STUDY ON DURABILITY IMPROVEMENT OF Cs-Te PHOTOCATHODE BY MEANS OF ALKALI HALIDE PROTECTIVE FILMS

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Abstract

We have been conducting basic and applied research for generating high quality electron beams, using 1.6 cell laser photocathode rf-gun. In our laboratory, Cesium Telluride (Cs-Te), one of the semiconductor photocathodes, is used as an electron source for accelerator experiments. This semiconductor photocathode is known for high quantum efficiency (Q.E.) about 5 to 10% and 3-month 1/e lifetime. High Q.E. photocathodes can reduce the power requirement of the laser system, and long lifetime photocathodes can decrease the maintenance frequency, contributing to an efficient experimental environment. For these reasons, high Q.E. and long lifetime photocathodes are necessary in accelerator experiments. To produce robust photocathodes and extend the lifetime, we have conducted covering Cs-Te photocathodes with CsBr and CsI protective films. In this paper, we report the thickness dependency on Q.E. and lifetime of Cs-Te photocathodes when we intentionally exposed oxygen gas to coated and non-coated Cs-Te photocathodes.

INTRODUCTION

Recently, high brightness electron beams are required because of its application to FEL and ERL [1, 2]. As the demand for high quality electron beams increases, more and more attentions are paid to photocathodes, which can contribute to low emittance beam generation. In our laboratory, we use Cesium Telluride (Cs-Te) photocathode as the electron source for our accelerator experiments because it has high quantum Efficiency (Q.E.) about 10 percent and 3-month 1/e lifetime, and it is better than other photocathodes in terms of the balance between Q.E. and lifetime.

However, while Cs-Te photocathode have some favourable features, it is very susceptible to residual gas such as oxygen, carbon monoxide, and carbon dioxide. In previous research, it is reported that Q.E. decreased to 20 percent of its initial value when exposed to around 100 Langmuir O_2 gas [3]. In fact, although Cs-Te photocathode have longer lifetime than the other semiconductor photocathodes, we must replace the electron source every six months because generated electron beam from the photocathode cannot satisfy our required charge.

Therefore, the development of the robust photocathodes with higher Q.E. and longer lifetime is required. For producing and evaluating robust photocathodes, we have conducted evaporating Alkali Halide protective films such as Cesium Bromide (CsBr) and Cesium Iodide (CsI) on Cs-Te photocathode. We have also conducted exposing oxygen gas to coated and non-coated Cs-Te photocathode to

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measure their lifetime. We report the thickness dependency of CsBr and CsI on Q.E. and lifetime of Cs-Te.

EXPERIMENT

Experimental Setup

Figure 1 shows the picture of the evaporation chamber. To extract photoelectrons and measure the quantum efficiency (Q.E.), a voltage of -100 V is applied on the molybdenum (Mo) substrate, which is illuminated by UV LED at 265 nm (DOWA: DF7VL-1H321). UV light is irradiated from the oblique direction against the surface of the substrate by using the movable mirror. A 6243 DC Voltage/Current Monitor (ADCMT) is used to measure the photocurrent. And the shutter (Suruga Seiki: F116) is placed between UV LED and the movable mirror to shield from UV light and measure the background.

We can achieve ultrahigh vacuum by use of two turbo molecular pumps (PFEIFFER: HiPace® 300 DN 100 CF-F, and EDWARDS: STP-301), an air-cooled dry pump (Kashiyama: NeoDry30E), a sputter ion pump (ULVAC: PST-100CX), and two NEG pumps (SAES Getters: CapaciTorr®). For measuring the pressure in the evaporation chamber, a B-A gauge (Canon ANELVA: M-922HG) is used. The vacuum pressure is around 3×10^{-8} Pa before fabricating Cs-Te photocathode, and $10^{-7} \sim 10^{-6}$ Pa while evaporating.
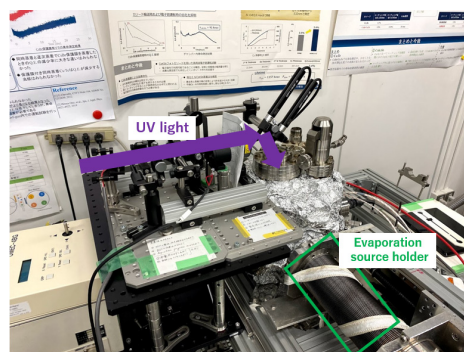

Figure 1: Picture of the evaporation chamber.

