

SURFACE CHARACTERIZATION OF THE LCLS RF GUN CATHODE*

A. Brachmann[#], F.-J. Decker, Y. Ding, D. Dowell, P. Emma, J. Frisch, S. Gilevich, G. Hays, Ph. Hering, Z. Huang, R. Iverson, H. Loos, A. Miahnahri, D. Nordlund, H.-D. Nuhn, P. Pianetta, J. Turner, J. Welch, W. White, J. Wu, D. Xiang
SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA, U.S.A.

Abstract

The first copper cathode installed in the LCLS RF gun was used during LCLS commissioning for more than a year. However, after high charge operation (> 500 pC), the cathode showed a decline of quantum efficiency within the area of drive laser illumination (fig. 1). We report results of SEM, XPS and XAS studies that were carried out on this cathode after it was removed from the gun. X-ray absorption and X-ray photoelectron spectroscopy reveal surface contamination by various hydrocarbon compounds. In addition we report on the performance of the second installed cathode with emphasis on the spatial distribution of electron emission.

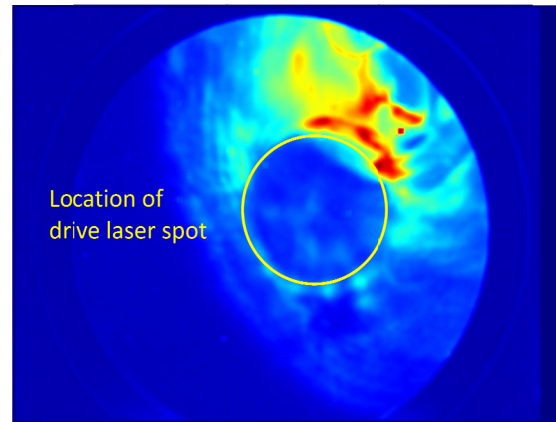


Figure 1: Electron beam image, low quantum efficiency where cathode is exposed to the drive laser beam (LCLS cathode 2)

MOTIVATION

We assume the reason for the decay of the cathodes quantum efficiency is the contamination of its surface by hydrocarbon species contained in the vacuum system of gun and adjacent beam line. The UV drive laser beam and/or the electron beam interact with the residual gas of the vacuum system or already physisorbed species, which are then ionized by drive laser beam and electron beam and deposited on the cathodes surface forming a chemisorbed layer resulting in an increased work function. Upon the removal of the cathode a dark ring of ~ 3 cm diameter on its surface, macroscopically visible, was discovered (fig. 2). It is unclear if the deposition of the ring occurred during RF processing of the gun or if it has formed during normal operation.

This study was conducted to confirm our assumptions for surface contamination and study the chemistry of the cathode surface layer, in particular the composition of the dark ring. In addition, a characterization of the surface by SEM techniques was desirable after ~ 18 months of operation.

X-RAY PHOTO-ELECTRON (XPS) AND X-RAY ABSORPTION SPECTROSCOPY (XAS)

X-Ray Photo-electron spectroscopy was carried out at SSRL's SPEAR 3 beam lines 8-2 and 10-1 [1,2] to investigate the surface chemistry on a qualitative level.

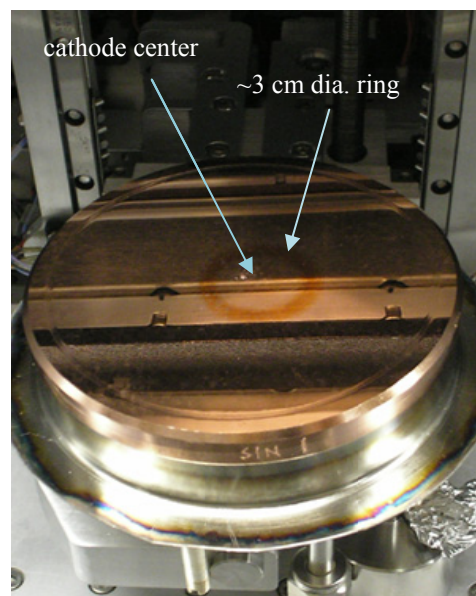


Figure 2: circularly shaped 'dark ring' contamination of cathode surface

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[#]brachman@slac.stanford.edu

The chamber's mounting system allowed a translation of the sample in x, y and z by a few inches in either direction. Photoemission spectra were recorded by a curved mirror analyzer system. X-ray Absorption Spectroscopy (XAS) spectra were recorded using the ratio of incident beam intensity and sample current.

