EXPERIMENTAL PROGRESS TOWARD LOW WORKFUNCTION CONTROLLED POROSITY DISPENSER PHOTOCATHODES*

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Abstract

Photoinjectors for accelerator applications require long-lived photoemitters with high quantum yield in the visible range. Multi-alkali cesium-based photocathodes are frequently used but suffer from short lifetime, due to loss of cesium. A novel dispenser cathode is proposed and demonstrated that provides controlled delivery of cesium to the cathode surface at <200°C. This method allows for *in situ* rejuvenation of the photoemitting surface and could dramatically extend the effective lifetime of many alkali-based high-efficiency photocathodes.

INTRODUCTION

Laser-switched photoemitters are a source of electrons for high current applications such as free electron lasers [1],[2][3]. Photoinjector systems consist of a drive laser producing short bunches of photons and an efficient photocathode, which converts photon bunches into electron beam pulses [4]. Development of both technologies is required, but the scope of this project is restricted to improvement of the photocathode. Most high-efficiency photocathodes employ cesium-based surface coatings to reduce work function and enable efficient electron emission in the visible range. Lifetime is severely limited by the loss of this delicate coating, which degrades rapidly in practical vacuum environments. More robust photocathodes exist, but have much lower efficiency, and place unrealistic demands on drive laser power and stability. 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 J_e and optical intensity I_λ according to:

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

This research proposes a novel dispenser concept that dramatically extends the lifetime of high QE cesium-based cathodes by continuously or periodically restoring the cesium surface monolayer during an *in situ* rejuvenation process. A prototype dispenser cathode was fabricated and tested for two modes of operation: continuous and periodic near-room temperature rejuvenation. The data are compared with a photoemission model of partially covered surfaces under design for integration with existing beam simulations.

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Overall performance suggests that this cesium-delivery mechanism can significantly enhance the efficiency and operational lifetime of a wide variety of present and future cesium-based photocathodes.

Dispenser Concept

A dominant degradation mechanism for high QE cesium-based cathodes is the loss of cesium either from a surface monolayer or a stoichiometric compound. Replenishing this layer with cesium continuously or periodically could restore cathode performance. Our concept of a cesium based dispenser photocathode involves three essential elements: a cesium reservoir, a photoemitting surface, and an interface between the two that controls the rate of cesium arrival. In this design, shown schematically in Figure 1, a small stainless steel cylinder contains a pellet of cesium chromate and titanium powders. A disk of made from 70% dense sintered tungsten (top) serves as both the photoemitting surface and the interface boundary [5]. During an initial heating process, the pellet breaks apart and releases elemental cesium, which diffuses through and across the sintered tungsten substrate to create a low workfunction photoemitting surface. This simple cesium-on-tungsten photocathode was used to characterize the behavior of the dispenser, but more complex cathodes such as cesium antimonide could also be built on the substrate.

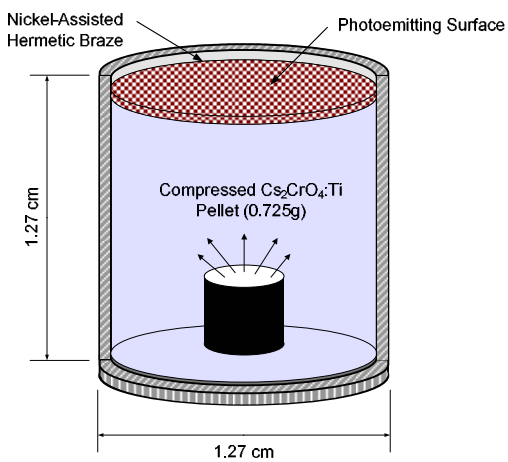

Figure 1: Schematic of Dispenser Cathode

Experimental Overview

In order to characterize the performance of the dispenser cathode, a detailed study of the photoemissive properties of cesium on tungsten was undertaken using the fabrication chamber shown in Figure 2.

