

PREPARATION OF THE POLYCRYSTALLINE COPPER PHOTOCATHODES FOR VELA RF PHOTOCATHODE GUN*

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Abstract

The Versatile Electron Linear Accelerator (VELA) is a high performance electron accelerator under commissioning at ASTeC. The photoinjector of the accelerator is based on a S-band photocathode RF gun operating with a copper photocathode which is driven by a third harmonic of a Ti: Sapphire laser (266 nm). The photocathode used in the RF gun is an integrated part of the gun cavity which is a polycrystalline Cu disk, polished to 1 μ m roughness, and is placed at the back wall of the first half cell in the gun cavity. One of the main aims was to establish a procedure to activate the Cu surface prior to installation. In order to do this Cu test samples with a roughness of 0.1 μ m were prepared by different techniques. The best results have been obtained by *ex-situ* plasma cleaning in an oxygen atmosphere. Analysis shows that there was no carbon on the surface and the surface was composed of copper oxide. After heating the sample in-situ to 200 C for 30 minutes almost all the surface oxide was removed. For this surface a QE of 2×10^{-5} was measured. Further heating to higher temperature did not result in any improvement either in surface composition nor a noticeable increase in QE. The VELA Cu cathode has been prepared in such a way and helped deliver 1st electrons from.

INTRODUCTION

The performance of a FEL is strongly related to the brightness of the electron beam generated by the photocathode. Hence the performance of the cathode will be strongly dependent on its preparation prior to its introduction in the gun. VELA [1] currently installed at the STFC Daresbury Laboratory will eventually drive a FEL facility in the future. VELA's photoinjector is based on a 2.5 cell S-band photocathode RF gun operating with copper photocathodes and driven by a third harmonic of a Ti: Sapphire laser (266 nm)[2] installed in a dedicated thermally stabilised room. Light pulses with energies of up to 2 mJ focused to a spot size of 1 mm and a length of 100 fs follow with a repetition rate of 10 Hz (eventually 400 Hz). The photocathode for the RF gun is a polycrystalline, oxygen-free, copper disc machined to 1 μ m roughness. It forms an integrated part of the 2.5-cell gun cavity and is placed at the back wall of the first half-cell. Once the cathode is installed, in-situ access to the cathode is only available through the 15mm electron exit aperture which makes it virtually impossible to process the cathode's surface without contaminating the gun cavity.

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To achieve an adequate quantum efficiency from the copper photocathode it is therefore necessary to establish a cleaning procedure that will produce a surface with the lowest achievable work function and at the same time minimise any changes to the surface topography, prior to installing the cathode in the gun. Similar studies has been carried out by D.T. Palmer [3,5] and P. Davis et al. [4] where they reported Quantum Efficiencies(QE) ranging from 2.5×10^{-4} to 9×10^{-5} for polycrystalline copper.

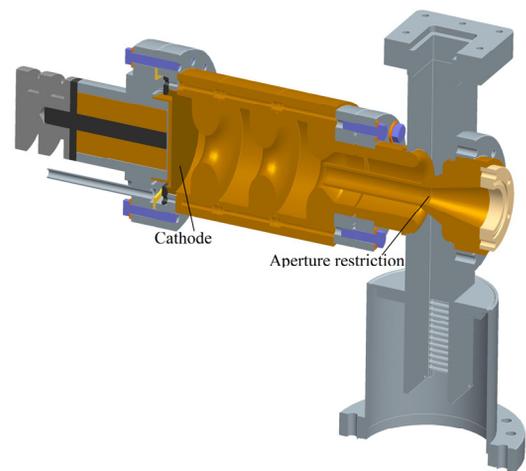


Figure 1: 2.5 cell S-band RF copper photocathode gun.

EXPERIMENTAL PROCEDURES

An analytical science facility (ESCALAB II) has been modified to characterise the cathode's surface chemical state as well as its Quantum Efficiency (QE). The system has the following surface characterisation techniques:

- X-ray Photoelectron Spectroscopy (XPS) - to determine surface and near surface (9nm) chemical composition state.
- Auger Electron spectroscopy (AES)/ mapping - to determine surface and near surface composition.
- Low Magnitude (5000) Scanning Electron Microscope (SEM)
- Ar⁺ ion gun and Atomic H gun to clean the photocathode by ion and atom bombardment at both room temperature and up to 700^oC.
- UV light source (white light source with monochromator and 265 nm UV LED) to quantify the QE.
- UHV compatible photodiode with 2.5cm² active area to measure the power of the incident UV light.

