Robust, Long-life Photocathodes

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Abstract—**Calabazas Creek Research, Inc. and the University of Maryland are developing high quantum efficiency (QE) reservoir cathodes for accelerators, free-electron lasers, ultra-fast electron microscopes and other applications. High QE materials are deposited on an emitter allowing diffusion of cesium from a reservoir. An integral heater provides a continuous flow of cesium to replace that lost by evaporation, thereby extending the lifetime of the cathode. Experiments demonstrated these cathodes can recover from poisoning events, including atmospheric contamination for some cathodes. A facility is nearing completion to fabricate the cathodes, including equipment for vacuum transport to user facilities.**

I. INTRODUCTION

Advanced accelerators and light sources use photoinjectors to produce the high quality electron bunches for acceleration and conversion to RF and light energy. The principal photoinjector component is the cathode, which must efficiently produce electron bunches using the photoelectric effect when triggered by an incident drive laser pulse. Calabazas Creek Research, Inc. (CCR) and the University of Maryland (UMD) are developing advanced photocathodes capable of high quantum efficiency (QE) and long life. The goal is a simpler, more cost effective and reliable photoinjector for commercial and scientific applications.

Photocathodes consisting of evaporatively deposited alkali antimonides provide quantum efficiencies exceeding 5% for green light; however, lifetimes are typically a few days with extremely good vacuum. Cesium telluride photocathodes provide similar efficiencies with longer lifetime, but they require a more expensive, shorter wavelength laser. Robustness is also an issue, as these materials are easily poisoned by small levels of gas contamination.

CCR and UMD are developing photocathodes by integrating two technologies: controlled porosity reservoir (CPR) dispenser photocathodes for extended lifetime, and selected surface coatings for enhanced QE with good robustness [1]. CCR developed advanced material for controlled porosity tungsten structures and successfully implemented it into thermionic cathodes for microwave and millimeter-wave RF sources. The engineered, porous tungsten material allows precise, uniform dispensation of work function enhancing material over the emitting surface. UMD demonstrated that photocathode lifetime could be extended by gently heating a sub-surface reservoir of cesium with a diffusion barrier, allowing cesium migration to the photoemissive surface. The controlled resupply of cesium rejuvenates the QE [2] by replenishing that lost by evaporation, back-bombardment, or contamination. UMD demonstrated that CPR tungsten photocathodes provide approximately 0.1% quantum efficiency with an extrapolated lifetime exceeding 30,000 hours. This represents the state-of-the-art in this efficiency class, with lifetime well beyond LaB_6 and Ba cathodes. CCR and UMD are extending the research to cesium antimonide (Cs_3Sb), cesium potassium antimonide (CsK_2Sb), and cesium auride (CsAu) photocathodes.

UMD is focused on the detailed physics of photoemission with the goal of identifying materials and operational procedures to improve efficiency and lifetime. CCR is optimizing cathode mechanical design and building a facility for photocathode fabrication. CCR is also developing a vacuum suitcase for transport to user facilities. A major task of the program will be high power testing of a photocathode at SLAC National Accelerator Laboratory.

II. DISPENSER PHOTOCATHODE PHYSICS

The University of Maryland is advancing photocathode physics with the goal of improving performance and reliability. The program is focusing on cesium antimonide and cesium auride photocathodes. The antimonides provide high quantum efficiencies; however, they are very susceptible to contamination. Cesium auride is air stable prior to activation, which provides a significant simplification for devices that can operate with lower QE.

Figure 1. Photograph of cesiated tungsten, reservoir photocathode

UMD is installing advanced diagnostic equipment, including:

- Auger spectrometer for elemental analysis of stoichiometeric composition,
- Polarization-dependent analysis to investigate different polarization states,
- Linear shifter and quartz crystal microbalance to study angular emission distribution.

Reservoir photocathodes are fabricated by depositing photoemissive materials on a porous tungsten surface. The precise composition and structure of the photoemissive film will impact the cathode's performance, so UMD scientists will be investigating the physics of these films, specifically to understand the impact on emission. Factors they will investigate include:

- surface emission energy barriers,
- band scattering structure,
- scattering mechanisms,
- optical absorption profile,
- electron escape depth, and
- optical reflectance.

UMD will investigate parameters affecting cathode lifetime and QE, including

- Film thickness
- Cesiation impact on:
    QE,
    surface elemental composition,
    Polarization dependence of QE,
- Depth profile of elemental composition,
- Behavior following rejuvenation,
- Angular emission distribution of evaporated cesium.

The research at UMD will advance fundamental physics of photocathode emission, particularly as it applies to photo emissive films on tungsten, reservoir structures.

