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MULTI-ALKALI PHOTOCATHODE R&D

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Abstract

CsKSb multi-alkali cathode is considered to be one of the best candidate of the high brightness electron source of the advanced electron accelerator such as ERL and FEL because of the excellent features: high quantum efficiency, long lifetime, and driven by visible light, for example green laser. We examine the cathode performances, such as quantum efficiency and the cathode lifetime, and study the dependence on the evaporation conditions, such as thicknesses and substrate temperature.

INTRODUCTION

Photocathode can generate a low emittance and short pulse beam. The cathode is essential device for electron source in advanced linear electron accelerator based applications, such as ERL [1] or FEL. ERL requires high average current electron beam in range of 10~100mA and low emittance down to 0.1mm.mrad. There are some candidates of photocathode for the advanced accelerator. NEA-GaAs cathode has very high QE over 10% and driven by visible or IR laser. However, the cathode has short lifetime in case of the high current operation. Pure metal cathode like Mg or Sm, has very long lifetime, however, the cathode has low QE below 0.2% and requires UV laser for photo-electron emission. Multi-alkali cathode has high QE about 10% and long lifetime with green laser. Green laser can be obtained easily as second harmonics of 1μm solid state laser, such as Nd:YAG or Yb:YAG. According to a study by Cornell University, 1/e lifetime of the cathode is estimated as 30 hours with 60mA extracted current [2]. We examined the cathode performances, such as quantum efficiency and the cathode lifetime, and studied conditions of multi-alkali evaporations, such as thicknesses and substrate temperature.

In our evaporation system, antimony(Sb), potassium(K), and cesium(Cs) are provided in an extremely high vacuum condition, typically 5.0×10^{-9}Pa. The cathode is made as thin-film by evaporation of these materials. Possible compounds of these material are Cs_3Sb, Cs_2KSb, CsK_2Sb, and K_3Sb. Among them, CsK_2Sb have high QE [3] [4]. However, the evaporation condition for generating CsK_2Sb cathode is not well established, such as substrate temperature, evaporation rate, thickness, etc.

EVAPORATION SYSTEM

In Hiroshima University, evaporation system for multi-alkali cathode study was constructed. The system is schematically shown in Fig. 1. With this system, the multi-alkali cathode is made by evaporation and its properties are measured. We can extract the photo-current by illuminating a laser light through a view port and QE (Quantum Efficiency) of photo-electron effect and the cathode lifetime are measured. Thicknesses and substrate temperature are important conditions in the cathode evaporation process [5]. To monitor evaporation thickness for each materials, a quartz thickness monitor is implemented. To measure the thickness simultaneously during the evaporation, the cathode substrate and the thickness monitor are placed symmetrically around the evaporation source. The evaporation source is also designed to generate the vapor symmetrically. The substrate temperature is monitored and controlled by a thermo-coupler and a ceramic heater mounted behind the substrate. The laser light illuminates the substrate diagonally in order to avoid interference between laser light and the substrate. Therefore, QE and thickness can be measured simultaneously. The substrate made by 30mm×30mm SUS304 is used. QE map of the substrate can be obtained by scanning the laser irradiation position to the substrate with moving stage mounted on mirror. Blue laser which has about 8mW power and 473nm wave length and green laser which has about 0.7mW power and 532nm wave length are used in our experiment.

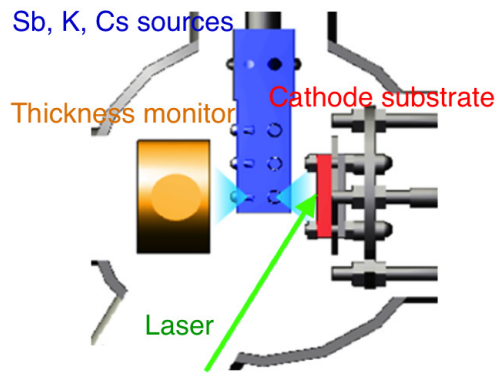

Figure 1: A schematic drawing of evaporation system in Hiroshima University.

Ultra-high vacuum is required during multi-alkali cathode evaporation and charge extracting from the substrate. Ion pump and NEG pump are used. Base vacuum pressure is about 5×10^{-9}Pa and 10^{-8} ~ 10^{-7}Pa during evaporation.

RESULTS

Cathode Evaporation Experiment

Multi-alkali cathode is made by Sb, K, and Cs evaporation in this order on the substrate. The typical process is following:

1. The substrate is heated to 600°C for heat cleaning. After that, it is cooled down and held temperature around 100°C.
2. Sb is evaporated up to a determined thickness.
3. K is evaporated up to a scheduled thickness.
4. Cs is evaporated until QE is saturated.

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5. The substrate is cooled down to room temperature.

