Development of a 500-kV Electron Gun for ERL

An energy-recovery linac (ERL) is considered to be a promising device for high-power free-electron lasers (FELs), next-generation X-ray light sources, and high-energy physics applications. The brightness and the intensity of the light source are determined on the basis of the electron-beam emittance that depends on the beam quality (which is, in turn, related to the size and the spread of the beam) and the beam intensity. Therefore, an electron gun used for producing small-emittance electron beams with a high-average current is the most important component of an ERL since the flux and the brilliance of such light sources rely on the emittance and the current of the electron beam.

A dc electron gun using negative electron affinity (NEA) GaAs photoemission cathode can generate a high-current electron beam that has an ultra-small initial emittance. Such electron guns are under development for future ERLs in many laboratories. These gun development programs are aimed to achieve an average current of 10–100 mA and a normalized emittance of 0.1–1 mm·mrad. To suppress the increase in emittance induced by a space charge effect, the gun voltage must be 500 kV or higher. In the electron gun, an acceleration voltage should also be applied within a short gap in order to generate a high-brightness electron beam. Therefore, a support-rod electrode needs to be located in the center of the ceramic insulator. This particular configuration leads to difficulties in achieving a high-voltage operation. Field-emitted electrons from the support-rod electrode may cause damage to the ceramic insulator. As a result, the stable operation of such electron guns at 500 kV has not yet been achieved in spite of the intensive gun development efforts around the world.

A 500-kV, 10-mA photocathode dc gun has been developed by a collaboration of Japan Atomic Energy Agency (JAEA), High-Energy Accelerator Research Organization (KEK), Hiroshima University, and Nagoya University (Fig. 1). The ceramic insulator is the most critical component in the development of a high-voltage dc electron gun. It needs to be well insulated and appropriately uniform resistance in order to avoid any local concentration of the electron charge and electric field that can irreversibly damage the ceramic because of cracking or a punch through. The collaboration employed a segmented insulator for use in the 500-kV gun. The design is similar to the JAEA thermionic cathode gun (250 kV) used for a high-power FEL and the polarized electron gun (200 kV) at Nagoya University, both of which have been operated with good robustness. Kovar hoops were stacked and blazed between segmented insulators and guard-ring electrodes were installed on each Kovar hoop on both the inner and the outer sides of the insulator (Fig. 2). The inner guard-ring electrodes shield the ceramic insulator from being hit directly by an electron emitted from the support-rod electrode.

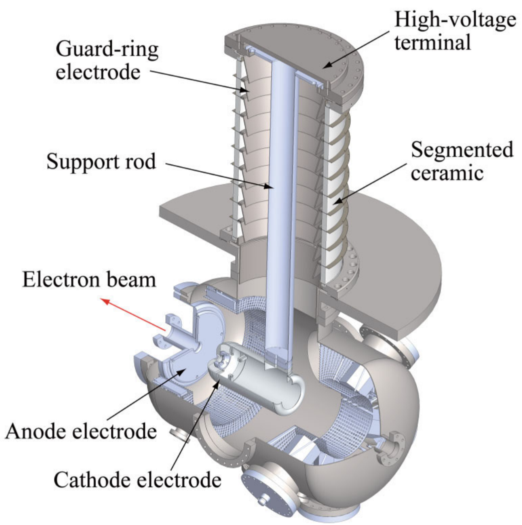

Figure 1
Schematic representation of the 500-kV dc photocathode electron gun.

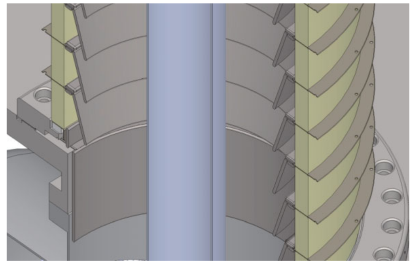

Figure 2
Enlarged view of the segmented ceramic and the support rod.

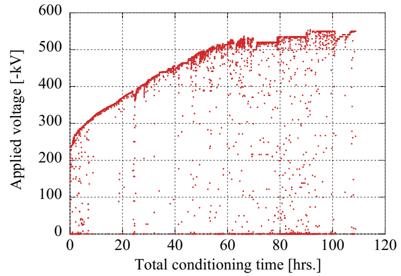

Figure 3
Applied voltage vs. total time during high-voltage conditioning.

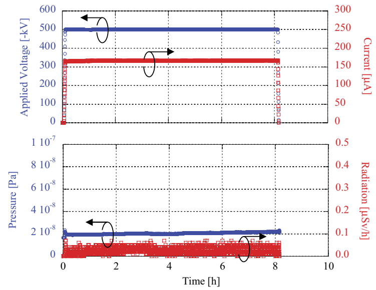

Figure 4
Results of a long-time high-voltage holding test for 8 h.

The 500-kV gun was assembled at JAEA. The ceramic insulator and the vacuum chamber were baked at 190°C for 8 h. After the baking, the chamber was pumped down to a pressure less than 3×10^{-8} Pa by a turbo molecular pump. To prevent the fatal damage of the electrodes during the high-voltage conditioning, the discharging current was limited in two ways. The peak current of the discharge was restricted by an output resistor of 100 MΩ. The average current during the discharge was clipped at a level less than 1 μA by the constant current circuit of the Cockcroft Walton generator.

Figure 3 plots the applied voltage against the total conditioning time. High-voltage activity appeared at a voltage of approximately 250 kV, and the gun was conditioned at a speed of approximately 4 kV/h up to 500 kV. The conditioning was carried out more slowly at a voltage of above 500 kV. Once the conditioning was completed up to 550 kV, we could increase the gun voltage from 0 to 550 kV in 3 min.

A long-time holding 500-kV test was carried out for 8 h, as shown in Fig. 4. As seen in Fig. 4, the gun could hold the voltage of 500 kV stably without any discharge. The key to a successful high-voltage operation is the specially designed ceramic insulator and guard-ring electrodes. The segmented cylindrical ceramic insulator covered with the guard-ring electrodes effectively prevents the breakdown of the high voltage and the fatal damage to the ceramic.

The cathode and the anode electrodes were installed, and a photocathode preparation system was connected to the gun. The beam test will be started soon.

REFERENCE

[1] R. Nagai, R. Hajima, N. Nishimori, T. Muto, M. Yamamoto, Y. Honda, T. Miyajima, H. Iijima, M. Kuriki, M. Kuwahara, S. Okumi and T. Nakanishi, *Rev. Sci. Instrum.* **81** (2010) 03304.

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