Figure 2 shows the schematic of the evaporation system viewed from above, and Fig. 3 shows the same schematic viewed from the side. Also, the picture of evaporation source holder (ESH) is shown in Fig. 4. A Cs dispenser (SAES Getters) is mounted on ESH. And W (Tungsten) baskets attached to ESH can accommodate a 99.9999% pure Te (Nilaco), a CsBr, and a CsI (Pier Optics). Each material is evaporated on the substrate by electrical heating. The thickness of the evaporated source is monitored by means of quartz crystal microbalance (QCM). ESH is located between QCM and the substrate.

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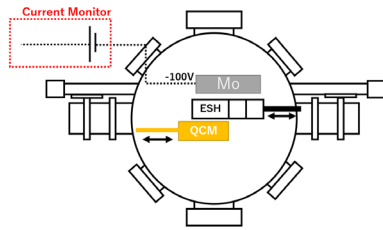doi:10.18429/JACoW-IPAC2021-WEPAB106

Figure 2: Schematic of the evaporation system (Viewed from above).
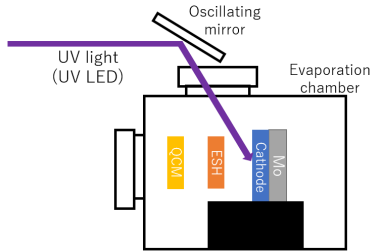

Figure 3: Schematic of the evaporation system (Viewed from the side).
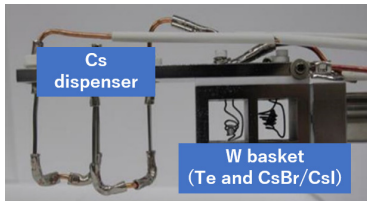

Figure 4: Picture of evaporation source holder.

Experiment

The experiment was conducted as follows:

1. Fabricate Cs-Te photocathode on Mo substrate.
2. Evaporate CsBr/CsI on Cs-Te photocathode at certain thickness.
3. Expose oxygen gas to the coated/non-coated Cs-Te photocathode.
4. Evaluate the degree of decrease in Q.E. to calculate lifetime L_0.

The procedure to fabricate Cs-Te photocathode was done by sequential deposition evaporation process. At first, Te was evaporated on Mo substrate at 20nm, then Cs until Q.E. reached 60 percent of its peak value[*]. The evaporation rate was 0.1 to 7 Å/s in case of Te evaporation and 0.1 to 0.3 Å/s in case of Cs evaporation. After that, CsBr or CsI was evaporated on Cs-Te photocathode at certain thickness (0, 5, 10, 20, 25, and 30 nm). And oxygen gas was exposed to the photocathode on purpose for 3 to 6 hours. We measured the Q.E. while CsBr/CsI coating and O_2 exposing in the same way as Cs evaporating.

After collecting the data, Q.E. while evaporating coating film and thickness of the film, we fitted its data to the equation as follows:

$$\alpha = A\exp\left(-\frac{x}{L_1}\right) + B\exp\left(-\frac{x}{L_2}\right), \quad (1)$$

where α is Q.E., x is coating thickness, A, B, L_1, and L_2 are fitting parameters. To tell L_1 from L_2, we call L_1 the attenuation length and L_2 the escape length. The relation is given by

$$L_1 < L_2. \quad (2)$$

Attenuation length L_1 corresponds with sudden drop in Q.E. and escape length L_2 corresponds with gradual drop in Q.E. as coating thickness increases. Based on these parameters, we determined the affinity of CsBr and CsI with Cs-Te photocathode.

After O_2 exposure, the Q.E. decay was fitted to the equation given as follows:

$$\alpha = \alpha_0 \exp\left(-\frac{L}{L_0}\right), \quad (3)$$

where α_0 is the initial Q.E. before exposing oxygen gas, L is the amount of exposure, and L_0 is lifetime determined by exposure. The purpose of the experiment was to figure out the optimum thickness of coating films to maximize L_0.

RESULT AND DISCUSSION

Thickness Dependency of Q.E.

We obtained four parameters for each coating film when coating thickness was 20 nm, 25 nm, 30 nm①, and 30 nm②. In other words, we collected eight data (four data were from CsBr and the rest were from CsI) for each four parameters. The averages of each four fitting parameters are given in Table 1. In addition, the relation between relative Q.E. and CsBr thickness is shown in Fig. 5, and the relation between relative Q.E. and CsI thickness is shown in Fig. 6. We found that the averaged A was larger and L_1 was smaller for CsI. We note that, in terms of A, the largest three data were for CsI if we put the eight data of the quantity A (four data were CsBr and the rest were for CsI) in order of its size. We also note that, in terms of L_1, all four data L_1 for CsI were larger than any data L_1 for CsBr. This means that the degree of decrease in Q.E. tend to be larger for CsI and that Q.E. drops more suddenly when evaporating CsI on Cs-Te photocathodes. Therefore, we can conclude that CsBr is better in terms of Q.E.

