ALKALI-ANTIMONIDE PHOTOCATHODE TRANSPORT IN A VACUUM-SEALED CANISTER

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Abstract

The high Quantum Efficiency (QE) and low Mean Transverse Energy (MTE) of alkali antimonide photocathodes enable the production of bright electron beams for a variety of accelerator applications. Growing alkali antimonide photocathodes requires a complex growth chamber and an operator with considerable expertise. Despite widespread use, their sensitivity to chemical poisoning which requires storage in an ultra-high vacuum environment, has posed a significant challenge to their commercialization. As a step towards commercialization, we developed a “cathode-in-a-can” system to enable delivery of air sensitive photocathodes across facilities. This system allows for an alkali-antimonide photocathode to be grown at one facility and shipped in a compact vacuum-sealed canister to another facility, where it can be removed from the canister under vacuum to preserve the cathode’s excellent photo-emitter qualities.

INTRODUCTION

Since their discovery in the 1950s [1] alkali and bialkali antimonide photo-emitting materials, such as Cs_3Sb, Na_2KSb and K_2CsSb, have found a variety of applications in photomultiplier tubes, streak cameras, image intensifiers and night vision goggles [2, 3]. As the electron source of a photoinjector they have been used extensively. Owing to their Positive Electron Affinity (PEA), alkali-antimonide photocathodes posses a small band-gap that yields a high quantum efficiency (QE) on the order of 10% with visible light photons and so, are commonly used in high beam current applications [4, 5]. An alkali-antimonide photocathode was used to set the world record in high average current from a photoinjector [6]. Moreover, for high brightness applications such as Ultrafast Electron Diffraction (UED) [7] alkali-antimonides are used because of their low Mean Transverse Energy (MTE) [8]. At photo-emission threshold, alkali antimonides are still relatively efficient compared to metal cathodes which allows for the production of very low MTE beams [9]. Although more sensitive to vacuum conditions than metal cathodes, a bialkali photocathode is robust enough to operate in an SRF photoinjector with a lifetime on the order of months [10].

Unfortunately these photocathodes are extremely susceptible to chemical poisoning and vacuum contamination. Their growth, characterization and use must take place in an ultra-high vacuum (UHV) environment. An exposure of only 10L of oxygen can reduce the photocathode’s QE to below a usable level [11, 12]. All accelerator facilities that utilize these photocathodes must grow them in a dedicated UHV growth chamber and transfer them into their beamlines under UHV. This requires significant cost, in both time and money. Commercially-available alkali antimonides photocathodes would simplify the process of using them in high-brightness and high-current accelerator applications.

As an important first step towards demonstrating the viability of commercially available alkali antimonide photocathodes, a “cathode-in-a-can” system has been developed: A photocathode is grown in a UHV growth chamber and sealed in a vacuum tight canister by the supplier. The sealed canister is then removed from vacuum and shipped to the user. The user then inserts the canister into their vacuum system and unseals the canister. The photocathode is then ready to be extracted from the canister and used for high-brightness applications. As a demonstration of the concept, an alkali antimonide photocathode will be grown and sealed at Radiation Monitoring Devices (RMD) in Watertown, MA and shipped 350 miles to Cornell University in Ithaca, NY. Once at Cornell the canister will be placed inside a specially equipped vacuum chamber that allows for the canister to be desealed and characterized to verify the cathode’s preservation in transport.

PHOTOCATHODE GROWTH, CANNING AND OPENING

The photocathode is to be grown on a ”hybrid puck,” which is a shell in the style of the Cornell/BNL puck that contains inside of it an INFN/DESY/LBNL/SLAC style mini-plug. The design is shown in Fig. 1. With this scheme, the canned cathode may, in principle, be used in photoinjectors requiring either cathode style. The sealed can encloses the hybrid puck, as shown in Fig. 1. The top and bottom plates on the canister are sealed with an indium alloy, and the back of the canister is fitted with a bayonet holder, so that it may be manipulated with a UHV transfer arm.

The photocathode growth and packaging system (PcGPS) has been completed and preparations are underway to relocate it to RMD’s facility in Watertown, MA. The system serves a dual purpose, the first being to synthesize alkali

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Figure 1: The hybrid puck with shell adapter and the miniplug are shown in *a-b)* . The adapter geometry is based on the Cornell/BNL model. The miniplug is held in place using two ball plunger screws engaging in a special groove on the miniplug. Once the puck is canned, the backplate (*c*) with springs will be slotted into the back of the photocathode puck, as shown in *d)*, and lowered into the sealable canister. *e)* The view inside the vacuum canister shows the tantalum NEG strips. *f-g)* Photos of a closed can, where the viewport on the bottom used for QE characterization is visible.

photocathodes with in situ characterization, and second, to package them in the vacuum-sealed canister. The system is comprised of three chambers (Fig. 2). The photocathode growth is performed in the process chamber (Fig. 2a) which houses the material sources as well as a quartz crystal microbalance to monitor material deposition thickness during a growth. The second chamber, called the exchange chamber (Fig. 2b), consist of a long transfer bellows and allows for the transfer between the process chamber (Fig. 2a) and the packaging chamber (Fig. 2c), where the cathode is sealed in the canister. The viewports allow for a laser to be incident on the cathode surface generating a photocurrent which enables in situ QE characterization of the cathodes both during and after growth.

