# LIFETIME STUDY OF CsK2Sb ROBUST PHOTO-CATHODE FOR A HIGH BRIGHTNESS ELECTRON SOURCE

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*Abstract*

$CsK_2Sb$ photocathode is one of the ideal cathode for accelerators requiring the high brightness electron beam. It can be driven with a green laser generated as SHG of a solid state laser. The QE (Quantum Efficiency) of photoelectron emission is as high as more than 10% with 532nm light. In this article, the robustness of the cathode is studied. Two indexes of lifetime regarding to time and extracted charge density were evaluated experimentally. The result shows that the cathode is robust enough for a high brightness accelerator.

## INTRODUCTION

Next generation accelerator project based on Linac such as linear colliders, ILC [1], FEL [2] and ERL [3] are under being studied and developed in recent years. In the linac, the electron beam performance can be superior to what is in a storage ring, but 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.

Photo-cathode electron gun is a device which generates electron beam by photoelectric effect by laser light. This electron gun has superior performance (low emittance, short pulse, spin polarization, etc.) by high operability with laser. For example, in a linear colliders (ILC and CLIC), polarized electron plays an important role and the photo-cathode is the only way to generate such beam practically. The photo-cathode with an optimized laser (spot size, temporal length, and wavelength) gives a minimum emittance. To provide such high performance beam with a required time structure and intensity, quantum efficiency (QE) of photoelectric effect (ratio of the numbers of laser photon and photo-electron) of the cathode should be high enough and should be maintained for a reasonable period. Otherwise, we need a huge power laser and/or frequent cathode replacement. The QE and the robustness are always practical issues for the photo-cathode. For example, NEA (Negative Electron Affinity)-GaAs [4] has a high QE (more than 10% at 530nm), but the cathode function is easily lost by residual gas molecules such as $H_2O$, $O_2$, etc. On the other hand, metal cathode (Cu, Mg, Pb and so on) is much robust, but QE is typically low ($10^{-4}$~$10^{-5}$) and need UV light for the excitation. Therefore, they are not suitable to generate high current electron beam.

Recently, multi-alkali photocathode is paid attention for the high brightness beam generation. This cathode is formed by evaporation with more than two kind of alkali metals. The high robustness is already demonstrated [5] and QE is as high as more than 10% at 532 nm [6]. According to these reasons, this cathode is suitable to generate a high brightness electron beam for FEL, ERL, and X-ray source by laser Compton scattering.

In Hiroshima University, $CsK_2Sb$ multi-alkali photocathode for the electron source of Linac is studied to establish the technique to develop the high performance cathode and understand the property of the cathode [6]. In this article, the $CsK_2Sb$ cathode was evaporated on a substrate in a high vacuum environment and examined the cathode performance to evaluate the cathode robustness.

## EXPERIMENTAL SETUP

### *Multi-alkali Test Chamber*

In this chapter, we explain the multi-alkali test chamber in Hiroshima University. This test chamber is made from SUS and the inner surface was electrically polished. Ultra-high vacuum in order of 10-9 Pa is kept with a NEG pump and an ion pump. Figure 1 shows the schematic drawing of the evaporation system in the test chamber [5]. The cathode is evaporated on a 31 mm x 31 mm substrate made of SUS304 whose surface was finished with the electrical polishing. 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 to measure the beam current. The typical bias voltage is -100 V. The evaporation head where the sources are mounted, generates the metal vapour symmetry to the substrate and the quartz thickness monitor. Owing to this system, 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 during the evaporation. To monitor the vacuum environment, an extractor vacuum gauge and QMS (Quadruple Mass Spectrometer) are placed.

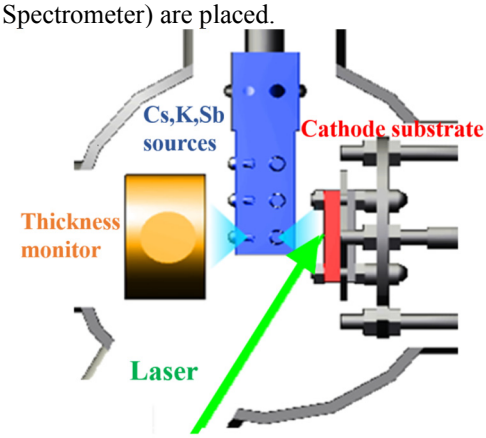


Figure 1: Layout of inside of the evaporation chamber.

