DEVELOPMENT OF A MULTIALKALI PHOTOCATHODE PREPARATION SYSTEM

N. Nishimori#, R. Hajima, R. Nagai, M. Sawamura, JAEA, Tokai, Naka, Ibaraki 319-1195, Japan

Abstract

We have developed a multialkali photocathode preparation system at JAEA to demonstrate high current operation of a dc photocathode gun. Quantum efficiency of 0.37% at 532 nm was obtained for a Cs_3Sb photocathode. The preparation system was connected to a photocathode gun equipped with a 250kV-50mA Cockcroft Walton high voltage power supply. The gun was high voltage conditioned up to 230 kV without a central stem electrode. Beam generation test from the multialkali photocathode is scheduled to be performed by the end of FY2015.

INTRODUCTION

A high-brightness and high-current electron gun has been developed worldwide for the next generation light sources such as an energy recovery linac (ERL) and a high-repetition rate X-ray free electron laser (XFEL). Long lifetime photocathode is important for such future light sources. Recently Cornell photoinjector demonstrated generation of record high current electron beam up to 75 mA with 1/e lifetime of 15,000 C from a multialkali photocathode dc gun [1]. High brightness specifications required for XFEL were also demonstrated at the Cornell photoinjector [2]. Thus the multialkali photocathode is anticipated as a promising photocathode for future light sources.

We have developed a 500-kV dc photocathode gun for ERL light sources in Japan and demonstrated generation of a 500-keV electron beam for high brightness beam generation [3]. The gun has been operated at the compact ERL (cERL) at KEK for more than two years and delivered CW beam up to 80 µA for laser Compton scattering experiment [4] as well as the cERL commissioning [5]. We plan to increase the beam current up to 1 mA by the end of FY2015 and to further increase the current up to 10 mA in a few years. However, the photocathode used at the cERL gun is GaAs and its lifetime is limited to a few kC [6], while that of a multialkali photocathode is measured to be greater than 15 kC [1]. Thus we have started to develop a multialkali photocathode preparation system to demonstrate high current beam generation at Japan Atomic Energy Agency (JAEA).

In this paper, our multialkali photocathode preparation system developed at JAEA is described. The system was connected to a photocathode gun equipped with a 250kV-50mA Cockcroft Walton high voltage power supply (HVPS). The gun was high voltage conditioned and beam generation test is anticipated by the end of FY2015.

nishimori.nobuyuki@jaea.go.jp

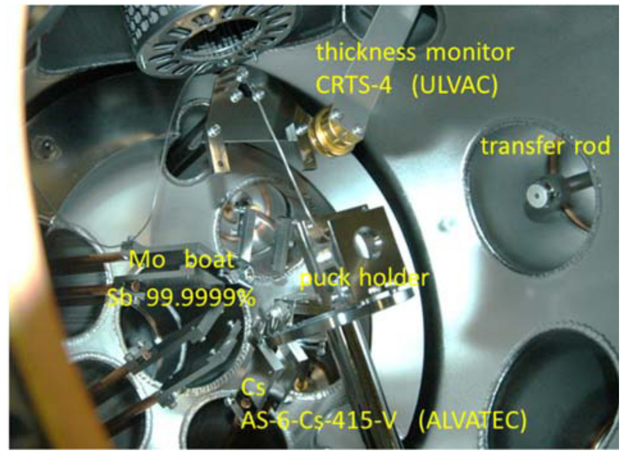

Figure 1: Inside view of multialkali photocathode preparation chamber.

MULTIALKALI PHOTOCATHODE PREPARATION SYSTEM

We have developed a multialkali photocathode preparation system following Refs. [7,8]. A silicon wafer of 0.5 mm thickness is used as a substrate. The wafer was attached on a molybdenum puck with indium seal. The puck is the same as that for GaAs photocathode used at the cERL [3] and can be installed at the cERL gun with a vacuum suitcase similar with JLab system [9]. The puck is housed in a puck holder on a rotating table and transported with a transfer rod to gun high voltage chamber for beam generation (see Fig. 1). A tungsten heater on a linear motion is used for heat cleaning of the wafer and heating the wafer during evaporation of antimony and alkali metals. The temperature is monitored with a thermocouple connected to the puck holder.

We decided to fabricate Cs_3Sb photocathode at first, because it is the simplest alkali antimony photocathode. A 99.9999% antimony bead (SB-020100: NILACO) was placed on a Mo boat. The boat was heated for evaporation. A caesium source (AS-6-Cs-415-V: ALVATEC) was placed 3 cm apart from the substrate surface. A thickness monitor (CRTS-4U: ULVAC) is used to calibrate thicknesses of both antimony and caesium. The photocathode preparation system was baked for 20 hours at 170 degree C with a 0.3 m^3/s turbo molecular pump. A 1.3 m^3/s NEG pump (SAES getters: CapaciTorr-B 1300-2) was activated after the baking. A 0.05 m^3/s ion pump (ULVAC: PST-050AU) is installed to pump noble gases and methane. The vacuum pressure of 5×10^{-9} Pa is obtained after NEG activation.

