CONTROLLED DEGRADATION OF A Ag PHOTOCATHODE BY EXPOSURE TO MULTIPLE GASES

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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 process including the work function, the intrinsic emittance and the quantum efficiency of the photocathode. These factors in turn define the ultimate electron beam quality, which is measurable as normalised emittance, brightness and energy spread. Strategies for improving these parameters vary, but understanding and influencing the relevant cathode surface physics which underpin these attributes is a primary focus in this area of accelerator research [1].

We present performance data for a Ag polycrystalline cathode under illumination at 266 nm subjected to progressive degradation through exposure to O_2, CO_2, CO and N_2 in which we use our Transverse Energy Spread Spectrometer (TESS) instrument [2] to measure the mean transverse energy (MTE) of the photoemitted electrons with data at room and cryogenic temperatures. Crucially the data shows the effect of progressive degradation in photocathode performance [3] as a consequence of exposure to controlled levels of O_2 and that exposing an oxidized Ag surface to CO can drive a partial recovery in QE.

INTRODUCTION

The intrinsic emittance of a photocathode is governed by multiple physical factors such as surface roughness, crystallographic face, surface contaminants, work function and the quantum efficiency (QE). The ultimate achievable emittance in a linear accelerator is limited by its electron source, so a deep understanding of the factors which affect the performance of the photocathode is crucial to optimise the performance of accelerators [4]. Minimising the mean transverse energy (MTE) of a beam is crucial as total emittance cannot be reduced by using electrostatic or magnetic lenses, which leads the photocathode community to minimise MTE at the cathode surface to achieve low-emittance electron beams [5].

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 causing the formation of new composites [6-8]. An inferred reduction of QE caused by gas adsorption may be observed, and such behaviour has been confirmed in previous work on alkali and semiconductor-based cathodes [3,9], and our work on an Ag (100) cathode [10].

The TESS experimental facility [2] measures the transverse energy distribution curve (TEDC) of a photocathode, and this data is analysed to extract the MTE [2,11]. The TESS is connected to a Photocathode Preparation Facility (PPF) [12] which supports in-vacuum photocathode transfer and storage, and provides thermal and atomic hydrogen photocathode cleaning. Investigations into the factors which affect photocathode performance require a multitude of diagnostic tools, and the Multiprobe system supports this work by providing a suite of complementary surface characterisation techniques [13].

EXPERIMENTAL DETAILS

Experiments were performed on a 6 mm diameter Ag polycrystalline cathode with an average roughness of 5 nm, as measured with our interferometric microscope. The sample holder was degreased in an ultrasonic acetone bath for 20 minutes before the sample was mounted. Once loaded into our Multiprobe system the photocathode underwent cycles of Ar+ ion bombardment for 20 minutes followed by annealing to 500°C via electron bombardment for 1 hour. This process was repeated until we observed a clean XPS survey spectrum without the presence of oxygen or carbon. The cathode was then transferred under XHV conditions in a vacuum suitcase from the Multiprobe to the PPF before performance was characterised in the TESS. TEDC measurements were taken under illumination at 266 nm, as described in previous publications [2,11].

