

DEVELOPMENT OF A 500-KV PHOTOCATHODE DC GUN FOR ERLS

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Abstract. We have developed a 500-kV, 10-mA photocathode DC gun for energy recovery linac (ERL) light sources. A segmented ceramic insulator with guard rings is employed to improve robustness at high voltage operation, because this structure can prevent field emission electrons from directly striking the ceramic surface. We have recently succeeded in applying 500 kV on the ceramics for eight hours without any discharge. This high voltage testing was performed with a simple configuration without NEG pumps, cathode and anode electrodes to mainly study the field emission from a tube supporting the cathode electrode. The same high voltage testing with a full configuration necessary for beam generation was carried out up to 380 kV where some increase of radiation was observed. Up-to-date status of our gun development is presented in detail.

1. 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 next generation Energy Recovery Linac (ERL) Light Sources (LS) worldwide [1, 2, 3]. A DC photoemission gun with a GaAs photocathode is one of the most promising candidates, since such a photoemission DC gun illuminated with 527 nm laser light has successfully provided 9.1 mA beam for the JLab 10 kW IR Upgrade FEL [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 be as high as possible to suppress the space charge effects as well. This high brightness gun is anticipated to be used in a 5-GeV ERL based hard X-ray synchrotron light source project in Japan [1], an X-ray FEL oscillator as an attractive option of the 5-GeV light source [5], and an ERL based high-flux Compton gamma-ray as a new nondestructive assay method for ²³⁵U, ²³⁹Pu, and minor actinides in spent nuclear fuel assembly [6, 7].

We have developed a 500-kV DC gun for the Japanese ERL light sources [8]. One of technological challenges of high brightness DC guns is to apply DC high voltage on a ceramic insulator with a tube supporting cathode electrode, since field emission from the tube causes discharge or punchthrough on the ceramic surface [11]. In order to mitigate the field emission

problem, a segmented insulator with rings which guard the ceramics from the field emission is employed. We have recently succeeded in applying 500 kV on the ceramics for eight hours without any discharge [9]. This high voltage testing was performed with a simple configuration without NEG pumps, cathode and anode electrodes to mainly study the field emission from the supporting tube. The next task is to apply the same high voltage on the ceramics with a full configuration necessary for beam generation. We have designed electrodes for the maximum surface electric field not to exceed 11 MV/m at 500 kV with the cathode/anode gap of 100 mm. NEG pumps with a pumping speed of 7200 l/s have been installed in the gun chamber. A photocathode preparation system was connected to the gun chamber. In the present paper, our current status of development of a photoemission DC gun is described.

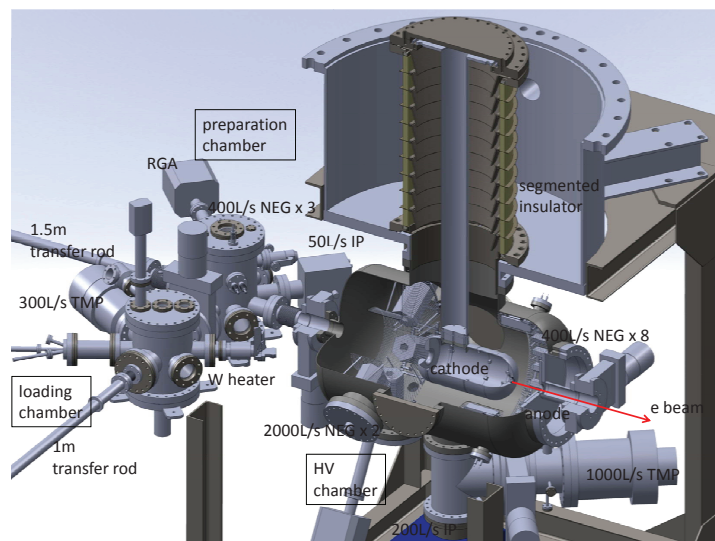


Figure 1. The 500-kV photocathode DC gun.

2. 500-kV DC photocathode gun

The 500-kV DC gun is shown in Fig. 1. A GaAs wafer on a molybdenum puck is installed in the loading chamber and heat cleaned by a tungsten heater. The puck is transferred by a magnetic coupling to the preparation chamber where cesium and oxygen are alternatively applied for negative electron affinity activation. The activated cathode is then transferred to the high voltage (HV) chamber and installed in the cathode electrode. The cathode electrode is connected to the high voltage terminal of the segmented ceramic insulator. The photoemission beam is accelerated by a static electric field applied between cathode and anode electrodes.