After the photocathode is grown it is transferred to the packaging chamber (Fig. 2c) by a magnetic transfer arm. An additional magnetic transfer arm on top of the chamber holds the canister's backplate. The backplate has springs that slot into the back of the photocathode puck locking it in place (Fig. 1c-d). It can then be lowered into the bottom portion of the packaging chamber that houses the body of the canister. Once the lid and body are mated, the canister is sealed shut by flowing a current through the tantalum strips inside the canister (Fig. 1e).

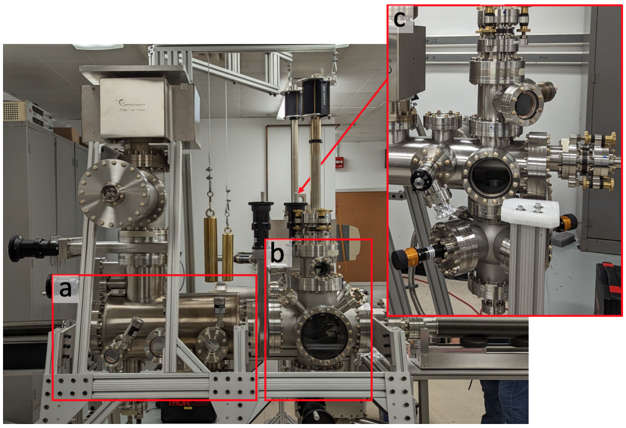

Figure 2: The photocathode growth and packaging system *a)* the process chamber where the cathode growth is preformed, *b)* exchange chamber and *c)* inset photo of the packaging chamber.

The tantalum strips serve a dual purpose: first when a voltage is applied across them, they behave as resistive heaters, melting the indium in the moat above, sealing the canister shut. The second purpose is after the tantalum strips have been heated they become ”activated” such that the metallic surface acts as a non-evaporative getter, absorbing residual gas molecules and helping to maintain UHV conditions inside the canister. Once sealed, the canister can be removed from the packaging chamber and transported to the end user. Lastly, the canister contains a glass window (Fig. 1g) on the bottom that can be used to verify that the cathode inside is maintaining its high QE and does not degrade when stored. For the initial QE verification test, the sealed cathode will be mailed to Cornell University.

Once the canned photocathode has been received by the Cornell group, it will be inserted into the UHV can-opening system, which was recently assembled. The canister will be put into a fast load lock (Fig. 3a), where the bayonet holder on the back of the canister will be attached to a transfer arm. After pumping down, the canister will be moved inside the can-opening chamber (Fig. 3b).

The canister is then unsealed by applying high voltage across the tantalum strips inducing enough resistive heating to remelt the indium foil. The back plate and hybrid puck are separated from the outer shell (Fig. 1d) and moved to a second holder. In this holder the back plate and hybrid puck are separated. At this point, the hybrid puck is held alone in the holder. A third magnetic transfer arm is used to grab and separate the INFN/DESY/LBNL/SLAC miniplug from the hybrid puck. With this, the miniplug is removed and brought into the QE chamber (Fig. 3c) which contains

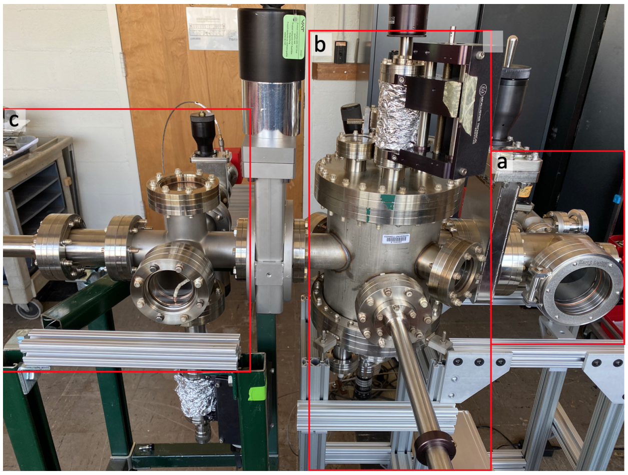

Figure 3: Photo of the photocathode opening system *a)* the fast load lock where the sealed can is inserted into vacuum. *b)* The can-opening chamber where the canister is unsealed and the miniplug is extracted. *c)* The QE chamber where the miniplug is mounted and the QE is measured.

an electrically-isolated, bias-able miniplug holder where the cathodes QE will be measured to verify the success of the cathode transport scheme. The entire process is reversible such that the entire canister assembly can be re-assembled and transported back in the load lock for retrieval.

OUTLOOK AND CONCLUSION

As a step towards commercialization of high quality alkali antimonide photocathodes, a cathode-in-a-can system has been designed and constructed. The first cathode growth is planned for Fall 2023, with transport and QE preservation testing to happen shortly after.

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