ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRI047

THE PREPARATION OF ATOMICALLY CLEAN METAL SURFACES FOR USE AS PHOTOCATHODES IN NORMALLY CONDUCTING RF GUNS*

R. Valizadeh, K.J. Middleman, A.N. Hannah, B.L. Militsyn and T.C.Q. Noakes#, ASTeC, STFC Daresbury Laboratory, Sci-Tech Daresbury, Daresbury, Warrington, Cheshire, WA4 4AD, UK
S. Mistry, Department of Physics, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK

Abstract

This work reports a study of various alternative metal samples as candidate materials for use as photocathodes in normally conducting RF guns. Clean surfaces were prepared using Argon ion bombardment and quantum efficiency measured using a 265 nm UV LED light source. Surface composition was studied using X-ray photoelectron spectroscopy and a Kelvin probe apparatus provided work function measurements. Data were taken both before and after annealing to 200°C, a temperature that is routinely achieved during RF gun vacuum baking. Ion bombardment typically leaves a very rough surface, so further work will focus on the use of Oxygen plasma cleaning of the best candidate alternative metals. An oxygen plasma treated Copper photocathode has been shown to produce an acceptable level of quantum efficiency in the VELA accelerator at Daresbury.

INTRODUCTION

The performance of a fourth generation light source is to a greater extent reliant on the properties of the electron bunches, with the fundamental limit controlled by the photocathode where the electrons are emitted. Normally conducting RF guns often use metal photocathodes, mainly due to their fast response time that allows very short pulses to be generated. However, they typically have very low quantum efficiency (QE) compared to semiconductor alternatives (GaAs or Cs_2Te). The drive to use higher QE metals is motivated by the need to minimise the laser power required to generate sufficient bunch charge for the downstream accelerator.

The use of Cu as the metal photocathode of choice is long standing. Other metals such as Mg have been evaluated due to their lower work function and perceived higher QE. Pb and Nb are also candidate materials because of their possible use in superconducting RF guns. Although these materials have been individually evaluated and indeed performance data collated [1], to date there has been little systematic data for a wide range of metals using identical surface preparation procedures. The work presented here addresses this issue.

EXPERIMENTAL

Clean metal surfaces were prepared using Argon ion bombardment and characterised by measuring QE, work function and surface composition via X-ray photoelectron spectroscopy. Data were collected on a VG ESCALAB Mk II instrument modified to allow it to achieve UHV conditions typically found in an RF gun. The instrument has a separate analysis chamber and a preparation chamber where samples can be argon ion bombarded for cleaning (typically 10 min, 5 keV and 50 μA, although multiple cycles were required for some of the samples with high oxygen affinity) and heated to anneal. Figure 1 shows an image of the ESCALAB Mk II system.

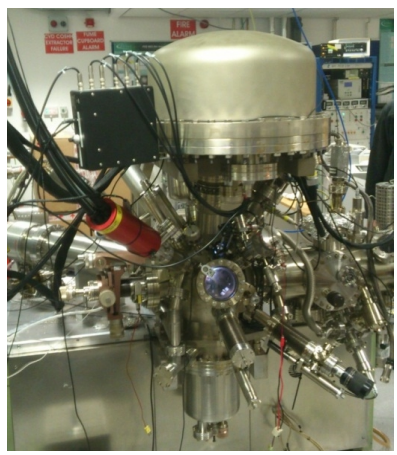

Figure 1: ESCALAB Mk II instrument.

The ESCALAB Mk II instrument is fitted with a non-monochromated Al Kα X-ray source which, with the hemispherical electron energy analyser, gives rise to an energy resolution of approximately 1.1 eV and a spatial resolution of about 100μm. The technique has high surface specificity and good sensitivity to known contaminants such as carbon and oxygen.

The analysis chamber also has Kelvin Probe contact potential difference equipment to measure work function. This commercially available apparatus is a KP Technology UHVKPm100, having < 3 meV resolution. Work function (along with the wavelength of the incident laser light) is likely to influence not only the QE of the photocathode, but also the energy spread of the emitted electrons.

QE measurements were made on the ESCALAB Mk II instrument using a Roithner LaserTechnik UVTOP260-HL-TO39 LED laser source of 265 nm wavelength, which has an integrated lens to ensure a small spot size at the sample. The source has a bandwidth of around 12 nm and intensity is calibrated using an Opto Diode Corp. AXUV100G large area UV sensor. The photocathode samples are electrically isolated to allow drain current

* The work is part of EuCARD-2, partly funded by the European Commission, GA 312453.
# tim.noakes@stfc.ac.uk

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRI047

measurements to be made using a Keithley 480 picoammeter.

