

CONTROLLED DEGRADATION BY OXYGEN EXPOSURE IN THE PERFORMANCE OF A Ag (100) SINGLE-CRYSTAL PHOTOCATHODE

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Abstract

The search for high performance photocathode electron sources is a priority in the accelerator science community. The surface characteristics of a photocathode define many important factors of the photoemission including the work function, intrinsic emittance and quantum efficiency of the photocathode. These factors in turn define the electron beam performance which is measurable as normalised emittance, brightness and energy spread [1]. Strategies for improving these parameters vary, but understanding and influencing the relevant cathode surface physics which underpin these attributes is a primary focus for the electron source community [2].

As such, pure metal photocathodes and their performance at UV wavelengths are of interest as seen at the LCLS at SLAC and CLARA at Daresbury. We present performance data for a Ag (100) single-crystal photocathode under illumination at 266 nm wave-length, with known levels of surface roughness, using our Transverse Energy Spread Spectrometer (TESS) [3] both at room and cryogenic temperatures. Crucially our data shows the effect of progressive degradation in the photo-cathode performance as a consequence of exposure to controlled levels of oxygen.

INTRODUCTION

The intrinsic emittance of a photocathode is governed by multiple physical factors such as surface roughness, crystallographic face, cleanliness, work function and the QE. As the intrinsic emittance is what usually determines the lowest achievable limit for the electron beam emittance within a linear accelerator, it is important to understand the effects that changing a photocathode surface has on these characteristics [4]. Minimising the mean transverse energy (MTE) of a beam is crucial as total emittance cannot be reduced by using electrostatic or magnetic lenses, so compelling us to minimise MTE at the cathode surface to achieve low-emittance electron beams [3].

Naturally, the state of the vacuum in which the photocathode resides and operates is important. Residual gases within the vacuum system may react with the cathode surface which causes new composites to form at the surface [5-7]. A continuous reduction of QE caused by the gas absorption and changing surface state is observed, and such behaviour has been confirmed in previous experiments on alkali and semiconductor-based cathodes [8, 9].

The TESS experimental facility is connected to a Photocathode Preparation Facility (PPF) [10] and can be used to measure transverse energy distribution curves (TEDC) of III-V semiconductor, multi-alkali and metal photocathodes [11, 12]. Investigations into the factors which affect photocathode performance require a multitude of diagnostic techniques. In addition to the TESS, The Accelerator Science and Technology Centre's (ASTeC) R&D facilities include XPS, LEED and AFM/STM on our Surface Analysis, Preparation and Installation (SAPI) system [13], with ex-situ interferometry for surface roughness measurements. With this range of surface analysis techniques, we have prepared a Ag (100) surface and have taken a series of MTE measurements at room and cryogenic temperatures.

EXPERIMENTAL DETAILS

Experiments were performed on a 6 mm diameter Ag (100) cathode with an average roughness (R_a) of 5 nm, as supplied by the Surface Preparation Laboratory. The sample holder was degreased in an ultrasonic acetone bath for 20 minutes before the sample was mounted. Once loaded into our SAPI system the photocathode underwent Ar⁺ bombardment for 15 minutes with a drain current of 2.0 μ A, followed by annealing to 550 °C for 1 hour. This process was repeated until we observed a clean XPS survey spectrum without the presence of oxygen or carbon, as well as a defined (100) LEED pattern. After its transfer in a UHV vacuum suitcase from the SAPI to the PPF, the photocathode would undergo a longer annealing cycle of typically 8 hours overnight, reaching a temperature of 550 °C, and then allowed to cool for 1 hour before measurements were taken.

TEDC measurements were as described in previous publications [11, 12] under illumination at a wavelength of 266 nm, with the cathode biased at -60 V at the source, the grid and MCP front plate biased at 60V and the MCP back voltage was maintained at 1055 V. The total drift distance between the cathode surface and the detector changes from 30.00 mm at 298 K to 30.16 mm at 173 K which is calculated as part of our data analysis program. This change in drift distance is included in the time of flight calculation for the analysis of the cryogenic data. During this experiment, the chamber base pressure was measured and a photoemission image recorded using the above parameters before any oxygen gas admission to the chamber.

