

MEASUREMENT OF LOW WORKFUNCTION CESIATED METALS FOR USE IN DISPENSER PHOTOCATHODES

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Abstract

Photoemission measurements of cesiated tungsten and silver are reported that support the theory and design of a custom *dispenser* photocathode. Most low-workfunction surfaces employ a delicate surface coating that enhances photoemission, but is vulnerable to contamination and is compromised with continued use. If this photosensitive layer could be periodically rejuvenated *in situ*, then the effective lifetime could be dramatically improved. A prototype dispenser cathode is presented, along with a simple method of determining its surface conditions. Lastly, the strong agreement between theory and experiment suggests that a model could eventually predict the efficiency and usefulness of more complex surfaces and coatings.

INTRODUCTION

Photoinjector performance is a limiting factor in the development of high powered FELs [1,2,3]. Presently available photocathodes have limited efficiency and short lifetime in an RF-gun environment, due to contamination or evaporation of a photosensitive surface layer.

An ideal photocathode should have high efficiency at visible wavelengths, long lifetime in practical vacuum environments, and prompt emission [4]. High efficiency cathodes typically have limited lifetime, and the needs of the photocathode are generally at odds with those of the drive laser [5]. A potential solution is the low work function dispenser cathode, where short lifetimes are overcome by periodic *in situ* regeneration that restores the photosensitive surface layer, analogous to methods used in the power tube industry [6]. The efficiency versus coverage behavior of cesiated metals is crucial to understanding the performance of a dispenser cathode and is largely the subject of this work. By refining a recent photoemission theory [7], the behavior of cathode substrates and surface coatings can be predicted and selectively chosen, based on the intended application. This is in contrast to the typical trial-and-error approach used to identify useful photocathode compounds and presents a significant advantage in developing high efficiency emitters.

A common figure of merit for photocathodes is quantum efficiency: the ratio of the number of photoemitted electrons to incident photons. It is related to photocurrent and optical intensity according to:

$$QE = \frac{\hbar\omega}{q} \left(\frac{J_e}{I_\lambda} \right) = 1.2398 \frac{J_e [A/cm^2]}{I_\lambda [W/cm^2] \lambda [\mu m]} \quad (1)$$

Another important characteristic, for metals, is the workfunction: the energy required to liberate an electron to vacuum. Because metals are reflective (in the visible) and have high workfunctions, they inherently have low quantum efficiency. An advantage, however, is prompt emission: because the optical penetration depth is shallow, photo-excited electrons have a very short distance to travel before reaching the vacuum barrier, and therefore a short delay in emission. Metals are also quite robust because they are not chemically reactive like semiconductors and for these reasons are still used in many photoinjector applications [4]. The low quantum efficiency requires both a high power and shorter wavelength drive laser, which is not feasible due to the non-linear frequency doubling involved.

Experimental Setup

Prior to developing the dispenser cathode, the photoemission properties (quantum efficiency vs. coverage) of cesiated metals were studied in order to validate and improve our predictive model [7]. Figure 1 depicts the UHV (<1 nanoTorr) vacuum chamber in which the cathodes were fabricated and measured.

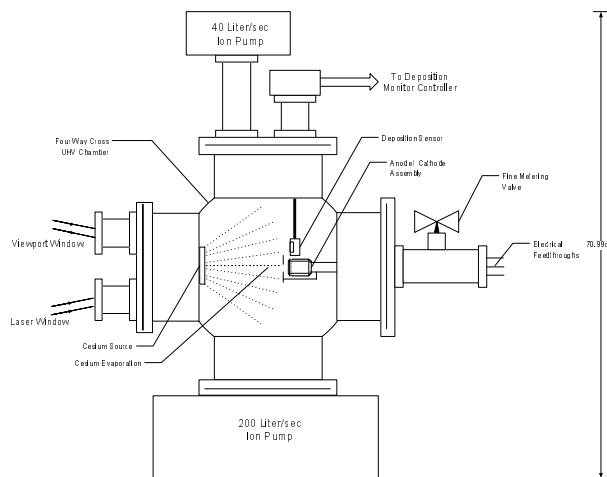


Figure 1: The UHV vacuum chamber.