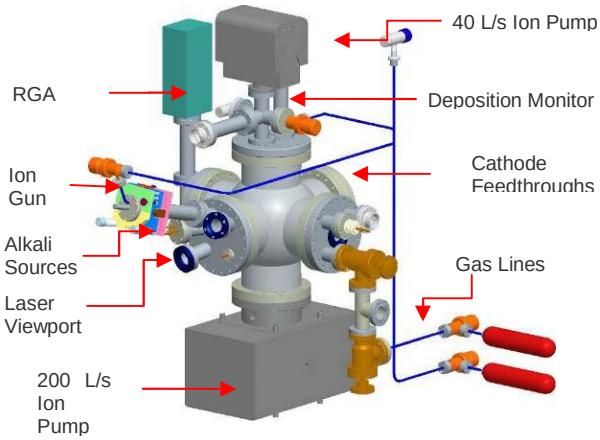

Figure 2: Vacuum Fabrication Chamber

Cesium was deposited externally using commercial sources onto a sintered tungsten disk identical to the one used to fabricate the dispenser cathode. QE was measured during deposition at several wavelengths as a function of cesium coverage, which was observed using a quartz crystal balance. Because cesium deposition occurred externally from an isotropic source, the resulting layer was assumed to be uniform. A characteristic curve was obtained whose shape and peak value depended upon the surface conditions of the cathode. Recall that for a dispenser cathode, cesium arrives at the surface through diffusion from within, so direct measurement of cesium coverage is not possible. Studying the effect of external, uniform deposition of cesium on tungsten, however, allows comparison of the dispenser's QE to that of a known system. This work is therefore divided in two parts: 1.) photoemission measurements of cesium on tungsten and 2.) characterization of the dispenser cathode.

Experimental Setup

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 +186 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. The entire circuit is isolated from the chamber and all connections are made using Triax to minimize noise and interference.

Five semiconductor CW lasers are sequentially 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 355nm, 405nm, 532nm, 655, and 808nm. A Labview-controlled, motorized translation stage selectively positions a desired laser at the UHV chamber viewport, enabling QE measurement at multiple wavelengths during a single evaporation run. The laser spot is circular and expanded to a FWHM size of 1 cm.

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 [6]. Minimizing contaminants *during* evaporation is difficult because both the dispenser cathode and 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 dispenser in a controlled manner at temperatures beneath that required to emit cesium.

EXPERIMENTAL RESULTS

Surface Metrology

The surface characteristics of sintered tungsten were studied in detail using optical, scanning electron, and focused ion beam microscopy. The porosity and thickness of the sintered disks used in the dispenser cathode were chosen such that extremes in either case were avoided. Figure 3 shows a side view of the sintered tungsten disk at 1000x magnification. Characteristic length scales of its polished surface were determined, including average pore diameter of 350nm, nearest-neighbor separation distance of 3.1μm, and average grain size of 4.8μm. The surface area each pore must coat with cesium was found on average to be 33.3μm^2 for uniform monolayer coverage. These lengths are significant because they estimate the surface diffusion length of cesium required to achieve complete coverage. Coverage uniformity is crucial because variation in the cesium surface coating causes similar variation in work function and electron emission.

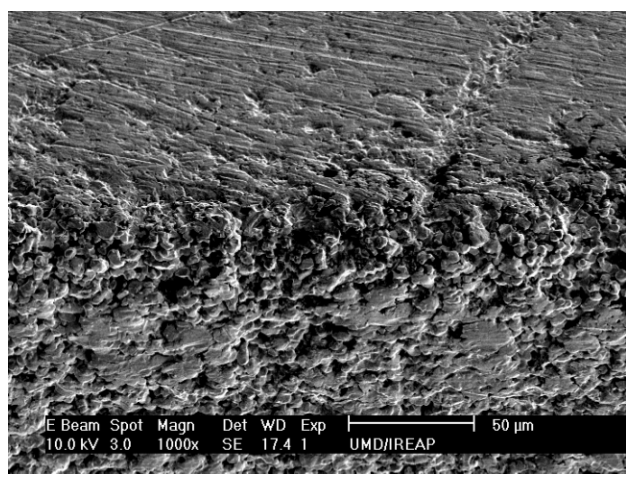

Figure 3: Side View of Dispenser Cathode

Cleaning Techniques

A standardized cleaning procedure using a 6.4keV ion argon beam was developed and shown to be remarkably effective in cleaning sintered tungsten. When cesium was deposited following the procedure, the effects of the treatment became apparent: a two-fold increase in QE with a peak QE of 0.11% in the UV, as shown in Figure 4.