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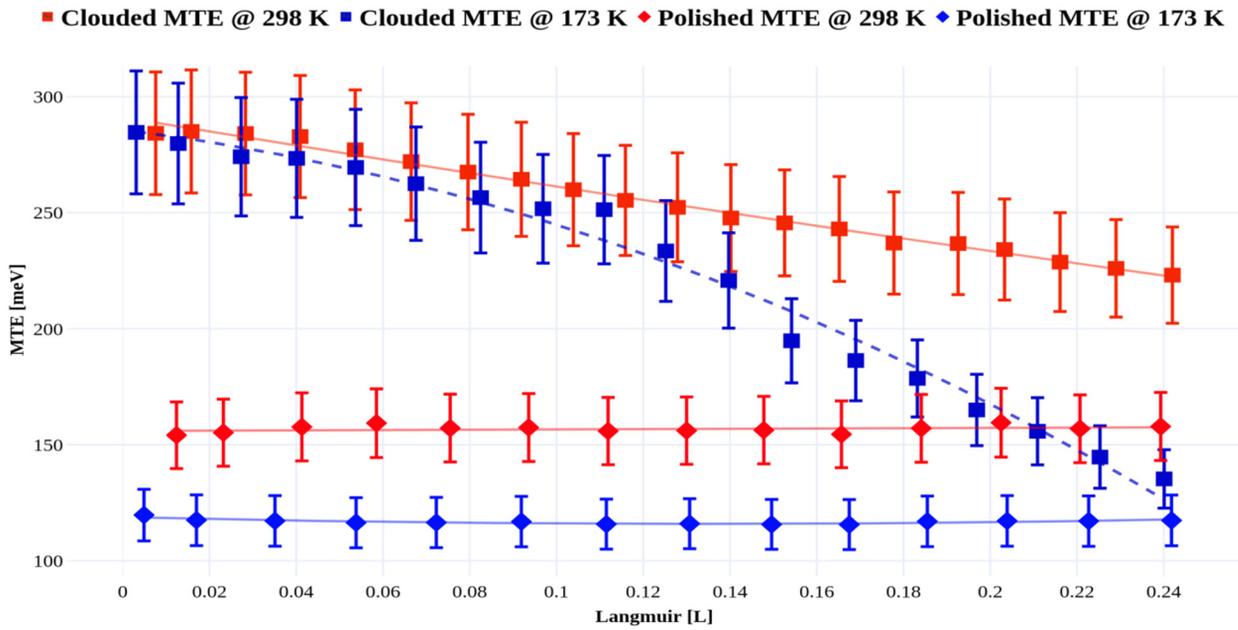


Figure 1: MTE of a Ag (100) cathode under illumination at 266 nm at a temperature of 298 K and 173 K as a function of progressive oxygen exposure, measured in 2 different positions on the sample surface, where the ‘polished’ position is with a known surface finish, and the ‘clouded’ position is the altered finish as a result of sample preparation.

Then as oxygen was admitted into the chamber and the photocathode subjected to degradation, pairs of data and dark images were taken, both with an exposure time of 30 seconds. The oxygen leak rate was kept as constant as possible through the use of a piezoelectric leak valve for both the room temperature and cryogenic temperature measurements. Throughout the experiment, the chamber pressure was measured and logged, and with knowledge of the initial base pressure of the TESS chamber, we were able to determine the oxygen exposure in Langmuirs over the period of the measurements taken.

EXPERIMENTAL RESULTS

The data presented were taken at two positions on the sample where the surface was visibly different following the sample preparation. The ‘polished’ positions retained the original finish whilst the ‘clouded’ position had become duller due to the sample preparation procedure.