III. PHOTOCATHODE MECHANICAL DESIGN

Reservoir photocathodes consist of an emissive surface supplied with cesium from a heated reservoir of cesium chromate. The diffused cesium replaces that lost by evaporation, thereby significantly increasing lifetime. The mechanical design controls the diffusion rate and uniformly distributes cesium over the emission surface. Figure 1 shows a photograph of a cathode, and Figure 2 shows a schematic. The cesium reservoir is contained in a stainless steel cylinder sealed at one end by a heater and the other by a porous tungsten cap. The heater drives cesium diffusion through the porous cap into a mixing region, which also serves as a thermal barrier. The cesium gas diffuses through another porous disk fabricated from sintered tungsten wires.

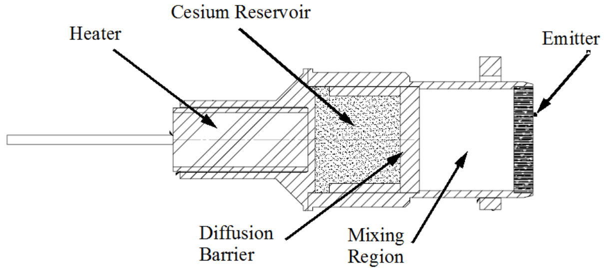

Figure 2. Mechanical design of reservoir photocathode

The mechanical design must address two critical issues for photoinjectors. Emittance will impact the performance of the electron beam device, and the surface must adequately support the high RF fields encountered in RF guns. For this project the goal is to operate the photocathode with RF fields exceeding 80 MV/m. These issues are being addressed by improving the surface finish of the emission surface. The program is investigating electro-polishing, lapping, and diamond turning. Recent results from diamond turning demonstrated significant improvement, and these results will be reported.

IV. PHOTOCATHODE FABRICATION

The photocathode outer shell is machined from stainless steel, and the porous tungsten cap over the reservoir is similar to those used in thermionic dispenser cathodes. The unique structure is the sintered wire cap forming the emissive surface, which was a recent development funded by the U.S. Department of Energy [1].

The high QE emissive film is applied in a high vacuum environment and carefully monitored. The CCR production facility is shown in Figure 3.

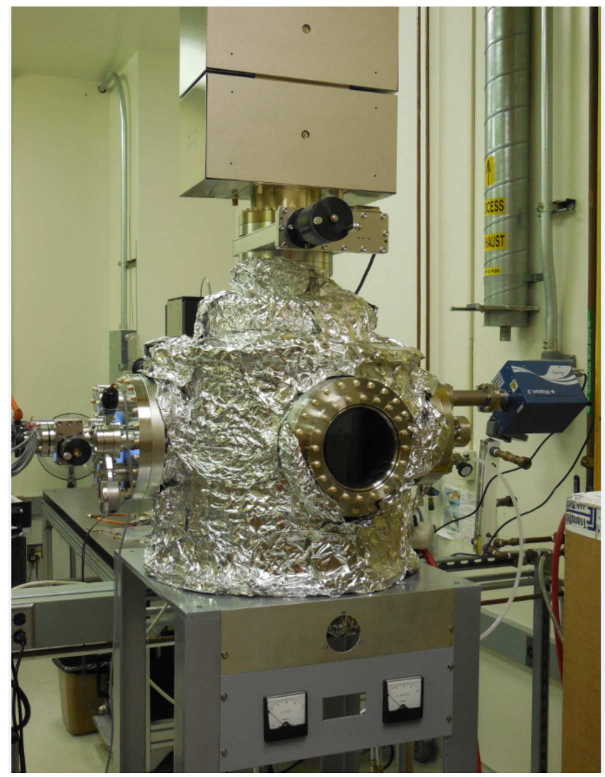

Figure 3. Photocathdode fabrication facilitiy

Once applied the emissive coating must be protected from exposure to atmosphere and contaminating gases. This requires transport in a vacuum suitcase from the coating chamber to the photoinjector. Figure 4 shows a photograph of the CCR suitcase.

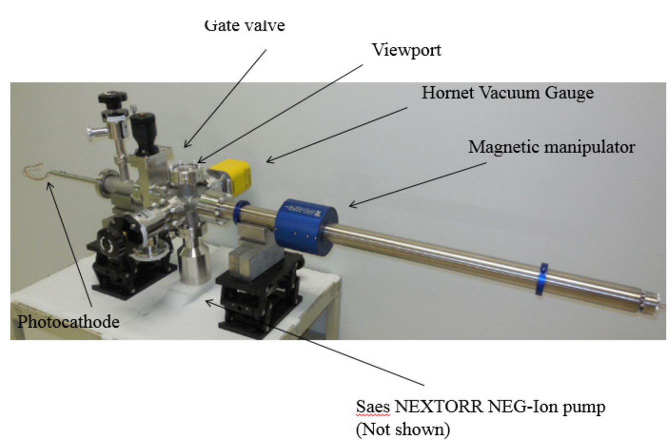

Figure 4. Vacuum suitcase

New photocathodes are mounted to a manipulator arm in the suitcase, which is then mounted to the coating chamber. The suitcase is evacuated, and the cathode positioned in the chamber. The cesium reservoir is heated to initiate diffusion while an evaporative source begins coating the surface. Initially, this will be antimony or potassium and antimony. A laser initiates a photoemissive current which is monitored by an anode disk. The coating is applied until a maximum current value is achieved, at which time the process is terminated. A quartz microbalance provides reference information on the coating thickness.

