A LIFETIME STUDY OF CSK$_2$SB CATHODE

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Abstract

We report a study of CsK_2Sb photocathode in Hiroshima University. High brightness electron source is one of the key components in advanced electron accelerators. For example, a future light source based on Energy Recovery Linac (ERL) requires high average current electron beam in a range of 10 - 100mA with an extremely low emittance down to 0.1mm.mrad [1]. A photocathode electron injector is expected to fill these requirements because of their superior performances over other technologies. However, there are trade-offs between operational lifetime (robustness), wavelength for drive laser, and Quantum Efficiency (QE) of photo-emission. A photo-cathode material with high robustness, high QE, and driven by visible or IR light is strongly desirable. CsK_2Sb multi-alkali photocathode is one of the candidates to satisfy these requirements. A new system to study CsK_2Sb was developed and the cathode was successfully produced by this system. QE was 3.8% after the activation and the 1/e lifetime was more than 3000 hours without beam emission. With a beam emission, 1/e lifetime regarding to amount of charge was more than 300C. In this article, the cathode evaporation system is explained and result of the initial experiment is presented.

INTRODUCTION

In advanced electron accelerator concepts, high intensity and low emittance electron beam is required. For example, a future light source based on ERL[1] requires high average current electron beam in range of 10 - 100mA with an extremely low emittance down to 0.1mm.mrad. Advanced photo-cathode technology can generate a wide variety of electron beam combined with the latest laser technologies. Among various photo-cathode materials, appropriate material choice is important for an optimized injector design. For example, NEA-GaAs photocathode has a high QE more than 10% and can be driven by visible or IR laser. On the other hand, it has a limited lifetime especially in high current condition. Another candidate is a metal cathode like Cu, Mg, etc. The metal cathode is robust, but its QE is in order of 1e-4 or less. In addition, it requires UV laser for photo-electron emission. It is not feasible for high current operation because of these limitations.

CsK_2Sb photocathode is another candidate for high brightness operation of photo-injector. This is a multi-alkali cathode which is popular as cathode material of photo-multiplier. CsK_2Sb has high QE ($\sim$10%) with the green laser [2]. Green laser light can be easily obtained as second harmonics of 1μm solid state laser like Nd:YAG, Yb:YAG, etc. Therefore, CsK_2Sb is feasible for a high brightness electron source if the robustness is confirmed. To confirm the robustness of CsK_2Sb cathode and establish the evaporation technique, we have developed a new system to study the CsK_2Sb photocathode in Hiroshima University in collaboration with ERL project in Japan[3]. In this paper, the experimental setup is explained followed by results of an initial pilot experiment.

EXPERIMENTAL SETUIP

To study the CsK_2Sb photocathode, a new system was constructed. This system is able to grow CsK_2Sb compound in ultra-high vacuum condition and perform photo electron emission experiments. A schematic view of the system is shown in Fig. 1. Cs, K, and Sb evaporation sources are mounted at an end of movable rod. The rod position is adjusted when one of the sources is evaporated on the substrate. A quartz thickness monitor is implemented to measure amount of evaporated material. The evaporator is designed symmetrically to generate its vapour in both sides: substrate side and thickness monitor side. Therefore, thickness of each evaporated material can be measured simultaneously in the cathode formation.

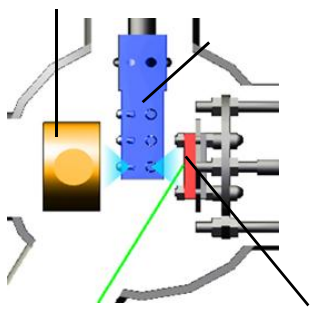

Figure 1: A schematic view of the evaporation system. A cathode substrate and a thickness monitor are placed symmetrically from the evaporation sources. The evaporation source mount is movable to evaporate each sources at center of the cathode substrate.

The cathode substrate is a 30x30 mm^2 plate made of stainless steel (SUS304). The SUS plate was employed because the cathode formed on SUS substrate showed high QE in comparison with other popular metals [4]. Prior to the evaporation, the substrate was cleaned by heating with a ceramic heater mounted in backside of the substrate. The temperature was monitored and controlled by thermo-coupler attached behind the substrate. The cathode mount was isolated to apply a bias voltage to perform photo-electron emission experiment. A typical bias voltage is -100V DC.

