COMMISSIONING OF Na_2KSb PHOTOCATHODE RF GUN IN S-BAND LINAC AT THE UNIVERSITY OF TOKYO*

K.Miyoshi†, K.Kambe, A.Sakumi, Y.Muroya, T.Ueda, M.Uesaka
Nuclear Professional School, School of Engineering, The University of Tokyo, Japan

Abstract

We have been developing a compact-sized cartridge-type cathode exchanging system installed in BNL-type IV photocathode RF gun. We can replace a cathode without breaking the vacuum of RF gun, so that a high quantum efficiency photocathode is not surrounded by oxygen or moisture. We propose the Na_2KSb cathode, which has the possibility to drive by visible light of 400 nm (violet range). The work function of Na_2KSb is 2.0 eV, which is lower than the photon energy of 400 nm. We tested the cathode and obtained the quantum efficiency of 1.1% at the wavelength of 266nm. The lifetime of $T_{1/2}$ is more than 100 hours surrounded at the vacuum pressure of 2*10-8[Torr]. To reduce the dark current we got the results by GPT simulation that high quality beam can be transported when the intensity of applied electric field is decreased. We also tested Na_2KSb photocathode by visible light 400[nm].

INTRODUCTION

The application of ultra-fast electron bunches has been attractive research in the field of electron accelerators. The progress of femtosecond electron generations has contributed to XFEL, high energy linear collider and radiation chemistry.

Pulse radiolysis method is a useful and powerful way to study ultra-fast radiation chemical reactions with water or other medicants[1][2]. Especially, the chemical reactions of hot or room temperature and/or critical water in a time-range of picoseconds and sub-picoseconds have been carried out by 18 MeV S-band LINAC system at the University of Tokyo with BNL-typeIV 1.6 cells RF gun.

In order to obtain high-brightness electron beam, we use photocathodes with high quantum efficiency and have been developing a compact-sized cartridge-type photocathode replacement system installed in BNL-Type IV RF gun.

EXPERIMENTAL SETUP

The experimental setup for sub-picoseconds pump- and probe-type radiation chemistry is shown in Fig.1. The S-band linac, which provides an electron bunch as a pump-beam, consists of the photocathode RF gun, an accelerating tube and a chicane-type bunch compressor. Driven laser for RF gun and a probe-laser are generated from a Ti:Sapphire oscillator, which produces a laser light with a wavelength of 795 nm, an energy of 35mJ/pulse, a pulse duration of 100 fs and a repetition rate of 10 pps[1]. The laser and RF pulse of Klystron (and relevant gun and accelerator) are synchronized by using same master Oscillator. The frequency of master Oscillator is 476 MHz, so that we generate sixth harmonic(2856MHz) for the Klystron and sixth sub-harmonic(79.33MHz) for the laser.

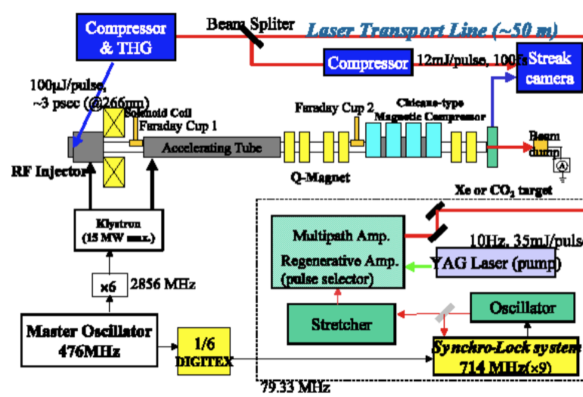

Figure 1: System of 18MeV Photocathode Electron Linac at the University of Tokyo.

