A STUDY OF OPERATIONAL LIFETIME OF CsK$_2$Sb PHOTO-CATHODE*

M. Kuriki[†], A Yokota, K. Negishi[††], R. Kaku, M. Urano,
Hiroshima University, Higashiiroshima, Japan
Y. Seimiya High Energy Accelerator Research Organization, Tukuba, Japan

Abstract

A high performance electron beam generated with a laser photo-cathode is one of the most important pieces in the advanced accelerator. Because the CsK2Sb photo-cathode is robust with more than 10 % quantum efficiency (QE) by green laser (532nm), it is considered to be the best candidates of the cathode for Energy Recovery Linac (ERL) and Free Electron Laser (FEL) requiring a high brightness beam. We developed a system to evaporate the cathode as a thin film in vacuum to study the cathode performance. The cathode operational lifetime regarding not only on time, but also extracted charge density was studied. We found the lifetime is long enough for practical use in an accelerator.

INTRODUCTION

Next generation accelerator project based on linear accelerator such as linear colliders [1], FEL[1] and ERL [1] are being studied and developed in recent years. In the linac, the electron beam performance can be superior than that in a storage ring. To overcome the beam performance by the storage ring, the beam quality from the electron gun has to be better than that in the storage ring. In addition, we have to provide a large current beam which is equivalent to that in the storage ring, too. In a linear colliders (ILC and CLIC), polarized electron beam plays a critical role. Photo-cathode electron gun satisfies these requirements.

The robustness and the quantum efficiency (QE) of the photoelectric effect (ratio of the numbers of laser photon and photo-electron) of a cathode are always practical issues for the photo-cathode. For example, NEA (Negative Electron Affinity)-GaAs, a kind of photocathode, has high QE, more than 10% at 530nm and can be excited by red and infrared light, but the NEA surface is fragile [2]. On the other hand, metal cathode (Cu, Mg and so on) is very robust, but QE is very low ($\sim 10^{-5}$) and need UV light for the excitation. Hence, it is difficult to generate high current electron beam with these cathode.

Recently, multi-alkali photocathode formed with more than two kind of alkali metals, is paid attention. This cathode is robust among semiconductor cathodes, has high QE more than 10% at 532nm, and can be excited by a green light. According to these reasons, this cathode is suitable to generate a high brightness electron beam for FEL, ERL, and laser Compton X-ray source. Multi-alkali photocathode has been used cathode in PMT, but less experience as cathode for accelerators.

In Hiroshima University, CsK2Sb multi-alkali photo-cathode is studied because of these advantages [3] [4]. We developed a vacuum chamber to perform the CsK2Sb evaporation and cathode performance test. In this article, we describe the test chamber followed by the cathode evaporation and life time measurement.

EXPERIMENTAL SETUP

Multi-alkali Test Chamber

The test chamber in Hiroshima University is made from SUS electrically polished. Ultrahigh vacuum in order of 10^{-9} Pa is kept with a NEG pump and ion pump. Figure 1 shows the schematic drawing of the evaporation system in the test chamber [8][9]. The cathode is evaporated on a 31 mm x 31 mm substrate made of SUS304. The substrate is mounted on a holder with a ceramic heater for the heat cleaning and temperature control. The holder is electrically isolated from the ground and is biased with a DC voltage supply. The typical bias voltage is -100 V. The evaporation head where the sources are mounted on, generates the metal vapour symmetry to the substrate and the quartz thickness monitor, so that we can monitor the amount of the evaporated metal on the substrate simultaneously. Laser light can be introduced through a view port to observe photo-electron emission. To monitor the vacuum environment, an extractor vacuum gauge and RGA (Residual Gas Analyzer) are placed.

QE 2D Mapping

To measure QE distribution on the cathode two dimensionally, we have developed a laser scanning system. The laser position is controlled in x and y direction (transverse plane to the cathode) by moving two oblique mirrors. The mirror position can be moved with two linear stages controlled by PC. With this system, the temporal evolution of the QE distribution can be obtained. In the experiment, the data was obtained with the following sequence. The QE distributions were taken with 532 nm and 405 nm laser, respectively. The step size was 3 mm. After the scan, 405 nm laser illuminates on a specific cathode position continuously. This sequence is repeated every two hours. In this experiment, the extracted current density of the specific position is significant, but the current density of the other place is negligible. By comparing the QE evolution on these two positions, we can extract the effect of the extracted current density on the cathode lifetime.