The evaporator is capable to make vapour of Cs, K, and Sb in front of the cathode substrate. For Cs and K sources,

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wire type alkali metal dispensers (SAES Getters) were employed. Sb is provided by Sb grains heated in a tungsten heater basket. These sources are designed symmetrically to be able to evaporate in opposite two directions, one for cathode substrate and one for thickness monitor. Due to this structure, amount of each material in cathode evaporation can be measured simultaneously.

A 532nm green laser was used to measure QE, but a white LED lamp was used to generate a large current electron beam because the power of the green laser was limited. These lights illuminate the cathode through a view port of the vacuum chamber.

Ultra-high vacuum is required during the cathode evaporation and photo-electron emission experiment. The vacuum chamber is made from chemically polished SUS. After an usual baking process up to 200°C to establish UHV condition, a 500 L/s ion pump (CANON ANELVA) is in operation as a main pump of the system. Vacuum pressure was measured with Leybold extractor gauge. The base vacuum pressure of the chamber was 6.0×10^{-8} Pa. All experiments were made with this condition.

RESULTS AND DISCUSSION

CsK_2Sb thin film cathode was made by Sb, K and Cs evaporation in order. Prior to the cathode formation, the substrate was cleaned by heating at 600°C. A typical procedure of the cathode formation was as follows.

1. The cathode substrate was heated to 600°C to clean and cooled down to less than 150°C.
2. Sb was evaporated 10 nm.
3. K was evaporated 30 nm.

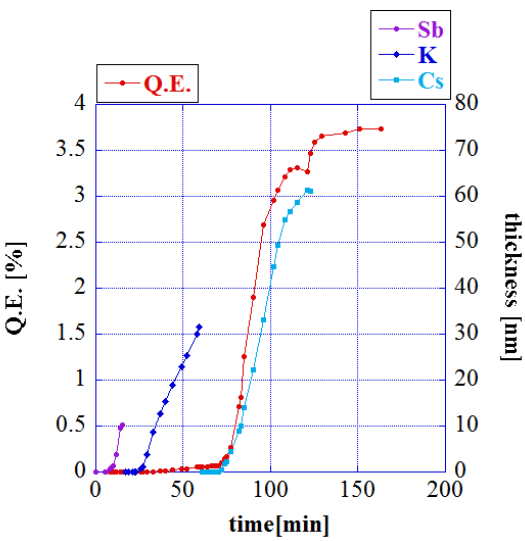

Figure 2: QE and thickness evolutions are shown. Thickness is that of each materials (not total).

4. Cs was evaporated. Simultaneously, a 532nm green laser illuminated the cathode substrate to measure QE. QE was saturated with 60 nm Cs deposition typically.
5. During the evaporation, the substrate temperature is controlled.

The procedure was determined by referring previous studies in references [2][5][6].

Figure 2 shows an example of QE evolution during the evaporation process. Left vertical is QE in % and left vertical axis is thickness of each materials measured by the thickness monitor. The thickness was plotted separately for each material. Horizontal axis shows time in minutes. QE became significant during K evaporation and rapidly increased when Cs evaporation was started. Finally, 3.8% QE with a 532nm green laser was observed in this evaporation.

After the cathode evaporation, a couple of lifetimes were measured. One was charge lifetime regarding to amount of charge extracted from a cathode. Charge lifetime is determined as 1/e decay constant as follows,

$$\eta(\rho) = \eta_0 e^{-\frac{\rho}{\Theta}} , \quad (1)$$

where η and η_0 are QE and its initial value, ρ is charge density extracted from the cathode, and Θ is charge lifetime. Figure 3 shows QE evolution as a function of the extracted amount of charge in C. The beam emission was made with the white LED lamp and the actual spot size of the beam emission was not well measured yet and that is why the life is given in charge rather than charge density. For the cathode evaporation spot area, we will discuss this issue in detail later. Anyway, 1/e charge lifetime was 366C from this measurement.

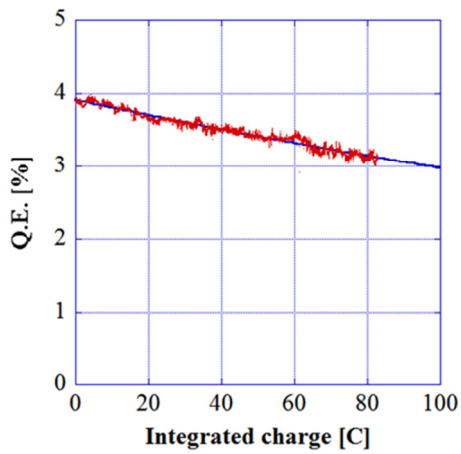

Figure 3: QE evolution as a function of extracted charge. 1/e lifetime was 366C.

