DEVELOPMENT OF A PHOTOEMISSION DC GUN AT JAEA

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Abstract

The next generation light source such as X-ray FEL oscillator requires high brightness electron gun with megahertz repetition rate. We have developed a photoemission DC gun at JAEA. By employing a segmented insulator with guard rings, we successfully applied 500 kV on the ceramics with a central stem electrode for eight hours without any discharge in 2009. In 2011 we reached 526 kV with NEG pumps and electrodes in place, before suffering another field emission problem from the cathode electrode. The problem may be attributed to small dust inside our gun chamber. We also generated high current beam up to 10 mA and obtained charge extracted lifetime of 30 C. In this paper, our current status of development will be presented.

INTRODUCTION

Electron guns which can deliver a high brightness electron beam with emittance lower than 1 mm-mrad and current up to 100 mA are being developed for Energy Recovery Linac (ERL) Light Sources (LS) worldwide [1]. A DC photoemission gun with a GaAs or multi alkali photocathode is one of the most promising candidates, since the JLab FEL photoemission DC gun has provided 9.1 mA beam [2] and the Cornell photoinjector recently demonstrated operation at 20 mA for eight hours [3].The gun high voltage equal to or greater than 500 kV is required to generate low emittance beam by reducing non-linear space charge effects in low energy region [4]. The accelerating field on the cathode surface should also be as high as possible to suppress the space charge effects.

This high brightness gun is anticipated to be used in a 3-GeV ERL based hard X-ray synchrotron light source project in Japan [5], an X-ray FEL oscillator [6], and an ERL based high-flux Compton gamma-ray as a new nondestructive assay method for ^{235}U, ^{239}Pu, and minor actinides in spent nuclear fuel assembly [7,8].

We have developed a 500-kV DC gun for the Japanese ERL light sources [9]. One of technological challenges of high brightness DC guns is to apply DC high voltage on a ceramic insulator with a central stem electrode, since field emission causes discharge or punch through on the ceramic surface. We have employed a segmented insulator with rings to keep the insulator safe from the field emission generated from the stem electrode. Although the emission from backside of the rings may still directly hit the insulator, its maximum electric field is more than three times smaller than that of the stem electrode. In this way, we have successfully applied 500 kV on the ceramics for eight hours in 2009 [10].

A prototype facility of 3 GeV ERL light source called compact ERL (cERL) has been constructed at KEK. Our photoemission DC gun is scheduled to be installed by this fall. Beam generation from the gun is anticipated by the end of this fiscal year. We need to demonstrate high brightness and high current beam generation by this fall. We reached 526 kV with cathode electrode in place and demonstrated 440 kV for eight hours. We also demonstrated 10 mA beam generation. In this paper, our current status of gun development will be presented.

HIGH VOLTAGE CONDITIONING

500-kV Photoemission DC Gun at JAEA

Details of our 500-kV DC gun are described elsewhere [9,10]. A GaAs wafer on a molybdenum puck is used as photocathode. The wafer is atomic hydrogen cleaned and transferred to the preparation chamber where cesium and oxygen are alternatively applied for negative electron

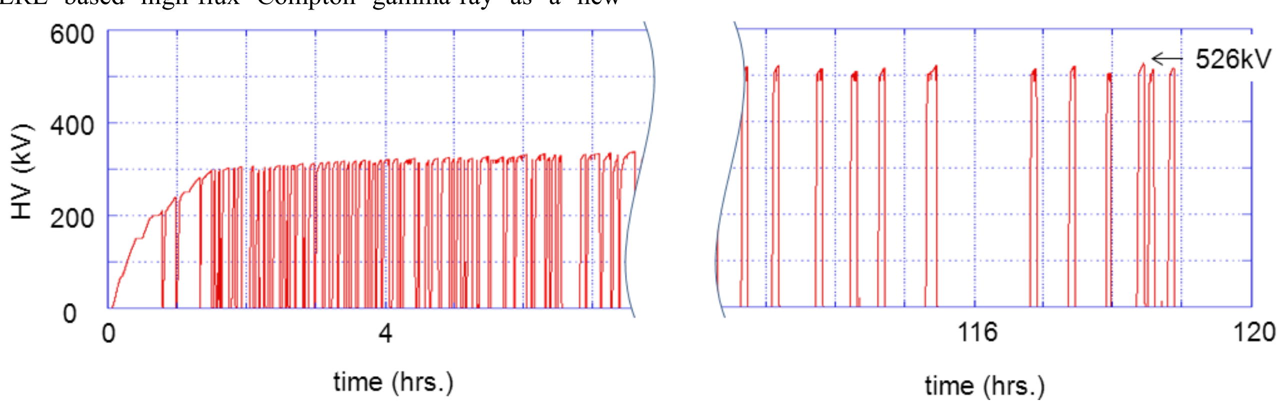

Figure 1: High voltage conditioning of the 500-kV photoemission DC gun with cathode electrode in place.

