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CSKSB PHOTOCATHODE R&D WITH HIGH QUANTUM EFFICIENCY AND LONG LIFETIME

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Abstract

Advanced electron linear accelerator such as Energy Recovery Linac and Free Electron Laser needs high brightness electron source. Photocathode is suitable for the high brightness requirement because some of them has low emittance and high quantum efficiency. In the photocathode, CsKSb multi-alkali photocathode has excellent features: high quantum efficiency, long lifetime, and driven by visible light, for example green laser. Therefore, the multi-alkali photocathode is considered to be one of the best candidates for the high brightness electron source of the advanced electron accelerator. We report developments of our evaporation system and results of quantum efficiency and lifetime measurement in Hiroshima University. Multi-alkali surface analyzation has being measured by ultra-violet photoemission spectroscopy to study conditions between the multi-alkali performances and the surface condition in Institute Molecular Science. We also report the status of the progress abort the study.

INTRODUCTION

Photocathode can generate a low emittance and short pulse beam by conditioning the spot size and pulse length of a laser, comparing to thermal cathode. The photocathode is essential device for high brightness electron source in advanced electron Linac such as Energy Recovery Linac (ERL) [1] or Free Electron Laser (FEL). For example, ERL requires high average current electron beam in range of 10~100mA and low emittance down to 0.1 mm.mrad.

Generally, a laser with shot wave length has lower power than that with long wave length. Multi-alkali cathode has high Quantum Efficiency (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. Therefore, the multi-alkali photocathode is considered to be one of the best candidates for the high brightness electron source of the advanced electron accelerator. 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 QE and the cathode lifetime, in Hiroshima University. Multi-alkali surface analyzation has also being measured by ultra-violet photoemission spectroscopy to study conditions between the multi-alkali performances and the surface condition in Institute Molecular Science (IMS). In our evaporation system, antimony(Sb), potassium(K), and cesium(Cs) are evaporated one by one in an extremely high vacuum condition, typically 4×10^{-9}Pa as a base pressure.

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EVAPORATION SYSTEM

In Hiroshima University, evaporation system for multi-alkali cathode study was originally constructed. The schematic layout in the evaporation chamber is shown in Fig. 1. The multi-alkali cathode is made by the evaporation system, and its properties and performances are measured. We can extract the photo-current by a laser irradiating a substrate through a view port and QE and the cathode lifetime are measured. To monitor evaporation thickness for each materials, a quartz thickness monitor is implemented in the system. Additionally, the cathode substrate and the thickness monitor are placed symmetrically around the evaporation source to measure the thickness simultaneously during the evaporation. The evaporation source is also designed to generate the vapor symmetrically. A ceramic heater mounted behind the substrate and the substrate temperature is monitored and controlled by a thermo-coupler. For the simultaneous measurement of QE and thickness, the laser light illuminates the substrate diagonally in order to avoid interference between laser light and the substrate. The substrate made by 30mm×30mm SUS304 is used. QE map on the substrate can be obtained by scanning the laser irradiation area on the substrate with moving stage mounted on mirror. This QE mapping is performed by a green laser first, and performed by a blue laser second. The mapping is done every two hours. It takes 12 minutes to get these both QE map and laser irradiate a special point we chose during the other time of the interval, two hours. Blue laser which has about 2.3mW power and 405nm wave length and green laser which has about 0.45mW power and 532nm wave length on the substrate are used in our experiment.

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 10^{-8} ~ 10^{-7}Pa during evaporation.

RESULTS

Cathode Evaporation Experiment

CsKSb 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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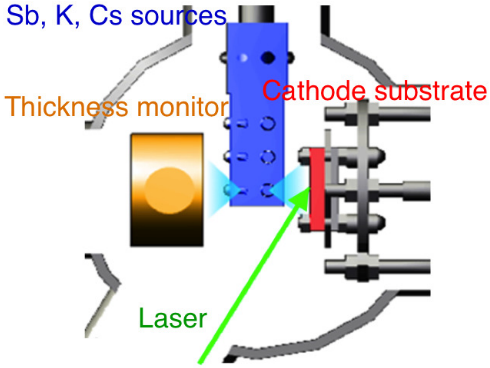

Figure 1: A schematic drawing of evaporation system in Hiroshima University.

5. The substrate is cooled down to room temperature.

During evaporation, QE is measured simultaneously. This procedure is referred to [3].

