DESIGN AND FABRICATION OF A 500-KV PHOTOCATHODE DC GUN FOR ERL LIGHT SOURCES

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Abstract

A 500-kV, 10-mA photocathode DC gun has been designed and is now under fabrication by the collaboration efforts of JAEA, KEK, Hiroshima Univ. and Nagoya Univ. We have employed a segmented cylindrical ceramic insulator, because this type of ceramic insulator has shown good stability and robustness at the 250-kV JAEA FEL gun and the 200-kV Nagoya polarized gun. All the vacuum chambers are made of titanium alloy with very low out-gassing rate. The Cockcroft-Walton voltage multiplier, the ceramic insulator, the vacuum chambers have been fabricated and a high-voltage test will be started soon. Up-to-date status of the gun development is presented in detail.

INTRODUCTION

Following the successful development of the JAEA ERL for a high-power FEL, we launched a research program for future ERL light sources, which will open a new era of photon science and industry [1][2]. Since the flux and the brilliance of such light sources rely on emittance and current of an electron beam, an electron gun is the most critical component in the ERL light sources.

In JAEA, a gun development program for future ERL light sources was initiated in 2004 and study of cathode material [3] design and construction of a 250-kV 50-mA photocathode DC gun [4] have been conducted. We have also developed a 500-kV 10-mA photocathode DC gun since 2008 in collaboration with KEK, Hiroshima Univ. and Nagoya Univ. The 500-kV gun is designed to satisfy the requirements of the Compact ERL, a test facility under construction at KEK site [5]. In this paper, we present design and construction status of the 500-kV gun. Status of the 250-kV gun is presented in the accompanying paper [4].

HIGH-VOLTAGE CIRCUIT

The high-voltage circuit for the 500-kV gun is a conventional Cockcroft-Walton (C-W) voltage multiplier and has a capacity of 50 kW (500 kV and 10 mA). We optimized the circuit design to obtain voltage ripple smaller than 10^{-4} in a peak-to-peak value. This is because that the voltage ripple, which appears at the frequency of the driver circuit, is one of the major sources of bunch-to-bunch fluctuation such as jitter in emittance, bunch shape, arrival time and average energy after the full acceleration [6]. We employ an LC filter to reduce the voltage ripple. Voltage ripple of a C-W voltage multiplier with a LC filter is given by

$$\Delta V = \frac{1}{16\pi^2 f^2 L_1 C_1} \frac{nI}{2fC},$$

where f is the driver frequency, n is the number of stages, C is capacitance of a stage, I is beam current, L_1 and C_1 are filter parameters. Note that this voltage ripple is calculated for a C-W multiplier with sinusoidal driving current, but our C-W multiplier is driven by high-frequency pulse circuit, which may cause larger peak-to-peak ripple than a sinusoidal driving case by some factor.

Table 1: Parameters of Cockcroft-Walton voltage multipliers for the 250-kV 50-mA gun (No. 1) and the 500-kV 10-mA gun (No. 2). The ripples are in peak-to-peak values.

	No.1	**No.2**
voltage	250 kV	500 kV
current	50 mA	10 mA
driving frequency	20 kHz	40 kHz
stage capacitance	8.4 nF	2.4 nF
the number of stages	6	12
filter inductance	1.2 H	2.0 H
filter capacitance	1.4 nF	0.2 nF
ripple (design)	3.5×10^{-5}	1.2×10^{-5}
ripple (measured)	1.9×10^{-4}	—

Parameters of Cockcroft-Walton voltage multipliers for the 250-kV 50-mA gun and the 500-kV 10-mA gun are listed in Table 1. We consider that this type of high-voltage circuit is scalable to a 500-kV 100-mA gun for a future ERL X-ray source with keeping voltage ripple smaller than 10^{-4}.

