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AN UPGRADE FOR THE CeC CATHODE DEPOSITION SYSTEM: CO-DEPOSITION OF K_2CsSb AND CsTe/GaAs FOR CeC USE*

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Abstract

Properties such as high quantum efficiency (QE), low thermal emittance, and longevity are crucial features for the rapidly developing electron accelerators. Compared to the traditional sequential deposition, the co-evaporation method is reported to yield better surface roughness, film crystallinity, and high quantum efficiency for photocathode materials. Here we present the effort in upgrading the coherent electron cooling (CeC) photocathode deposition system to adapt the co-evaporation growth method, the development of the co-evaporation recipe, and the preparation of K-Cs-Sb photocathode using the developed system. QE of about 6.3% at wavelength 532 nm was obtained for co-deposited K_2CsSb photocathode, where stoichiometry was determined by the deposition rate of each element. The system upgrade also enables the preparation of GaAs photocathodes activating with Cs-Te. In our study, both CsTe and CsTe/CsO activated GaAs are prepared using the "yo-yo" method. QE of about 3.6% and 5% at wavelength 532 nm are obtained respectively. Lifetime measurements are performed and results are reported.

INTRODUCTION

One of the main challenges in accelerator physics is to cool high energy hadron beams. Coherent electron cooling (CeC) has the advantage of rapid cooling of high-intensity, high-energy hardon beams [1-3]. In the CeC photoinjector, semiconductor photocathodes are used for source of unpolarised electron beam [3], requiring a photocathode to have high quantum efficiency (QE), low emittance, and long operational lifetime. Compared to the traditional sequential deposition, the co-evaporation method is reported to yield better surface roughness, film crystallinity, and high quantum efficiency for photocathode materials [4, 5].

In this proceeding, we report the upgrade of cathode growth system to co-evaporation deposition system for the CeC cathodes at BNL. We also present the growth details of K_2CsSb. Activation of GaAs photocathode using CsTe/CsO and CsTe along with QE measurements are presented in the last section of this report.

SYSTEM UPGRADE

UHV CeC photocathode growth system is upgraded to enable (1) grow of alkali antimonide, cesium telluride photocathodes with co-evaporation of different materials (Cs, K, Te, Sb etc) and (2) multi-purpose photocathode growth like activation of photocathode with gases like O along with alkali materials and (3) also allows to measure QE during and after growth as well as performing QE maps. This system is consist of three main chambers (i) Transfer chamber [Fig. 1(b)], (ii) Pre-heating and QE map chamber, (iii) Deposition Chamber [Fig. 1(a)]. Figure 1(a) shows picture of the whole system. Deposition chamber has two deposition positions, each have one port for source loading and one laser port for QE measurements. Figure 1(c) – 1(e) shows the magnified view of the flange and tube where two source clusters (A & B), two laser ports (A & B) are attached. Figure 1(f) shows picture of a source cluster having electrical connections with sources on top. Figure 1(g) shows top view of source cluster during source test, where getter sources of alkali materials (Cs, K) and crucible for Te/Sb attached for thermal evaporation are indicated. Figure 1(h) shows sectional view of the source flange which clearly indicates that sources and laser are centred to the sample (puck). The source clusters can be moved towards and away from the sample to adjust distance between sample and sources. Figure 1(i) shows schematic of co-deposition and QE measurements. Figures 1(j) and 1(k) show cathode mask and heater with puck. The puck holder has advantages to heat and to cool the puck.