An evaporation experiment with this procedure is shown by Fig. 2. QE was measured with the blue laser. During Sb evaporation, QE was very low. QE rose during K evaporation and was increased rapidly when Cs evaporation started. Finally, QE was reached to around 9% with the blue laser. We measured the QE map and lifetime with this cathode. In this report, we ignore the reduction of laser power by passing through view port. If we consider the reduction, QE with blue laser is about 1.25 times higher and QE with green laser is 1.1 times higher according to the specifications of the view port.

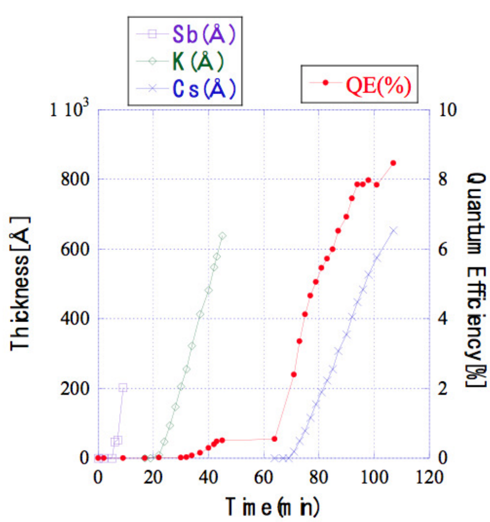

Figure 2: Time course of QE and evaporation thicknesses.

Cathode Lifetime Measurement

As cathode degradation, two kinds of phenomenological definitions are considered. One is regarding to time, lifetime. The other is regarding to charge density extracted from the cathode. This is called as charge density lifetime.

In this report, we estimate cathode lifetime as follows:

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

specially, charge density lifetime is also considered at a continuously irradiated area,

$$\eta(t,\rho) = \eta_0 \exp(-\frac{\rho}{\Theta}), \quad (2)$$

where, η is QE, η_0 is initial value of QE, t is time, τ is lifetime, ρ is extracted charge density, Θ is charge density lifetime. The result of lifetime measurement with the blue laser is shown in Fig. 3. Lifetime τ is estimated by Eq. 1 to be 5300 ± 80 hours that is correspond to about 7 months. It is long enough for accelerator operation.

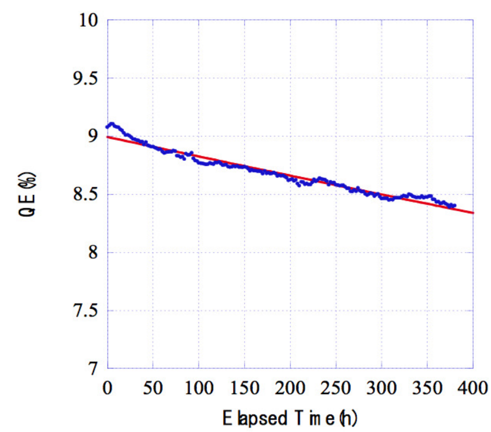

Figure 3: QE degradation as a function of time with blue laser at continuously irradiated area.

The charge density lifetime is also measured at continuously irradiated area. In this measurement, the blue laser spot size was 0.63mm^2, average current was 67μA, and vacuum pressure was about $4{\times}10^{-8}$Pa. Charge density lifetime can be derived according to Eq. 2. The result is shown in Fig. 4. Charge density lifetime Θ is estimated to $1830\text{C/mm}^2 \pm 30$.

QE map measurement

The substrate is scanned every 3 mm for each axis for QE mapping. QE map is measured every two hours for 6 minutes with each laser. Any other time of QE mapping, the laser irradiated to an area we chose. Fig. 5 shows QE map with blue laser on the substrate. Black circle in the figure shows a continuously irradiated area.

Since QE mapping is performed every constant time, we can show lifetime map (hour) on the substrate as shown Fig. 6. The figure shows lifetime at continuously irradiated area is almost same as that of around the area. Therefore, QE degradation by the extracted current 67μA seems to be small compared to the degradation of lifetime, according to this measurement result.