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### *QE 2D Mapping*

To measure QE distribution on the cathode and measure the lifetime of the cathode two dimensionally, we have developed a laser scanning system. The laser position is controlled in x and y direction which are parallel to the cathode. 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 spatial step size was 3 mm. After the scan, 405 nm laser illuminates on a specific spot of the cathode 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.

## RESULTS AND DISCUSSION

### *$CsK_2Sb$ Evaporation*

Multi-alkali photocathode is produced by evaporating Sb, K, and Cs in this order according to the previous studies [7-10]. The typical procedure of evaporation is

1. Heat-cleaning substrate at 600 ℃ for 1 hour.
2. Cool down the temperature of substrate to 120℃.
3. Evaporate Sb up to predefined thickness.
4. Evaporate K up to maximize QE.
5. Cool down the temperature of substrate to 100℃
6. Evaporate Cs to maximize QE.
7. Decrease the temperature of substrate to that of room.

In this study, QE is defined by the number of emitted electrons over the number of incident photons. In evaporation, QE became significant in K evaporation. QE was then enhanced in Cs evaporation. Finally, QE reached up to 12.1% measured by 405 nm laser.

### *Lifetime Analysis*

In a practical use of photo-cathode as the electron source in an accelerator, the operational lifetime is important. It could be very critical for a high current and high duty accelerator. To examine the cathode operational lifetime, we assume two components of the cathode lifetime, one is regarding to time (temporal lifetime) and another is regarding to the charge density (charge lifetime). Assuming these two components of the cathode lifetime, the QE evolution can be described as

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

$\eta$ and $\eta_0$ are QE and its initial value, $t$ is time, $\tau$ is the temporal lifetime, $\rho$ is the extracted charge density, $\Theta$ is the charge density lifetime. In the acquired data points, except the point where the laser was continuously illuminated, the charge density is negligible [5] [8]. Figure 2 shows QE evolution of several 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 % to pick up the area where the cathode is successfully formed. The results were 6200 ± 1700 ± 400 hours (405 nm), and is 2200 ± 400 ± 300 hours (532 nm) [5]. In this measurement, the average vacuum pressure was $2.5\times10^{-8}$ Pa. First error of $\tau$ is the RMS of individual $\tau$, and second error is statistical error.

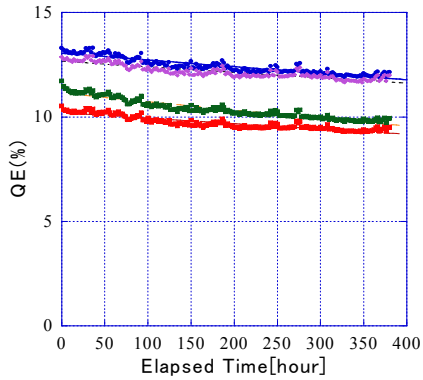


Figure 2: QE evolution of the cathode where the extracted charge density is negligible. Data of typical four positions are shown. By fitting these data to the formula, we evaluated the temporal lifetime [5].

If the temporal lifetime is dominated 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. We measure the lifetime under the different vacuum pressure, by turning off the ion pump and change the amount of derived current to examine the hypothesis. Figure 3 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 described,

$$\tau = \frac{C}{P} \qquad (2)$$

where $P$ is vacuum pressure (Pa), $C$ is a constant (hour ×Pa). Looking at figure 3, data points agreed well to each curves. The constant $C$ is $1.1\times10^{-4}$ for 405 nm laser and $4.6\times10^{-5}$ for 532 nm laser. Because the $\tau$ measured by 405 nm is larger than that of 532 nm. The constant $C$ of 405 nm laser is larger than that of 532nm.

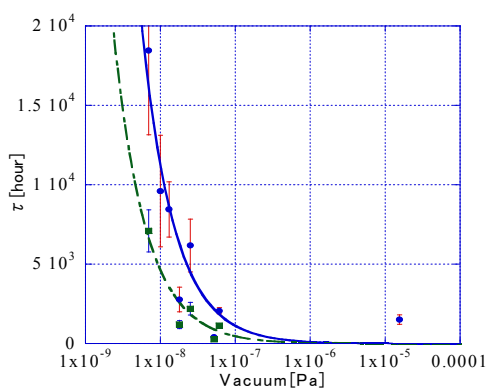



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Figure 3: The temporal lifetime of the cathode as a function of vacuum pressure.

