MEIS studies of oxygen plasma cleaning of copper for fast response time photocathodes used in accelerator applications

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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 minimize 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. However, the preparation of an atomically clean surface is thought to be key to achieving a high enough QE to be used in an RF gun. At STFC Daresbury laboratory a preparation procedure has been developed that has allowed a QE of approximately 10^{-5} to be achieved. This coupled with a high power UV laser system has allowed electron bunches of up to 250 pC to be generated in the Versatile Electron Linear Accelerator (VELA) facility [1]. However, there is very little understanding of how the cleaning procedure leads to the required surface properties for electron emission and hence a detailed study has been initiated.

The experiments were carried out using 99.99% purity polycrystalline copper samples with an ‘as rolled’ surface finish. Oxygen plasma treatment of the copper samples was carried out using a Henniker Plasma HPT-200 system, which is fed using 99.998% pure oxygen. However, the actual purity of the gas during operation is likely to be limited by the ultimate pressure of the scroll pump used for evacuating the chamber, which is around 0.1 mbar. The two parameters which can be varied for the plasma treatment are the power level and the treatment time. Power levels of between 10 and 100% were evaluated, along with treatment times of between 5 and 20 minutes. Samples were removed from the plasma chamber and transferred in air to the UHV MEIS analysis system. Post treatment annealing of the samples was carried out in the separate preparation chamber using radiative heating at lower temperature of 300°C and electron bombardment heating for the higher temperature of 600°C.

MEIS analyses were carried out using the newly re-established UK instrument in the International Institute for Accelerator Applications at the University of Huddersfield (see Fig.1). Whilst the ion source and beam line has been completely reconfigured, the end station equipment, including the analysis chamber remains essentially unchanged from its previous incarnation at Daresbury [2]. The analyses were performed using 100 keV He ions with a spot size of 0.5 x 1.0 mm and a dose of 1.25 μC per tile. The beam was moved to a different spot on the sample at regular periods during analysis to avoid damage buildup. Since the samples were amorphous, a piece of

crystalline silicon was first inserted into the beam and used to ensure that the detector was at 90° scattering angle. The incidence angle of the beam on target was set at 35.3° for all the samples analyzed.

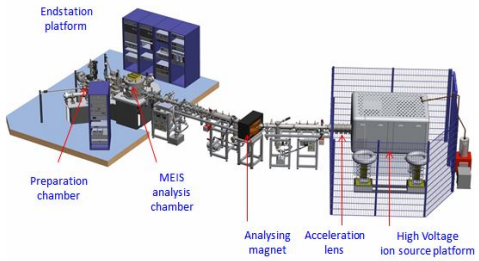

Figure 1: MEIS Instrument at the University of Huddersfield

Data analysis was carried out using the SIMNRA 5.02 code [3]. This version is preferred over more recent versions because of its capability for fitting layer thickness and composition independently. The data were fitted using a four layer model where the bottom layer is essentially bulk pure copper which allows the calibration of particles per steradian to be fitted. The top layer was fixed at approximately five monolayers thickness and the composition allowed to vary to produce a fitted value for the composition at the very surface. The subsequent layer, which represents the majority of the oxide layer, was allowed to have both variable thickness and composition. Finally, there is an interfacial layer between the film and the bulk. This layer probably has gradually varying composition, but is modelled by a single composition with some film roughness added to smear out the signal and improve the fit. From the perspective of understanding the effect of oxygen plasma treatment, the important parameters are the total film thickness and the composition of the film and surface region.

Data for the surface region were typically very similar to the oxide film beneath, with if anything a slight depletion in oxygen for some samples. The thickness of the oxide layer showed the expected dependence on treatment time with a significant increase as the time increased. The observed dependence of film thickness on plasma power was less expected, since there was a maximum at around 50% power level, after which there was a gradual decline. Annealing the films to around 300°C gave rise to an overall reduction in the oxygen content, without much change in the film thickness. Annealing to 600°C appeared to remove all the oxygen from the surface region leaving pure copper.

In practice, the photocathodes used in VELA are only annealed to 250°C after oxygen plasma treatment and loading into the gun vacuum system, although they are held at this temperature for over a week. It is therefore unlikely that a completely oxygen free surface is produced. It can be speculated that the high-power UV laser used during operations also has some cleaning effect and further analyses are required to investigate this potential effect.

References.

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