The sub-harmonic generator (DIGITEX) also synchronizes detectors or other components. The laser Oscillator is synchronized with the frequency of 714MHz (9th harmonic) and the laser stretches from 100 fs to 300 ps. After the stretcher the laser is amplified and retrieved with the frequency of 10 Hz. In order to achieve good synchronization, we use fs-Ti: Sapphire laser beams which separate to driven laser for RF gun and probe laser: A driven laser is compressed and irradiates to a third harmonic generator (THG), which is provided the third harmonic laser with a wavelength of 265 nm, an energy of 100 J/pulse and pulse duration of several picoseconds. A spot size of the laser on the surface of the cathode is about 3 mm in diameter. Another laser beam is also compressed to the time duration of 100 fs with the beam energy of several mJ for probing beam. The total time resolution, which is determined by pump beam length, probe beam length of the pump-and-probe analysis, jitter between pump and probe beam, S/N ratio totally, is less than 10 ps and the maximal resolution reaches 4 ps. The time resolution is limited by the S/N ratio of the pump-and-probe, so that we will upgrade the high

* Work supported by JST Program for Basic Technology Development of Quantum Beam Sources
† kmiyoshi@utnl.jp

charge beam as pumping beam for high brightness beam. In order to supply high current beam, high quantum efficiency cathode is desirable. However the high quantum efficiency cathode is very weak for oxygen or moisture, so that we set up a system in which we can handle a cathode in vacuum throughout the preparation of the cathode, such as a cartridge-type photocathode system with a cartridge-type vacuum tube [2][3][5]. We have developed the compact-sized cartridge-type photocathode system in collaboration with Hamamatu Photonics. The cartridge-type photocathode system is composed of a cartridge-type vacuum tube with a cathode plug, a linear feeder to transport the tube in vacuum, R/L motion feedthrough with a micrometer for fine adjustment, a RF cavity with a back plate that has a centre hole for the replacement of a cathode, and a gate valve between the RF cavity and the linear feeder. The cartridge-type vacuum tube consists of a Mo cathode plug with a cathode surface layer, flanges made of Kovar on the both sides of the tube, and a vacuum bellows to move the cathode plug. A cathode formed on the plug is sealed in the vacuum tube. The diameter of the plug is 7.2 mm. Vacuum tubes are produced in a factory and the tubes of high quantum efficiency cathode are selected from these tubes. The vacuum tube is set in the linear feeder and transported to the back plate. A pair of cutters before the back plate cut the Kovar foil and then the cathode is inserted into the hole. While exchanging the cathode, the RF cavity is not exposed to ambient air, since the gate valve between the RF cavity and the linear feeder is closed. The cartridge-type photocathode system is very useful for the performance test of cathode because of the easiness of replacing a cathode. High quantum efficiency cathode works in ultra-high vacuum pressure, so that we set 3 getter pumps and 2 ion pumps. The Vacuum pressure behind back plate reaches $2{*}10^{-8}$[Torr].

EXPERIMENTAL RESULTS

Na_2KSb photocathode have been widely used for photomultipliers which can be driven by visible light. The workfunction of Na_2KSb is 2.0[eV], which is sum of the Energy gap 1.0[eV] and the Electron affinity 1.0[eV]. Hamamatsu Photonics K.K. tested that the QE of Na_2KSb reaches 8% at 400[nm] and several % at 500[nm]. We installed that photocathode into RF cavity and did RF aging. After aging, we irradiated the 266[nm] UV light for commissioning the antimony cathode. We measured the lifetime and the QE reduction of Na_2KSb photocathode.The maximal Qe after acceleration by RF gun reached 1.1%. The results are shown in Fig.2. The half life time of that cathode $T_{1/2}$ was about 100 hours. The QE rapidly damped when RF was applied and reached one-fifth ($T_{1/2}$) after 280 hours. Afterward the QE curve dwindled slowly and remained about 0.1% until 500 hours. We observed the saturation of the beam current due to space charge limit. We also measured the lifetime of the cathode at the same condition. The results we got is shown in Fig.6.