### *Charge Density Lifetime*

The charge density lifetime is obtained by measuring QE evolution as a function of the extracted charge density. The spot size of the 405nm laser is about 0.6 mm$^2$ and the photo-current is typically 70 μA. The average vacuum pressure was $2.5\times10^{-8}$ Pa. Figure 4 shows QE evolution as a function of the charge density. The red and green solid circles show the measured and corrected QE, respectively. The correction is to remove the component of the temporal lifetime as shown in eq.(1). The corrected QE is obtained multiply the measured QE with $\exp(t/\tau)$, where $\tau$ is the average of the measurement, $\tau$ = 7900 hours. Green dashed and red solid lines show fitting curves to the data by assuming the exponential function as shown in Eq.(1), respectively. The charge density lifetime $\Theta$ was found to be $8000\,^{+3000}_{-2000}$ ± 2000 C/mm$^2$. The first error is coming from error of $\tau$ used in the correction, and the second error is the statistical error. This result indicates the high robustness of the cathode for the charge extraction.

Vacuum pressure dependence of $\Theta$ was examined. We measured $\Theta$ in two different vacuum pressures as summarized in Table 1. If the charge density lifetime was caused by residual gas, e.g. ion effect generated by the electron beam, the lifetime should be inversely proportional to the vacuum pressure. The result in Table 1 show that there is no vacuum pressure dependence on the lifetime, or, at least, two numbers are consistent within error.

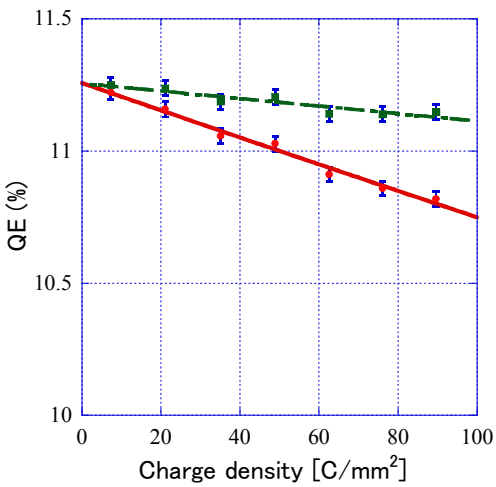


Figure 4: red and green solid circle show that total QE degradation and QE degradation caused by extracted charge effect, respectively.

Several issues in our measurement can be pointed out. One is feasibility of the correction by the temporal lifetime. We assume that it is common over the cathode area, but it could depend on the position. The second issue is the accuracy of the measurement. $\Theta$ and $\tau$ are, fortunately, too large and the correction could enhance the experimental error. One way to solve this issue is to increase the laser power to compensate the experimental error by "accelerating" the cathode degradation. We introduce a higher power laser for this purpose. The specification of the laser is as follows; wavelength is 405 nm, MAX power is 3000 mW, beam divergence is 100mrad. With an appropriate focus optics, the spot was 16 mm$^2$ in 4σ diameter giving power density of 48 mW/mm$^2$ which is 10 times larger than the current system. With this high power laser system, we will measure the charge density lifetime, again.

Table 1: The Result of Charge Density Lifetime

| | | |
|---|---|---|
| Vacuum[Pa] | $2.5\times10^{-8}$ | $7.0\times10^{-9}$ |
| Charge Density Lifetime [C/mm$^2$] | $8000\,^{+3000}_{-2000}$ ±2000 | $6000\,^{+2000}_{-1000}$ ±2000 |

## SUMMARY

We developed a system to study CsK2Sb multi-alkali photo-cathode and find the recipe to evaporate CsK2Sb which has 12% QE (measured by 405 nm laser) and 4% QE (measured by 532 nm laser). The temporal lifetime was 6200 ± 1700 ± 400 hours (405 nm) and 2200 ± 400 ± 300 hours (532 nm). The charge density lifetime was $6000\,^{+2000}_{-1000}$ ±2000 (405nm) C/mm2 at 7.0×10-9 Pa. It was confirmed that the temporal lifetime is inversely proportional to the vacuum pressure. To examine the vacuum pressure dependence of the charge density lifetime, we introduce a high power laser to improve our measurement accuracy.

## ACKNOWLDGEMENT

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