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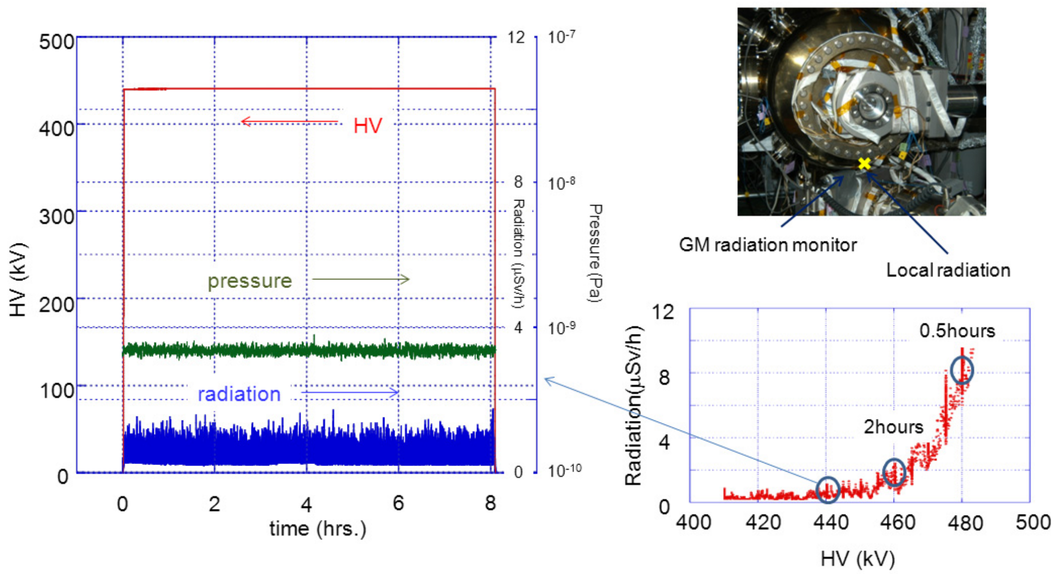

Figure 2: High voltage testing at various voltages when field emission is observed.

affinity activation. The activated cathode is then transferred to the cathode electrode in the high voltage (HV) chamber. The photoemission beam is accelerated by a static electric field applied between cathode and anode electrodes.

The cathode/anode gap is surrounded by twenty of 400 l/s NEG pumps (SAES: CapaciTorr D400-2) to reduce residual gas. The NEG pumps are covered with mesh HV shields made of titanium wire with 1 mm in diameter. Five ICF203 ports of the HV chamber are used to install five 2000 l/s NEG pumps (SAES: CapaciTorr D2000). A 200 l/s ion pump (ULVAC PST-200AU) is installed at the bottom of HV chamber to pump noble gases and methane.

The ceramic insulator and the HV chamber were baked at 180 degC for 50 hours after assembling the gun system. A 1000 l/s turbo molecular pump is used during the baking. After the activation of NEG pumps, the base pressure of the HV chamber is measured to be 8 x 10^{-10} Pa (N_2 equivalent) with a BA gauge (ULVAC: AxTRAN).

Conditioning without Cathode Electrode

We performed high voltage conditioning without cathode electrode in 2009. A dummy cap was connected to the bottom of the stem electrode instead of the cathode electrode. The output voltage of high voltage power supply (HVPS) is 510 kV when 500 kV is applied on the insulator. This is because an external resistor of 5 GΩ of the segmented insulator is connected to an output resistor of 0.1 GΩ in series. In the following paragraphs, HVPS voltage is used instead of the voltage on the ceramics. We could ramp up to 550 kV and demonstrated applying 510 kV for eight hours without any discharge. The details of conditioning without cathode electrode are described elsewhere [10].