EXPERIMENTAL

K_2CsSb Co-evaporation Growth

The Molybdenum (Mo) puck and GaAs puck is used for activation of photocathodes. Mo puck is loaded to the preheating chamber and heat cleaned with temperature at 400°C up to 7 hours in UHV condition. In order to grow K_2CsSb using co-evaporation growth process, sources of Sb, K and Cs are set to certain deposition rates to match the stoichiometry K_2CsSb, where rates of each materials are obtained using a Quartz crystal microbalance (QCM). In order obtained our target stoichiometry and smooth surface with co-evaporation deposition process, growth has performed at substrate temperature at 85°C with a base pressure of $3x10^{-10}$ Torr. K, Cs were deposited with deposition rates of 0.96 nm/min, 0.78 nm/min respectively, where K, Cs deposited using SAES getter sources and that of Sb has deposited using thermal evaporator with average deposition rate of 0.1 nm/min.

Activation of GaAs Photocathode

GaAs puck is shown in Fig. 2(a) and cap of the puck is shown in Fig. 2(b), where GaAs substrate can be placed below the cap. Prior to activation, GaAs puck with GaAs substrate is loaded to the pre-heating chamber and heat cleaned with temperature at 580°C for 2 hours in UHV condition. GaAs has been activated with Cs and O with an interlayer of Te at room temperature. The final structure is CsO-Te-CsO/GaAs, where about 1 nm of Te is deposited. CsO was

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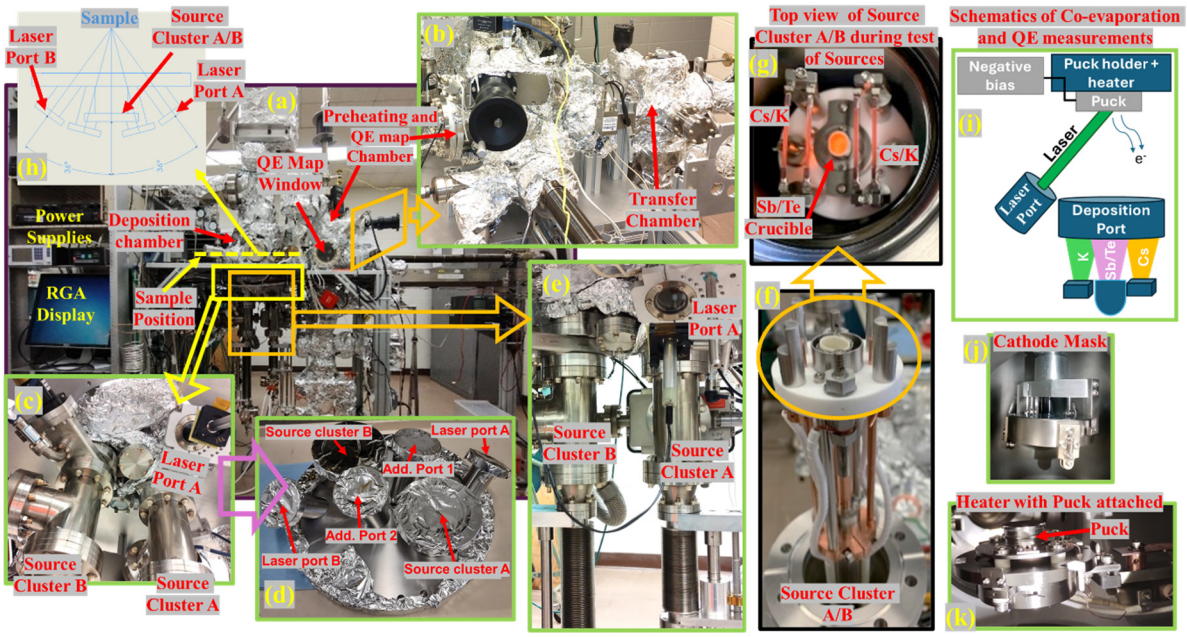

Figure 1: (a) The BNL UHV CeC photocathode growth system at IO, BNL, with in situ QE measurements and QE map measurements. (b) magnified perpendicular view the system where transfer chamber is indicated, (c) and (d) magnified view of source flange where co-evaporation source clusters and laser ports are attached are clearly indicated, (e) magnified view of attached tube having source cluster inside, (f) both source clusters with electrical connection and crucible, (g) top view of source cluster having alkali material getter source and Sb/Te crucible are indicated, (h) sectional view source flange indicating laser and source clusters are to the centre of the sample (puck), (i) schematic of co-evaporation and QE measurements, (j) Cathode mask, (k) heater with puck attached.

deposited by traditional "yo-yo" process. The amount of oxygen flow was controlled by a leak valve. GaAs is also activated by CsTe, where CsTe was deposited by the traditional "yo-yo" process.