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† mkuriki@hiroshima-u.ac.jp
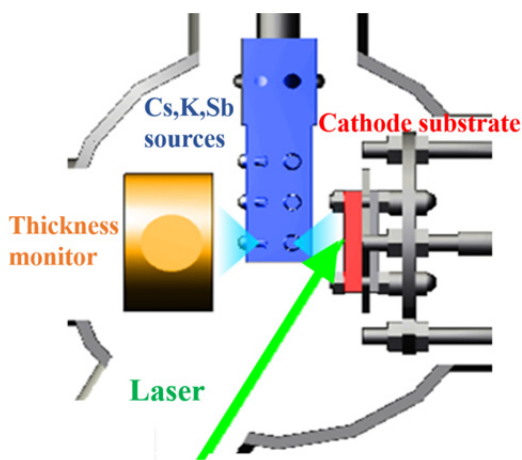†† Current affiliation is Iwate University, Morioka, Japan.

Figure 1: Layout of inside of the evaporation chamber. The evaporation head generates metal vapor symmetrically to quartz thickness monitor and SUS substrate.

RESULTS AND DISCUSSION

CsK₂Sb Evaporation

Multi-alkali photocathode is produced by evaporating Sb, K, and Cs in this order according to the previous studies [5][6][7]. The typical procedure of evaporation is

1. Heat cleaning substrate at 600 ℃ for 1 hour.
2. Cool down the temperature of substrate to 100℃
3. Evaporate Sb up to predefined thickness.
4. Evaporate K up to predefined thickness.
5. Evaporate Cs to maximize QE.
6. Decrease the temperature of substrate to room temperature.

In this study, QE is defined by the number of emitted electrons over the number of incident photons.

Figure 2 shows an example of QE evolution measured by 405 nm laser. QE became significant in K evaporation. QE was then enhanced in Cs evaporation. Finally, QE reached up to 11.6%.
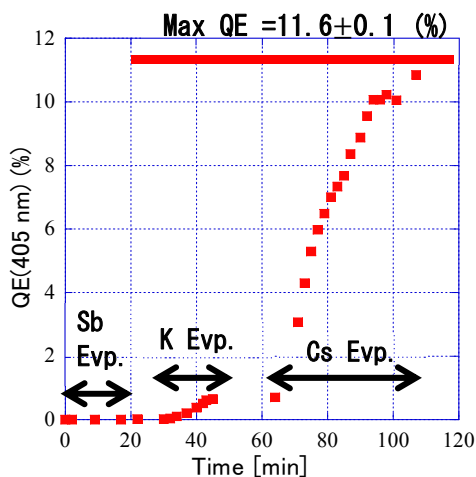

Figure 2: QE evolution during the evaporation process. Sb, K, and Cs was evaporated on SUS substrate in this order. QE measured by 405 nm laser was launched during K evaporation and much enhanced in Cs evaporation.

Lifetime Analysis

In a practical use of photo-cathode as the electron source in an accelerator, the operational lifetime is important. It is critical for accelerator operating in high average current such as ERL SR facility up to 100mA. QE of cathode is known to deteriorate by several processes such as adsorption of residual gas, etc. In this study, we assume two components of cathode QE degradation. One is regarding to time and we call this component as "temporal lifetime", and the other is regarding to the extracted charge density and we call it as "charge density lifetime". Assuming these two components of the cathode lifetime, the QE evolution is described as

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

η and η_0 shows QE and its initial value, t is time, τ is the temporal lifetime, ρ is amount of the extracted charge density, Θ is the charge density lifetime. In the acquired data points, except the point where the laser was continuously illuminated, the charge density is negligible[8]. In this article, we concentrated on the temporal lifetime. Figure 3 shows QE evolution of several of these points. QE was measured by 405 nm laser in this figure. We evaluated the average of the temporal lifetime over the data points with the initial QE more than 10 %. That was 6200 ± 1700 ± 400 hours (405 nm), and is 2200 ± 400 ± 300 hours (532 nm). In this measurement, the average vacuum pressure was 2.5×10^{-8} Pa. First error of τ is the dispersion of individual τ, and second error is statistical error.
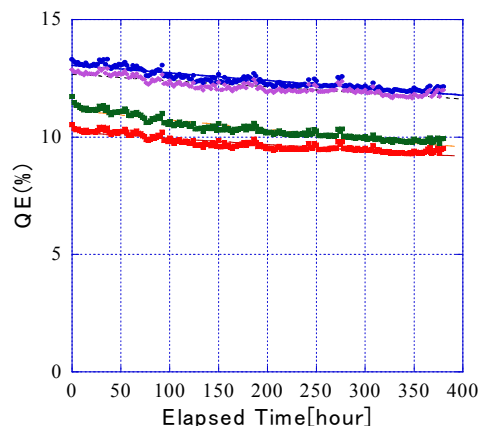

Figure 3: QE evolution of the cathode where the extracted charge density is negligible. Data of typical four positions are shown. By fitting these data to the formula, we evaluated the temporal lifetime.

