BEAM GENERATION FROM A 500KV DC PHOTOEMISSION ELECTRON GUN*

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Abstract

The next generation light sources such as energy recovery linac (ERL) light sources and X-ray FEL oscillator require high brightness electron gun with megahertz repetition rate. We have developed a DC photoemission electron gun at JAEA for the Japanese ERL light source project. This DC gun employs a segmented insulator with guard rings to protect the insulator from field emission generated from central stem electrode. We have successfully applied 500-kV on the ceramics with a cathode electrode in place and generated beam from the 500kV DC photoemission gun in October 2012. Details of the beam generation test at 440 kV as well as 500 kV are presented.

INTRODUCTION

Electron guns which can deliver a high brightness electron beam with emittance lower than 1 mm-mrad and currents up to 100 mA are being developed for Energy Recovery Linac (ERL) light sources and free electron lasers (FELs) 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 mA beam [2] and the Cornell photoinjector recently demonstrated a record high current of 65 mA [3].The gun high voltage equal to or greater than 500 kV is required to generate a low emittance (high brightness) beam by reducing non-linear space charge effects in low energy region [4]. Although this type of gun was proposed in 1991 [5], the operational voltage has been limited to 350 kV or lower owing to the field emission problem which causes electrical breakdown or punch-through on the ceramic insulator surface.

We have developed a 500-kV DC photoemission gun [6] for a 3-GeV ERL based X-ray synchrotron light source [7], an X-ray FEL oscillator [8], and an ERL based high-flux Compton gamma-ray source to develop a nondestructive assay method of ^{235}U, ^{239}Pu, and minor actinides in spent nuclear fuel assembly [9,10]. To solve the field emission problem, we have employed a ceramic insulator with rings to keep the insulator safe from the field emission generated from a central stem electrode [11]. Although field emission electrons from the reverse side of the rings may still directly hit the insulator, its maximum surface electric field is less than one-third that of the stem electrode. As a result, the amount of field emission towards the ceramic surface is dramatically suppressed.

High-voltage conditioning without the cathode electrode was performed in 2009. A dummy cap was connected to the bottom of the stem electrode instead of the cathode electrode in this experiment. We could ramp up to 550 kV and were able to demonstrate the application of 510 kV for 8 h without any discharge. The details of the conditioning without the cathode electrode are

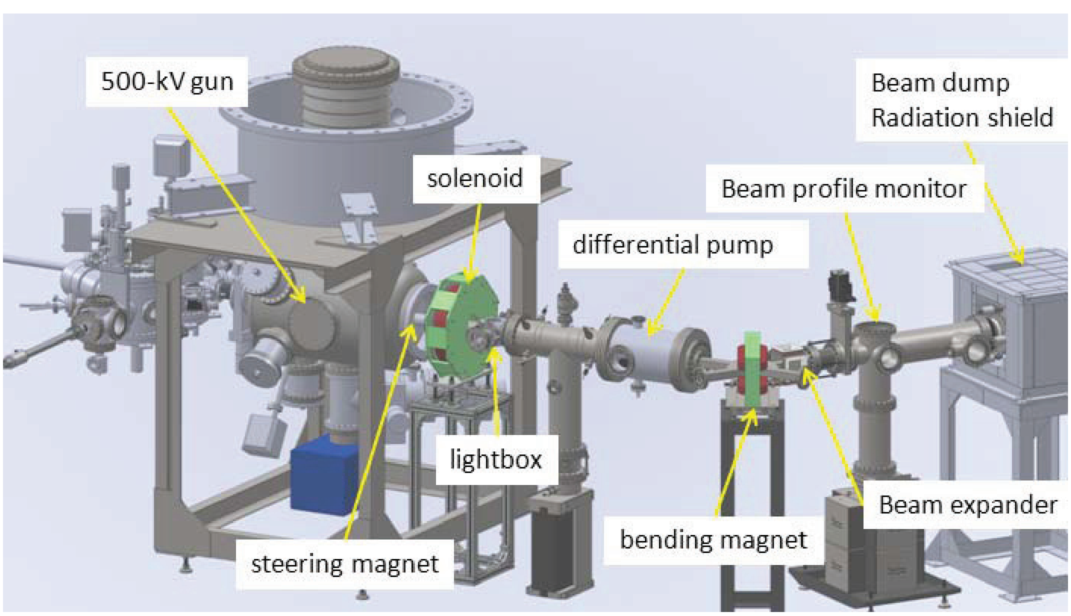

Figure 1: A 500-kV DC photoemission gun with a downstream beam line.