Cesium is deposited onto the surface of a clean metal disk using SAES sources, while coverage is measured using an Inficon quartz crystal deposition monitor situated directly above the cathode. A circular anode biased at +170 volts is separated from the cathode by a distance of one centimeter. Photocurrent is measured across the anode-cathode gap using a Keithley 486 picoammeter, connected as shown in figure 2. The entire circuit is isolated from the chamber and all connections are made using Triax to minimize noise and interference.

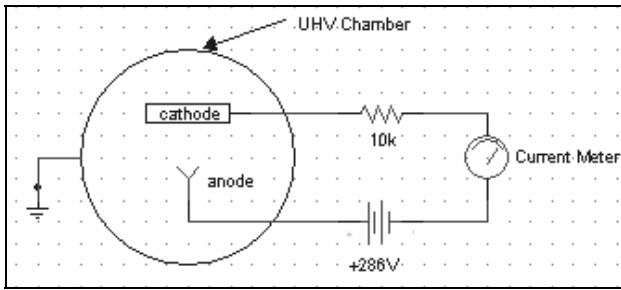


Figure 2: Photocurrent circuit.

One of four semiconductor CW lasers are shown onto the cathode while photocurrent, cesium coverage, laser intensity, background pressure, and cathode temperature are recorded using Labview.

The lasers have output powers of 5mW with 2% stability at 405nm, 532nm, 655, and 808nm. A Labview-controlled, motorized translation stage selectively positions a desired laser at the UHV chamber viewport, enabling QE measurements at multiple wavelengths during a single evaporation run. The laser spot is circular and expanded to a FWHM size of 1 cm using the optics shown in figure 3.



Figure 3: Solid state lasers.

Surface preparation of the cathode is crucial and argon discharge cleaning, combined with a high temperature anneal is used to remove adsorbed contaminants. Tungsten was heated to 1100°C [8], while silver was heated to only 600°C to avoid approaching its melting point of 962°C. If silver was heated to within two hundred degrees of its MP, it was observed that thin film coatings formed on the chamber viewports.

Because a DC potential is used to extract charge from the cathode, ion back-bombardment occurs, where positively charged contaminants within the chamber accelerate toward and collide into the cathode, damaging and/or removing the surface layer of cesium [9]. Minimizing contaminants *during* evaporation is difficult because the cesium sources (having been exposed to atmosphere) contain trapped gases and traces of impurities that are emitted along with cesium. This effect is minimized by first outgassing the cesium source in a controlled manner at temperatures beneath that required to emit cesium. This outgassing is done while both the chamber and cathode are held at elevated temperature to minimize adsorption of impurities.

Deposition Process (Coverage vs Time)

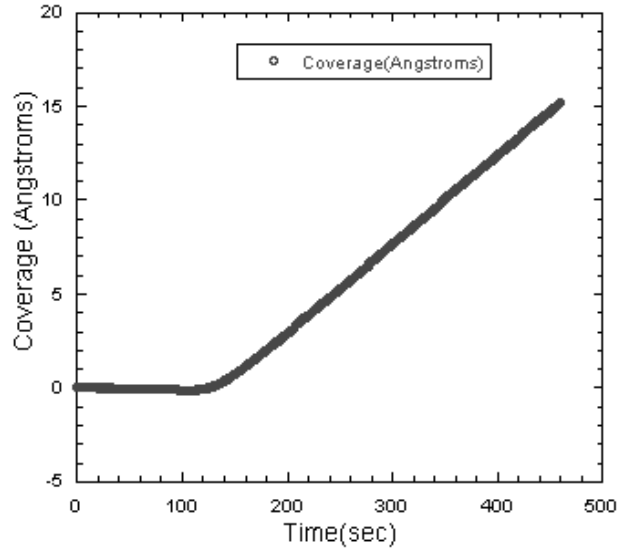


Figure 4: Cesium deposition vs time.