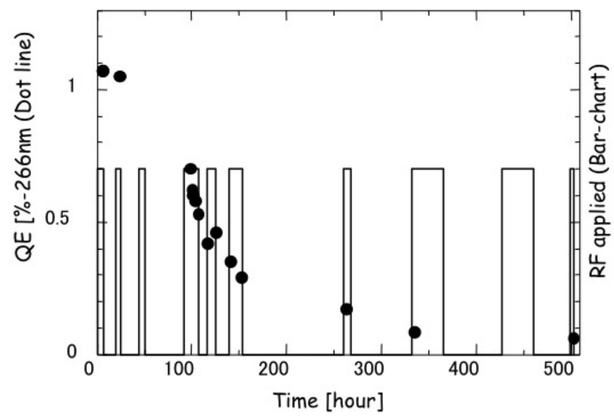

Figure 2: QE reduction in time.

Figure 4 shows the charge after RF gun vs. the laser power. We observe the reduction of the QE when the laser power increases.

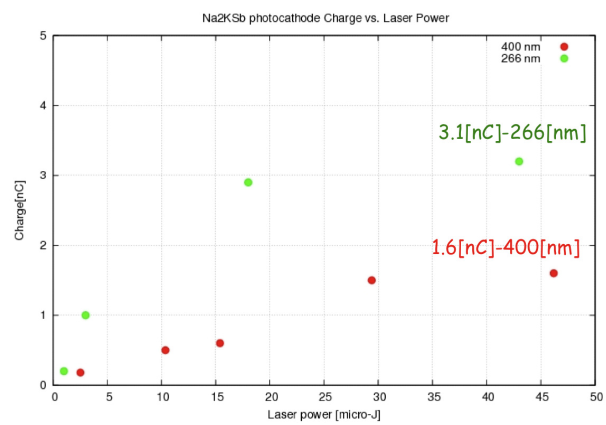

Figure 3: Charge vs laser power.

We also tested using 400[nm] visible wave length which is generated by second harmonic of Ti:Sa laser. In that experiment we only got 1.5[nC] and the QE was 0.02%. There were many problems to have to be solved in the 400[nm] operation such as low charge saturation (vs. laser power), discharge phenomenon and so on. But We assume that Na_2KSb photocathode has the possibility to be driven by visible light.

DISCUSSION

As discussed above, Multi-Alkali photocathode has the good possibility as a electron source which has high quantum efficiency and low workfunction. However the surface of the cathode is sensitive over the electric field of 100[MV/m] in a RF gun(Fig.4), the amount of dark current and the degradation by discharge is not negligible.

The less electric field is applied to the cathode, the longer the life time of cathode gets. In order to reduce such a dark

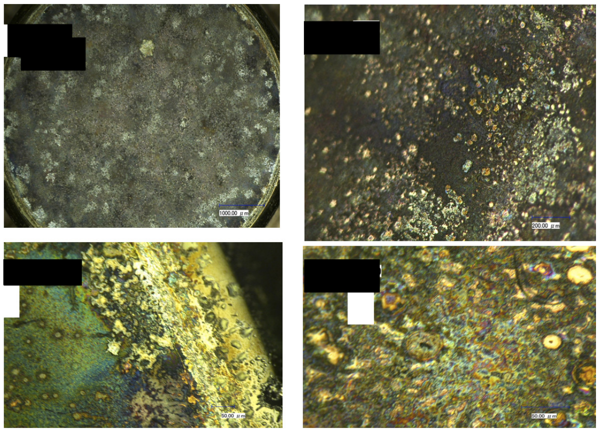

Figure 4: The surface of Na_2KSb cathode after discharge observed with a microscope.

current, we consider the valance of the electric field between half-cell and full-cell of BNL-IV RF gun by numerical simulation using GPT code[4]. We simulated the beam transport from the RF gun to the end of solenoid which locates behind the RF gun for emittance compensation.