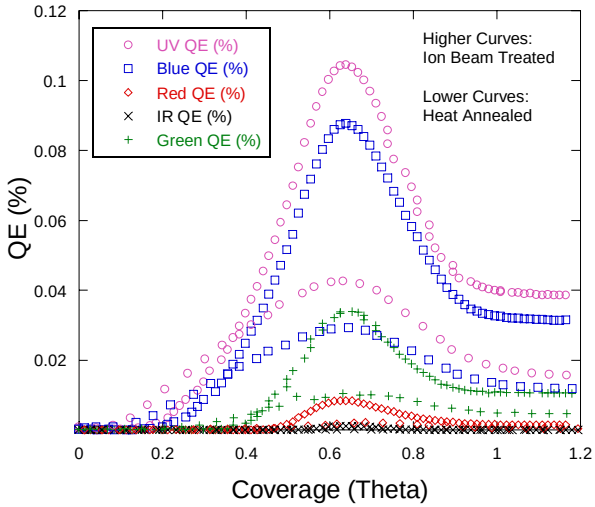

Figure 4: Effects of Ion Beam Cleaning

Coverage θ is reported in the above graph as a fraction of a monolayer, where $\theta = 0$ corresponds to bare tungsten and $\theta = 1$ is a full cesium monolayer. A single 45 minute treatment provided a 40mC dose of 6keV argon ions which was sufficient to produce apparent atomic cleanliness. This claim is justified because increasing the number of consecutive ion treatments and/or the energy of the ion beam did not produce further improvement in QE. Because cesium was deposited uniformly on an atomically clean surface, the QE of 0.11% can be said to be characteristic of a uniform, optimal cesium coating. This cleaning technique dramatically reduces the amount of time required to prepare a cathode for cesium deposition because it eliminates the need for a lengthy high temperature anneal.

Theory Comparison

The model used in this work is based upon the Fowler-DuBridge treatment of photoemission [6],[7] and follows the Gyftopolous-Levine approach of accounting for the effects of cesium coverage [9]. A distinguishing factor about the modified model is that an effort has been made to systematically reduce or eliminate unknowns, either by means of models or approximations, which were arbitrarily assigned or used as fit parameters in other treatments. The components of the model relevant to the experiments in this program are described in detail elsewhere [10]. Data describing the effect of surface cesium coverage on the work function and QE of metal photocathodes was compared to the model's predictions and found on average to be within 22% agreement, as shown in Figure 5. Similar agreement was found for cesium-on-silver and suggests that the theory is capable of predicting performance of metallic-based photocathodes. This experiment enables theory comparison for an important set of operation parameters: low drive laser intensity and low accelerating electric field. These parameters are typically much higher and are usually cited as reasons for drastic discrepancies between theory and experiment (e.g., laser heating, damage to cathode surface, etc.).

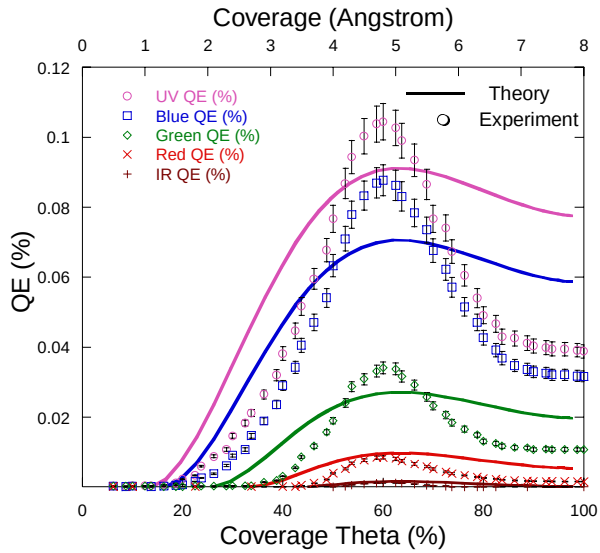

Figure 5: Comparison of Theory and Experiment

The inputs to the theory were simply generalized material parameters that could be widely applied to any number of different photocathodes.