The XPS spectrum indicates a surface layer composition containing oxygen, nitrogen and carbon. A variety of peaks can be attributed to the bulk material (Cu, Pb, Bi and S). An overview spectrum is given in figure 3.

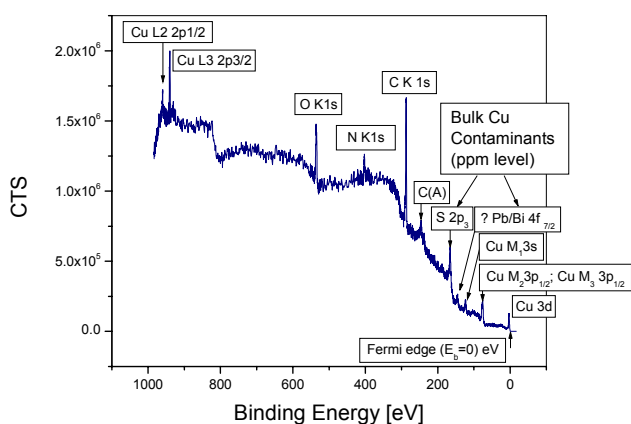


Figure 3: Overview XPS spectrum

To determine the location of the 'dark' ring (see fig. 2), measurements of the C-K1s and Cu-3d peak were performed in a grid pattern and their ratio was used to obtain information on the relative C distribution (fig. 4).

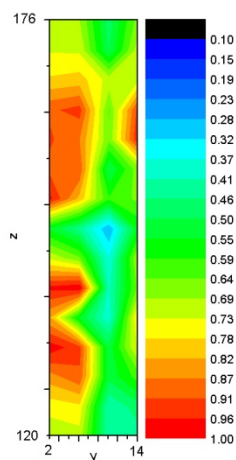


Figure 4: Ratio of the C-K1s/Cu-3d XPS peak (normalized)

Higher resolution measurements of the carbon peak and peak deconvolution were carried out to resolve the speciation of the surface carbon layer (fig. 5).

X-Ray absorption spectroscopy was used to further determine the nature of the carbon layer. An overview spectrum is given in fig 6. The spectrum shows the absorption of photons 260 – 370 eV. The main feature is the carbon absorption edge. Adjacent areas of the

spectrum show the absorption spectrum of oxygen and copper species. Both are the result of absorption of higher order photons. A detailed spectrum of the carbon edge is shown in fig. 7.