Another lifetime is dark lifetime defined as exponential decay constant without beam emission as follows,

$$\eta(\rho) = \eta_0 e^{-\frac{t}{\tau}} , \quad (2)$$

where t is time and τ is the dark lifetime. The dark lifetime was determined from QE evolution without beam emission. The result was shown in Fig. 4. QE was measured with the green 532nm laser only when data points were plotted in this figure. Then, actual emission current was negligibly small. From this decay curve, the

dark lifetime was extracted as 3500 hours. This number is extremely long in comparison with that of NEA GaAs by considering the vacuum pressure, 6.0×10^{-8}Pa[7].

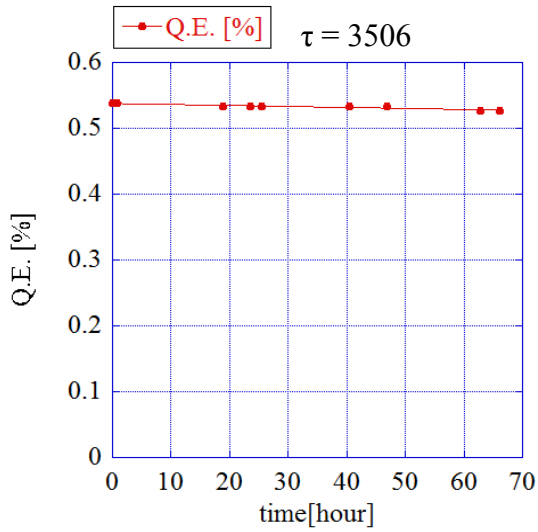

Figure **4**: QE evolution without beam emission. The dark lifetime was extracted as 3500 hours.

To confirm quality of cathode formation by the evaporation, spatial distribution of QE on the cathode was measured. The measurement was made with the green 532nm laser and the laser position was scanned in horizontal and vertical directions, respectively. For each positions, photo-current was recorded and QE was calculated. The result was shown in Fig. 5. Each axes correspond to horizontal and vertical axes on the cathode. Colour shows QE value measured at each positions: red is

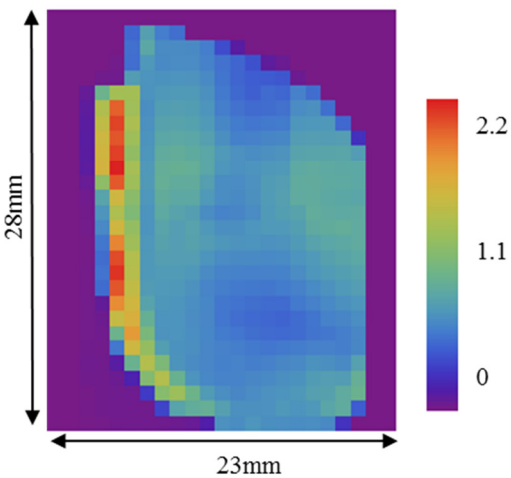

Figure **5**: Result of QE mapping on the cathode. Red area and purple area have high and low QE, respectively. Each axes correspond to real geometry of the cathode.

high (2.2%) and purple is low (0%). According to the result, the cathode was formed on an area 15 mm in horizontal and 20 mm in vertical, but QE was not uniform. Hot spot(s) where QE was higher than other area, was observed. It was reasonable that the hot spot was shaped vertically long, because the K and Cs dispensers were placed along this axis. It was not fully understood why the relatively low QE region was formed in such large area. This area might be made by different compound from CsK_2Sb with less Cs and K amount, but has a finite QE. The reason will be clearer by further study, e.g. QE mapping during evaporation process.

SUMMARY

We developed a new system to study CsK_2Sb multi-alkali photo-cathode. The system was designed to measure thickness of each material films during evaporation simultaneously. As a result of pilot experiment, 3.8% QE was observed with more than 3500 hours dark lifetime and 350C charge lifetime with 532nm green laser. QE mapping was made with the same green laser and a vertically long hot spot where QE was high up to 2.2% was found. The reason of this in-uniformity will be studied eventually. For further optimization of the cathode formation, cathode properties as functions of various parameters like each material amounts, temperature during the evaporation will be measured.

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