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# DEVELOPMENT OF A MULTIALKALI PHOTOCATHODE DC GUN FOR HIGH CURRENT OPERATION

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*Abstract*

We have developed a DC gun test stand at National Institutes for Quantum Radiological Science and Technology (QST) for high current electron beam generation. The gun test stand consists of an alkali antimonide photocathode preparation chamber, a DC gun with a 250kV-50mA Cockcroft Walton high voltage power supply, and beam line with a water cooled beam dump to accommodate 1.5 kW beam power. We successfully fabricated a $Cs_3Sb$ photocathode with quantum efficiency of 5.8 % at 532 nm wavelength and generated 150 keV beam with current up to 4.3 mA with 500 mW laser at 532 nm wavelength. Unfortunately, we encountered a vacuum incident during beam transport of high current beam and the development has been halted. We will fix the vacuum problem and restart the gun development as soon as possible.

## INTRODUCTION

A high-brightness and high-current electron gun has been developed worldwide for the next generation light sources such as a high power EUV FEL for semiconductor lithography based on an energy recovery linac (ERL) [1]. Such a gun can also be used as a compact and high-power THz light source based on coherent Smith Purcell radiation technique in combination with an appropriate grating [2].

We have developed a photoemission DC gun test stand at National Institutes for Quantum Radiological Science and Technology (QST) for generation of high-brightness and high-current electron beam [3]. An alkali antimonide photocathode preparation system was added to the gun test stand, because electron beam generation with current up to 75 mA was demonstrated at the Cornell photoinjector and the charge lifetime of the multialkali photocathode was measured to be greater than 15 kC [4].

In this paper, fabrication result of a $Cs_3Sb$ photocahode is reported. The preparation chamber for $Cs_3Sb$ photocahode has been developed since 2013 [3]. The quantum efficiency (QE) in our latest fabrication reached 5 %, which was more than 15 times greater than our previous value [3]. A photoemission gun system has been prepared for beam generation. A cathode electrode was replaced to accommodate a photocathode puck compatible with the compact ERL (cERL) at KEK as well as to reduce the surface electric field [3]. High voltage at 210 kV has been successfully applied with cathode electrode in place for more than eight hours without any discharge. A beamline for high current beam generation has also been prepared. We have generated electron beam from the $Cs_3Sb$ photocathode with current up to 4.3 mA at 150 kV. The results of beam generation are described.

## FABRICATION OF CAESIUM ANTIMONIDE PHOTOCATHODE

Details of our alkali antimonide photocathode preparation chamber are described elsewhere [3]. The QE obtained in the first fabrication in March 2015 was 0.37 % at 532 nm. The QE decreased to almost zero one year later, though the puck had been kept under vacuum pressure of $2\times10^{-9}$ Pa. A silicon wafer of 0.5 mm thickness is used as the substrate. We decided to reactivate the Si wafer with similar way with our previous procedure. The wafer was heat cleaned at 550-degree C for two hours. The evaporation of antimony and caesium was performed another day.

Figure 1 shows our fabrication procedure. The distance between the wafer and alkali and antimony sources is 3 cm. The temperature during the fabrication was monitored with a thermocouple connected to the puck holder. The antimony was evaporated at monitor temperature of 140-degree C. The duration of evaporation time which

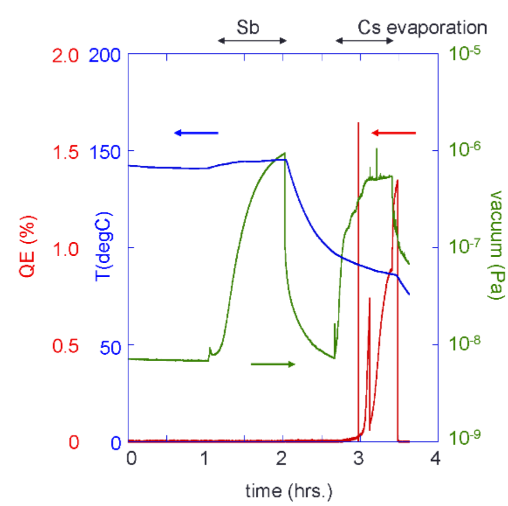


Figure 1: The $Cs_3Sb$ photocathode fabrication procedure. The blue curve shows temperature of puck holder measured with a thermocouple. The green curve shows the vacuum pressure in the fabrication chamber. The antimony is evaporated at the monitor temperature of 140-degree C and caesium is evaporated at 90-degree C. The QE (red curve) is derived from photo current measured with a charge collector in front of a $Cs_3Sb$ photocathode and laser power at 532 nm.