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described elsewhere [11].

DC PHOTOEMISSION GUN AT JAEA

After the segmented insulator with guard rings was proved to be effective in suppressing the field emission effect from a stem electrode, we set a cathode electrode and non-evaporable getter (NEG) pumps in place for beam generation. The schematic view of the 500-kV photoemission gun and downstream beam line is shown in Fig. 1. A GaAs is used as a photocathode. The photoemission beam is accelerated by a static electric field applied between cathode and anode electrodes. The acceleration gap between cathode and anode electrodes is surrounded by twenty 400 l/s NEG pumps (SAES getters: CapaciTorr D400-2) to reduce residual gas, which is the source of back-bombardment ions. These NEG pumps are covered with mesh HV shields made of titanium wire having a 1 mm diameter. Five ICF203 ports of the high voltage (HV) chamber, which are located behind the cathode electrode, are used to install five 2000 l/s NEG pumps (SAES getters: CapaciTorr D2000). In total, the HV chamber is equipped with 18000 l/s NEG pumps. A 200 l/s ion pump (ULVAC: PST-200AU) is installed at the bottom of the HV chamber to pump noble gases and methane.

The HV chamber, cathode and anode electrodes, and stem electrode are made of chemically polished (CP) titanium. This choice of material is mainly because the outgassing rate of CP titanium is measured to be much smaller than that of stainless steel [12]. After the gun system is assembled, the ceramic insulator and the HV

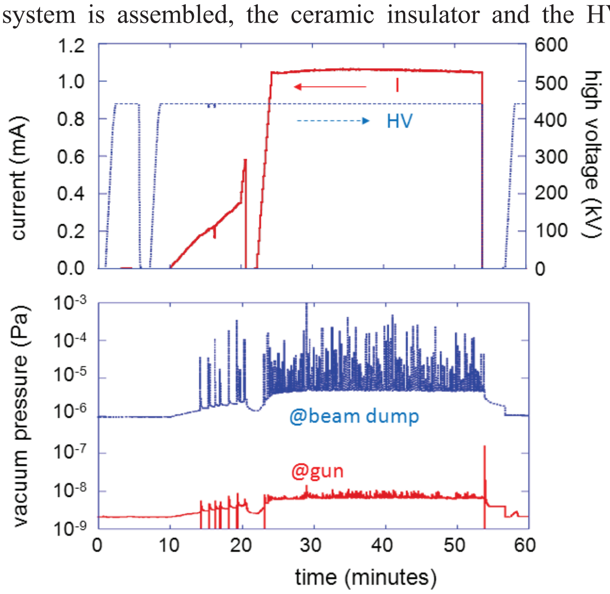

Figure 2: Top: Beam current (red solid line) and gun high voltage (blue dotted line) as a function of time. The 440 keV electron beam with currents slightly above 1 mA was continuously generated for 30 minutes. Bottom: Vacuum pressures of the gun (red solid line) and beam dump (blue dotted line).

chamber are baked at 170 degree C for 50 h. A 1000 l/s turbo molecular pump is used during the baking. After the activation of the NEG pumps, the base pressure of the HV chamber is measured to be 8×10^{-10} Pa (N_2 equivalent) with an ionization gauge (ULVAC: AxTRAN).

The details of the high voltage testing with cathode electrode in place are described in elsewhere [13,14]. We changed the accelerator gap between the cathode and anode electrodes from the original design value of 100 to 160 mm to reduce the surface electric fields of both cathode and anode electrodes. The decrease in the cathode electric field was roughly 10%, whereas that of the anode electrode was >50%. Those reductions of surface electric fields allowed us to finally ramp up to 550 kV with cathode electrode in place.