2.1. Gun electrodes

The bottom center of Fig. 2 shows cross section of the high voltage vacuum chamber around the cathode electrode. The cathode/anode gap is 100 mm to obtain an accelerating field as high as possible on the photocathode surface without high-voltage breakdown. A static electric field calculation (POISSON [10]) shows the maximum field on the cathode electrode and accelerating field on the photocathode center are 10.3 MV/m and 6.75 MV/m at 500 kV, respectively (see right of Fig. 2). The cathode/anode gap is surrounded by NEG pump units. Eight 400 l/s NEG pumps (SAES: CapaciTorr D400-2) were installed in the chamber. The unit of NEG pumps is shown in Fig. 3. The number of the pumps will be increased to twenty in the near future, which

corresponds to 8000 l/s pumping speed for hydrogen. 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, which are located behind the cathode electrode, are used to install 2000 l/s NEG pumps (SAES: CapaciTorr D2000). The distance between the cathode tail and NEG pumps along the beam line is 64.5 mm. The POISSON calculation shows the maximum electric field on the cathode electrode is 10.51 MV/m (see left of Fig. 2). Two 2000 l/s NEG pumps were already installed in the chamber. The number of the pumps will be increased to five in the near future. A 200 l/s ion pump (ULVAC:PST-200AU) is installed at the bottom of HV chamber (see Fig. 1) to pump noble gases and methane.

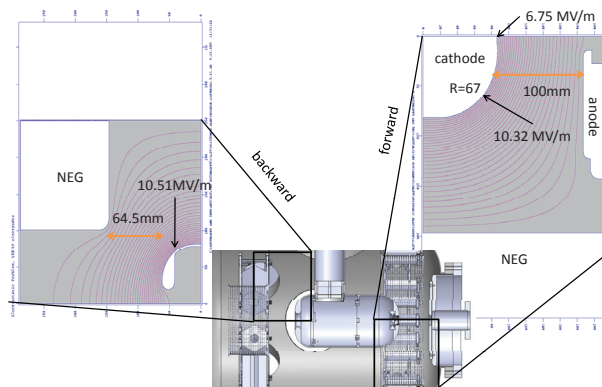


Figure 2. Static electric field calculation around cathode and anode electrodes.

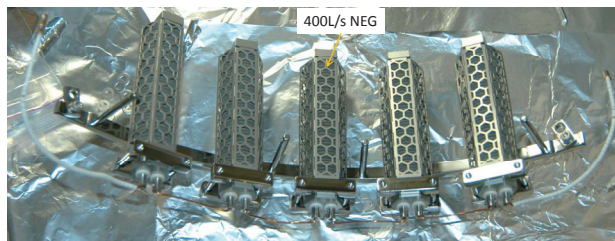


Figure 3. A unit of five 400 l/s NEG pumps installed around the cathode/anode electrodes in the HV chamber.

The cathode electrode consists of three separate parts, head, body and tail. A photocathode is housed in the electrode head and the support tube is connected to the electrode body (see Fig. 1). All electrodes are made of titanium. We can easily switch to electrodes with different shapes and materials.

The ceramic insulator and the HV chamber were baked at 180°C for 50 hours after assembling the gun system. A 1000 l/s turbo molecular pump installed at the bottom of HV chamber is used to pump down the chamber during the baking. After the activation of NEG pumps, the base pressure of the HV chamber is 1.8×10^{-9} Pa measured with a BA gauge (ULVAC: AxTRAN).

2.2. High voltage conditioning

A high voltage conditioning was performed after the base pressure reaches below 2×10^{-9} Pa. We have to avoid discharge damage on the ceramics during the conditioning. Three techniques are employed to mitigate the damage. The first is a usual current limit register (100 M Ω)

connected between the HV power supply and the insulator to limit abrupt current drawn from HV terminal in case of discharge. The next is a technique to clip average discharge current. The HV power supply needs to provide current running through its internal registers and the dividing registers of the segmented insulator. We set current limit at the current necessary for the high voltage set-point plus just $1 \mu\text{A}$. If the average discharge current exceeds $1 \mu\text{A}$, the HV power supply switches to constant current (CC) mode from constant voltage (CV) mode and the voltage drops quickly. This voltage drop helps to stop discharge. Then the voltage recovers gradually as the power supply charges its capacitor up. Finally the operational mode returns to CV mode. The last is an interlock system for vacuum and radiation. The high voltage power supply was interlocked with pressure above 1×10^{-6} Pa and radiation above $3 \mu\text{Sv/h}$. The BA gauge is used to monitor the pressure and a NaI radiation detector is placed 0.2 m downstream the anode flange to monitor the radiation increase due to discharge.

Figure 4 shows the applied voltage (top), radiation (middle) and pressure (bottom) as a function of time during the conditioning. The gun was conditioned up to 250 kV within two hours. Above 250 kV, it takes an hour to increase 4 or 5 kV up to 380 kV. The conditioning was halted at 380 kV, since radiation increase was observed above 370 kV. We have performed radiation survey around the HV chamber and found locally strong radiation at one of the five ICF203 ports which are used for installation of 2000 l/s NEG pumps (see Fig. 5). To further increase the high voltage, we need to open the high voltage chamber and fix the radiation problem. Before that, we plan to demonstrate beam generation at 300 kV.