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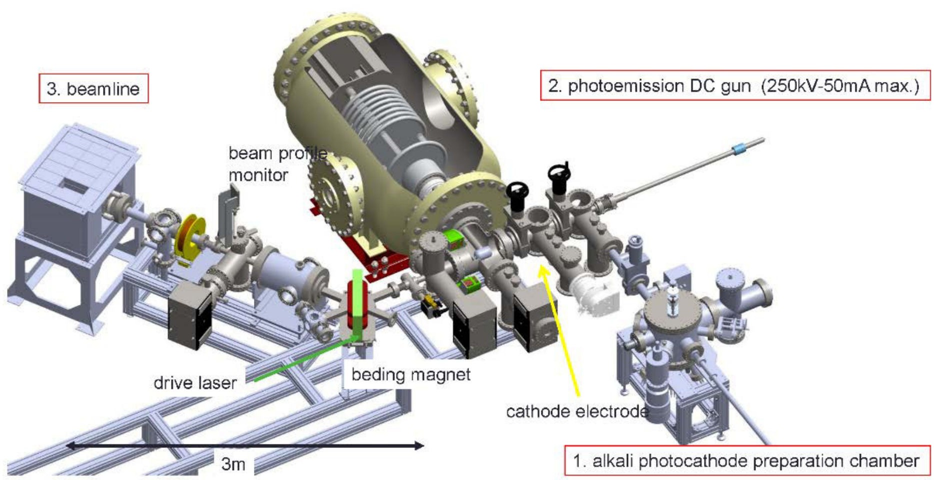


Figure 2: Gun test stand for high current beam generation at QST. The test stand consists of an alkalai antimonide photocathode preparation chamber, a 250kV dc gun, and a beamline.

corresponds to 40 nm of antimony was calibrated in a separate experiment with a thickness monitor. After the antimony evaporation, the monitor temperature was decreased to 90-degree C for the caesium evaporation. A laser with maximum power of 5 mW was used for the present photo current measurement, while the maximum laser power was 125 µW in the previous fabrication. This allowed us to detect small amount of photo current increase. Once the photo current increase was detected, the heater power for caesium evaporation was increased until optimum condition was established and the laser power was decreased with ND filter. We stopped the caesium evaporation when QE exceeded 1 %. The QE reached 2.5 % two days later. The amount of QE is one order of magnitude higher than our previous value and reaches similar values of Ref. [5] and a textbook [6].

The reason why the QE increased one order of magnitude is unclear at this point. The $Cs_3Sb$ fabrication process is similar and the same wafer is used. The differences are substrate temperature during caesium evaporation and laser power to monitor the photo current. The caesium temperature was roughly 20-degree C below the previous procedure. The increased laser power was helpful for small signal detection.

## GUN TEST STAND

We have a dc gun with a 250kV-50mA high voltage power supply (HVPS), as shown in Fig. 2. The gun has been originally developed as a dc gun equipped with a GaAs photocathode to establish fundamental technologies for high-brightness and high-current beam generation for future light sources. Generation of 1 µA beam at 180 kV from a GaAs photocathode was already demonstrated. The details of the gun are described in Refs. [7,8]. The gun system consists of a SF6 tank, a high voltage chamber, a GaAs preparation chamber. The alkali antimonide photocathode preparation system was connected to the GaAs preparation chamber. The gun cathode electrode was replaced to accommodate a photocathode puck compatible with the cERL as well as to reduce the surface electric fields for high voltage operation. The details of electric field calculation and high voltage test without cathode electrode are described elsewhere [3]. Figure 3 shows the high voltage holding test with cathode electrode in place. The high voltage at 210 kV has been successfully applied for eight hours without any discharge.