If the temporal lifetime is caused by residual gas adsorption on the cathode surface and the process is in first order, the lifetime is supposed to be inversely proportional to the vacuum pressure as long as the vacuum content does not change during the experiment. To examine this speculation, we carried out the lifetime measurement again at the different vacuum pressure, by turning off the

ion pump. Figure 4 shows the temporal lifetime as a function of the average vacuum pressure. Blue solid circle and green solid circle show that measured by 405 nm laser and measured by 532 nm laser respectively. Blue solid curve and green dashed curve are fitting curves to the data by assuming $\tau = C/P$, where P is vacuum pressure, C is a constant. Looking at figure 4, data points agreed well to each curves except a few points.

The experiment was performed after the substrate was exchanged to a new one. To confirm the effect of this exchange, we plotted the results according to order of measurements in Fig. 5. The vertical axis is a product of τ and vacuum pressure (normalized temporal lifetime) to compensate the vacuum pressure dependence. Horizontal axis shows the order of measurement. Blue and green solid circles show the data measured by 405 nm laser and 532 nm laser, respectively. We exchanged the old substrate (SUS) for the new substrate after the second measurement. In the third and fourth measurements, the results were significantly lower than the others, but it was back to the "nominal" value in the fifth measurement and later. The cathode formed on a virgin substrate might have different performance. We will study this issue to analyse the vacuum content using QMS (Quadruple Mass Spectrometer).
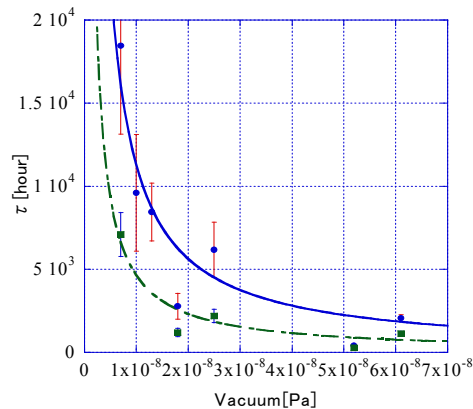
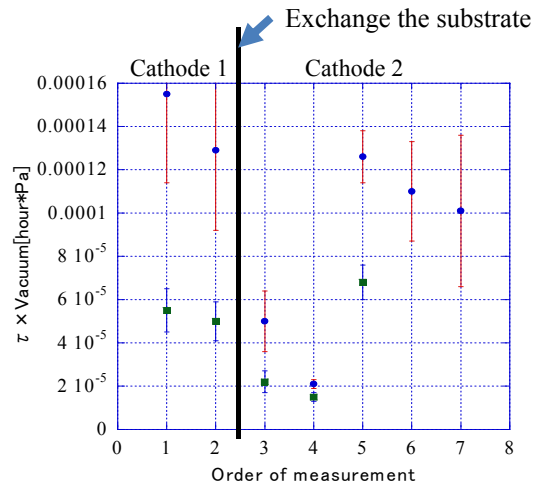Figure 4: The temporal lifetime of the cathode as a function of vacuum pressure.

Figure 5: The normalized temporal lifetime in order of the measurements. Blue solid circle and green solid square show the that measured with 405 nm and 532 nm lasers.

SUMMARY

We developed a system to study CsK_2Sb multi-alkali photo-cathode. We find the recipe to evaporate CsK_2Sb cathode which has 12% QE (measured by 405 nm laser) and 3% QE (measured by 532 nm laser). It is confirmed that CsK_2Sb cathode has the temporal lifetime of in order of thousands hours and it is enough for a medium current accelerator. According to the study of the vacuum pressure dependence of the temporal lifetime, it was inversely proportional to the vacuum pressure. The substrate condition and/or the vacuum content have a significant effect.

ACKNOWLEGEMENT

REFERENCE

[1] Design Study of Compact ERL, KEK-Report 2007-7, 2007.

[2] Photocathode-wiki,
    http://photocathodes.chess.cornell.edu/wiki/

[3] C. Ghosh and B. P. Varma, *J. Appl. Phys.* 49, 4549, 1978.

[4] B. Dunham *et al.*, "Photocathode Development for the Cornell Injector", presented at ERL'11, 2011.

[5] D.H. Dowell *et al.*, Nucl. Instrum. Methodes Phys. Res. A 356, page167-176 (1995).

[6] L. Cultrera *et al.*, in *Proc. PAC'11*, 2011, paper WEP244.

[7] J. L. McCarter *et al.*, presented at PAC'11, 2011.

[8] M. Kuriki *et al.*, in *Proc. IPAC'13*, 2013, paper MOPFI013.

[9] N. Yamamoto, in Proc. *10th Annual Meeting of Particle Accelerator Society of Japan,* Nagoya, Japan, Aug. 3-5, 2013.