Prior to gas admission, the chamber base pressure was measured and an initial photoemission image recorded using the previously mentioned parameters. With the chamber base pressure monitoring enabled, gas was admitted into the chamber and the photocathode subjected to progressive degradation. Pairs of photoemission data and dark background images were taken, both with an exposure time of 30 seconds. During each degradation experiment at both room and cryogenic temperatures, the leak valve was adjusted to maintain a constant gas pressure. With knowledge of the initial base pressure, an absolute value was determined for the cumulative level of gas exposure experienced by the photocathode during the experiments, and the consequent evolution of the MTE was determined from the photoemission images.
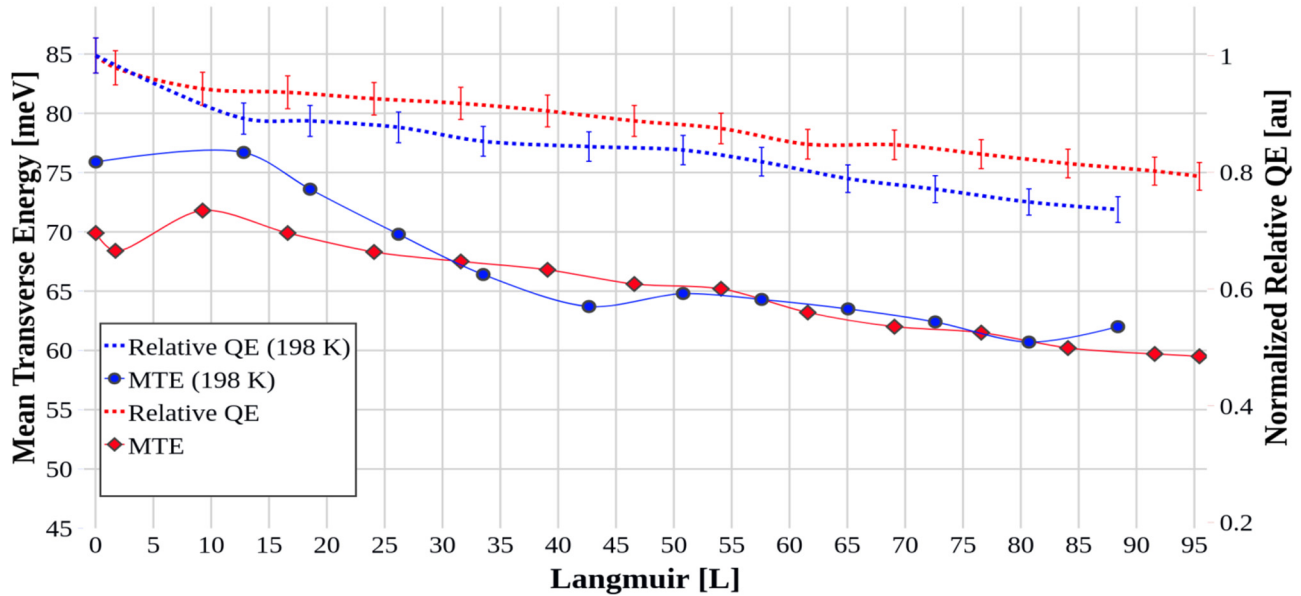
Figure 1: MTE measurements and normalized relative QE values for a Ag polycrystalline photocathode as a function of progressive oxygen exposure at 293 K and 178 K.
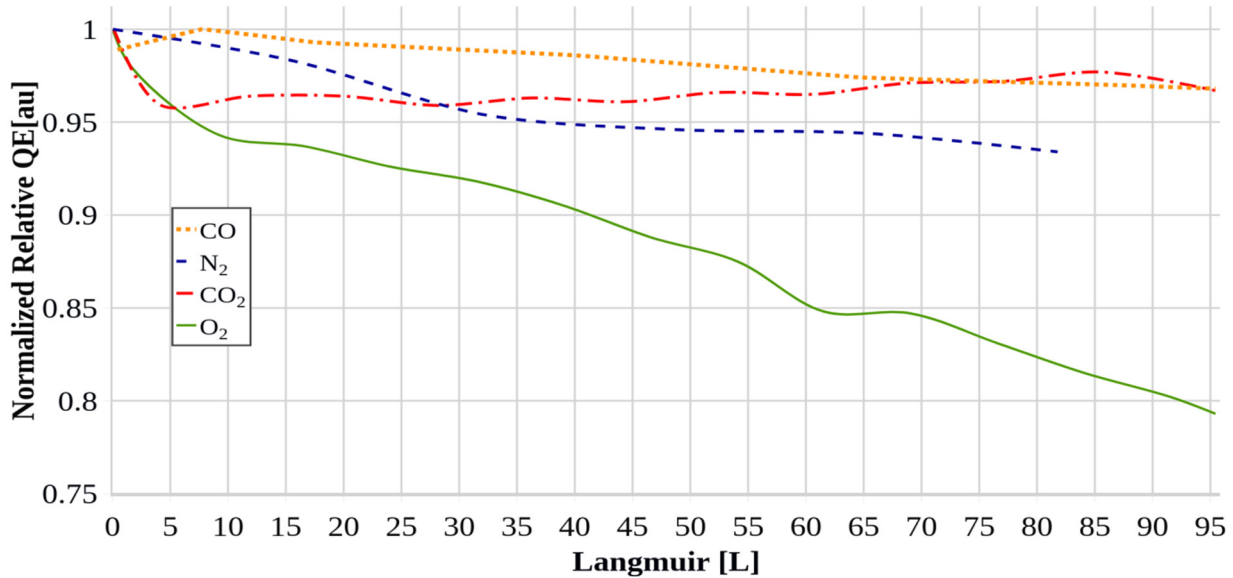

Figure 2: Normalized relative QE of a Ag polycrystalline photocathode at 293 K as a function of progressive exposure to multiple gases.

EXPERIMENTAL RESULTS

Figure 1 shows the MTE and the normalized image intensity for the Ag polycrystalline surface under illumination at 266 nm. The first set of measurements, shown in red, were taken at 293 K with the absolute pressure of the TESS chamber rising from a base pressure of 7.0×10^{-11} mbar to a maximum pressure of 7.0×10^{-9} mbar under oxygen exposure. The second set of measurements, shown in blue, were taken at 198 K with a base pressure of 4.0×10^{-11} mbar to a maximum pressure of 6.5×10^{-9} mbar. There is a slight difference in the gas

exposure rate between the two experimental runs, but ultimately the absolute gas exposure in Langmuirs is comparable.

The data presented shows that the estimated relative QE degrades faster under cryogenic conditions. All MTE data points have an associated experimental error of ± 10 % applied to them. This experimental error was determined by performing a long series of measurements at 266 nm to determine the detector response over multiple measurements of the same parameters, and an error of ± 3 % is ascribed to the total image intensity data points to account for fluctuations in the optical power. During both data sets

the leak valve was operated to provide a fixed leak rate of gas. We observed the total image intensity degrade at a faster rate during the experiment at 198 K than what is observed during the 293 K measurements due to the effect of cryopumping [14].

