STUDY ON CsKSb PHOTOCATHODE FOR THE RF ELECTRON GUN

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Abstract

At Waseda University, we have been developing a Cs-Te photocathode S-band RF electron gun and application experiments of the electron beam. On the experiments, charge amount is important factor, which strongly depends on laser power and photocathode quality. At present, we are studying CsKSb photocathode to increase the charge amount of an electron beam, and to make laser system more simple and lower requirement. As a result of using CsKSb photocathode in the RF-cavity, we obtained as much charge as using Cs-Te photocathode but the lifetime was shorter than that of Cs-Te. In order to lengthen the photocathode lifetime, we tried to coat a protective film on CsKSb photocathode surface. In this conference, we report current status of fabricating coated photocathode and future prospects.

INTRODUCTION

Photocathode is a type of electron source which can emit electrons by photoelectric-effect and widely used in accelerators and photomultipliers. Especially CsKSb photocathode is expected to be a next generation electron source for high current beam extraction since it can emit electrons by visible light such as second harmonic of YAG laser (532 nm). Therefore research and developments of CsKSb photocathode are performed in the world [1, 2]. But the lifetime of CsKSb photocathode is shorter than metal or Cs-Te photocathode (utilized at Waseda University), so ultra-high vacuum environment is required to use CsKSb photocathode. Therefore CsKSb photocathode is generally used for DC electron gun and not for RF-Gun because of poor vacuum condition of RF-cavity. There was one report from D. H. Dowell et al. [3] that high current beam operation with CsKSb photocathode in the Boeing 433 MHz RF-cavity had been succeeded. However the robustness of CsKSb photocathode for strong RF field such as 100 MV/m is not clear.

Waseda University has a UHV photocathode fabrication chamber and S-band RF electron Gun with Cs-Te photocathode for application experiments such as coherent THz radiation [4], Laser Compton Scattering [5] and pulse-radiolysis. We started to research the optimum fabrication method of CsKSb photocathode for the RF-Gun and to research the possibility of its usage in S-band RF-cavity. As a result of beam generation test with CsKSb photocathode in RF-Gun, we judged that the durability of our CsKSb photocathode is not enough for the vacuum condition of cathode transport system and RF-cavity.

For making longer lifetime photocathode, we have been trying to coat the CsKSb surface by CsBr film that is chemically sustainable in the air pressure. A. Buzulutskov et al. [6] reported that CsKSb photocathode protected by CsBr film whose thickness is 28nm maintained the Q.E. (@416 nm) for 5 minutes in 150 Torr vacuum condition. Their research was for photon detector and there is no example that protected CsKSb photocathode is used in electron accelerator. In this Conference we report the result of beam generation with CsKSb photocathode in S-band RF-Gun and the present state of making surface protected CsKSb photocathode.

EXPERIMENTS

Photocathode Evaporation & Operation Test

CsKSb photocathode is fabricated by sequential evaporation process in UHV chamber at Waseda University. Figure 1 shows external appearance of the photocathode evaporation chamber. Internal space is evacuated by scroll pump, two turbo molecular pumps, ion pump, two NEG pumps and pressure can reach to $4\times10^{-8}\ Pa$~$4\times10^{-7}\ Pa$. We can use two types of substrate in this chamber; Mo plug which can be inserted in RF-cavity, and Mo plate with heat cleaning system.

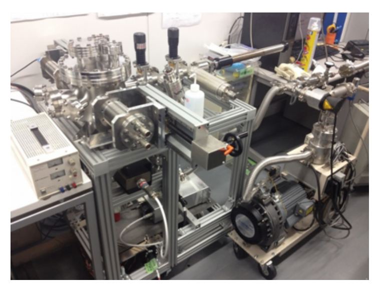

Figure 1: Photocathode evaporation chamber.

In fabricating CsKSb photocathode, substrate heating typically makes final quantum efficiency higher but we don’t have a system which can heat up the Mo cathode plug. So we have researched optimum evaporation method without substrate heating. Basic cathode evaporation procedure at Waseda University is following. First, Antimony is evaporated around 20 nm~100 nm on the substrate. And Potassium is evaporated until Q.E. at 262nm or 532nm light reaches maximum value. Prove light is generated by a Xe flash lump and a monochrometer. Finally, Caesium is evaporated until Q.E. reaches peak value. Usually Q.E increases Just after the Caesium evaporation finished. By this method we can obtain CsKSb photocathode with the Q.E. 0.5 %~2.5 % at 532 nm light.

We fabricated a CsKSb photocathode film on Mo plug and transported to the RF-cavity with the transfer rod. The Q.E. of the cathode in fabrication chamber was 1.6 % at 532 nm light. After the insertion of cathode plug in RF-gun, beam generation test was carried out. The incident laser to the cathode is 523 nm light: second harmonic of Nd: YLF laser.