Figure 4 shows the evaporation process after outgassing has been completed. A current of 7.5 A is passed through the source and after a warm-up period, the cesium evaporation rate is constant for several hundred seconds.

EXPERIMENTAL RESULTS

QE Results for Cs-W

With proper surface preparation, a QE of about 0.03% was observed for cesiated tungsten with a 1/e lifetime of about 24 hours. A striking characteristic in measurements at all wavelengths is the peak in QE at approximately one monolayer coverage of cesium. A monolayer is defined as coverage such that the thickness is an atomic diameter. The covalent diameter of cesium is 5.2 Angstroms. Figures 5-7 show the QE vs. coverage behavior at 405 nm, 532 nm, and 655 nm, respectively. Photoemission at 808 nm (infrared) was observed, but because the photon energy was so close to the workfunction the response was small and noisy.

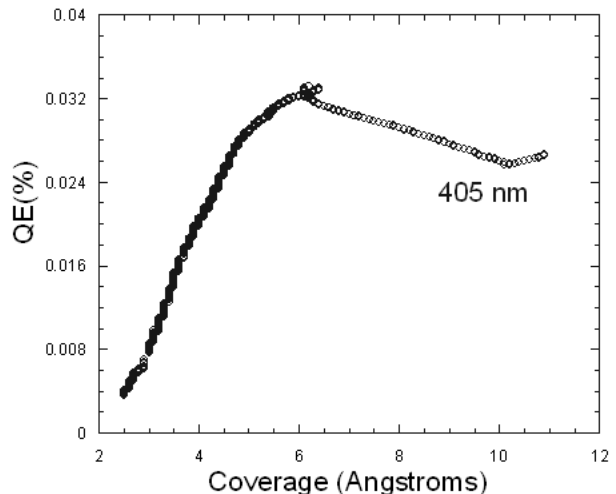


Figure 5: QE vs. coverage for 405 nm illumination..

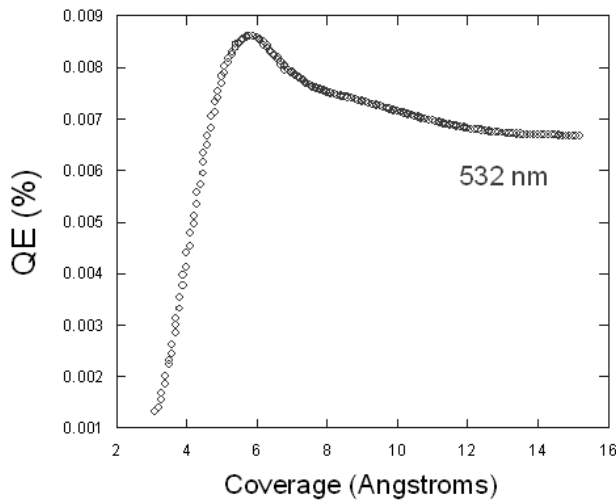


Figure 6: QE vs. coverage for 532 nm illumination.

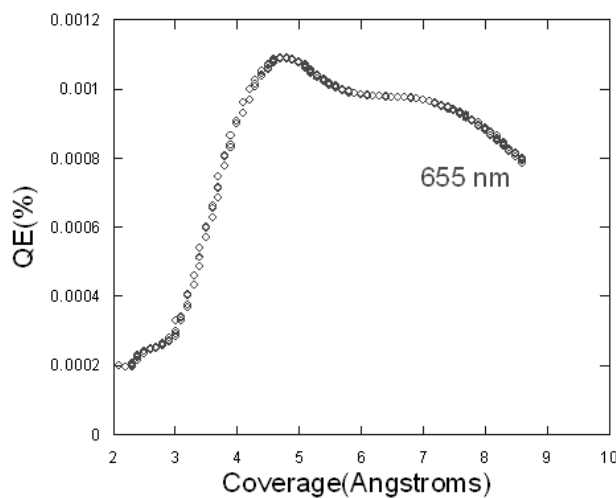


Figure 7: QE vs. coverage for 655 nm illumination.

