystal (SC) copper cathode used for ~3 years, in the Gun Test Facility (GTF) gun at SSRL and then stored under dry nitrogen atmosphere, was cleaned with the H-ion beam to high-QE and then exposed first to 25 torr of laboratory nitrogen with 0.5 ppm of H_2O (LN_2 tank boil-off) for 80 minutes, and then to ambient air for one hour. The initial QE at 255nm was too small to be measured. After H-ion cleaning the QE at 255nm increased to $5.2x10^{-5}$, after 80 minutes in 25 torr of nitrogen the declined to $3.1x10^{-5}$, and one hour in air reduces it to $1.5x10^{-6}$.

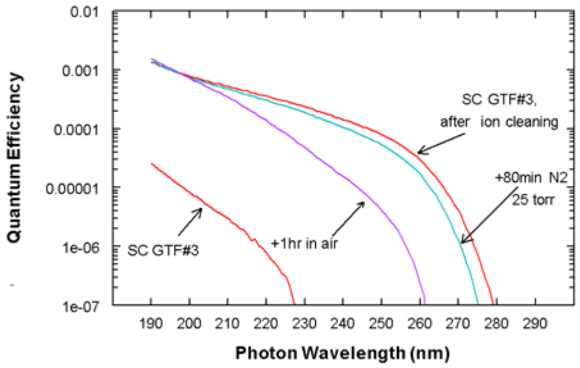

Figure 3: The QE vs. wavelength history of cathode GTF#3. SC GTF#3: After ~3 years of operation and ~1 year of storage; SC GTF#3 after ion cleaning: The QE curve for GTF#3 after H-ion cleaning; +80 min N2 25 torr: the QE curve after 80 minutes exposure to 25 torr of nitrogen; and +1hr in air: The cathode QE after 1 hour in atmospheric gasses.

Results of thermal cleaning

Heating the cathode can also clean the cathode to high QE. Figure 4 gives the result of baking a sample at 230degC for 100 minutes, which increases the QE approximately 2 ½ orders of magnitude.

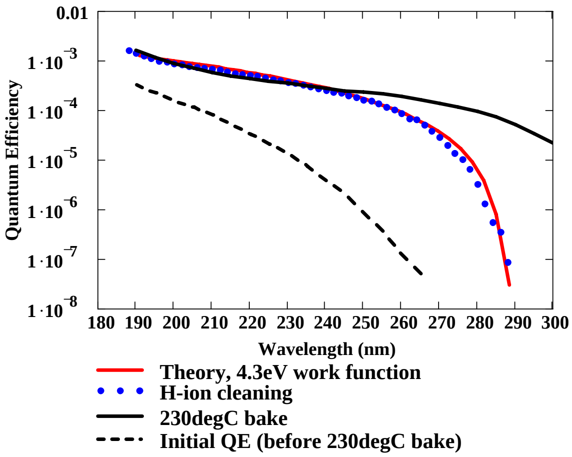

Figure 4: QE vs. wavelength before and after baking a hand-polished sample at 230degC for 100 minutes. The data is reproduced from Ref. [2].

The shape of the QE curve after baking is distinctly different than that obtained after H-ion cleaning. The tail to long wavelengths suggests a lower work function than given by the ion cleaning and the free electron gas model [1]. This suggests an additional phenomenon is causing the higher QE's at these wavelengths.

QE dependence upon surface contamination

The XPS measurements provide information on the contaminants within approximately 50 angstroms of the surface. Figure 5 shows the reduction in surface contaminants and the associated increase in exposed copper when the sample is baked and H-ion cleaned. The data show that baking is effective at removing the oxygen and much of the carbon. The H-ion cleaning removed the carbon and oxygen to below 10% coverage. The final bake actually increased the carbon coverage while it drove the oxygen further down.

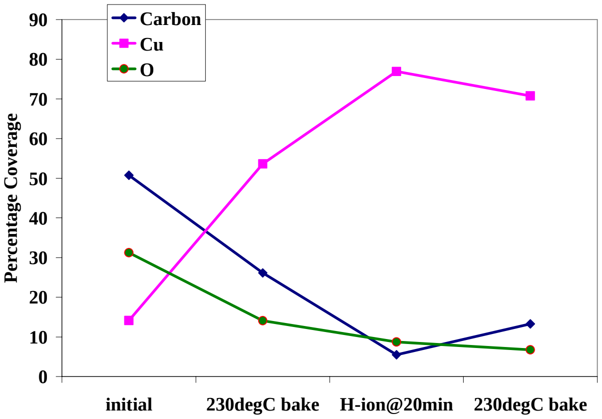

Figure 5: Percentage coverage of carbon, copper and oxygen for a sample first baked, H-ion cleaned and baked again.