CsBr Coating

We evaporated CsBr film on the CsKSb surface just after fabrication of CsKSb. CsBr fragment was quarried from disk-shaped window material (Pier Optics Co., Ltd. Japan) and set on the evaporation source holder. In this experiment, we evaporated CsBr at the evaporation rate 0.1~0.3 Å/s and final thickness of 5.2~9.0 nm.

After CsBr coating, we kept measuring Q.E. for several days in the evaporation chamber and compare the lifetime with that of non-coated CsKSb photocathode. In the middle of last year, we discovered first deposition of K on the substrate just before the sequential three evaporation processes makes final Q.E. higher. So we became able to obtain the CsKSb with the maximum Q.E. 3.4 % and the longest 1/e lifetime 1157 hours at 9×10^{-8} Pa.

RESULTS & DISCUSSION

Beam Generation Test with CsKSb Photocathode

For the beam generation test, we fabricated a CsKSb photocathode sample on Mo plug. We succeeded to make a CsKSb film with the final Q.E. 1.6 % at 532 nm. Figure 2 shows the transition of film thickness and Q.E. value during each evaporation process.

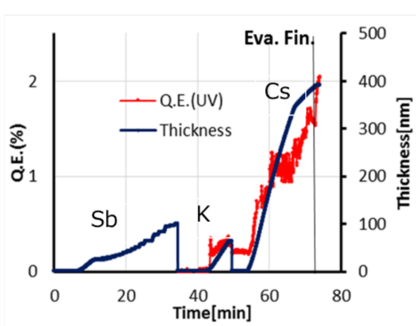

Figure 2: Q.E. transition during the photocathode fabrication. Q.E. was measured with 262 nm light during K and Cs deposition.

The CsKSb photocathode sample was transported from evaporation chamber to the RF-cavity with transfer rod, inner pressure of which is order of magnitude of 10^{-6} Pa. Cathode transport takes about 4hours and it is important to supress the cathode degradation during this process.

After the new cathode was installed in the RF-gun, we must perform cathode conditioning in the strong RF-field. The result of beam extraction test during the cathode conditioning phase is shown in figure 3. A large jump of extracted charge happened while raising RF power. This is considered to be surface cleaning effect of electric discharge or ion back bombardment due to the strong RF-field. Maximum charge amount during conditioning process was 4.8 nC/bunch, which is as much charge as when we utilized Cs-Te photocathode and UV pulse laser (wavelength: 262 nm) at Waseda University. And the maximum Q.E. calculated by green laser power and maximum charge amount is 0.016 %. This value is much smaller than just after the cathode evaporation. That means cathode degradation during transport phase must have occurred.

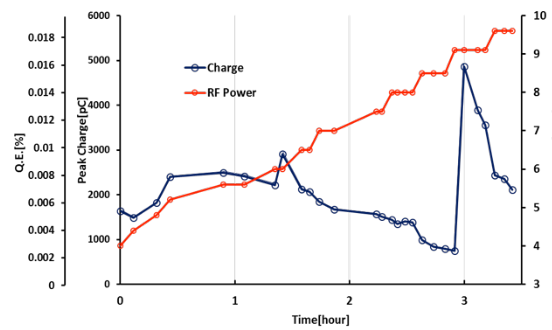

Figure 3: Transition of beam charge during the conditioning process. Blue plot indicates peak charge and converted Q.E. value of each phase scan measurement like figure 4.

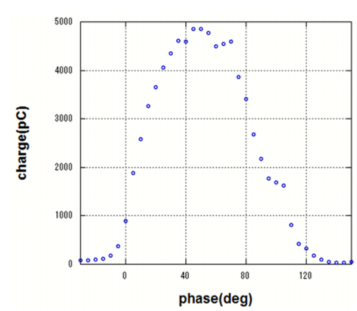

Figure 4: Phase scan by using CsKSb at the maximum Q.E. during the beam generation test.

After the cathode conditioning process, we continued e-beam generation with the RF power fixed and assessed the lifetime of CsKSb photocathode in the RF-Gun. The result of the lifetime measurement is shown in Figure 5. Charge amount decreased to about 300 pC/bunch over half a day. But it repeated rising and declining to maintain more than 200 pC over 33 hours. So we might be able to utilize CsKSb photocathode for applied experiments with low charge requirement for a week or more. The Q.E. value calculated from the final charge amount 288 pC is 0.001 % (wave length: 523 nm): this value is comparable to that of metallic cathode at 262 nm light. To gain higher

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charge amount per bunch and to keep Q.E. high, we have to take measures to the poor vacuum condition in cathode transfer rod and RF-cavity (ex: CsBr coating). Although the effect of strong RF-field (like electric discharge and ion back bombardment) may be one of the reasons of cathode degradation, the effect of poor vacuum environment seems to be larger according to the Q.E. decrease during cathode transport phase.