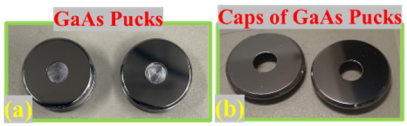

Figure 2: (a) GaAs pucks with cap attached on it and (b) Caps of the pucks.

RESULTS AND DISCUSSIONS

In this section, the results of co-evaporation growth of K_2CsSb and the activation of GaAs are discussed.

K_2CsSb Co-evaporation Growth

QE about 6.3 % at wavelength 532 nm is obtained from the co-evaporation growth of K_2CsSb photocathode [Fig. 3(a)]. Figure 3 (a) shows QE curve during the co-evaporation process, plotting the QE evolution as cathode thickness increases [6]. After certain film thickness (about 1 hour of growth) curve start saturating. Jiang et al shows simulated QE of K_2CsSb saturated approximately at 20 nm film thickness [6]. Similar results are found in our co-evaporated growth.

We terminate the photocathode growth once the QE saturates and starts decreasing. Once cooled down to room temperature, cathode puck is transferred to the pre-heating chamber for QE mapping. Figure 3(b) shows the 2D QE map where x and y axis are the lateral dimensions on the photocathode surface. Colour scale is shown on the right side of Fig. 3(b). Figure 3(c) shows the QE map in 3-dimension. QE map depicts that K_2CsSb is grown with a uniform surface with QE over 6% at 532 nm. The inset of Fig. 3(a) is a picture of the completed K_2CsSb photocathodes.

Activation of GaAs Photocathode

Figure 4 (a) shows the activation curve of GaAs with CsO using traditional "yo-yo" method. QE about 3.5 % at 532 nm is obtained from CsO activated GaAs. Figure 4(b) shows further activation curve with Te as an interlayer on top of the CsO activated GaAs photocathode to improve the cathode tolerance to poor vacuum conditions [7, 8]. Similar "yo-yo" process is used for further activation for this cathode. As shown in Fig. 4(b), QE about 5 % at 532 nm is obtained from CsO activated GaAs with final structure being CsO-Te-CsO/GaAs.

Figure 4(c) shows the cathode degradation study of QE vs time and vacuum. There is no degradation observed with time up to ~90 hours. However, QE drops from ~5 % to ~1 % is observed with chamber pressure changing from ~few 10^{-10} to ~10^{-9} Torr. Figure 4(d) shows the picture of GaAs puck with GaAs substrate attached.

GaAs is also activated with CsTe using "yo-yo" process, where QE about 3.6 % at 532 nm is obtained.

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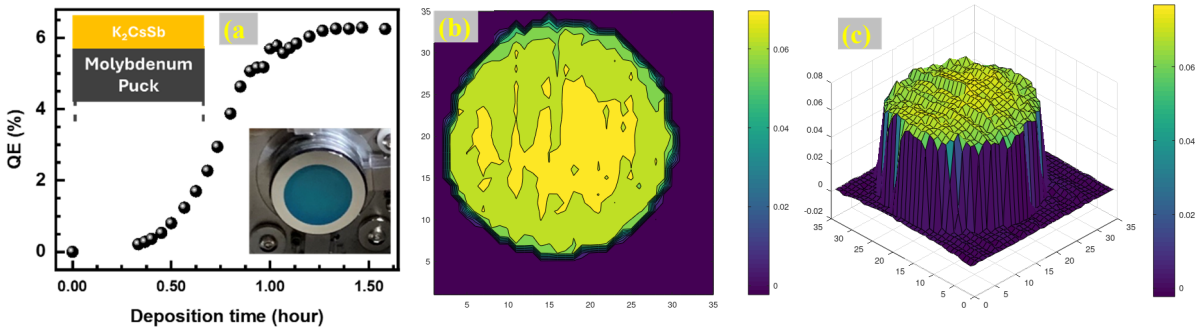