Dispenser Cathode

The two basic procedures for operating the dispenser cathode are activation and rejuvenation. Activation occurs at higher temperatures and initiates a chemical reaction between the powders inside the cell, while rejuvenation occurs at much lower temperature and involves bringing atomic cesium to the surface in a controlled manner. Initial activation prepared the dispenser for use, as seen by the onset of photoemission at 425°C, followed by complete activation at 477°C, which produced a reduction in work function such that a large thermionic current was measured. Because of the elevated temperature, a significant amount of cesium was released throughout the chamber, producing up to a 50Å coating on an adjacent deposition monitor. This release is expected, however, and is not considered problematic because 1.) a large quantity of cesium remained within the dispenser following activation, and 2.) the activation procedure for a working dispenser cathode would most likely occur in a chamber separate from the actual electron gun (whose contamination with cesium would lead to field breakdown).

Following activation, the dispenser was allowed to cool and its 1/*e* lifetime was measured to be 5.2 days. After 65 hours of continuous operation, its QE decayed from its peak of 0.11% in UV to 0.06%. Complete rejuvenation was demonstrated when QE returned to its previous peak value of 0.11% upon heating to 140°C, as shown in Figure 6. Less than 3Å of cesium was deposited during this process, suggesting that *in situ* rehabilitation of the cathode is possible. Coverage at peak QE was indirectly measured to be about 64% using the relationship between cesium coverage and QE.

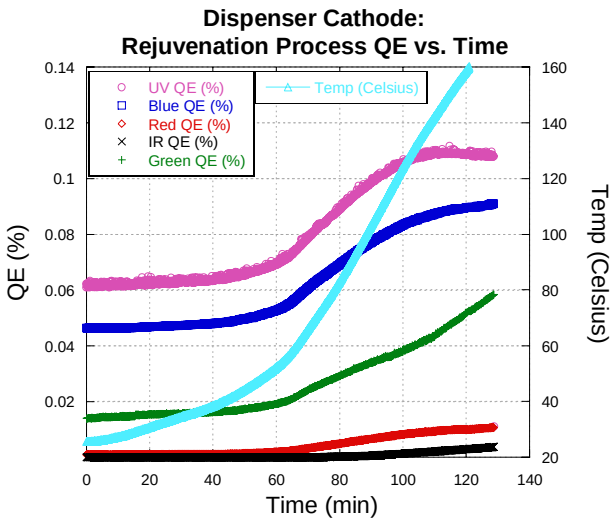

Figure 6: Rejuvenation of Cathode Surface

Two modes of cathode operation were demonstrated: periodic and continuous rejuvenation. For the continuous mode, temperature is held between 160-180°C, resulting in constant replenishment of the cesium layer. The 1/*e* effective (continuous duty cycle) lifetime in this mode was an astounding 47 days.

CONCLUSIONS

A prototype design for a near-room temperature dispenser cathode was proposed and demonstrated for the case of cesium-on-tungsten using commonly available components: thin-walled stainless steel and porous sintered tungsten. It is distinguished from other dispenser-type cathodes [11] by its low operating temperature, which makes it a good candidate technology where cathode thermal management is a concern. A method for conveniently integrating cesium chromate into the dispenser cell was demonstrated by forming the powder into a solid pellet under high pressure. The peak QE of the activated dispenser cathode, following an ion beam cleaning treatment, was 0.11%. This QE value was shown to correspond to that of a uniform, optimal cesium coating and suggests that the sintered tungsten interface facilitates uniform cesium coverage. This result suggests that the surface diffusion length of cesium across tungsten at temperatures ranging from 200-400°C is at least 5μm. The overall performance of the dispenser cathode suggests that its design could serve as a temperature-controlled cesium dispensing platform onto which a variety of high QE cesium-based photocathodes could be built.

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