CERAMIC INSULATOR AND GUARD RINGS

In the development of a high-voltage DC electron gun, a ceramic insulator tube is the most challenging part. The ceramic insulator should have good insulation and appropriate resistivity to avoid local concentration of electron charge, which causes fatal damage on the ceramic due to cracking or punch-through. So far, ceramic insulators with

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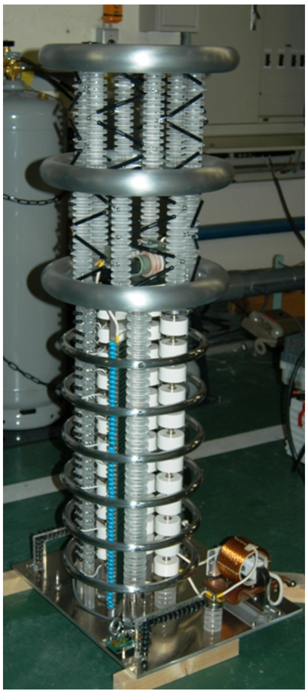

Figure 1: Cockcroft-Walton voltage multiplier for the 500-kV gun. The height is 1250 mm including the output registers on the top.

surface resistivity by special coating and ceramic with bulk resistivity have been used for photocathode DC guns [7]. Stable operation at a voltage of 500 kV, however, has never been achieved in such guns, yet.

We employed a segmented insulator tube for the 500-kV gun, where multiple ceramics are stacked in series. This design is similar to the JAEA thermionic cathode gun (250 kV) for a high-power FEL [8] and the polarized electron gun (200 kV) at Nagoya University [9], both of which have been operated with good stability and robustness. In the segmented insulator for the 500-kV gun, a Kovar electrode is sandwiched between two ceramics and blazed and the electrodes are connected by 500 MΩ registers at each segment. Guard rings are installed on each Kovar electrode at both inner and outer sides. We optimized the number of segmentation and the shape of guard rings to minimize the surface electric field. Trajectories of field emitted electrons from the cathode-supporting rod were also taken into consideration, because secondary electron emission from the ceramic is a major source of a ceramic break-down.

The fabricated ceramic insulator tube for the 500-kV ERL gun is shown in Fig. 2 together with the old insulator used in the 250-kV FEL gun.

Figure 3 shows the final design of the insulator tube with guard rings for the 500-kV gun. We have fixed the geometrical parameters as follows: the number of segmentation 10, the length of each segmentation 65 mm, the outer diameter of the ceramic insulator 400 mm, the diameter of the supporting rod 106 mm. The guard rings are designed to be installed in two ways, normal and reverse con-

Figure 2: Multi-segmented ceramic insulator tubes for the old 250-kV JAERI FEL gun (right) and the 500-kV ERL gun (left). The guard rings are not installed at the 500-kV insulator.

figurations. The normal configuration is preferable to reduce surface electric field on the supporting rod and the guard rings. From a POISSON simulation, we found that $E_{max} = 7.9$ MV/m on the rod and $E_{max} = 8.4$ MV/m on the guard rings. In the reverse configuration, the electric field has rather larger values, $E_{max} = 8.6$ MV/m for the rod and $E_{max} = 13.7$ MV/m for the guard rings. However, the reverse configuration is suitable for suppressing secondary electron emission from the ceramic surface triggered by X-rays emitted from the cathode and anode electrodes. We plan to examine both configurations in a high-voltage testing.

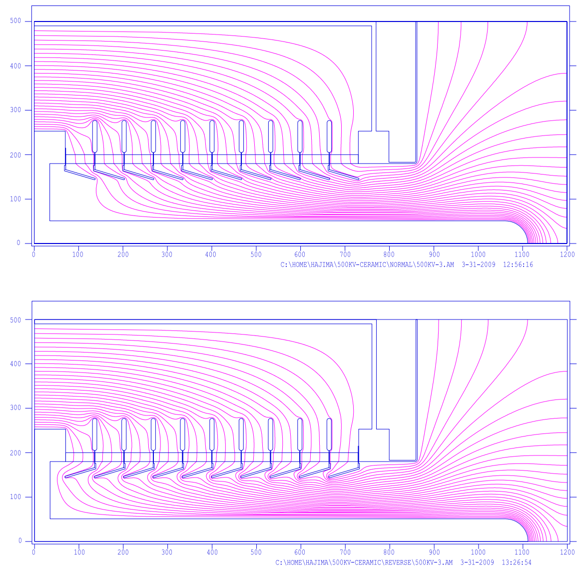

Figure 3: Design of guard rings: normal configuration (top) and reverse configuration (bottom).