Conditioning with Cathode Electrode in Place

In June 2011, we reached 510 kV after 100 hours of conditioning the gun with cathode electrode in place. However after a discharge at 500 kV, we suffered from field emission. The field emission started from 350 kV,

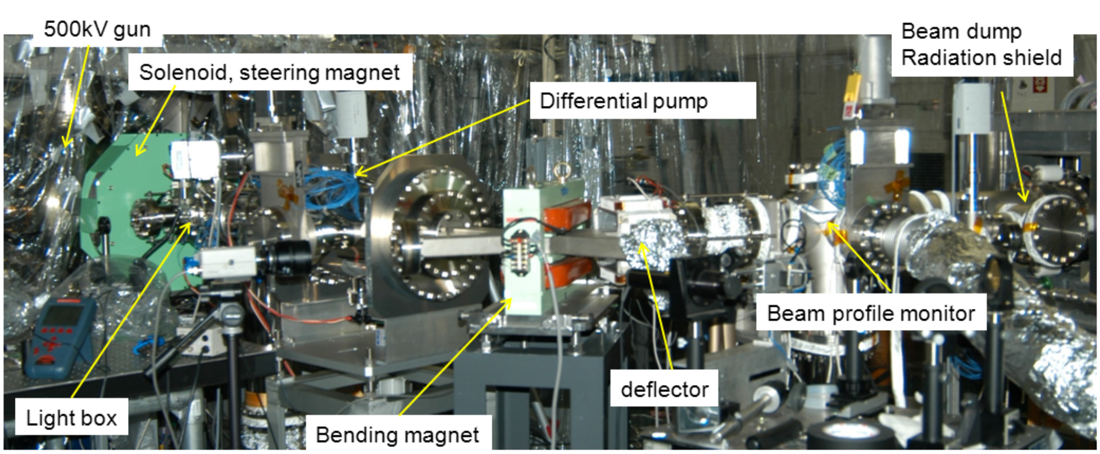

Figure 3: Downstream beam line for 500-kV photoemission DC gun at JAEA.

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and the emission spot could be easily identified from radiation survey. It was difficult to continue the current conditioning because the radiation soared and discharge occurred many times at low voltage. We decided to vent the HV chamber with dry nitrogen and wiped the cathode electrode with a lint free tissue with care to minimize air exposure of gun chamber.

The gun chamber was evacuated without baking to $1x10^{-8}$ Pa with NEG pump reactivation. It takes only a few days from nitrogen exposure of the gun chamber to resumption of conditioning. We could ramp up to 445 kV within one hour, probably because the HV chamber was already conditioned. This also indicates wiping cathode electrode is an effective way to remove the field emission site. We reached 526 kV in Aug. 2011, but another field emission site was found by radiation survey. The radiation spot slid to different but similar place.

We performed high voltage testing at various voltages when field emission from cathode electrode was observed. A GM survey meter placed close to the emission spot was used to measure radiation as a function of high voltage (see top and bottom right in Fig. 2). The radiation started from 440 kV. We measured how much time the gun system could be held without any discharge. We could demonstrate more than 8 hours at 440 kV (see left in Fig. 2), but discharge occurred in two hours at 460 kV and in 0.5 hours at 480 kV. The vacuum pressure of the HV chamber stays constant around $8x10^{-10}$ Pa when HV is applied to the gun (see left in Fig. 2). The vacuum pressure only changes when discharge occurs.

Inert Gas Conditioning

The inert gas conditioning is a promising way to remove field emission site on the cathode electrode without air exposure, since the field emitter can be melted or its surface properties can be changed by ion back-bombardment [12,13]. We performed Helium and Krypton conditioning with various gas pressure from 10^{-2} Pa to 10^{-5} Pa. Unfortunately we could not remove the field emission site with our inert gas conditioning.

HIGH CURRENT OPERATION

Our current goal is to generate high brightness beam with high average current of 10 mA. The diagnostics beamline for the high average current operation is shown in Fig. 3. A steering magnet and a solenoid magnet are used for beam transport from the gun exit to the beam dump. A lightbox to deliver drive laser is placed just after the solenoid. The laser is injected to the lightbox through an AR coated quartz window (Hamamatsu Co.) and reflected by a sliver coated molybdenum mirror (Rocky Mountain Instrument Co.) onto the photocathode. The incident angle is roughly 2.3 degree. The reflected laser is ejected out of the lightbox with another pair of mirror and window. A differential pumping chamber is placed after the lightbox. The chamber consisting of eight NEG modules (WP38/950 St707, SAES getters) has conductance limiting orifices with 3cm diameter and 3cm long at its entrance and exit. A 60 degree bending magnet followed by a beam expander magnet is placed after the differential pumping chamber. A beam profile monitor is