During evaporation, QE is measured simultaneously. This procedure is referred to [6].

An example of a evaporation experiment with this procedure is shown by Fig. 2. QE was measured with the blue laser. QE rose during K evaporation and was increased rapidly when Cs evaporation started. The vacuum pressure was about 2×10^{-8}Pa during Sb evaporation, 1×10^{-7}Pa during K and Cs evaporation. Finally, QE was reached to around 6%.

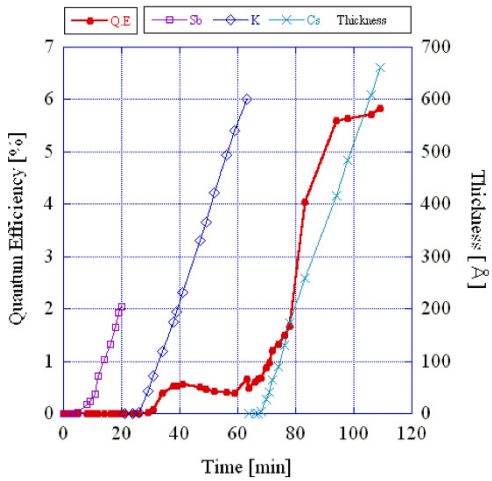

Figure 2: Time course of QE and evaporation thicknesses.

Cathode Lifetime Measurement

As cathode degradation, two kinds of phenomenological definitions are considered. One is regarding to time. This lifetime is called as dark lifetime because it is significant also if there is no beam emission. The other is regarding to charge density extracted from the cathode. This lifetime is called as charge density lifetime. QE degradation is represented by these two lifetime as follows,

$$\eta(t,\rho) = \eta_0 \exp(-\frac{t}{\tau}) \exp(-\frac{\rho}{\Theta}), \quad (1)$$

where, η is QE, η_0 is initial value of QE, t is time, τ is dark lifetime, ρ is extracted charge density, Θ is charge density lifetime. QE degradation without beam emission is described by

$$\eta(t) = \eta_0 \exp(-\frac{t}{\tau}). \quad (2)$$

Dark lifetime is measured in zero emission current limit. The result of dark lifetime measurement with the green laser is shown in Fig. 3. Dark lifetime τ is estimated to be 3506 hours that is correspond to about 5 months. It is long enough for accelerator operation.

The charge density lifetime is measured with continuous laser irradiation. In this measurement, blue laser was used unlike the case of dark lifetime measurement with green laser, the blue laser spot size was 0.82mm^2, average current was 90μA, and vacuum pressure was about 2.8×10^{-8}Pa.

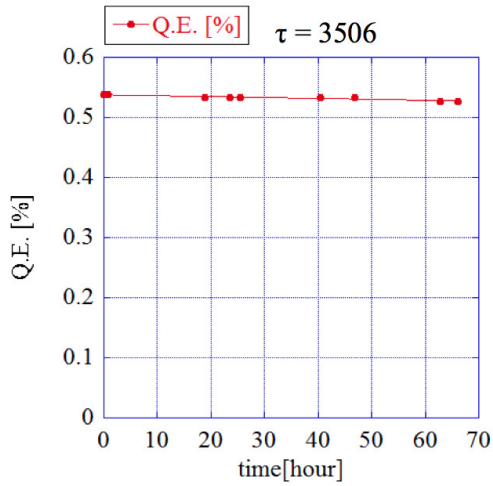

Figure 3: QE degradation caused by time course effect.

Charge density lifetime can be derived according to Eq. 1. The result is shown in Fig. 4. Red plot shows that time and charge density degradation. Green plot shows that charge density degradation estimated by removing the dark lifetime component measured as in Fig. 3 from the red plot in Fig. 4, by assuming that the cathode lifetime is independent from laser wave length and QE value. In this case, charge density lifetime Θ is estimated to 8300C/mm^2. If extracted current 100mA, laser spot diameter 3mm, and the cathode usage until 1/e^2 of initial QE are supposed, the cathode can be used for 324 hours. This is corresponded to two weeks, which equal to maintenance period of accelerator. Charge density lifetime Θ' without compensation of dark lifetime can be derived by Eq. 3. Θ' is 1220C/mm^2, this result is consistent to that in a prior research by Cornell University.

$$\eta(t,\rho) = \eta_0 \exp(-\frac{\rho}{\Theta'}) \quad (3)$$

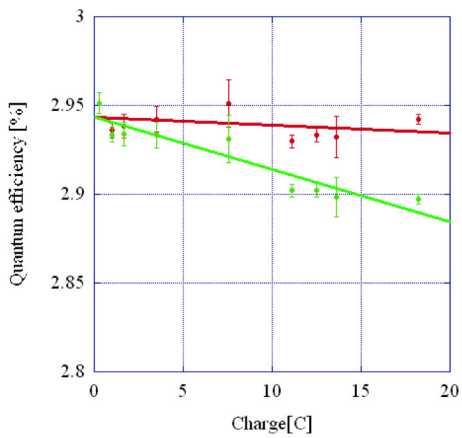

Figure 4: Green and red show that total QE degradation and QE degradation caused by extracted charge effect, respectively.