We also prepared a beam line shown in Fig. 2 for high current beam generation. The beam line consists of a solenoid magnet followed by a bending magnet, a differential pump system, a beam profile monitor, and a beam dump. Laser beam is injected through a window of the bending magnet chamber onto the photocathode. The differential pump system is used to separate the gun vacuum from the beam dump vacuum. The beam dump is water cooled to handle 1.5 kW beam power and is surrounded by lead radiation shield blocks. The transverse beam size at the beam dump is expanded by a beam expander magnet.

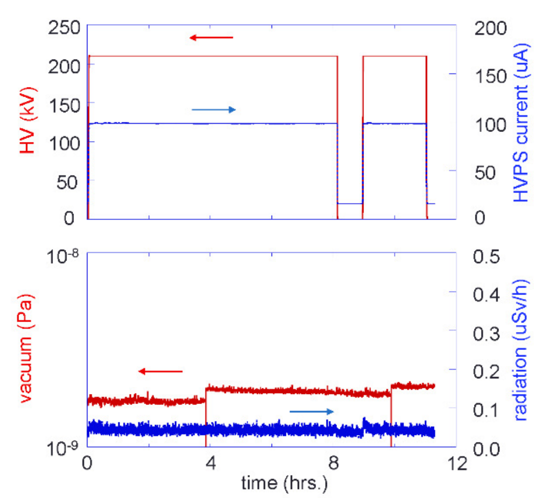


Figure 3: High voltage (HV) holding test with cathode electrode in place. Top shows HV (red curve) and HVPS current (blue curve). Bottom shows vacuum pressure (red curve) and radiation (blue curve).

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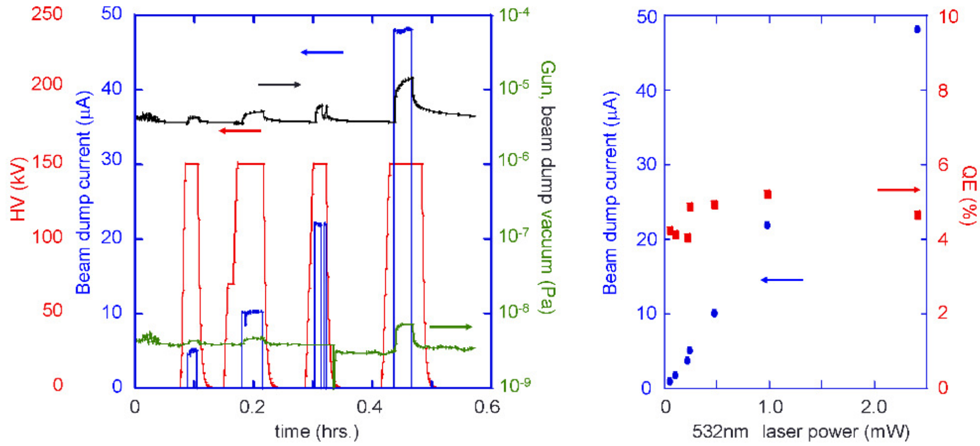


Figure 4: The left figure shows beam current (blue curve) measured at a beam dump, high voltage (red curve), gun vacuum (green curve) and beam dump vacuum (black curve). The right figure shows beam dump current (blue circles) and QE (red squares) as a function of laser power at 532nm. The laser with maximum power of 5 mW is used for this measurement.

## BEAM GENERATION

The first beam generation test was performed in April 2016, one week after the $Cs_3Sb$ photocathode fabrication. After beam profile was observed at the monitor, beam current was measured at the beam dump. The beam current was 1.26 μA for 51 μW laser power at 532nm. This corresponds to QE of 5.8 %. The QE was twice higher than the value measured at the fabrication chamber, even after the photocathode was transferred to the gun chamber from the fabrication chamber. This indicates QE increased under XHV vacuum condition, or photocurrent was not correctly captured in the charge collector in the fabrication chamber. The QE value was derived from the laser power measured in front of the window of the bending magnet and beam dump current.