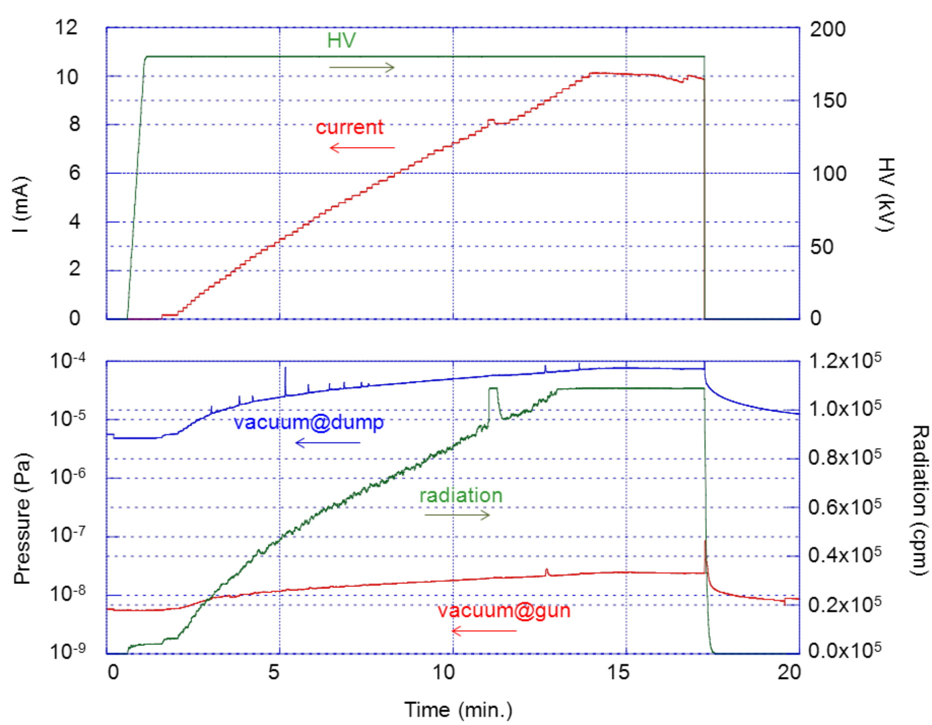

Figure 4: High average current operation test. The top shows current as a function of time. The bottom shows vacuum pressures at the gun (red) and beam dump (blue), and the radiation (green) measured by a GM survey meter.

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placed at the middle of the expander magnet and a beam dump. The beam dump, which is a water cooled copper pipe, is covered by 10 cm thick Pb block as radiation shield. The expanded beam size at the dump was estimated to be 4cm×4cm. A 1 kΩ resistor is connected between the dump and ground to monitor the beam current.

A DC laser, Millenia Pro (Spectra Physics Co.), is used as a drive laser. The wavelength is 532 nm and its maximum power is 5 W. The laser spot size on the photocathode is σ_x=0.1 mm. The laser is irradiated on the photocathode center in the present high current operation. The laser power is remotely controlled by rotating a half-wave plate. The laser power of 2.3 W is required for 10 mA operation with 1% QE photocathode. The laser power at the exit of the lightbox is 20% of that at the entrance, while the reflectivity of GaAs wafer for 532 nm laser light is 32%. Further study on the laser power loss in the lightbox is needed.

Figure 4 shows the beam current is gradually increased up to 10 mA, as the laser power was increased. The laser power for 10 mA beam was 1.6 W and QE was 1.5%. The radiation was monitored by GM survey meter (TGS-133, ALOKA) placed near the lightbox and a radiation monitor equipped in the experimental hall. The dump current was cross checked by the current of HVPS. The dump current is 7% greater than the dump current and its ratio is almost constant.

We could deliver 10mA beam for about two minutes, but the current rapidly decreased and suddenly the HVPS was interlocked. Heat load in the connector between the HVPS and CW circuit in SF6 tank might be a problem. We will fix the problem soon. The vacuum pressure at the beam dump increased to 7.6×10^{-5} Pa for 10 mA operation.

Long time operation at 5 mA was also demonstrated. The laser power was fixed to 1.37 W. The beam current gradually increased and then decreased. The 1/e charge extracted lifetime of 30 C was obtained. This result is a few times smaller than JLab results for on center operation [14].

The present high current operation was performed after a high voltage conditioning. Unfortunately, dark current due to small dust in HV chamber appeared above 200 kV during the conditioning. This is reason why the high voltage was limited to 180 kV for the present high average current operation. We will try the high current operation at higher voltage after removing the field emission site on the cathode electrode.

SUMMARY

We have developed a 500-kV photoemission DC gun. We reached 526 kV and demonstrated applying 440 kV on the ceramics with cathode electrode in place for more than eight hours. We still need to develop an effective way to solve the field emission problem. We have generated 10 mA beam from the gun at 180kV. We plan to perform high current operation at higher voltage.

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