DEVELOPMENT OF A 500-KV PHOTO-CATHODE DC GUN FOR ERL LIGHT SOURCES*

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Abstract

Energy recovery linac (ERL) based next generation light sources require high brightness electron gun. We have developed a 500-kV, 10-mA photocathode DC gun. A segmented ceramic insulator with guard rings is employed to improve robustness at high voltage operation by keeping field emission electrons away from 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. Up-to-date status of our gun development will be presented in detail.

INTRODUCTION

Electron guns capable of delivering 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 considered to be 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 low emittance required for ERL-LS demands the DC high voltage equal to or greater than 500 kV for reduction of nonlinear space charge effects in low energy regime [4]. The accelerating field on the cathode surface should be as high as possible to suppress the space charge effects as well.

A 5-GeV ERL based hard X-ray source is a goal of our future synchrotron light source project in Japan [1]. An X-ray FEL oscillator is anticipated as one of the most attractive options for the 5-GeV light source [5]. An ERL based high-flux Compton gamma-ray is proposed as a new nondestructive assay method for ^{235}U, ^{239}Pu, and minor actinides in spent nuclear fuel assembly, in combination with nuclear resonance fluorescence based detection system [6, 7].

We have developed a 500-kV DC gun for the Japanese ERL light sources [8]. It is however difficult 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. In order to mitigate the field emission problem, we have employed a segmented insulator with rings which guard the ceramics from the field emission. 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 step is to repeat the same high voltage testing 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 while keeping the distance between electrodes 100 mm for high brightness beam generation. NEG pumps with a pumping speed of 7200 l/s has 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.

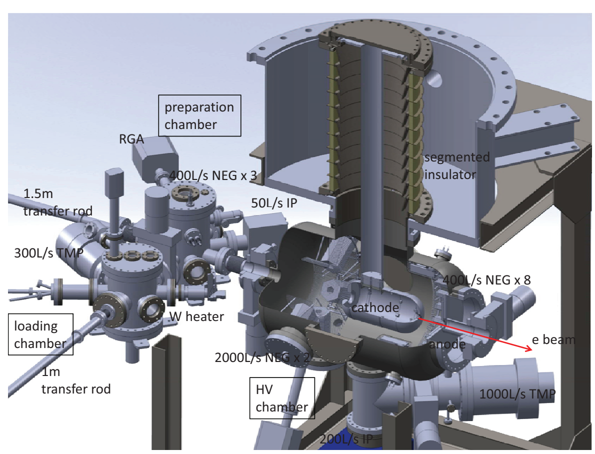

Figure 1: The 500-kV photocathode DC gun.

500-KV DC 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

* This work was supported in part by MEXT Quantum Beam Technology Program, and JSPS Grants-in-Aid for Scientific Research in Japan (20360424).
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transferred to the preparation chamber for negative electron affinity activation. The activated cathode is 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.

Cathode and Anode Electrodes

The bottom center of Fig. 2 shows cross section of the high voltage vacuum chamber around the cathode electrode. We chose cathode/anode gap to be 100 mm to obtain high accelerating field and to avoid the high-voltage breakdown. A static electric field calculation (POISSON [10]) shows the maximum field on the cathode electrode and accelerating field on the cathode 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 1mm 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 employed to pump noble gases and methane.

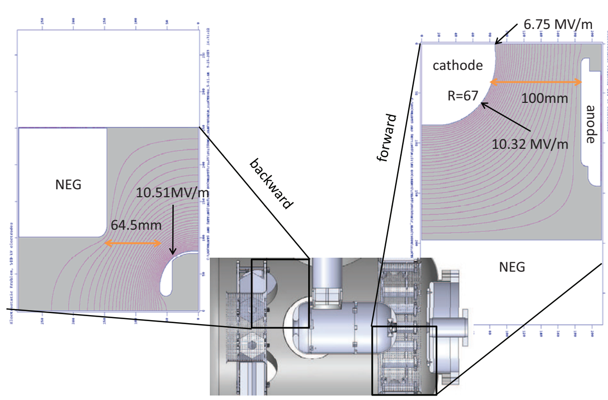

Figure 2: Static electric field calculation around cathode and anode electrodes.

The cathode electrode consists of three separate parts, head, body and tail. A photocathode is housed in the head and the support tube is connected to the body. All electrodes are made of titanium. We easily change electrodes with different designs and materials.

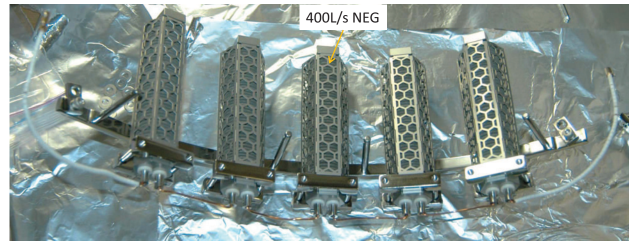

Figure 3: A unit of five 400 l/s NEG pumps installed around the cathode/anode electrodes in the HV chamber.

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 was 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).

High Voltage Conditioning

A high voltage conditioning was performed after the base pressure reaches below 2×10^{-9} Pa. We used three techniques to avoid damage on the ceramics during the conditioning. The first is usual current limit register (100 MΩ) 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 register and the dividing registers of the segmented insulator. We set current limit at the current necessary for this high voltage set-point plus just 1 μA. If the average discharge current exceeds 1 μA, the HV power supply switches 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 μSv/h. The NaI radiation monitor is placed 0.2 m downstream of the anode flange.