Each of the above graphs corresponds to different deposition runs, and so the peaks in QE do not exactly coincide in terms of coverage because each began with slightly different initial conditions. Because the cesium source was being slowly depleted of its cesium supply from one deposition to the next, the deposition rate varied slightly each time. Also, an unknown amount of residual cesium is suspected to have remained on the surface from trial to trial.

It is important to consider the processes which remove cesium even while it is deposited. Because of ion bombardment, surface desorption is enhanced and some small amount of cesium evaporation naturally occurs. This means that cesium leaves the cathode surface during deposition, but this change does not register on the deposition monitor. The situation leads to a discrepancy between actual cesium coverage and that measured by the crystal balance. A convenient way to express coverage is in terms of % monolayer (θ), found by dividing the crystal balance reading by a characteristic length scale (α). This length depends upon the relative rate of desorption: for the 405nm case, cesium was deposited rapidly, so

desorption was minimal and $\alpha=0.52\text{nm}$, the covalent bond length of cesium. For 532nm and 655nm, the deposition occurred more slowly, lengthening the scale to $\alpha=0.80\text{nm}$.

The Cs-W data was compared to theory by shifting the peak along the coverage axis until it aligned with the workfunction minimum predicted by Gyftopolous-Levine [7] to occur at 63.537% monolayer coverage. Taking all this into account, the coverage is given by:

$$\theta(x) = \alpha(x_{\text{exp}} - x_{\text{max}}) + 63.537\% \quad (2)$$

The remarkable agreement with theory is shown in figure 8 with all 3 curves plotted on the same scale.

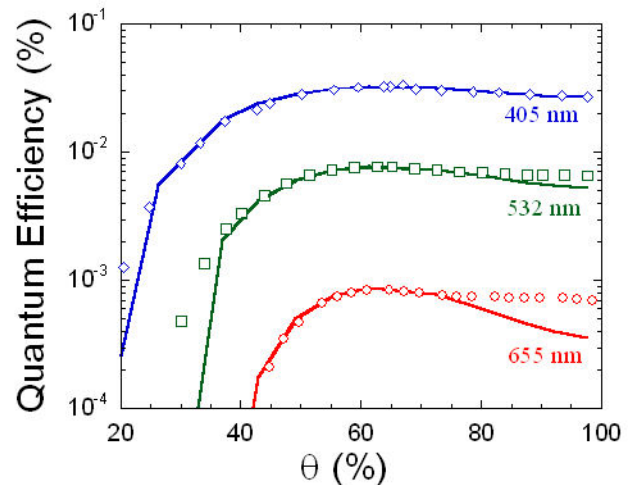


Figure 8: Cs-W comparison of experiment and theory.

While the study of Cs-W was an important step in validating theory, its QE is obviously too low to serve as a photoemitter in practical applications [10]. Photoexcited electrons in tungsten undergo a large amount of scattering with other electrons as they attempt to reach the surface barrier. After just one collision, their probability of reaching the surface with sufficient energy to escape is nearly zero [11]. Theory has predicted that other metals with lower electron scattering rates should have higher QE. For the case of cesiated silver, an order of magnitude increase in QE over that of Cs-W is predicted.

QE Results for Cs-Ag

Figure 9 shows that the measured QE of Cs-Ag is roughly 1/3 that of the predicted value. This is believed to be due to surface contamination of the silver prior to cesiation. Because silver has a lower melting point than tungsten, it cannot be heated (and cleaned) as thoroughly. The result is a "patchy" photoemission area, where localized regions with low workfunction are surrounded by areas of higher workfunction [11]. This assumption is supported by the fact that the addition of a layer of oxygen prior to cesiation does not increase QE. If the surface were indeed pure silver, then the presence of oxygen should increase the dipole moment, reduce workfunction, and increase QE.