Polycrystalline oxygen free copper test samples with surface roughness of 0.1 μm were degreased with Acetone, IPA and de-ionised water. A set of samples were then chemically etched in a HCl/IPA solution (1:10 by volume) for 2, 5, 10 and 20 minute duration. Another set of samples were plasma cleaned in an Oxygen atmosphere 100 mbar using a Diener plasma source for 20 minute. Both of these steps were carried out prior to introducing samples into vacuum. The surface topography was determined ex-situ using an interferometric microscope. The measurement was carried out in Extended mode. In this mode interference fringes are only formed within the depth of focus of the objective. The appearance of fringes means that part of the surface is in focus. Scanning the vertical position of the sample and recording the vertical position at which the fringes occur allows the measurable height range to be increased to 100 μm , but the penalty is the vertical resolution is reduced to the nanometre level.

RESULTS AND DISCUSSION

Figure 2 represents the XPS wide spectra of copper samples under different processes. The pure copper surface is represented with two groups of peaks Cu2p3/2 at 933eV and Cu2p1/2 at 953eV due to spin – orbit coupling. For the Cu-oxide surface there are two additional peak corresponding to Cu-O bonding which appear at 943eV and 963eV.

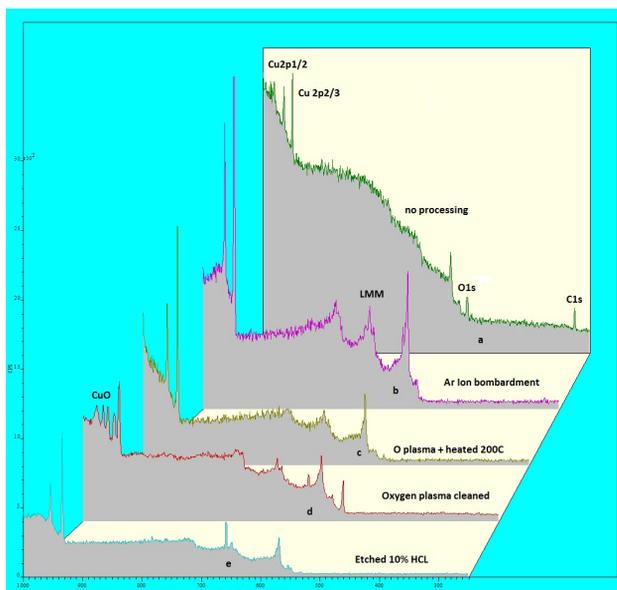


Figure 2: XPS wide spectra of copper samples processed with different cleaning procedure: a) just degreased, b) after Ar⁺ bombardment, c) oxygen plasma processed and heated to 200°C, d) oxygen plasma processed and e) etched in a HCl/IPA solution (1:10) by volume.

Oxygen O1s and carbon C1s are represented by peaks at 530eV and 285eV respectively. It can be seen that carbon is only present in significant amounts only when

the sample has gone through a degreasing step. Both plasma cleaning and HCl etching prior to introducing the sample into vacuum will remove the carbon contamination from the surface and with the latter also remove all the oxide built up on the surface. However plasma cleaning enhances the oxidation process and creates a fully oxidize surface. During the plasma cleaning, the sheath potential accelerates positive oxygen ions from the plasma and these energetic species can ion scrub the surface to remove contaminants on the surface. Oxygen ions from plasma can react with contaminants on the surface, forming volatile reaction products that leave the surface. For example, oxidise hydrocarbons will volatize as CO, CO₂, and H₂O. Once the surface contaminants are removed Cu-oxide is promoted through reaction of oxygen ions with clean Cu surface. Further heating in-situ at 200°C for 20 minutes dissolved all the oxygen down to traces level. Oxygen reactive plasma cleaning was carried out in oxygen gas pressure of 100 mbar where the plasma particle density was high and the mean free path for collision was small. Under these conditions it is impossible to accelerate ions to high kinetic energies, therefore reducing any probability of surface sputtering which can produce rough surfaces. *In-situ* Ar⁺ ion bombardment also produced a pure copper surface.

Figure 3 represents the RMS values of surface roughness of the samples after etching in a HCl/IPA solution (1:10) by volume for varying amounts of time and the sample plasma cleaned for 20 minutes in an oxygen atmosphere of 100 mbar prior to their introduction into vacuum.

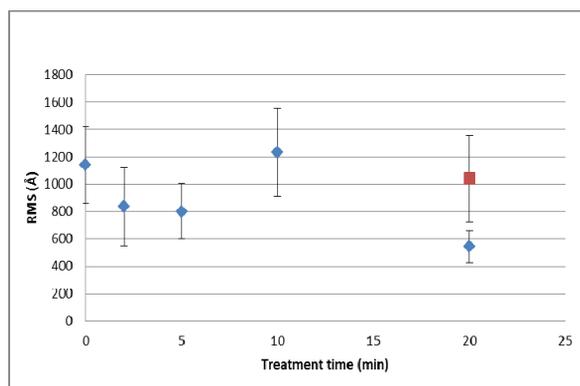


Figure 3: Average RMS values of etched, (in blue), and plasma, (in red), treated copper for different treatment times, error bars of ± 1 standard deviation.