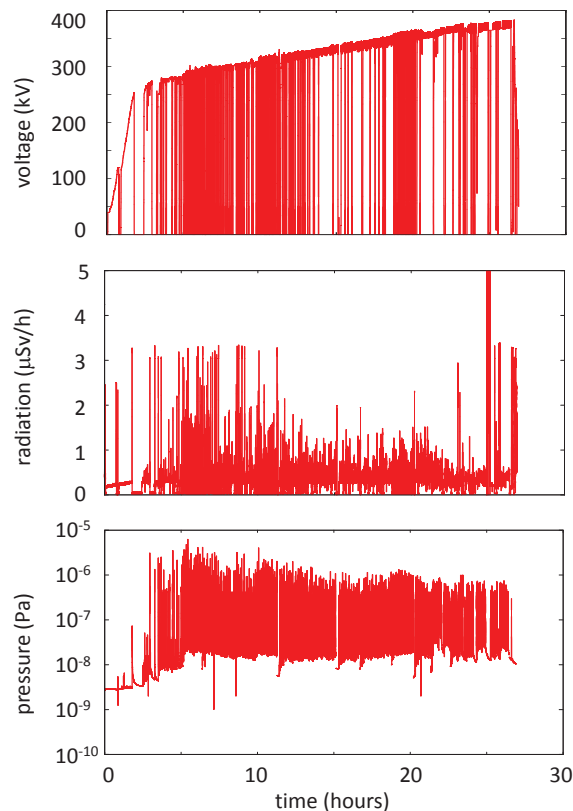


Figure 4. A high voltage conditioning result. The voltage (top), radiation (middle) and pressure (bottom) as a function of time.

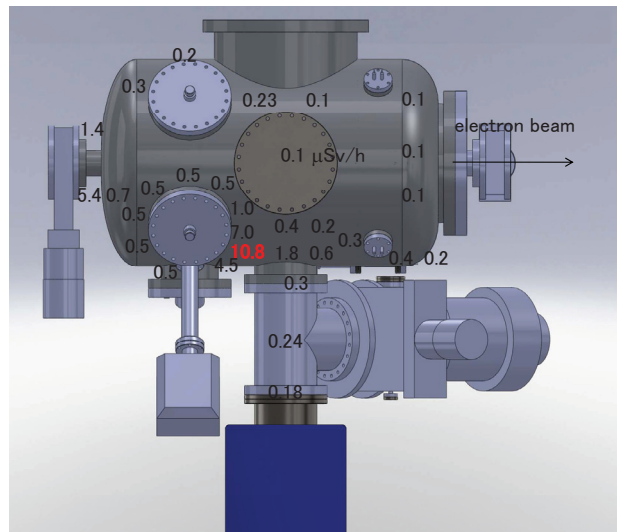


Figure 5. Radiation survey result for the right side of HV chamber when 370 kV is applied on the HV terminal. The figures represent radiation in units of $\mu\text{Sv/h}$ measured with a NaI detector.

3. Cathode loading and preparation system

A cathode preparation system was connected to the high voltage chamber. A 1.5 m magnetic coupling is used to transfer a puck between the preparation and high voltage chambers. The details of the system are described in Ref. [12]. A GaAs wafer installed into the loading chamber is heat cleaned to 550°C for five hours by a tungsten heater. The pressure rises to 3×10^{-5} Pa during the heat cleaning. The cleaned wafer is transferred to the preparation chamber, and then it is activated by alternative application of cesium and oxygen. The preparation chamber is equipped with three 400 l/s NEG pumps (SAES: CapaciTorr D400-2) and a 45 l/s ion pump (ULVAC: PST-050AU). The base pressure is 1.8×10^{-9} Pa.

The photocurrent is measured with a charge collector positively biased at 40 V, which is 1 cm in front of the photocathode, as a function of time under intermittent illumination of $20 \mu\text{W}$ laser light at wavelength of 532 nm. Typical quantum efficiency of 7 % at maximum is obtained. The static 1/e cathode life in the preparation chamber is 270 hours, as shown in Fig. 6.

4. Summary

We have developed a 500-kV photoemission DC gun. High voltage conditioning with full configuration for beam generation was carried out up to 380 kV, The conditioning was halted by radiation increase problem. We first plan to try beam generation at 300 kV and then to fix the radiation problem for further conditioning to 500 kV.

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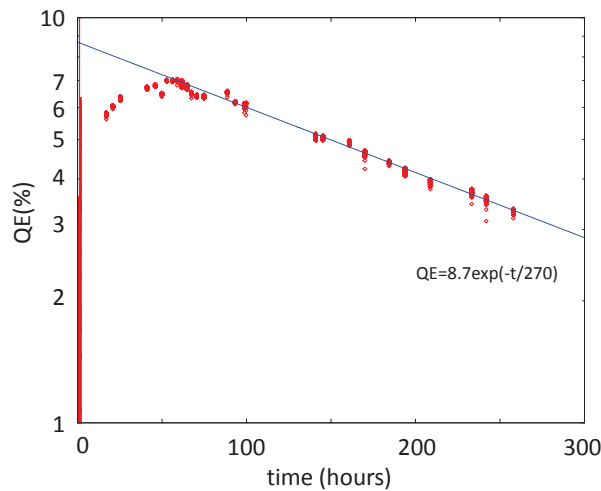


Figure 6. Static life of GaAs cathode measured in the preparation chamber. The decay time is 270 hours.

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