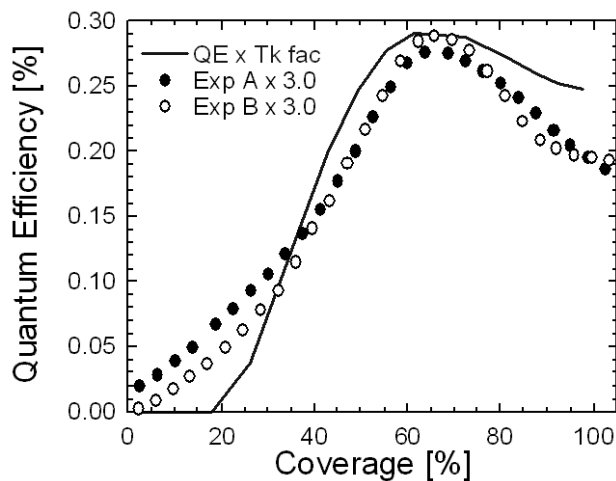


Figure 9: Cs-Ag comparison of experiment and theory.

If surface contaminants are already present, however, adding oxygen should only worsen the situation. Exposure to high purity nitrous oxide (5E-8 Torr for 4 minutes) caused QE to decrease by 0.02%. This suggests that surface impurities are present and are probably responsible for the factor of 3 difference between theory and experiment. The 1/e lifetime of cesiated silver is a remarkable 166 hours a large improvement over the 24 hour lifetime of Cs-W.

Prototype Dispenser Photocathode

The basic concept of the dispenser cathode is illustrated in figure 10: a cesium reservoir is situated beneath a sintered tungsten substrate, upon which a host of compounds could be deposited. Cesium plays its usual role of reducing workfunction, but as it leaves the surface over time, it could be replenished as cesium diffuses from beneath. Figure 11 shows the canister which contains titanium and cesium chromate powder (5:1) and is capped with a sintered tungsten disk having 40% porosity.

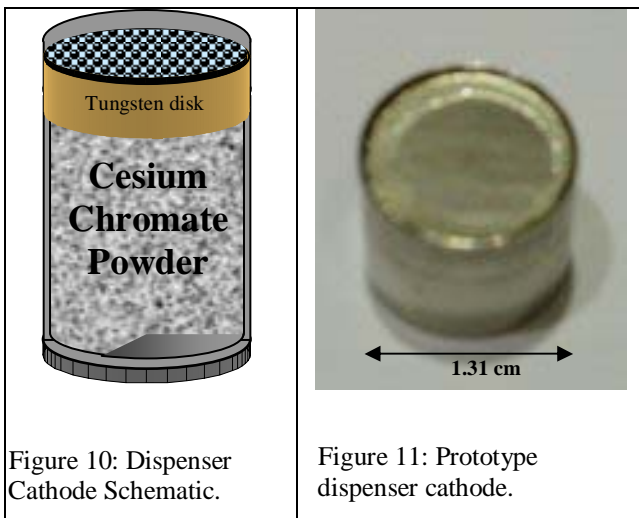


Figure 10: Dispenser Cathode Schematic.

Figure 11: Prototype dispenser cathode.

At about 600°C, the cesium chromate reacts with titanium to produce elemental cesium which begins to

diffuse to the surface. More work must be done to adjust the porosity to accommodate and/or limit the diffusion of cesium. If too much cesium arrives at the surface, it will simply evaporate (because cesium does not stick well to itself) and potentially contaminate the vacuum chamber.

CONCLUSIONS

Measurements of quantum efficiency vs. coverage agree well with theory, validating the theory's potential to predict the behavior of other (more complex) cathode compounds. Cesiumated silver exhibited a higher QE than Cs-W, although not as much as predicted. Surface contamination was shown to be present and most likely responsible for discrepancies. Cs-Ag has a long lifetime (166 hours) as a photoemitter with 0.1% QE in the visible. A prototype dispenser cathode was designed and fabricated to replenish cesium at the cathode surface. The controlled porosity cathode surface is made from sintered or drilled tungsten, onto which other materials can be deposited. The dispenser photocathode, therefore, presents a versatile method of extending the effective operational lifetime of cathodes requiring the presence of cesium.

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