For the etched samples, there is a decrease in surface roughness as treatment time is increased, though the result for 10 minutes treatment appears to be anomalous to this, i.e. its RMS is far too high and statistically no different from the untreated sample. The reason for the high roughness with the 10-minute etch may be due to the original copper disc having an atypically high initial roughness, some fault in the treatment of this sample

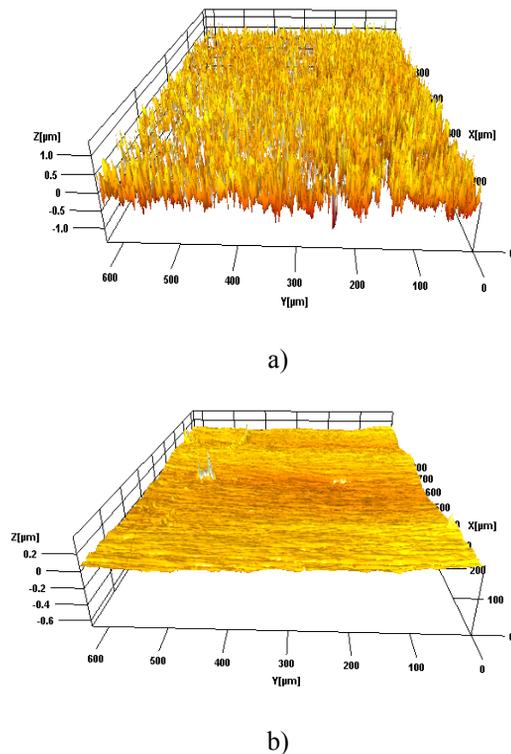


Figure 4: 800 x 600 μm^2 map of a) Argon-ion bombarded copper, b) non bombarded area, scanned in extended mode.

resulting in much reduced material removal, or just incorrect sample labelling. To resolve this anomaly, another 10-minute sample should be made and examined.

Figure 4(a,b) represent the extended mode micrograph of the argon ion bombarded surface (a) which shows that the surface has very deep pits with an RMS roughness of 256 nm. The non-bombarded surface (b) has an RMS roughness of 60 nm.

The XPS analysis showed that without any surface treatment the surface was composed of Copper oxide and carbon. As a consequence, no photocurrent from this surface was observed.

Argon ion bombardment with 5 KeV argon and a sample current of 50 μA for 10 minutes resulted in significant material removal (several microns) and a dramatic increase in surface roughness with deep pits that made the roughness measurement somewhat unreliable. However this resulted in removing all the oxide and carbon layer from the surface as shown in Fig. 3b and gave a QE of 4.5×10^{-5} .

Chemical etching with a HCl/IPA solution (1:10) by volume, resulted in smoothing the surface and the longer the etch time the smoother the surface. A 20 minutes etch resulted in a decrease of roughness from 100 nm to 60 nm. XPS analysis showed there was no significant oxide layer or carbon on the surface. However no photocurrent was observed even after heating up to 300 $^{\circ}\text{C}$.

Plasma cleaning in an Oxygen atmosphere for 20 minute resulted in no change in the surface roughness. XPS and Auger analysis both showed that after ex-situ plasma cleaning there was no carbon on the surface and the surface was composed of copper oxide. For this surface no measurable QE was observed. However after heating the sample in-situ to 200 $^{\circ}\text{C}$ for 20 minutes almost all the surface oxide was removed. For this surface a QE of 2×10^{-5} was obtained. Further heating to higher temperature (440 $^{\circ}\text{C}$) did not result in any improvement either in surface composition nor a noticeable increase in QE.

CONCLUSION

For the etched samples, there is a decrease in surface roughness as treatment time is increased. The argon-ion bombarded copper showed significant material removal and dramatic increase in surface roughness. The plasma treated sample has an RMS roughness that is not statistically different from the untreated sample. Photocurrent activity under UV (266nm) irradiation was only registered for either a sample bombarded in-situ with Ar^+ ions or a sample oxygen plasma cleaned plus in-situ heating. The latter is the preferred method of photocathode preparation for VELA, since as well as producing adequate QE, it also do not affect the surface roughness, a parameter which is important for beam emittance. The etched sample did not produce any measurable photocurrent, therefore more analysis is needed to establish the surface work function after each treatment. This can be determined by using a Kelvin probe which is currently being added to the system.

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