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Cs Over-Evaporation

By scanning the laser position, we can observe spatial distribution of cathode QE on the substrate. In our evaporation system, QE evolution in time is not uniform during Cs evaporation [6]. An uniform distribution is obtained by keeping Cs evaporation up to 1500Å as shown in Fig. 5 which shows QE 2D distribution on the substrate. QE is almost uniform, 6%. QE is measured with the blue laser.

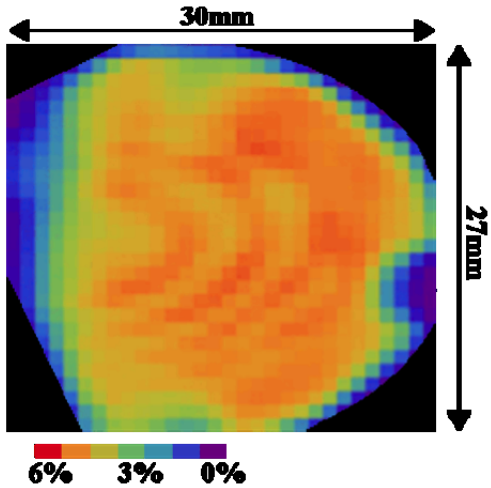

Figure 5: QE distribution on the substrate is shown.

QE and Evaporation Conditions

We examined the thickness and temperature dependence of the cathode performance. Fig. 6, Fig. 7, and Fig. 8 show QE as functions of Sb-thickness, K-thickness, and the substrate temperature, respectively. Fig. 6 and Fig. 7 were measured at 100°C substrate temperature. Fig. 8 was measured with the same thicknesses. In these figures, QE was measured with the blue laser. Fig. 6 shows that QE is high around 200Å Sb thickness and Fig. 7 shows QE is not sensitive to K thickness. Fig. 8 shows QE is sensitive to substrate temperature and QE is maximized at 100°C substrate temperature. In all of these measurement, QE is over 3% with the blue laser. The reproducibility and more detail of the relations will be confirmed.

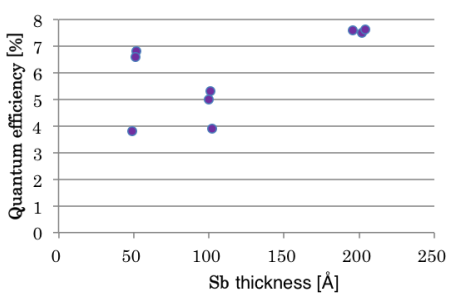

Figure 6: Relation between Sb thickness and QE.

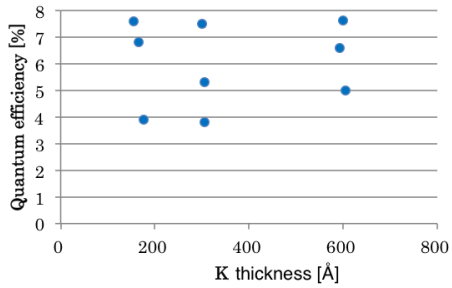

Figure 7: Relation between K thickness and QE.

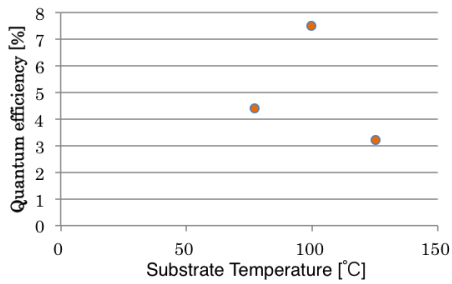

Figure 8: Relation between substrate temperature and QE.

SUMMARY

We studied CsKSb multi-alkali cathode as a good candidate of advanced accelerator concepts. We measured QE and lifetime of the milt-alkali cathode and thicknesses and substrate temperature dependences were studied. Dark lifetime was about 3500 hours. Charge density lifetime is estimated to 8300C/mm^2 by assuming an identical dark lifetime for 532nm and 473nm laser. An uniform QE distribution more than 6% (473nm) is obtained by Cs over-evaporation. Temperature and thickness dependences were studied and we found that QE is high around 200Å Sb thickness and not sensitive to K thickness. QE is sensitive to substrate temperature and QE is maximized around 100°C. Reproducibility of the measurement will be confirmed.

ACKNOWLEDGEMENT

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