The SF_6 tank was designed so that the high voltage circuit, output register and the ceramic insulator are placed in a straight line. This configuration will help one get an axially symmetrical field around the insulator and the power supply. The existing SF_6 tank for JAEA thermionic cathode gun is reused as the SF_6 tank for 500 kV gun.

VACUUM DESIGN

It is known that lifetime of a NEA photocathode depends much on vacuum condition during the operation. In our design of 500-kV gun, therefore, we paid much attention to the vacuum issues.

The 500-kV gun system consists of three vacuum chambers: a main chamber, a loading chamber and a preparation chamber. In the design of these chambers, vacuum pumps, gauges and baking procedure should be considered carefully. We use titanium for the vacuum chamber material, because titanium with a special chemical processing has very small out-gassing rate. A chamber made of titanium after 20-hours of 150-°C baking has out-gassing rate of 6×10^{-13} Pa m/s at 300K, which is 2-3 orders smaller than a general SUS chamber [11] [12].

The main chamber to accommodate the cathode and anode electrodes has dimensions: a diameter of 508 mm, a length of 935 mm, surface area of about 1.4 m^2. The chamber is equipped with NEG pumps (18000 litters/s in total), and a 500-litters/s ion pump.

CATHODE LOADING AND PREPARATION SYSTEMS

Loading and preparation of a photocathode is performed in a similar way to other load-locked guns. A piece of GaAs wafer is installed on a cathode puck and introduced into the loading chamber. In the design of the cathode puck, we considered the following issues: reliability of cathode transportation, reduction of dark current, availability of a small emittance beam. Design of the cathode puck is based on a puck used in the Nagoya University polarized electron gun (NPES3) with some modification. Outer diameter of the puck is chosen at 27mm to accommodates a GaAs wafer of ϕ 22mm or square 15 mm on a side. The GaAs wafer is held on the molybdenum base-plate of the cathode puck by two means indium soldering and a tantalum retaining ring. This cathode holding method is similar to the JLAB gun [13].

The loading chamber has a tungsten heater and an atomic hydrogen source for cleaning the cathode surface. After obtaining a clean surface of the GaAs wafer, the cathode puck is transfered to the preparation chamber and a NEA surface is formed by introducing Cs and O_2 alternatively.

The loading and the preparation chambers are also made of titanium for its small out-gassing rate. In both chambers, a cathode puck is fixed by a holder on a rotating table and three pucks can be processed in series. This multi-puck loading system is useful for studying various cathode materials. It was reported that GaAs and GaAsP show different temporal response [10], and AlGaAs has longer life than GaAs [3]. Testing these cathode materials in a reproducible manner will be helpful to establish photocathode technologies required for future ERL light sources.

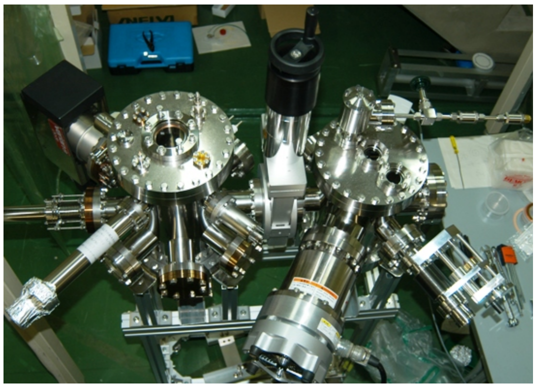

Figure 4: The loading (right) and the preparation (left) chambers of the 500-kV gun under an off-line test.

CURRENT STATUS

Current status of the 500-kV gun development is as follows: the C-W voltage multiplier was tested in SF_6 gas at a voltage up to 550 kV. The ceramic insulator tube, the guard rings and the cathode-supporting rod have been delivered. We will begin a high-voltage test of the ceramic insulator tube soon. The loading and preparation chambers have been assembled and a vacuum check was done in an off-line test separated from the main chamber. A test of cathode-puck handling in the chambers was also completed. Trial of NEA surface preparation will be soon started.

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