ISBN 978-3-95450-183-0

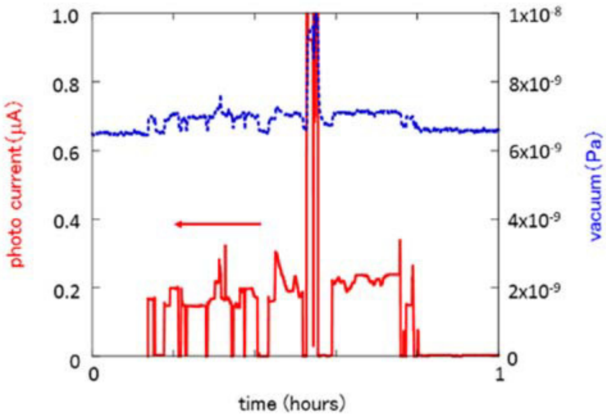

Figure 2: Photo current (red curve) measured with a Faraday cup in front of a Cs_3Sb photocathode with 532 nm laser of 125 μW. The QE is estimated to be 0.37%. The vacuum pressure rises with laser irradiation.

The wafer is heat cleaned at 550 degree C for 2 hours and then cooled to 170 degree C. The antimony was evaporated with thickness of 40 nm and the caesium was evaporated until maximum photo current is obtained. Figure 2 shows the photo current collected at a Faraday cup in front of the puck holder with 532 nm laser. The laser power is measured to be 125 μW. The QE of Cs_3Sb photocathode is estimated to be 0.37 %, which is one order of magnitude smaller than textbook [8] and recent results [7,9]. Further improvement is required for our alkali antimony preparation system.

GUN TEST STAND FOR HIGH CURRENT BEAM GENERATION

We have a dc gun with a 250kV-50mA HVPS. The gun has been originally developed as a GaAs photocathode dc gun as a test stand for future light sources. The details of the gun are described in Refs. [10,11]. The gun system consists of a SF6 tank, a high voltage chamber, a GaAs preparation chamber, a solenoid, a lightbox, and a diagnostic beam line (see Fig. 3). The multialkali photocathode preparation system was connected to the GaAs preparation chamber. The gun was used to study

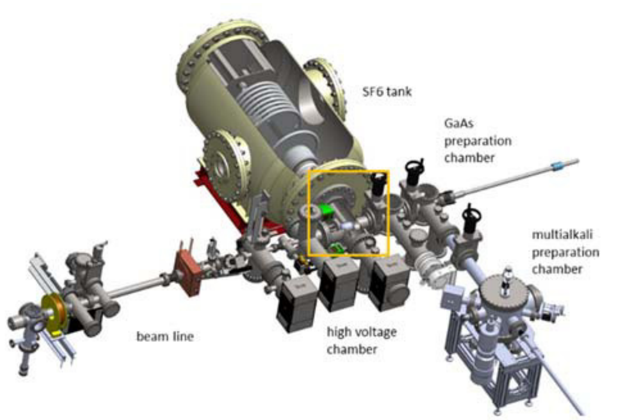

Figure 3: Gun test stand for high current beam generation at JAEA.

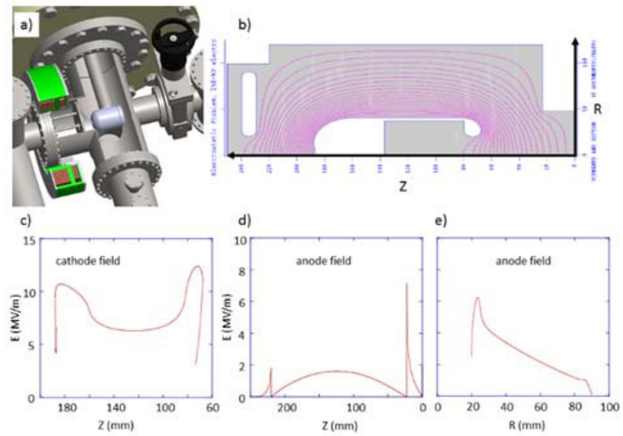

Figure 4: (a) Cutaway drawing of gun high voltage chamber and (b) radial cross section showing static electric field calculation for the gun chamber. Surface electric field distributions at 250 kV (c) of the cathode as a function of Z, (d) of the HV chamber as a function of Z, and (e) of the anode electrode as a function of R.

magnetic emittance with 1 μA beam [11]. The operational voltage at that time was limited to less than 180 kV because of field emission generated from cathode electrode. We redesigned the cathode electrode to reduce the surface electric field. Figure 4 shows the calculated surface electric field of the new cathode and anode electrodes. The maximum cathode electric field decreases from 14 MV/m to 12 MV/m. The maximum anode electric field decreases from 8 MV/m to 6 MV/m.

