PREPARATION AND RESEARCH OF CSBR-COATED CS3SB PHOTOCATHODES

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Abstract

Abstract Cs_3Sb photocathodes are promising electron sources for accelerators because of their high quantum efficiency (QE) under visible light, but the low robustness under low vacuum limits practical operation. In this work, Cs_3Sb photocathodes coated with CsBr were prepared and characterized. The experimental results indicate that the coating improved the pressure adaptability of the photocathodes by approximately two orders of magnitude, although it inevitably reduced the initial QE. After exposure, the QE of the coated photocathode can be recovered by annealing to its original value.

INTRODUCTION

Advanced accelerator facilities such as free electron lasers (FELs) and energy recovery linacs (ERLs) require high brightness electron beams and therefore impose stringent requirements on photocathodes with respect to quantum efficiency (QE), intrinsic emittance, visible light operation, and operational stability [1,2]. Semiconductor alkali antimonide photocathodes are attractive because of their high QE together with low intrinsic emittance under visible light [1,3]. Among them, Cs_3Sb is a promising candidate for accelerator electron sources [4,5].

However, Cs_3Sb photocathodes are chemically reactive and highly sensitive to residual gases, which can lead to rapid QE degradation and limited 1/e lifetime. Coating photocathodes with thin protective films has been considered a promising route to improve their robustness. Among the candidate materials, CsBr is a representative material for protective films on alkali antimonide photocathodes [6–8]. Such protective films can improve the robustness, but usually unavoidably leading to the QE loss associated with electron transport through the interface and in the coating film [7,8]. In the present work, a CsBr film was deposited on Cs_3Sb photocathode, and the coated photocathodes were evaluated by vacuum adaptability tests and post annealing experiments. Particular attention was paid to the vacuum pressure at which rapid QE degradation began and to the recovery of QE by annealing after exposure.

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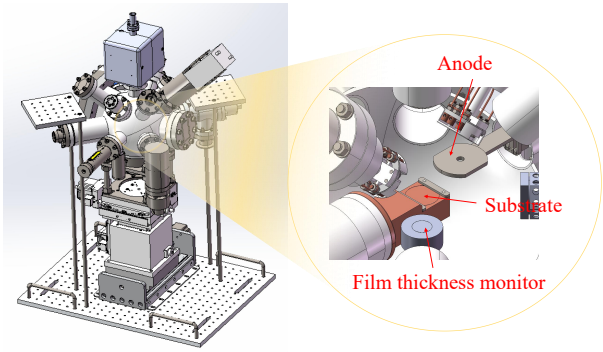

Figure 1: Schematic of the ultra-high-vacuum photocathode preparation apparatus.

EXPERIMENTS

Experimental Setup and Preparations

A dedicated ultra-high-vacuum (UHV) in-situ characterization and preparation equipment, as shown in Fig. 1, was used in this work. At room temperature, the vacuum pressure of the chamber can be maintained at approximately 1×10^{-8} Pa. Two evaporator source holders are mounted, and each holder can equipped with three types of evaporation sources-Cs, Sb and CsBr. A quartz crystal microbalance (QCM) is installed besides the substrate for in situ monitoring of deposition rate. Substrate temperature is monitored by a thermocouple mounted in the substrate holder. The anode is placed above the substrate for photocurrent collection.

Before assembly to the equipment, the Mo substrates were cleaned in ethanol in ultrasonic bath. Prior to photocathode preparation, the Mo substrate was degassed at 500 °C for 6 h, and the chamber was pumped down to 1×10^{-8} Pa.

Following the substrate preparation, Cs_3Sb photocathodes were prepared on Mo substrates by sequential deposition of Sb and Cs layers in a manner similar to the yo-yo process [9]. During the deposition, the pressure was kept below 1×10^{-7} Pa to minimize the interference of rest gases. The growth was started by depositing an initial thin 1 nm Sb layer on the substrate at substrate temperature of 75 °C. Then Cs layer was deposited, while the QE was monitored using a laser at 405 nm. While Sb and Cs deposition were repeated several times for best QE, in most cases, the peak QE (~3%) was already achieved after the first round, as presented in Fig. 2.

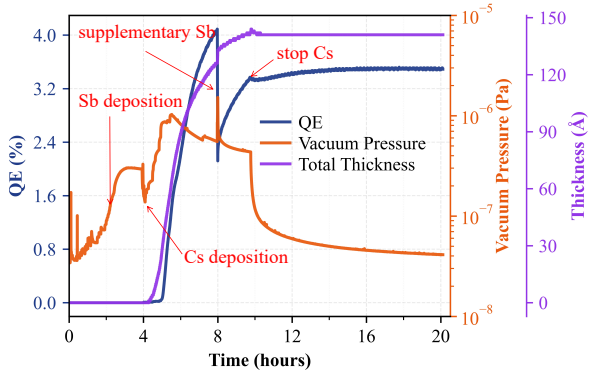

Figure 2: Representative time evolution of QE at 405 nm, chamber pressure, and cumulative deposited thickness during Cs_3Sb photocathode growth.

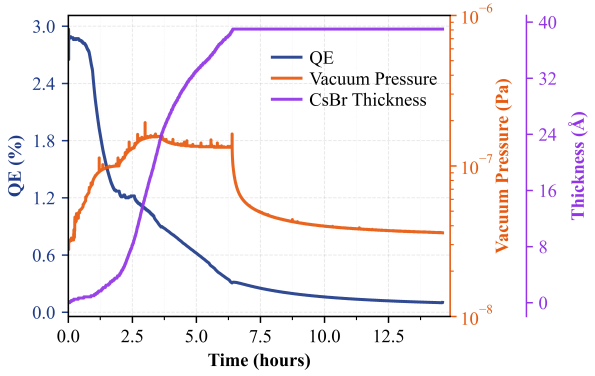

Figure 3: Representative time evolution of QE, chamber pressure, and cumulative CsBr thickness during CsBr protective layer deposition on the Cs_3Sb photocathode.