The effect of carbon coverage on the work function of copper can be seen in Figure 6. The details of these measurements and analysis are given in Ref [1]. The ambiguity near 12% coverage may be caused by other contaminants such as oxygen whose effect has not been included. However, the observation that the work function decreases by ~1 eV between 30% and 10% carbon coverage is clear, and the analysis presented in Ref [1] shows the QE is nearly that for an atomically clean surface below 10% coverage.

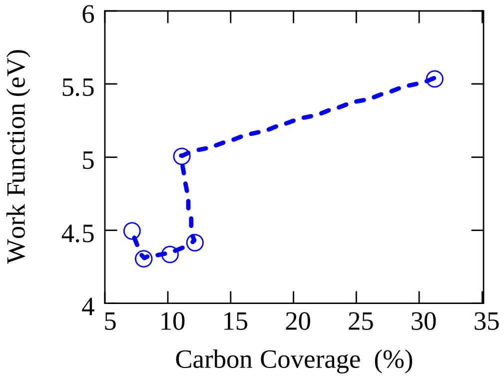

Figure 6: The work function vs. carbon coverage. See Ref [1] for details of the analysis technique and theory.

Surface roughness measurements

The surface roughness is another important parameter for cathodes which need to operate at RF fields of 100MV/m or higher. There are two methods which are commonly used to prepare the metal cathode surface: mechanical hand-polishing and precision machining with a diamond tool. Both the hand-polishing and the diamond-turning produce excellent surfaces, with the polished surface having random spatial frequencies with a roughness of approximately 50 nm peak-to-peak. The AFM measurement for the diamond-tool machined surface is shown in Figure 7, and shows a single spatial frequency transverse to the direction the tool travels. The peak-to-peak height of these grooves is approximately 30 nm with a spatial period of ~9 microns. The sample machining was done on a state-of-the-art machine by an optics diamond turning company [3]. This type of surface quality will be used for the LCLS gun cathodes.

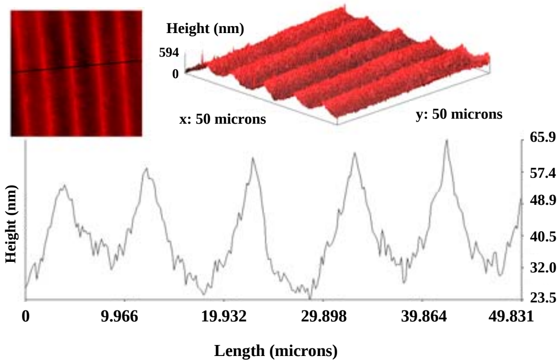

Figure 7: Surface modulation after machining with a precision diamond tool.

CONCLUSIONS

This paper described preliminary studies of H-ion cleaning of copper cathodes. The process is found to be reproducible and capable of cleaning cathodes used in the rf gun to QE's greater than 10^{-4}. Contamination of the cathodes is dominantly due to carbon and oxygen (and their compounds) of which H-ion cleaning is effective at removing both. Data indicates baking at 230 degC removes oxygen but is less efficient with carbon removal when compared with H-ion cleaning. A carbon coverage of less than 12% results in work functions near 4.5 eV and QE's near 10^{-4}. The QE's at long wavelengths for the heat cleaned cathode are larger than for H-ion cleaning. Given that the H-ion data is explained well-explained by the free electron gas model [1], this result implies an additional phenomenon is occurring during the heating process. This effect will be studied in future experiments.

The surface roughness of diamond-turned samples was also measured to qualify the fabrication technique for the LCLS cathodes. A peak-to-peak modulation of 30 nm with a period of 9 microns was found for surfaces produced by high quality diamond turning equipment.

REFERENCES

[1] D. H. Dowell et al., "In-situ cleaning of copper cathodes using a H-ion beam," Proceedings of 27th International Conference on Free Electron Lasers, p.172, Stanford University, Palo Alto, CA 2005 http://accelconf.web.cern.ch/accelconf/index.html. A more comprehensive version has be published in D. H. Dowell et al., PRST-AB **9**,063502(2006).
[2] D. Palmer et al., SLAC-PUB-113551.
[3] Diamond Turning, Inc.