Figure 1 shows the MTE data collected on the Ag (100) surface at the two positions. All MTE data have an experimental error of $\pm 9.3\%$ and an error of $\pm 3\%$ is considered for the total image intensity data points to account for fluctuations in the light source during measurements.

The first set of measurements, shown in red, were taken at 298 K with the absolute pressure of the TESS chamber rising from a base of 2.0×10^{-11} mbar to a maximum pressure of 1.5×10^{-10} mbar. The second set, shown in blue, were taken at 173 K with a base pressure of 2.3×10^{-11} mbar to a maximum pressure of 1.5×10^{-10} mbar.

This slight difference in the base pressure leads to a small mismatch in the leak rate of oxygen between the two measurements.

Figure 2 shows the effect on the total image intensity of cooling and then exposure to oxygen of the Ag (100) surface. The data shows a drop of image intensity from 298 K to 173 K of 2.0×10^7 over 28 minutes. The surface was then left for 11 minutes before the piezoelectric leak valve was opened and oxygen admitted into the chamber, during which time the intensity dropped from 4.91×10^8 to 4.87×10^8 .

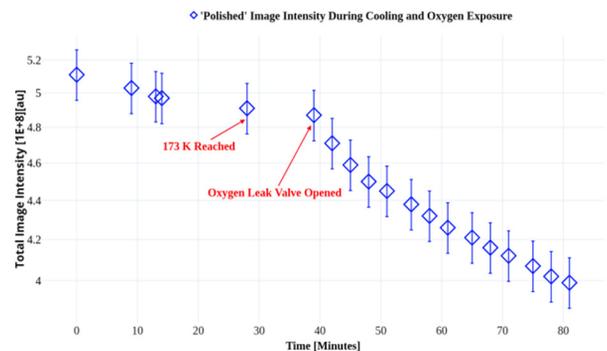


Figure 2: Total image intensity of the “polished” cryogenic data during the cooling process from 298 K to 173 K in comparison to the total image intensity during oxygen exposure.