The second beam generation test with 5 mW laser at 532 nm was performed in August 2016 after the beam dump was surrounded with lead radiation shield blocks. The beam dump current was measured as a function of laser power, as shown in Fig. 4. The beam dump current was 48 μA for 2.4 mW laser power at 532nm. This corresponds to QE of 5 %. This indicates the dark lifetime of our $Cs_3Sb$ photocathode over four months is pretty long. The QE value was almost constant irrespective of laser power, as shown in Fig 4. The gun high voltage was set to 150 kV, and the gun vacuum pressure was $4 \times 10^{-9}$ Pa when the beamline valve just after the gun was open. Although the vacuum pressure at the beam dump was three orders of magnitudes higher than that of the gun, the increase of the gun vacuum pressure was roughly twice thanks to the differential pump system.

The third beam generation test was performed in November 2016, after we installed 3W laser at 532 nm for high current beam generation and a water cooling system for the beam dump. Figure 5 shows the beam generation

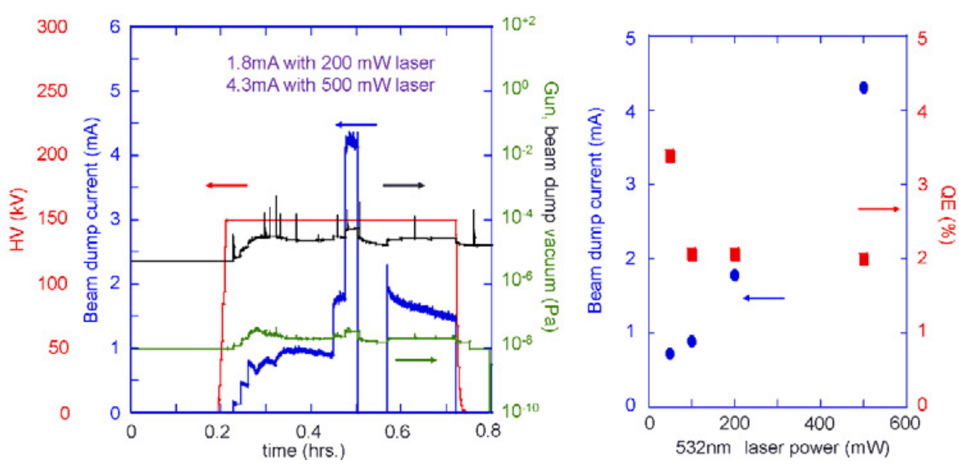


Figure 5: The left figure shows beam current (blue curve) measured at a beam dump, high voltage (red curve), gun vacuum (green curve) and beam dump vacuum (black curve). The right figure shows beam dump current (blue circles) and QE (red squares) as a function of laser power at 532nm. The laser with maximum power of 3 W is used for this measurement.


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test result. Maximum beam current of 4.3 mA was generated with 500 mW laser power. The QE was 2 %.

We tried to decrease radiation level by adjusting beam transport. When we gradually increased the beam current, a vacuum incident suddenly happened. The gun vacuum level went up to 1 Pa from $10^{-8}$ Pa. We found a small hole on a bellow placed just downstream the gun. We also noticed that only 3.6 mA beam was transported to the beam dump for 500 mW laser, while it was 4.3 mA before adjustment of beam transport. Presumably certain amount of beam hit the bellow and made a leak hole.

## SUMMARY

We have developed a DC gun test stand at QST to generate high current beam from the gun. The test stand consists of an alkali antimonide photocathode preparation chamber, a DC gun, and a beam line with a water cooled beam dump. We successfully fabricated a $Cs_3Sb$ photocathode with quantum efficiency of 5.8 % at 532 nm wavelength and generated 150 keV beam with current up to 4.3 mA with 500 mW laser at 532 nm wavelength. Unfortunately, we encountered a vacuum incident during beam transport of high current beam. We will fix the vacuum problem and restart the gun development. Though the photocathode was exposed to air of 1 Pa pressure, we will fabricate the $Cs_3Sb$ with the same wafer to check reproducibility.

## ACKNOWLEDGMENTS

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