Measurements of work function, QE and composition (XPS), were made for as-loaded samples and after Ar ion bombardment. Work function and QE were re-measured after XPS analysis and measurements were also made after annealing the samples to 200°C for 20 minutes, a temperature which can be typically achieved when externally baking an RF gun for vacuum conditioning.

RESULTS AND DISCUSSION

Figure 2 shows a series of wide area scans for the various metals included in this study. XPS data were used to assess the degree of cleanliness of the metal samples surface and so detailed spectra were also collected for the O 1s and C 1s regions (not shown). The XPS data is qualitatively summarised in Table 1. Where the signal for O or C was below the background level this has been interpreted as 'none' and where the signal is just larger than the background as 'trace'; higher signal levels are described as 'significant'. Nearly all the samples evaluated displayed significant levels of both C and O at the surface in the as received state. Ion bombardment always reduced the level of both C and O although in not all cases was O completely removed. In particular, those metals with a high affinity for O tended to retain a trace level at the surface and in the case of Al this remained even after seven repeat cycles of ion bombardment. Mg also has a tenacious oxide, which although reduced, still lead to significant O present at the surface after ion bombardment. For the other samples the bombardment treatment either completely removed the O or only left a trace amount. In the case of C contamination this appeared to be removed by the ion bombardment with only Al and Zr showing even trace amounts. Data for bombarded samples that were heated to 200°C showed very little change with the exception of Cu where the trace amount of O present disappeared presumably by dissolution into the bulk. For some of the samples data after heating is not presented. This was typically because of poor vacuum conditions during annealing, which would lead to significant recontamination of the surface.

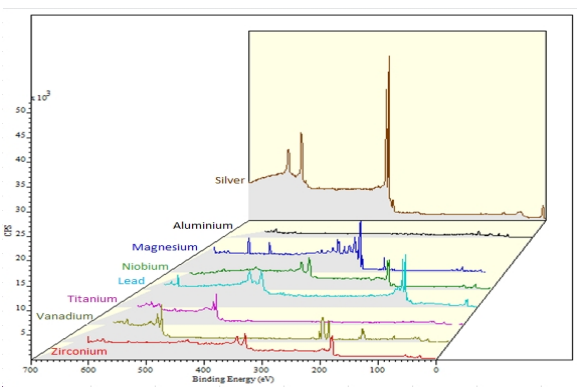

Figure 2: Wide energy range XPS scans for the various metal samples tested.

Table 1: Summary of Data for Various Metal Samples

Sample	XPS# O 1s / C 1s	Work Function (eV)	Quantum Efficiency
Ag			
As received	T / T	5.09	8.5×10^{-6}
Ion bombarded	N / N	5.21	4.2×10^{-5}
After XPS		5.11	5.1×10^{-5}
Heated 200°C	N / N	5.06	8.4×10^{-5}
Al			
As received	S / S	4.02	9.5×10^{-6}
Ion bombarded*	S / T	4.91	2.2×10^{-5}
Cu			
As received	S / S	5.35	5.0×10^{-6}
Ion bombarded	T / N	5.41	4.3×10^{-6}
After XPS		5.32	1.1×10^{-5}
Heated to 200°C	N / N	5.23	1.7×10^{-5}
Mg			
As received	S / S	3.39	6.0×10^{-6}
Ion bombarded	S / N	3.37	1.7×10^{-3}
Mo			
As received	S / S	5.07	1.5×10^{-7}
Ion bombarded	T / N	5.18	2.5×10^{-6}
Nb			
As received	S / S	5.30	3.9×10^{-7}
Ion bombarded	T / N	4.71	1.9×10^{-4}
After XPS		5.36	
Pb			
As received	S / S	4.57	2.4×10^{-5}
Ion bombarded	N / N	4.66	2.2×10^{-4}
Ti			
As received	S / S	4.75	0.0
Ion bombarded	T / N	4.47	3.3×10^{-4}
After XPS		4.96	
V			
As received	S / S	5.51	1.4×10^{-6}
Ion bombarded	T / T	5.00	1.5×10^{-5}
After XPS		5.57	2.2×10^{-5}
Heated 200°C	T / T	5.32	1.0×10^{-5}
Zr			
As received	S / S	4.43	3.9×10^{-6}
Ion bombarded	T / N	4.26	2.9×10^{-4}

S = significant, T = trace, N = none

* Seven cycles

Table 1 also shows the work function measurements from the various metal samples. The measurements for all samples are higher than quoted literature values [2]. For some samples the work function was seen to drop after ion bombardment (Mg, Nb, Ti, V and Zr) whereas for others it increased (Ag, Al, Cu, Mo and Pb). An increase was not expected, since the oxide and carbonaceous layer would be expected to be insulating, leading to higher

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRI047

work function than the clean surface. When the work function was re-measured subsequent to XPS scans, changes were observed, although these were again not systematic with Ag and Cu falling whilst for Ti and V it rose.