Figure 4 shows the applied voltage (top), radiation (middle) and vacuum pressure (bottom) as a function of time during the conditioning. The gun was conditioned up to 250 kV within two hours. It was conditioned to 380 kV at an average rate of 4 to 5 kV per hour. 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. We will first try to generate beam at 300 kV and then study the radiation problem in more details.

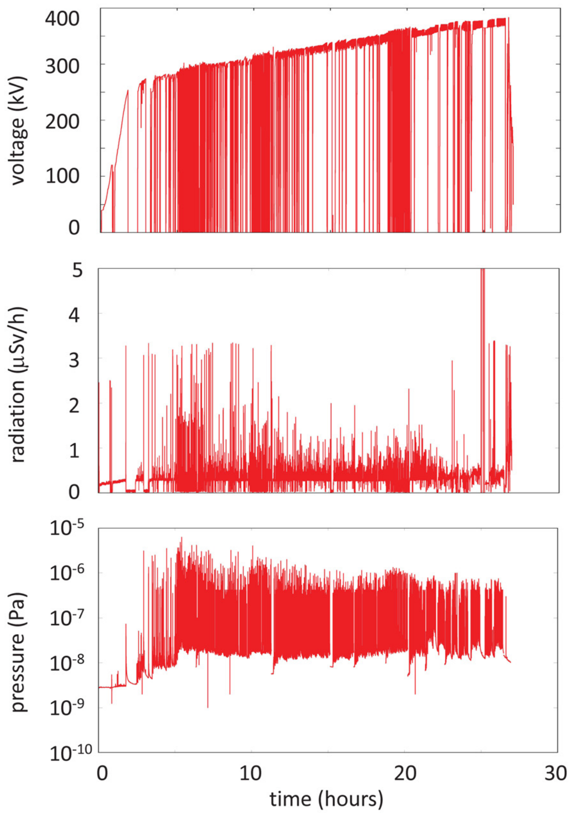

Figure 4: A high voltage conditioning result. The voltage (top), radiation (middle) and vacuum pressure (bottom) as a function of time.

CATHODE LOADING AND PREPARATION SYSTEMS

A cathode preparation system was connected to the high voltage chamber. A 1.5 m transfer rod is used to transfer a puck between the preparation and high voltage chambers. The details of the system is described in Ref. [11]. 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 Cs 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 photo current is measured with a charge collector positively biased at 40 V, which is 1 cm in front of the photo cathode, as a function of time under intermittent illumination of 20 μW laser 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. 5.

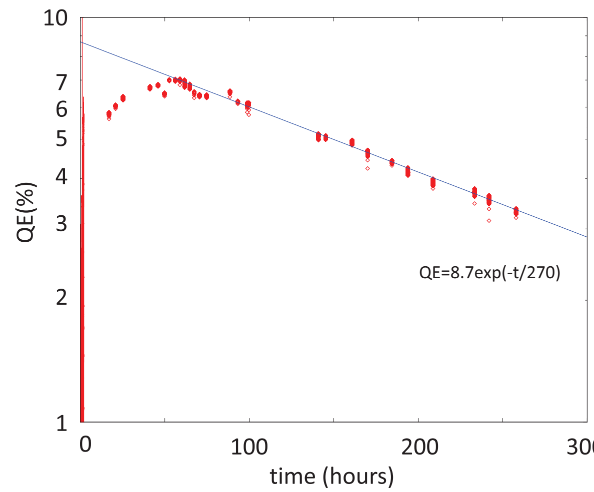

Figure 5: Static life of GaAs cathode measured in the preparation chamber. The decay time is 270 hours.

SUMMARY

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

REFERENCES

[1] S. Sakanaka *et al.*, "Status of ERL and cERL projects in Japan", in these proceedings, TUP004 (2010).

[2] B. M. Dunham *et al.*, "Performance of a Very High Voltage Photoemission Electron Gun for a High Brightness, High Average Current ERL Injector", PAC2007, 1224 (2007).

[3] C. Hernandez-Garcia *et al.*, "A High Average Current DC GaAs Photocathode Gun for ERLs and FELs", PAC2005, 1795 (2005).

[4] Ivan V. Bazarov and Charles K. Sinclair, Phys. Rev. STAB **5**, 034202 (2005).

[5] R. Hajima and N. Nishimori, "Simulation of an X-ray FEL Oscillator for the multi-GeV ERL in Japan", FEL2009, 568 (2009).

[6] T. Hayakawa *et al.*, NIMA 621, 695 (2010).

[7] R. Hajima *et al.*, "Design of a multi-turn ERL for hybrid K-edge densitometer", Proc of FEL2010 (2010).

[8] N. Nishimori *et al.*, AIP Conf. Proc. 1149, 1094 (2009).

[9] R. Nagai *et al.*, Rev. Sci. Instrum. 81, 033304 (2010); "High-voltage test of a 500-kV photocathode DC gun for the ERL light sources in Japan", IPAC2010, 2341 (2010).

[10] J. H. Billen and L. M. Young, LA-UR-96-1834 (1996).

[11] N. Nishimori *et al.*,"Development of a 500-kV photocathode DC gun for the ERL light sources in Japan", FEL2009, 277 (2009).