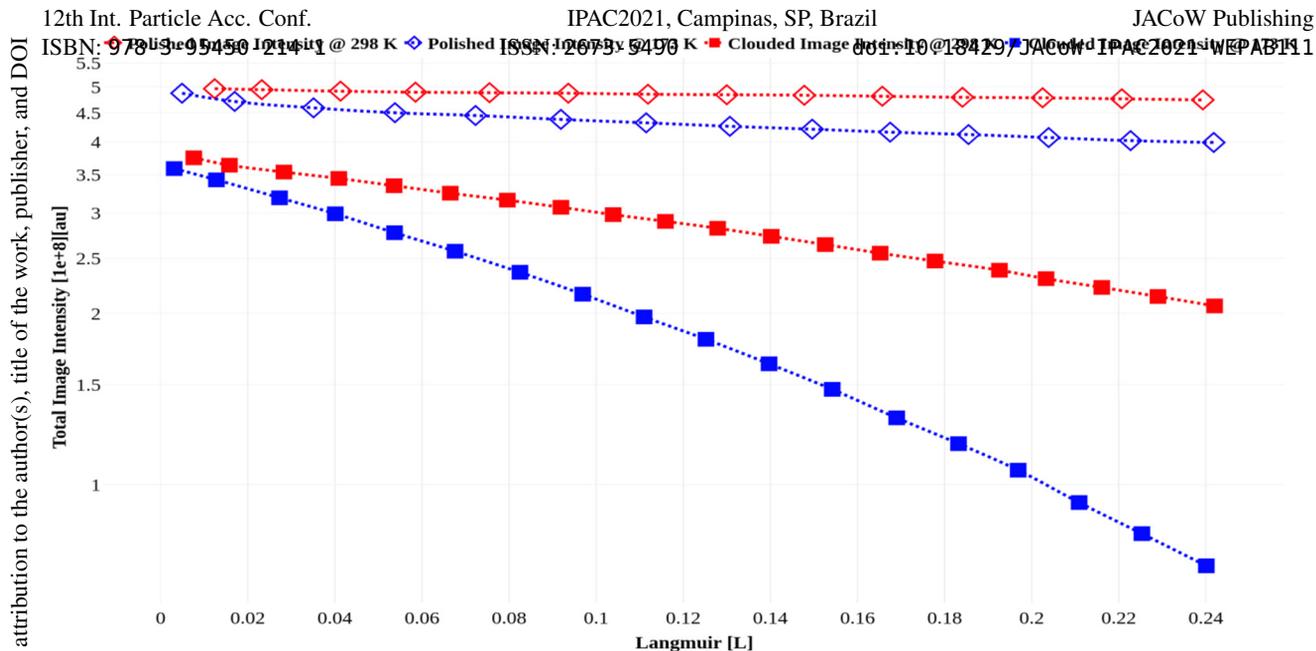


Figure 3: Total image intensity representing the change in quantum efficiency of a Ag (100) cathode under illumination at 266 nm at a temperature of 298 K and 173 K as a function of progressive oxygen exposure in 2 positions.

The surface was then left for 11 minutes before the piezoelectric leak valve was opened and oxygen admitted into the chamber, during which time the intensity dropped from 4.91×10^8 to 4.87×10^8 . After the leak valve was opened to allow for a fixed rate of gas flow, we observe the total image intensity at the polished cathode position degrade at a faster rate than what is observed during the cooling process and while held at 173 K within the base vacuum environment. Figure 3 shows the effect of cooling a photocathode on the QE degradation during oxygen exposure, represented by the total image intensity in the TEDC measurements. The final integrated intensities of the photoemission footprints at around 0.24 L have a large difference between them, and while we do observe a drop in total image intensity in all data sets as a result of oxygen degradation, the largest factor shown is the difference between the two sample positions and how they interact with the increased presence of oxygen in the vacuum chamber.

DISCUSSION

We have observed a marked increase in QE degradation on exposure to oxygen at cryogenic temperature from both the ‘polished’ and ‘clouded’ parts of the Ag crystal. The temperature affects two relevant properties of the metal. Firstly, the work function of Ag (100) increases as the temperature falls [14]. Secondly, we can assume there will be a cryo-pumping effect caused by a larger sticking coefficient for oxygen on the surface at cryogenic temperatures. The sticking coefficient for single crystal Ag has been shown to decrease significantly with relatively gentle heating [15], but the published measurements do not show the effect of oxygen adsorption on a cryogenically cooled surface.

With this information, a few assumptions can be made. As the cathode is cooled, the sticking coefficient of oxygen on the Ag (100) surface increases; this encourages the formation of surface compounds due to the adsorption of molecules happening more quickly. Finally the crystal lattice structures on the surface change as a function of temperature, which drives a more significant increase in the work function. These effects combined help explain the increased degradation rate of Ag (100) while cooled. The difference in results between the two positions implicates an effect on part of the Ag (100) surface, which while not seen during post-experiment surface characterisation, can be seen visibly on the surface and in the performance characterisation.

CONCLUSION

The measurements presented here on the degradation of Ag (100) confirm that the performance of a cathode is affected significantly under controlled degradation simulating exposure to the residual gas found in a vacuum system. Our results show that with a total exposure of 0.24 L we witnessed the QE fall by 6.2% in the room temperature measurements, and by 24.0% in the cryogenic measurements at the polished position, and at the clouded position we saw a 45.1% fall in QE at room temperature and by 87.5% at cryogenic temperatures, with a drop in QE by a factor of 8 between the polished and the clouded positions.

FURTHER WORK

We plan to repeat this experiment on a polycrystalline copper cathode due to its use in current accelerators as an electron source. We also plan to do additional degradation experiments on other photocathode candidate materials in the future.

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