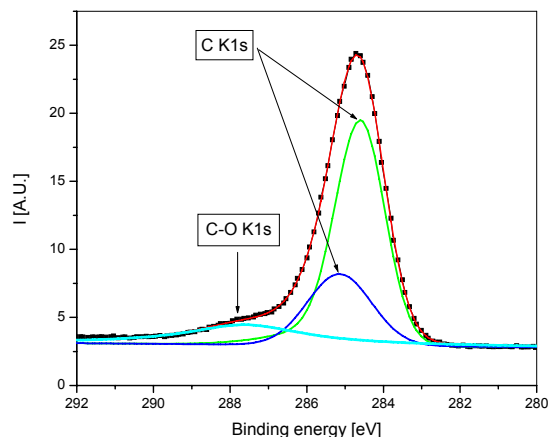


Figure 5: Deconvolution of the C K1s XPS peak

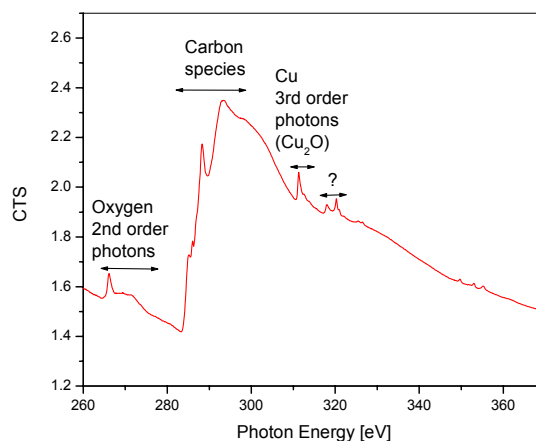


Figure 6: XAS Overview spectrum

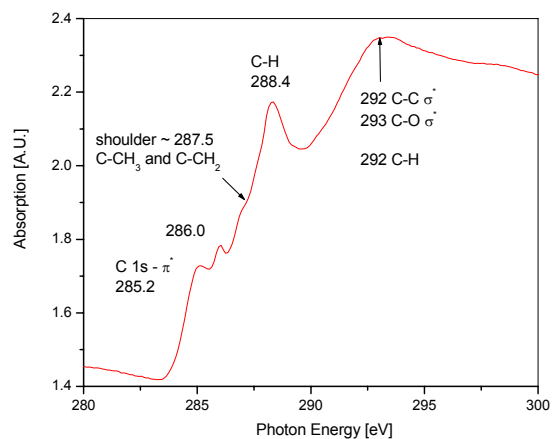


Figure 7: XAS details of Carbon (C K1s) absorption edge

ANALYSIS OF XPS AND XAS

XPS spectra were aligned to the Fermi edge of the spectrum, thereby converting the spectrum to units of binding energy in electron volt. XAS spectra were calibrated using the exciton peak of a highly oriented pyrolytic graphite (HOPG) reference spectrum (291.65 eV). For peak assignment of carbon, nitrogen and oxygen species, the data in [3] were used as a reference. Main emphasis was the analysis of the surface layer Carbon distribution and speciation. For other species, the tables published by the Center for X-ray Optics and Advanced Light Source of the Lawrence Berkeley National Laboratory were used [4].

The measurement of the spatial distribution of the carbon to copper ratio indicates a continuous layer of carbon species across the entire cathode. The carbon XPS peak (C K1s) was observed at any location on the cathode. A larger fraction of carbon is evidence of a larger thickness of the carbon layer. The XPS measurements of the distribution of the C/Cu ratio confirm the presence and carbon containing composition of the macroscopically visible dark coloured ring. Higher resolution measurements of the C K1s peak at various locations reveal the complex structure of the observed carbon species. Slight intensity shifts of the peaks contributing to the spectrum were found at different locations. Qualitatively, spectra are very similar across all regions of the cathodes surface. The peak at ~ 284 eV indicates the presence of elemental carbon. Deconvolution of the XPS spectra show a main peak of elemental carbon but also indicate a significant fraction of C-O bonds (~ 288 eV, fig. 5).

A more detailed carbon speciation is possible using X-Ray absorption spectroscopic measurements of the C K1s absorption edge (see fig. 7). The main identified features are the π^* antibonding state of graphitic carbon located at ~ 285 eV as well as states in the region of 287-289 eV that are associated with C-CH_x and C-CH bonds. The broad peak at ~ 292 eV can be attributed to the σ^* orbitals of C-C and C-O bonds. A C-H bond can also be expected here.

SEM ANALYSIS

SEM imaging and EDX analysis were carried out on an Aspek PSM-76 LS scanning electron microscope. Various areas of the cathode surface were analyzed. In particular, a clearly macroscopically visible dark ring of surface deposits (~ 3 cm in diameter), the center of the cathode and other surrounding areas were studied. A variety of features were observed:

1. Surface damage due to RF breakdowns that occurred during RF processing of the gun and cathode (fig. 8).
2. Surface perturbations that are results of 'laser cleaning' of the surface (fig 8).
3. Contamination by particles

In general, EDX analysis revealed the foreign nature of particulates (mainly composed of C, O, Mg, Al, Si Ca and Ti). Surface carbon was detected; however a conclusive study was impossible due to the rapid alteration of the surface layer by the impinging electron beam.

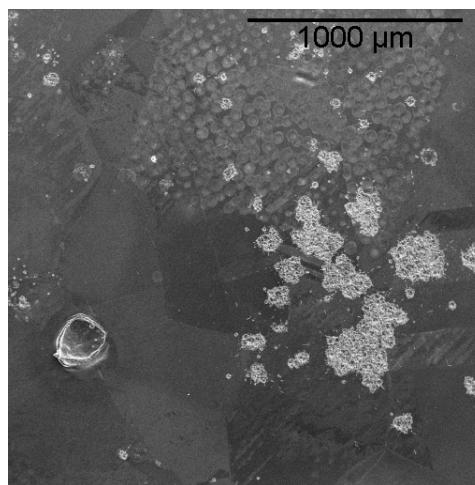


Figure 8: SEM detail of cathode surface: center and lower left – RF breakdown events, upper middle – artefacts of laser cleaning

CONCLUSIONS

As expected, the XPS and XAS measurements confirmed the presence of complex hydrocarbon chemistry on the cathodes surface. Similar phenomena currently occur on the second installed LCLS Cathode. In general it is apparent that this process cannot be entirely avoided. A study of ion migration within the LCLS RF gun and a discussion of possible surface contamination mechanisms is given in [5]. It is therefore desirable to have the cleanest UHV system as possible to ensure a slow speed of surface contamination. Further experiments are planned to investigate this process in more detail, and to develop techniques for surface cleaning and passivation.

ACKNOWLEDGEMENT

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