We could hold the gun high voltage at 550 kV for 10 min. This suggests that the high voltage at 510 kV could be maintained for more than 8 h according to our previous experiments without the cathode electrode [11]. We could however hold the voltage without any discharge for up to 40 min at 510 kV and 3 h at 390 kV, respectively. The reason for such short holding times at voltage much lower than 550 kV was difficult to discern. Recently, we found failures of two out of ten segments of our insulator. Thus, the reason that the holding time was so short could be attributed to those failures, since we could successfully hold more than 8 h at 400 kV by connecting short bars between the electrodes of the two failed ceramic segments. We plan to fix the problem of the failed segments in the near future for aiming at stable operation at 500 kV.

BEAM GENERATION

The downstream beamline for 500-keV beam generation is shown in Fig. 1. A steering magnet and a solenoid magnet are used for beam transport from the gun exit to a beam dump. A lightbox to deliver a driving laser onto the photocathode is placed immediately after the solenoid. The laser is injected into the lightbox through an antireflection-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 2.3degree. The reflected laser is ejected out of the lightbox with another mirror and window pair. A differential pumping chamber is placed after the lightbox. The chamber, consisting of eight 430 l/s NEG modules (SAES getters: WP38/950 St707), has conductance-limiting orifices with a 3 cm diameter and 3 cm length 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 placed between the expander magnet and an insulated beam dump. After the beam position is confirmed at the profile monitor, the beam is transported to the beam dump. The beam dump, which is a water-cooled copper pipe, is covered with a 10-cm-thick lead block as a radiation shield. The expanded beam size at the dump is estimated to be 40 mm square. A 1 kΩ resistor is connected between the insulated dump and ground to monitor the beam current.

A frequency-doubled laser diode, Millenia Pro (Spectra Physics Co.), is used as a driving laser. Its wavelength is 532 nm and its maximum power is 5 W. The photocathode center is illuminated with the laser of a spot size of σ_x = 0.1 mm. The laser power is remotely controlled by rotating a half-wave plate. The laser power at the exit of the lightbox is 20% of that at the entrance, whereas the reflectivity of the GaAs wafer for 532-nm laser light is 32%. Further study on the laser power loss in the lightbox is needed.

The demonstration of generation of a 500 keV electron beam with currents up to 1.8 mA is described elsewhere [13]. The beam current was limited by the capacity of high voltage power supply of our DC gun. We will correct this problem in a future work, aiming at 10-mA operation at 500 kV, while we have already demonstrated 10-mA beam generation at 180 kV [14].

Figure 2 shows beam generation test at 440 kV. The top shows the beam dump current (red solid line) and high voltage (blue dotted line). The 440 keV beam was continuously generated for 30 minutes with currents slightly above 1.0 mA. The beam current is almost constant during the beam generation test. The extracted electron charge was 1.8 C and 1/e charge life is estimated to be 46 C. The laser power is 0.37 W for 1 mA beam generation. The quantum efficiency of the photocathode is estimated to be 0.68 %. The bottom shows vacuum pressures of the gun chamber (red solid line) and beam dump (blue dotted line). The gun vacuum pressure slightly increased during the beam generation depending on the amount of beam current. The reason of the spikes observed in the vacuum pressure of the beam dump is under investigation.

SUMMARY

We have demonstrated 500-keV electron beam generation from a DC photoemission gun. The maximum beam current generated was 1.8 mA limited by the capacity of high voltage power supply. We have generated 440-keV electron beam with 1 mA current for 30 minutes. The gun was successfully conditioned up to 550 kV without suffering from the field emission problem and the gun was held for 10 min without any discharge at 550 kV. The gun has recently been moved to the compact energy recovery linac (cERL) facility at the KEK site, where it is connected to an adjoining injector accelerator. Beam commissioning of the cERL injector will be commenced soon [15].

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