Before replacing the cathode electrode, we performed high voltage conditioning without central stem electrode. We had vacuum discharge at 240 kV and did not try to further push the HV processing. This is because the vacuum pressure started to increase with applied HV after the discharge event and we set our operational HV to about

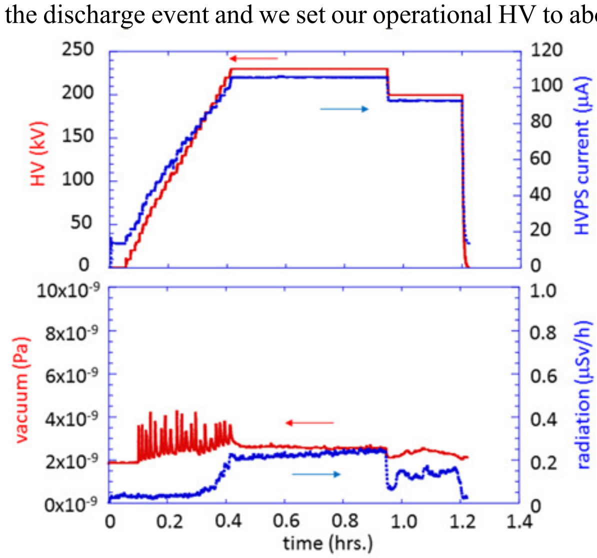

Figure 5: High voltage holding test without central stem electrode. Top shows HV (red curve) and HVPS current (blue curve). Bottom shows vacuum pressure (red curve) and radiation (blue curve). The vacuum pressure and radiation slightly increase with HV.

ISBN 978-3-95450-183-0

200 kV. The vacuum pressure recovered from 8×10^{-9} Pa to 4×10^{-9} Pa after holding HV at 230 kV for four hours. Figure 5 shows the HV holding test at 230 kV after the vacuum recovery. The top shows the gun HV (red curve) and the HVPS current (blue curve). The bottom shows the vacuum (red curve) and radiation (blue curve). The application of 200 kV on the ceramic tube leads to slight increases of vacuum and radiation. These data can be used to obtain increases of vacuum and radiation caused by central stem and cathode electrodes in the future experiment.

SUMMARY

We have developed a multialkali photocathode preparation system and obtained QE of 0.37% at 532 nm for a Cs_3Sb photocathode. The QE is one order of magnitude smaller than the textbook [8]. The system thus needs to be further improved. The system was connected to the existing dc gun equipped with a 250kV-50mA HVPS at JAEA for beam generation. The gun was high voltage conditioned up to 230 kV without a central stem electrode. Beam generation test from the multialkali photocathode is planned to be performed by the end of FY2015.

ACKNOWLEDGMENTS

This work is supported by Photon and Quantum Basic Research Coordinated Development Program from the Ministry of Education, Culture, Sports, Science and Technology, Japan and is partially supported by JSPS Grants-in-Aid for Scientific Research in Japan (15K13412).

REFERENCES

[1] L. Cultera et al., Appl. Phys. Lett. 103 (2013) 103504.
[2] C. Gulliford et al., Appl. Phys. Lett. 106 (2015) 094101.
[3] N. Nishimori et al., Appl. Phys. Lett. 102 (2013) 234103.
[4] R. Nagai et al., “Demonstration of High-flux Photon Generation from an ERL-based Laser Compton Photon Source”, in Proc. of IPAC2015, Richmond, VA, 2015.
[5] S. Sakanaka et al., “Recent Progress and Operational Status of the compact ERL at KEK”, in Proc. of IPAC2015, Richmond, VA, 2015.
[6] J. Grames et al., Phys. Rev. STAB 14 (2011) 043501.
[7] Luca Cultera, “Fabrication, characterization, and use of alkali antimonides in a dc gun”, Photocathode Physics for Photoinjectors 2012, Ithaka, NY, 2012.
[8] A. H. Sommer, “Photoemissive Materials”, John Wiley & Sons, Inc. New York (1968).
[9] R. R. Mammei et al., Phys. Rev. STAB 16 (2013) 033401.
[10] R. Nagai et al., “Development of a 250-kV Photocathode Electron Gun for the ERL Light Sources at JAEA”, in Proc. of PAC2009, p. 545-547, Vancouver, BC, Canada, 2009.
[11] R. Nagai et al., Rev. Sci. Instrum. 83 (2012) 123303.

ISBN 978-3-95450-183-0