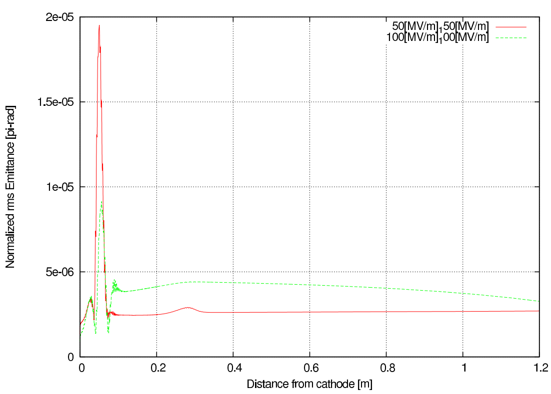

Figure 5: GPT simulation of the rms emittance along the linac from the cathode surface to the end of solenoid. The RF gun locates from 0 to 0.12[m] and solenoid from 0.2 to 0.4[m]. The simulation conditions are ; Number of particles 2000, total electron charge 500[pC], laser radius 1[mm], laser pulse length 10[pC], the peak solenoid magnetic field 0.3[T].

Fig.5 shows that emittance calculation by GPT in case that the valance of applied electric field between half-cell and full-cell is 1:1 (100[MV/m]-100[MV/m], green line) and 1:3 (50[MV/m]-150[MV/m], red line). high quality electron beam can be transported on the condition that appled electric field in half and full cell is about 50[MV/m] and 150[MV/m] respectively. The emittance is almost same at 1.2[m] in the linac.

To make a valance of half-cell and full-cell, we also propose to use side-couple 2.5 cell $\pi/2$ mode RF gun in stead of BNL-Type gun. Of course we can change the ratio of half- and full-cell electric field in BNL-type gun, but in that case the field is not stable. It is so easy for side-couple RF gun to change the valance of electric field by changing the size of the second full-cell. We are now designing the new type RF gun to reduce applied field to cathode surface. Fig.6 shows the geometry of side-couple 2.5cell gun and electric line of forced calculated by SUPERFISH.

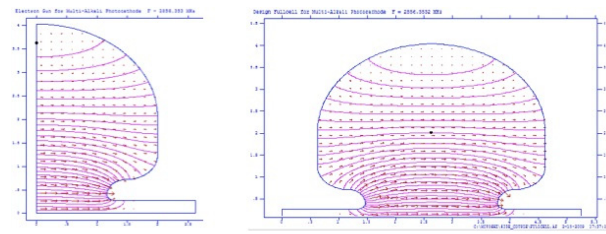

Figure 6: Pre-designed side-couple $\pi/2$-mode S-band RF gun by SUPERFISH.

We are now optimizing geometric parameters of the RF gun and plan to simulate beam dynamics of electrons from the cathode to the end of the beam line.

CONCLUSION

We developed the compact-sized cartridge-type photocathode system, which is able to replace a cathode without breaking the vacuum of RF gun zto use a high quantum efficiency photocathode.The quantum efficiency and the half life time of Na_2KSb photocathode has been measured. We observed the 1.1% quantum efficiency of Na_2KSb cathode and 0.1% after more than 500 hours operation. We also tested Na_2KSb cathode by visible light and we observed maximal charge of 1.5[nC]. We has propose to make an intensity valance between half- and full-cell in BNL-TypeIV RF gun to reduce dark current and discharge. We calculated the beam transport dynamics from the cathode to end of the solenoid. We have been designing the new side-couple $\pi/2$-mode S-band RF gun.

REFERENCES

[1] M.Uesaka et al., Radi.Phys. Chem., 60 (2001)

[2] Y.Muroya et al., Nucl.Instr.Meth. A, 489 (2002)

[3] H.Iijima et al., Proc.2002 EPAC 1771-1773

[4] `http://www.pulsar.nl/gpt`.

[5] A.Sakumi. et al., Proc. 2002 EPAC 1771-1773

[6] J.Sasabe et al., Nucl. Instr. Meth. A, 528 (2004)