Experimental Procedure

CsBr films were deposited on the prepared Cs_3Sb photocathodes at room temperature by thermal evaporation. Figure 3 shows a representative time evolution of QE, chamber pressure, and cumulative CsBr thickness during CsBr deposition. During deposition, the QE decreased as the increase of the thickness of CsBr. After the evaporation, the pressure decreased to 1×10^{-8} Pa with the final QE of 0.1 %.

RESULTS

Vacuum Adaptability

To evaluate vacuum adaptability, the chamber pressure was increased in a controlled manner from 1×10^{-8} Pa to approximately 1×10^{-4} Pa by admitting ambient air into the chamber. The protection capability of the CsBr film was represented by the pressure at which rapid QE degradation began.

Figure 4 shows the relative QE as a function of pressure for Cs_3Sb photocathodes and CsBr coated Cs_3Sb photocathodes during the vacuum adaptability test. For the Cs_3Sb photocathode, the QE remained nearly constant below 1×10^{-6} Pa

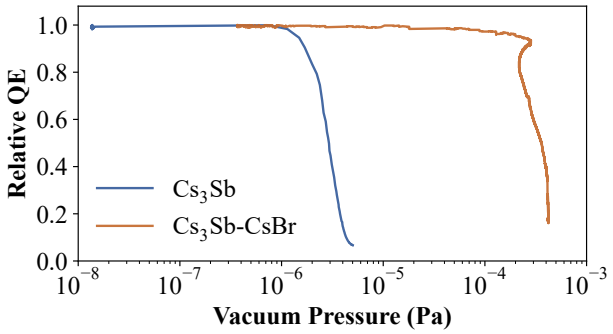

Figure 4: Relative QE as a function of chamber pressure during the vacuum adaptability test for uncoated and CsBr coated Cs_3Sb photocathodes.

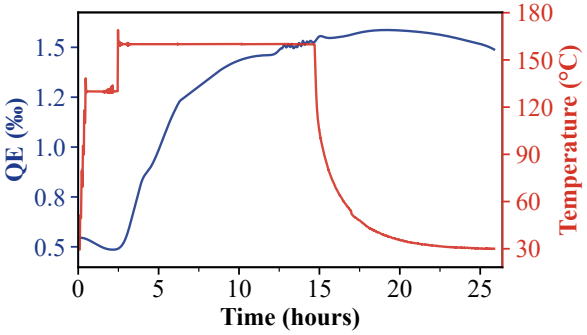

Figure 5: QE evolution of a Cs_3Sb photocathode coated with CsBr during annealing in vacuum at 160 °C

and then dropped rapidly as the pressure increased further. In contrast, the QE of CsBr coated Cs_3Sb sample maintained stable beyond 1×10^{-4} Pa, and a pronounced decrease was observed only at higher pressure. The pressure at which rapid QE degradation began was shifted by about two orders of magnitude after CsBr coating. This result indicates that the CsBr protective film effectively improves the vacuum adaptability of Cs_3Sb photocathodes at elevated pressure.

Post-Annealing Recovery

After the vacuum adaptability test, a CsBr-coated photocathode was annealed in order to recover its QE.

Figure 5 shows the evolution of QE and substrate temperature for a coated Cs_3Sb photocathode during annealing. The temperature was first raised from room temperature to 160 °C, maintained for 9 h. During this process, the QE recovered from 0.1 % to 0.15 %, indicating a pronounced recovery of the QE during annealing. Nevertheless, the CsBr protective film also improves the thermal stability of the Cs_3Sb photocathode, as previous work has shown that Cs_3Sb dissociates below below 120 °C [10].

DISCUSSION

In this work, CsBr-coated Cs_3Sb photocathodes were prepared and evaluated in a dedicated UHV system. The CsBr protective film significantly improved the vacuum adaptability of Cs_3Sb photocathodes, as demonstrated by a shift of two orders of magnitude in the pressure at which rapid

QE degradation began. In addition, annealing in UHV at 160 °C recovered the QE of the coated photocathode to a value slightly higher than that measured before exposure, indicating that the QE loss caused by exposure to ambient air is reversible under the present annealing condition.

The present results demonstrate that the CsBr coating substantially enhances the vacuum adaptability of Cs_3Sb photocathodes. The most direct inference is that the CsBr overlayer acts as an effective barrier against gas in the ambient environment, thereby mitigating the oxidation of Cs_3Sb and maintaining its crystal structure. This interpretation is supported by the observed shift, by approximately two orders of magnitude, in the pressure at which rapid QE degradation sets in. However, the CsBr overlayer also results in the decay of initial QE, probably due to the increase of electron affinity of the outmost layer.

The annealing result further suggests that exposure to air did not induce irreversible damage in the underlying Cs_3Sb layer. A reasonable explanation is that vacuum annealing removed adsorbed oxides introduced during atmospheric exposure, thereby restoring a more favorable interfacial or near-surface condition and lowering the effective electron emission threshold. This can account for the recovery of QE and for the final QE slightly exceeding the value measured before exposure to the atmosphere. Clarifying the microscopic origin of this behavior will require direct surface-sensitive characterization, such as XPS and RHEED, which will be carried out in future work.

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