For the QE measurements presented in Table 1, in nearly all cases ion bombardment led to a significant increase in the measured value. Where the QE was re-measured after XPS analysis a further increase was always observed. Annealing the samples to 200°C gave rise to even higher QE for Ag and Cu although for V it decreased slightly. This could be because V is more reactive than either Ag or Cu and therefore more susceptible to some re-oxidation during any pressure rise associated with the annealing process.

Comparing the QE and work function results it is clear that there is no direct correlation between the measured values for the two. The obvious conclusion from this is that the processes going on at the surface and near surface region when a sample is bombarded are more subtle than simply a reduction in the work function. In particular, the changes in properties seen before and after XPS were unexpected and are thought to arise primarily because of the time delay rather than any effect of the X-ray beam or electron emission process itself. Potential reasons for these changes could be time dependent structural or topological changes or even small amounts of re-contamination of the surface below the detection limits of the XPS technique. Unambiguous explanation of these effects may be challenging.

From the samples tested, the best QE was achieved for Mg, despite the significant O levels remaining on the surface after bombardment. This is perhaps not surprising since Mg, particularly in thin film form, has long been suggested as high QE photocathode material [3]. More unusually, good results were obtained both Pb and Nb which could be used in a superconducting gun. The Nb result represents a significant improvement on previously published values [1].

Oxygen Plasma Treatment

Although Argon ion bombardment clearly allows the preparation of clean surfaces with little or no oxygen or carbon contamination, it does not represent a good method of preparing 'real' photocathodes for use in an injector. The bombardment process typically leaves a very rough surface [4]. Figure 3 shows a comparison of as received and ion bombarded Cu surfaces and clearly shows the gross roughening that occurs. Surface roughness is thought to be a key parameter leading to higher intrinsic emittance from the photocathode.

It is for this reason that other surface preparation procedures are under investigation and, specifically at Daresbury, O plasma cleaning of metal photocathodes. For a Cu sample, no measurable QE was detected directly after plasma treatment but a simple anneal to 200°C is sufficient to generate a significant level of 2.0×10^{-5}. This is because the plasma treatment leaves just a thin layer of oxide at the surface which dissolves into the bulk on annealing. The oxide surface effectively provides a protective layer for the photocathode during transfer from the plasma cleaner to the gun under atmospheric conditions. A photocathode prepared using this technique and installed in the VELA photoinjector at Daresbury has been seen to give very similar QE (although a number of assumptions regarding the reflectivity of the laser optics have been made in this estimate).

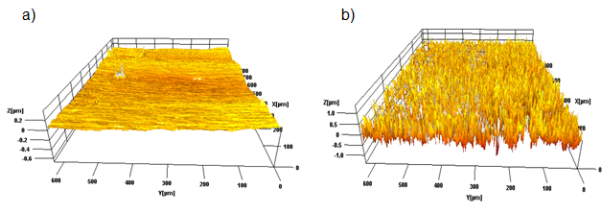

Figure 3: Extended mode optical interferometry images of a) as received and b) Argon ion bombarded Copper.

Similar oxygen plasma treatments will be evaluated for the other metal samples analysed here. Many of these materials have the same property of high solubility of oxygen within the bulk that makes the process work successfully for Cu. The ultimate intention is to test the best of these candidate materials using the RF gun of the VELA accelerator.

CONCLUSION

A comparison of the QE and work function of metal samples has been made to try to identify candidate materials for use as photocathodes in normally conducting RF photoinjectors. Ion bombardment cleaning was seen to remove C and the majority of O present leading to higher QE. Excellent results were obtained for Mg and in addition, for Pb and Nb, which could also be used in superconducting guns. A direct comparison suggests that the improvement in QE is not simply due to a reduction in work function, but may have more complex origins. Since ion bombardment typically leaves a very rough surface, further work will concentrate on O plasma cleaning. A Cu sample prepared using this technique has exhibited good QE, a property that has been replicated in the VELA accelerator at Daresbury.

REFERENCES

[1] D.H. Dowell et al., "Cathode R&D for future light sources", NIM A 622, 685 (2010).

[2] H.B. Michaelson, "The work function of the elements and its periodicity", J. Appl. Phys. 48, 4729 (1977).

[3] T. Nakajyo et al., "Quantum efficiencies of Mg photocathode under illumination with 3rd and 4th harmonic Nd:LiYF4 laser light in RF gun" Jap. J. Appl. Pys. 42, 1470 (2003).

[4] R. Valizadeh et al., "Preparation of the poly-crystalline copper photocathodes for VELA RF photocathode gun", MFPOI069, IPAC'13, Shanghai, China.