Figure 3: (a) QE curve during growth of K_2CsSb on Molybdenum puck, (b) QE map in 2-dimensions, where color scale represents QE of K_2CsSb photocathode, (c) 3-dimentional QE map of K_2CsSb photocathde where 3rd dimension is QE. In upper left coner of (a) is schamatic of phtocathode. And lower right corner of (a) shows picture of a grown K_2CsSb.

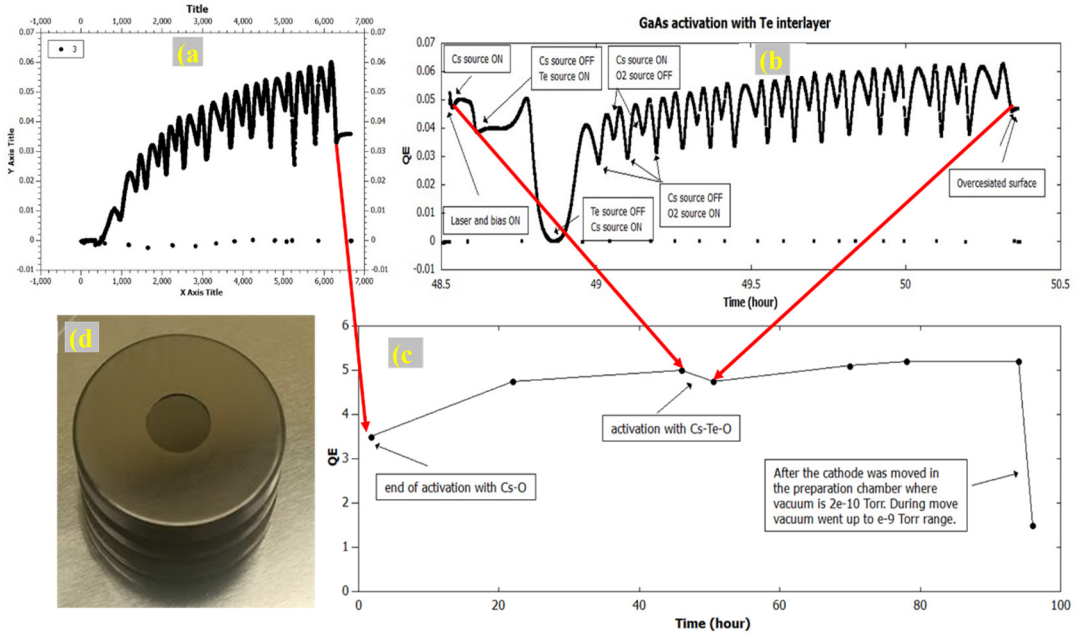

Figure 4: (a) QE curve during acitvation of GaAs with CsO, (b) QE curve during acitvation of GaAs with CsO with Te as interlayer (c) QE degradation study with time, (d) GaAs puck.

CONCLUSION

In conclusion, we have successfully upgraded the CeC photocathode growth system to a co-evaporation growth system for use of multi purpose growth of photocathodes. K_2CsSb photocathodes are prepared using co-evaporation deposition process and obtained QE ~6.3% at wavelength 532 nm. We have also activated GaAs photocathode with Cs/O and Te as interlayer and obtained QE ~5 % at 532 nm, with long term stability under UHV condition. We have also activated GaAs photocathode with CsTe and obtained QE ~ 3.6% at 532 nm.

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