Figure 2 shows the effect on the calculated relative QE of a Ag polycrystalline photocathode subjected to progressive degradation by exposure to N2, O2, CO and CO2.

Following the same procedure as that outlined earlier for the data shown in Fig. 1, we estimate the total cumulative gas exposure in each experiment to be up to 95 L. Between each experiment, the cathode was moved back to the PPF for thermal and atomic hydrogen cleaning before commencing the next experiment, with the initial photoemission images used to confirm that the cathode was effectively restored to a consistent starting condition.

We can see clearly that the O2 exposure caused the largest degradation in the implied QE of the cathode, with the image intensity dropping quite significantly over the course of the experiment. Nitrogen gas appears to have the second largest effect on the Ag polycrystalline surface,

Figure 3 shows the effect of CO gas exposure of over 100 L on a Ag polycrystalline photocathode after it had undergone an O2 exposure of 95 L. Unlike Fig. 2 where the surface of the cathode degrades slightly over a long exposure to CO, the cathode with some level of oxidation appears to rejuvenate instead, implying the oxygen on the surface is interacting with the CO gas, changing the surface chemistry [15].

DISCUSSION

In the data presented in Fig. 1, we can see the affect that temperature has on the photocathode. It is well known that the work function of a metal has a linear relationship with temperature [16], this coupled with the cryo-pumping effect which has been inferred to increase the sticking coefficient of oxygen to the surface [14], leads us to conclude that degradation due to the adsorption of oxygen more readily occurs at cryogenic temperatures. In comparison to the Ag (100) single-crystal photocathode we investigated in previous work [10], the Ag polycrystalline photocathode required a much larger cumulative exposure to drive the same level of degradation. The reason for this is due polycrystalline samples favouring the (111) and higher-indexed crystallographic faces [17, 18], which have fewer open terminating positions than the other low-indexed (110) and (100) surfaces.

The results of the CO exposure experiment of an oxidized Ag polycrystalline photocathode, shown in Fig. 3, indicates a rejuvenation in QE over the course of the experiment. The mechanism behind this rejuvenation is due to oxygen adatoms [19], which lie on the crystal surface, that have been shown to adsorb between 1 molecule and 2 molecules of CO depending on surface conditions [15]. It is assumed that the CO-O configurations present on the surface affect the surface condition to the point where a noticeable increase in image intensity is

showing a slower degradation than O2. While this effect is significant, we have reason to believe that the gas exposure during this particular experiment was not pure nitrogen. Both CO and CO2 seemed to have very minor effects on the surface, with CO degrading the cathode slightly over the course of 95 L, and CO2 initially dropping the image intensity significantly over a shorter exposure of 5 L, before reaching a level maintained for the rest of the experiment.
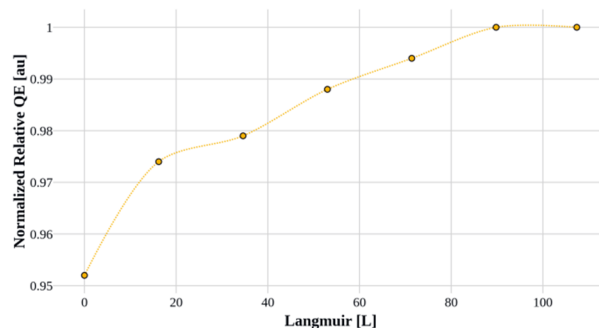

Figure 2: Normalized relative QE of an O2 degraded Ag polycrystalline cathode as a function of CO exposure.

seen, therefore showing a small increase in the relative QE. We believe this is the most likely case, as oxygen which adsorbs onto the surface of Ag (111) has been shown to be present in both its molecular and atomic forms at room temperature [20].

The order in which the experiments presented in Fig. 2 were carried out was with O_2 gas, then CO_2, CO and finally N_2. This order is significant, as the degradation seen in the N_2 experiment was not expected. We attribute this to two factors. The larger effect we believe is during gas bottle exchanges, as the gas regulator does see atmosphere. While a significant portion of this can be purged and pumped away there may still be trace amounts of residual water vapour in the line. Secondly, the N_2 gas bottle used, while extremely pure, does contain traces of O_2 (2ppm) and H_2O (3ppm). Any trace amounts of O_2 in the gas line from the previous experiment, the length of the experiment and the exchanging of gas bottles, may be enough to see an additional level of degradation beyond what is expected in the N_2 experiment.

CONCLUSION

The measurements we present show the effect that different gas species have on photocathode performance, even taking into account the points made in the discussion section, we see that O2 has the largest contribution to photocathode degradation in the range of gases that we have investigated. Our results show that the relative QE of a Ag polycrystalline photocathode falls by 20% in all of our room temperature measurements, and by 26% in our cryogenic measurement when the photocathode is subject to a O2 degradation of 95 L. The results seen here demonstrates that polycrystalline silver is a suitable photocathode candidate as the degradation levels are small, indicating that it may be more robust to common residual gases than the more routinely used metal photocathodes.

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