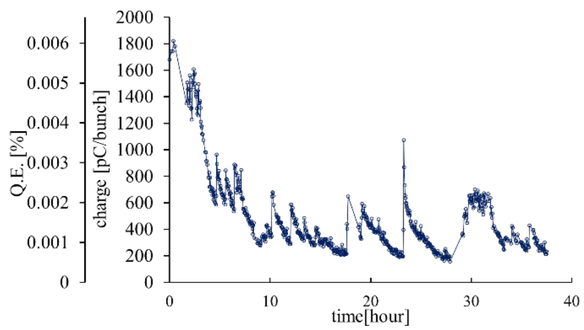

Figure 5: Result of lifetime measurement in the RF-Gun.

Table 1: Summary of Extracted Charge and the Q.E. Value During Lifetime Measurement

	Charge [pC]	Q.E. @ 523 nm[%]
Just after the cathode conditioning	1680	0.006
End of the operation test	288	0.001

CsBr Coating

An example of Q.E. transition during CsBr evaporation on the CsKSb surface is shown in Figure 6. CsBr dep-osition causes Q.E. down, which is acute at present. The extent of Q.E. decrease determines the potential coating thickness and to supress the Q.E. down is important. Table 2 indicates CsBr thicknesses and Q.E. values before and after CsBr coating on two CsKSb photocathode samples.

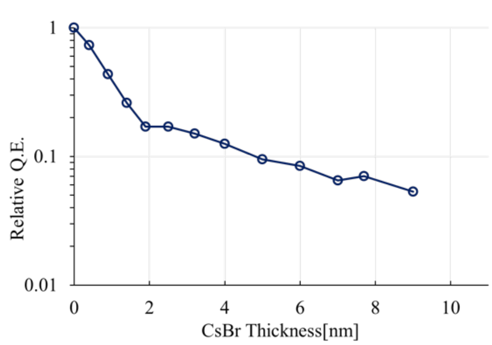

Figure 6: Q.E. transition during CsBr coating on CsKSb photocathode.

Table 2: Detail of the Two Cathode Samples with CsBr Protective Film

Cathode No.	Q.E. before coating (532 nm) [%]	Coating thickness [nm]	Q.E. after coating (532 nm) [%]
#1	0.6	5.2	0.03
#2	2.0	9.0	0.1

It can be assumed that coating thickness influences the lifetime of the cathode. Therefore we researched correlation between CsBr thickness and cathode lifetime. Figure 7 shows the result of lifetime measurement of two cathodes indicated on Table 2. From Figure 7, thicker protective film seems to make cathode more robust. However, the lifetime of coated cathode is shorter than 1/e lifetime of general CsKSb photocathode (at least 200 hours in comparable inner pressure). So much thicker coating film than present is needed to lengthen the cathode lifetime. We are going to try to evaporate CsBr film with better crystallinity so that electrons excited in CsKSb can migrate through the coating film with low energy loss. Our temporary goal is to fabricate cathode with the Q.E. more than 0.1 % (at green light) in spite of 20 nm coating, and to make cathode which maintains Q.E. during cathode transport and long operation of RF-gun.

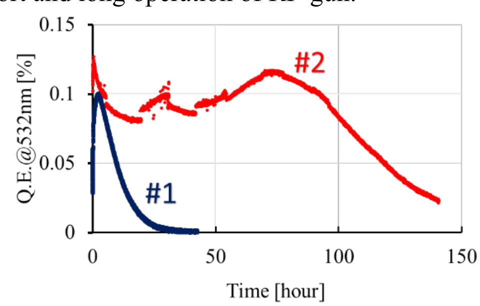

Figure 7: Lifetime of the two cathode samples. Cathode numbers refer to those of Table 2. Inner pressure was 6.8×10^{-8} Pa ~1.2×10^{-7} Pa.

CONCLUSION

We researched optimum fabrication method of CsKSb and performed its usability test in the RF-Gun. We succeeded to gain as much charge as with Cs-Te photocathode. But when the CsKSb cathode was installed in RF-Gun, the Q.E. value had heavily decreased and the lifetime was shorter in the RF-cavity due to the poor vacuum condition. Making robust cathode will enable to gain the much higher charge and the long operation possibility in the RF-Gun.

For making long lifetime cathode, we have been trying CsBr protection on cathode surface. CsBr deposition decreases Q.E. value of cathode and cathode protection with enough thickness film could not be achieved. At present, thicker coating film tend to make cathode more robust. We are going to test the protected photocathode in the RF-gun after positive effect of surface coating in vacuum chamber is verified.

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