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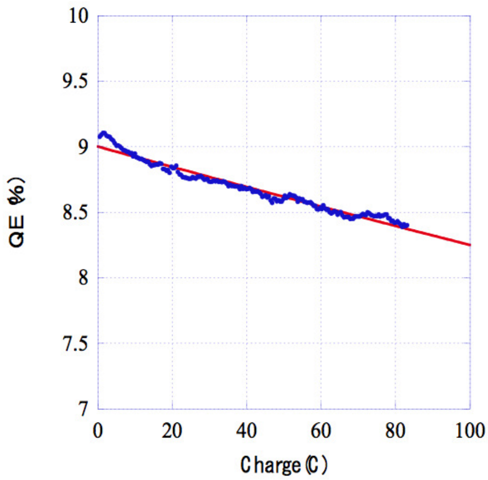

Figure 4: QE degradation as a function of extracted charge with blue laser at continuously irradiated area.

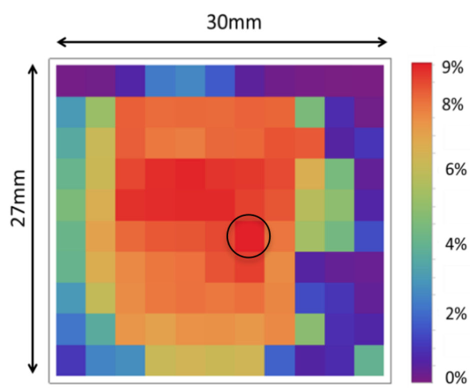

Figure 5: QE map with blue laser on the substrate.

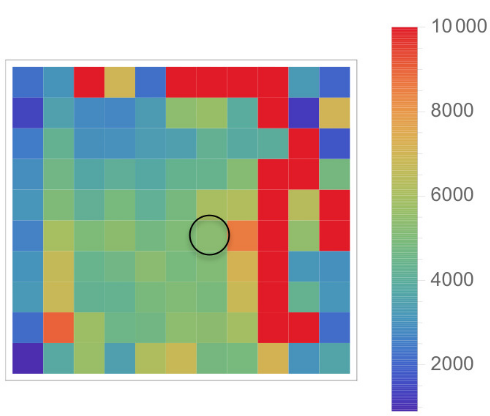

Figure 6: Lifetime map with blue laser on the substrate (hour).

Photoemission Spectroscopy

Ultraviolet photoemission spectroscopy (UPS) measurement is starting to study conditions between the multi-alkali performances and the surface state. We newly established and developed an evaporation chamber in IMS. The chamber is attached with UPS measurement chamber and a cathode folder evaporated by CsKSb in the evaporation chamber can be transferred to UPS measurement chamber. As a substrate, Si is used. Fig. 7 shows an example of UPS spectrum for CsKSb. UPS spectral shift by time progression will give important information about the cathode degradation process.

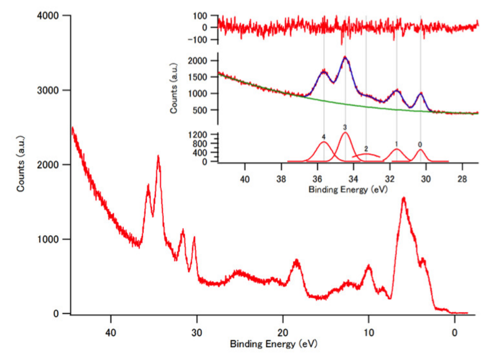

Figure 7: Multi-alkali UPS spectrum as a function of binding energy.

SUMMARY

We studied CsKSb cathode as one of best candidate of advanced accelerator concepts. Our measurement system is upgraded so as to obtain QE map with two kinds of laser and two kinds of lifetimes on the substrate. Lifetime was about 5300 hours at the continuously irradiated area and about 5000 hours around continuously irradiated area under vacuum pressure 4×10^{-8} Pa. Charge density lifetime was estimated to 1830 C/mm^2 under following conditions: the extracted current 67 μA, vacuum pressure 4×10^{-8} Pa, with the blue laser. In 18mm × 18mm area on the substrate, about 8% QE and 5000 hours lifetime was obtained with the blue laser. QE degradation by the extracted current 67 μA seems to be small according to our measurement result.

Multi-alkali surface was measured by ultra-violet photoemission spectroscopy. We newly established evaporation device and developed in IMS. We will study the relationship between UPS spectral change and temperature or degradation process.

ACKNOWLEDGEMENT

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REFERENCES

[1] Design Study of Compact ERL, KEK-Report 2007-7 (2007).
[2] B. Dunhum et al., Appl. Phys. Lett. 102, 034105 (2013).
[3] M. Kuriki et al., proc. of IPAC2013, MOPFI013 (2013).