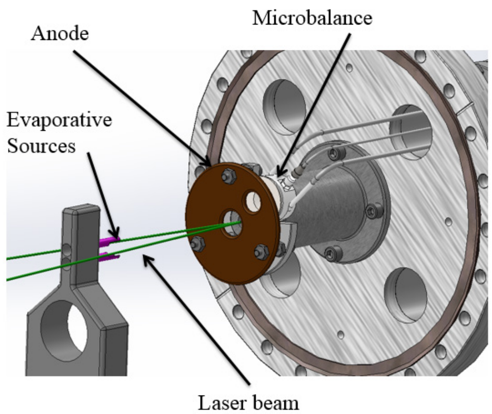

Figure 5. Configuration of applying thin film emissive coating

Following coating, the photocathode is retracted into the suitcase, gate valves closed, and the suitcase removed from the chamber. The suitcase includes a getter-ion pump to maintain vacuum during transport.

III. RESULTS AND GOALS

This research began with cesiated tungsten (CsW) photocathodes to develop the basic reservoir cathode technology. The program successfully increased the lifetime of CsW photocathodes from a few hundred hours to more than 30,000 hours, as illustrated in Figure 6. This was extended to M-type photocathodes by applying an osmium-ruthenium coating on the tungsten. The stars in Figure 6 indicate program achievements to date.

The goals now include increasing lifetime for Cs_2Sb and K_2CsSb photocathodes and increasing both QE and lifetime for CsAu photocathodes, also as indicated in Figure 6. These cathodes will begin with the same reservoir structure shown in Figure 2 with the appropriate coating applied using the facility shown in Figure 3. Coating facilities are being established at both UMD and CCR with the facilities at CCR designed for commercial production, while UMD will focus on photocathode physics research. The CCR facility and transport capability will be tested by shipping photocathodes from CCR's facility in Palo Alto, CA to UMD in College Park, MD, where the performance will be evaluated.

III. HIGH POWER TESTING

Following verification of the fabrication and coating facilities, a photocathode will be tested using an RF gun at SLAC National Accelerator Laboratory. Since the existing gun uses a simple copper plate, CCR will design a new cathode assembly to accommodate the vacuum suitcase and provide cavity tuning. To function in the RF gun, the photocathode surface must support at least 80 MV/m RF field gradients at the emission surface. This is the minimum field that will extract electron bunches from the cavity at the 1.3 GHz operating frequency.

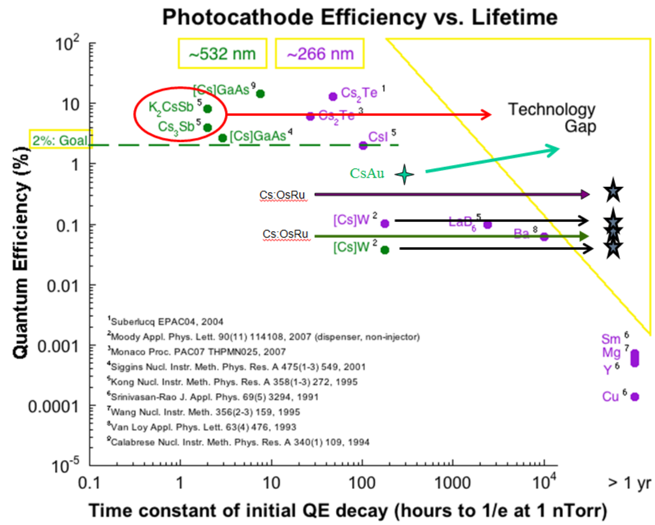

Figure 6. QE versus lifetime for photocathode materials. The stars represent achievements to date, and the red and green arrows indicate goals for the current program.

III. SUMMARY

Calabazas Creek Research, Inc. and the University of Maryland are significantly improving the performance of photoinjectors by developing photocathodes capable of both long life and high quantum efficiency. The research increased the lifetime of cesiated tungsten cathodes by more than two orders of magnitude. The program is now focused on higher QE materials, including cesium antimonide, potassium cesium antimonide, and cesium auride.

The University is installing advanced diagnostic equipment to increase understanding of photo emission as it related to thin films on reservoir cathode structures. CCR is developing a production facility to fabricate these improved photocathodes for the user community. Cathode performance will be evaluated using the analytical facilities at the University and by high power RF testing at SLAC National Accelerator Laboratory.

III. ACKNOWLEDGEMENT

This research is funded by U.S. Department of Energy Small Business Innovation Research contract DE-SC0006212.

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