Moreover, the quantity L_2 is on the order on tens of nm for both CsBr and CsI, and this is consistent with the escape length of alkali halides [4]. Therefore, we conclude that L_2 corresponds with the so-called escape length.

Table 1: The Averages of Fitting Parameters.

Coating material	$A[-]$	L_1[nm]	$B[-]$	L_2[nm]
CsBr	0.71	0.58	0.30	29
CsI	0.78	0.34	0.23	30

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[*] This is because we can empirically fabricate the photocathode whose Q.E. tends to decrease in the way.
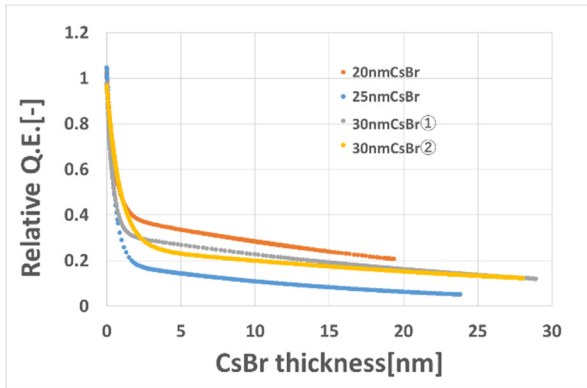
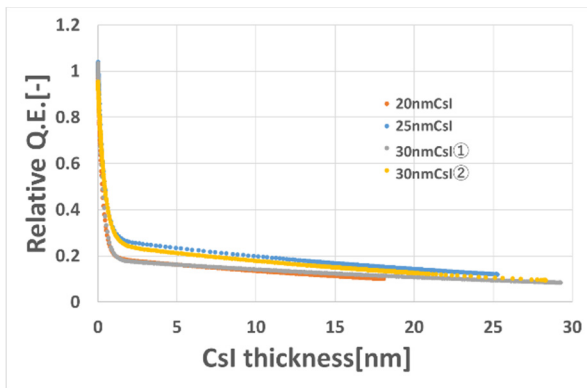Figure 5: Relation between relative Q.E. and CsBr thickness.

Figure 6: Relation between relative Q.E. and CsI thickness.

Thickness Dependency of Lifetime

Figure 7 shows the coating thickness dependency of the lifetime determined by exposure. We found that, for both CsBr and CsI, L_0 increases from 0 nm to 20 nm and decreases at more than 20nm. We assume that the increase in L_0 can be attributed to the decrease in the interaction between Cs-Te and oxygen gas. And we think the decrease in L_0 may have been caused because electrons were scattered before leaving the coated Cs-Te photocathodes. In addition, the graph revealed that we could maximize L_0 when coating CsBr/CsI at 20 nm. In terms of lifetime, we can conclude that CsI is better than CsBr.
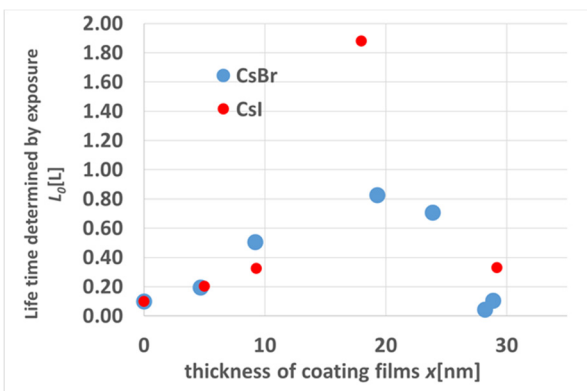

Figure 7: Relation between lifetime L_0 and coating thickness.

CONCLUSION

We studied the affinity of CsBr/CsI with Cs-Te photocathodes. We found that the decrease in Q.E. is smaller when coating CsBr on Cs-Te. Also, we studied the optimum thickness of CsBr/CsI in terms of lifetime. We saw that we can maximize lifetime L_0 when evaporating coating films on Cs-Te at 20nm and that L_0 is larger for CsI than CsBr at 20 nm. Therefore, if we want higher Q.E., we should evaporate CsBr on Cs-Te and if we want longer lifetime, we should evaporate CsI on Cs-Te.

For future prospect, we think the research in initial Q.E. dependency on lifetime is required because, in our experiments, there was a big difference in the initial Q.E. before exposure between CsBr and CsI at 20 nm. We want to compare the lifetime when evaporating CsBr with the lifetime when CsI at the same thickness and initial Q.E.

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